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INVITED LECTURES / VABLJENA PREDAVANJA

VIRTUAL MIRROR FOR ASSESSMENT AND TRAINING OF LOWER EXTREMITIES

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Abstract

The paper proposes the use of visual biofeedback through virtual mirror as a modality of lower-extremities training in virtual reality. A kinematic model of a human body and a corresponding virtual figure were developed, in order to visualize the movements of the subject in a real-time virtual environment on a large display, which represented a virtual mirror. An optical system with active markers was used to assess the stepping movements of a training subject. A preliminary investigation was conducted with a group of healthy subjects, who performed the stepping test by tracking the movements of the reference virtual figure, which represented a virtual instructor. Both figures, the training subject and virtual instructor, were superimposed and shown from the desired angle of view. The subjects performed four stepping tasks. The results obtained included basic kinematic and temporal parameters of adaptation, thereby providing quantitative measures of subject's immersion in the virtual training environment.

INTRODUCTION

Virtual reality (VR) is powerful tool in rehabilitation, providing the use of visual biofeedback as one of the most important augmentations compared to traditional therapy (1). The number of VR rehabilitation applications has been increasing rapidly over the last years; however, most of them have focused on the upper extremities (2). For lower-extremities training, we propose the use of a virtual mirror (VM). This is a large screen in front of which the subject performs the movements and observes them in a three-dimensional (3D) virtual environment from arbitrary viewing angle (Figure 1). The motion in VM is visualized through a human-like figure whose movements correspond to those performed by the subject in real time. In our study we used two virtual figures simultaneously, where the other figure represents the virtual instructor (VI). The motion of the VI was preprogrammed by measuring and recording the movements of a healthy subject. VI figure was rendered yellow transparent in appearance, opposed to the subject's figure which was solid grey. The task of the training subject was to track the movements of the VI as accurately as possible, trying to minimize the pose difference of both figures in the VM throughout the duration of the training.

We studied the ability of adaptation to the VI's movements by using the VM in a group of healthy adults performing stepping-in-place (SIP) tasks (3). Differences between the subjects' and the VI's movements were studied and analyzed for each task. It was our aim to assess and establish the ability of the healthy population to adapt to the VI as a ground for further studies and applications intended for patient training using VM.

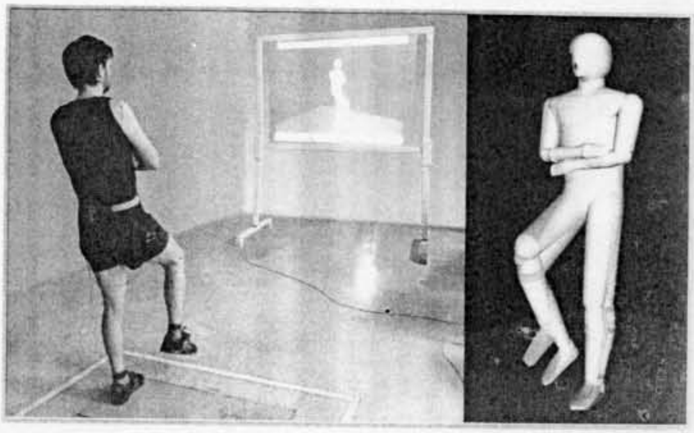

Figure 1: Virtual mirror: a large screen showing movements of the subject in real time (left), superimposed virtual trainee and virtual instructor enlarged (right).

METHODS AND SUBJECTS

Visualization in VM was based on the simplified kinematic model of the human body (4, 5). In order to obtain the values of joint angles, 11 active markers were placed on the skin over anatomical landmarks. The positions of the markers were measured using the OPTOTRAK (Northern Digital Inc.) system with a 70-Hz sample rate. Kinematic data were fed to the virtual environment which was facilitated by using VRML 2.0 (Virtual Reality Modelling Language). We achieved 35-Hz refresh rate without detectable lagging, which was sufficient to enable a proper real-time visualization, engaging the subjects' visual biofeedback.

The subjects were instructed to follow the SIP movements of the VI during the test as closely as possible. VI had been preprogrammed with 4 different SIP tasks, featuring cadences of 60, 60, 90, and 120 beats per minute (BPM), whereas the maximal hip angles were 45°, 90°, 90°, and 45° respectively. The number of steps was 30 for all tasks.

A test group consisted of 10 healthy male subjects (age 23 - 39 years; mean value = 28.5 years, standard deviation = 4.7 years). None of the subjects had a medical history of any relevant medical condition.

RESULTS

Results include the maximal angles of the hip and knee joints achieved in each step, the swingphase duration and the SIP period duration, shown in Figure 2. The solid horizontal line

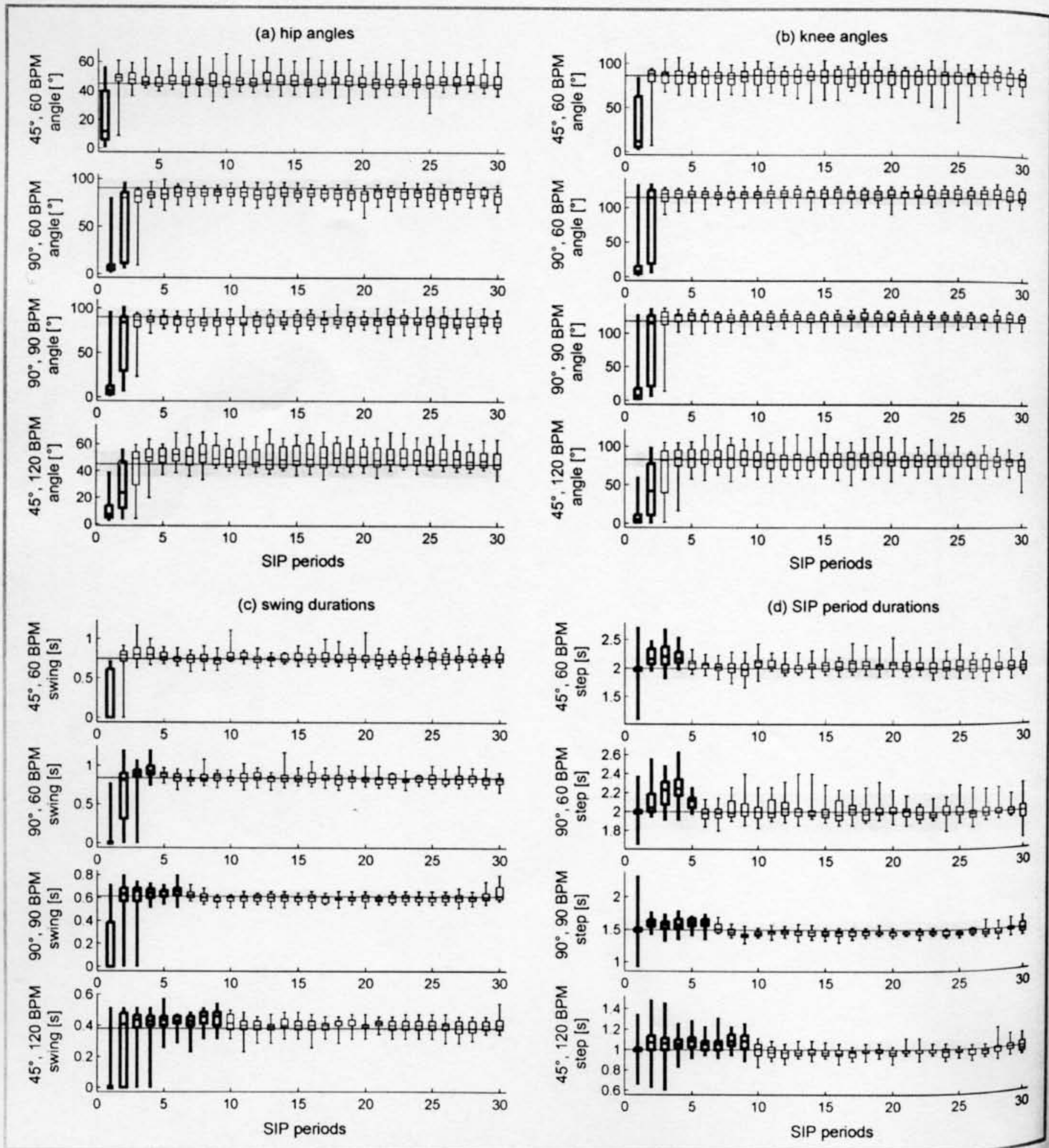

Figure 2: SIP parameters (a: hip angle, b: knee angle, c: swing time, d: SIP period time) for SIP periods 1-30, showing 25th percentile, median value, 75th percentile, maximal, and minimal value in each SIP period.

represents the reference value of the virtual instructor. The boxes indicate the 25th percentile, median value, and the 75th percentile in step, while the error bars show the maximal and minimal angles measured in the group of 10 subjects. Grey bands indicate ±10% deviation. Bold lines indicate the steps that were significantly different from the steps that follow ($p < 0.001$ for all tasks, one-way ANOVA).

DISCUSSION

The results suggest that healthy subjects can adapt to the virtual mirror quickly with the proposed tasks, achieving both consistency, and accuracy of kinematic and temporal adaptation; however, kinematic adaptation was generally achieved sooner than temporal adaptation, especially in the more demanding tasks. This phenomenon suggests the use of further modalities in the virtual environment, such as audio devices, to enhance the feedback and improve temporal coordination. Less demanding tasks than those proposed in our study should be considered in clinical practice.

CONCLUSION

The current study offered a preliminary insight into using the VR and visual biofeedback in lowerextremities training. Introducing a virtual mirror enabled active inclusion of subjects in the training process. The adaptation to the VI among a group of 10 healthy persons was evaluated by performing the virtual SIP training. We concluded that healthy subjects were able to track the virtual instructor during SIP which suggests further applicability of the virtual mirror to other forms of lower-extremities virtual training. Introducing the virtual mirror in the rehabilitation environment could be potentially beneficial in terms of process quantification, standardization, and VR-related effects (2).

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