35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Changes in EMG Latencies during Balance Therapy Using Enhanced Virtual Reality with Haptic Floor

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Abstract— **In the paper a research on enhanced experience of virtual reality supported balance training is presented. Haptic floor, mounted on the dynamic standing frame was used as a biofeedback at collisions in virtual environment. Electromyographic muscle activity of soleus, gastrocnemius, tibialis anterior, semimembranosus, rectus femoris, tensor fasciae latae and erector spinae at the time of onset and recovery of postural perturbation were monitored using surface electrodes. 12 neurologically intact young adults participated in the research study. The main goal was to identify the differences in postural response strategies at collisions in the virtual world w/o haptic feedback. We found more dynamic responses in all subjects when applying haptic floor, especially in the ankle complex, stabilizing the tibia at the onset of perturbation. Choosing different strategies using the haptic floor may significantly enhance the telerehabilitation experience and thus increase the effectivness of the tele-balance training. Besides telerehabilitation, such system may be also effective for postural reponse assessment and thus simplified telediagnostics. However, the findings call for further study to support the proposed proof of concept.**

I. INTRODUCTION

Currently, it is estimated that 1.1 million stroke occur each year only in the European Union and due to changing demography, we may expect this number will rise up to 1.5 million by the year 2025. Vestibular and balance related problems are among the most frequent in stroke survivors. Therefore the restoration of static and dynamic balance has been one of the major issues for rehabilitation of stroke population since ever. Kwakkel et al [1] demonstrated that intensive therapy with repetitive and targeted tasks should be applied to get effective results. Repeatability during intensive physiotherapy can be assure either by accurate, but strenuous manual work or by appropriate assisting device. Active devices (e.g. KineAssistTM, kinea design llc, USA) use motors or other energy to support the subjects and maintain the desired posture, while passive devices (e.g. BalanceTrainer, medica MedizinTechnik, Germany) only limit the balance range and require certain amount of subjects activity. However, both types of devices can assure safety, body weight support, trunk and pelvis stabilization, but the passive devices e.g. for balance training require certain amount of subjects voluntary activity. Using such devices may not have only an important role to assure repeatable conditions and subjects safety, but also free the therapist of strenuous manual work.

Recently the targeted task have been implemented using computer graphics and virtual reality (VR) technology. Besides attractiveness and motivating factor that also should not be neglected, the VR technology can offer much more that basic task in real environment. The medical experts can supervise the subject's activity, the repeatability of the rehabilitation process and enable the user to gradually increase the level of difficulty. Additionally the virtual environment (VE) can be modified due to motivation, fatigue, boringness without changing the basic goal of the task [2]. Several authors reported on improvement of motor functions in gait, posture and balance [3], [4], [2] using VR.

Information communication technologies (ICT) nowadays also play an important role in remote treatment and communication with the patients after being discharged from the hospital [5]. In combination with active of passive therapeutic devices and VR technology we may offer completely new telerehabilitation and telediagnostic services and improve balance in stroke patients [6]. Some authors reported on importance of action/reaction activities in lower extremities [4]. This inspired us to transfer the knowledge from haptic robotics and add the haptic interface to the VR task [7]. Such system detected the collision with the object in the VR world and caused an adequate postural perturbation at the level of feet. This required from the subject to respond to the postural perturbation and needed to activate the postural mechanisms [8] to return to the equilibrium without lifting or moving the feet.

Hereby we examined the differences in postural responses when the subject was exposed to the VR collision only and the situation when the VR collision was accompanied by postural perturbation induced by the haptic floor. We hypothesized that subjects in haptic conditions would choose different postural strategy and use ankle complex to stabilize the calf, which may be useful for postural response telediagnostics.

II. METHODS

A. Equipment

At our Institute a standing frame for balance training was developed [9] that later became commercially available under the name BalanceTrainer (Medica Medizintechnik, Germany) . The standing frame was made of aluminum; upper frame fixed to the base with passive controllable springs (Fig. 1). The standing frame tilt in two degrees of freedom (2 DOF) was limited within 15^o in both sagittal and frontal

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This work was supported by the Slovenian Research Agency (Grant Nr. P2-0228) and Slovenian Technology Agency (Grant Nr. P-MR-10/07).

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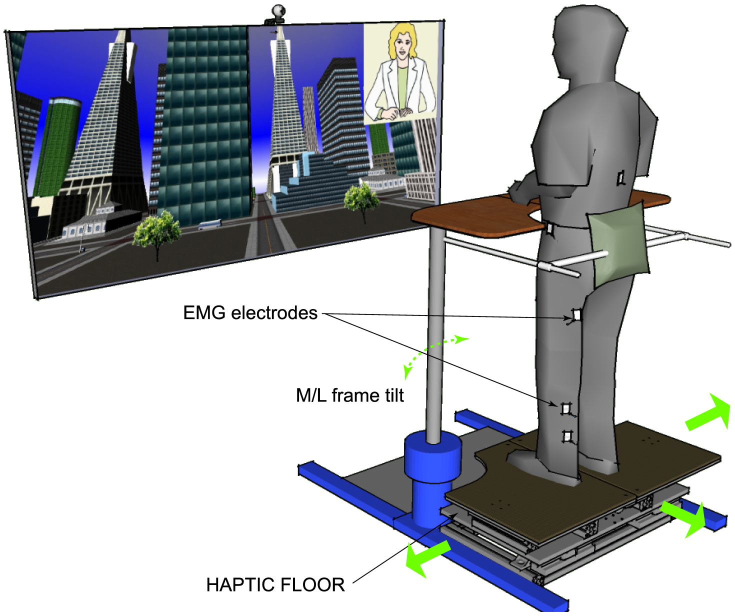

Fig. 1. Telerehabilitation system for balance training and postural response assessment with virtual world, teleasssitance and haptic floor. The haptic floor provide biofeedback from the VR task and therefore enhance the experience and enable postural response therapy and telediagnostics. In the study we used EMG to explore the differences in responses when haptic floor was added.

plane and its stiffness was adjustable with passive springs. The tilt of the frame was measured by a three-axis tilt sensor (XSens Technologies, Enschede, The Netherlands). The tilt information served as an input for VR environment (VRML, blaxxun plug-in). The avatar position and collision information from VR was sent to the haptic floor via UDP interface (Matlab, The MathWorks, Inc., Natick, MA, USA). The haptic floor [7] mounted between the aluminum frame of the BalanceTrainer was able to translate in all directions in transversal (horizontal) plane. The device was constructed using aluminium profiles and guide rails with moving platforms in two layers. A DC motors (Maxon DC RE40, 150W, Encoder HEDS 5540, Maxon, Planetary Gearhead GP 52, Switzerland) moved the lower layer using steel wires in medial-lateral (M/L) direction and upper platform in anterior-posterior (A/P) direction. TTL signals from encoders (A, B and I) were sampled with National Instruments (NI) high-speed digital I/O module (NI 9403, USA). The real-time quadrature decoding and control algorithm were implemented in real-time controller (NI cRIO-9014, USA). The DC motors were controlled with analogue output (NI 9263 AO, USA) and the power for DC motors came from the servo amplifier Maxon 4QDC (ADS 50/10, pulsed (PWM) 4QDC Servo amplifier 50 V / 10 A) The algorithms were written in Labview 8.5 FPGA (NI).

The trigger and haptic plate position signals were sent via NI controller to the measurement unit to synchronize data assessment. The electromyographic (EMG) activity of left soleus (SOL), gastrocnemius (GAS), tibialis anterior (TA), semimembranosus (SEM), rectus femoris (RF), tensor fasciae latae (TFL) and erector spinae (ESI) during VR supported balance training were sampled at 1 kHz with Noraxon system (Noraxon 2000 EMG system, Noraxon Inc., Arizona, USA) using surface electrodes (3M Red Dot Repositionable Electrodes). Center of gravity (CoG) was recorded (200 Hz) with force plates (made of Nintendo Wii Balance board sensors). Data were recorded with laptop computer equipped with Keithley KPCMCIA-12AI data acquisition card and custom made interface (Matlab, The MathWorks, Inc., Natick, MA, USA).

B. Subjects

12 neurologically intact young adults (8 male, 4 female 29.1 SD 2.9 years, 71.0 SD 15.2 kg, 173.5 SD 10.6 cm) participated in the study. The volunteers had no muscular-skeletal impairment or any disease that would affect motor control, cognitive or vision capabilities. None of the subject had any experience nor with the BalanceTrainer, nor with the VR task. The subjects had less than 5 min. introduction and testing of the task just at the beginning of the session.

The methodology was approved by local ethics committee and the subjects gave informed consent.

C. The task and the protocol

The VR task was taken from the existing telerehabilitation system [6]. The subjects stood in the balance standing frame (Fig. 1) and begin a virtual walk on the path full of obstacles (can, bench, pool, statue). Subjects can control the VR by tilting in the standing frame; with A/P tilt set the speed of the movement and with M/L tilt turns left or right in VR world. However, in this study the walking speed was set to constant - the speed was high enough that the subject had no time to think which way to go. The subjects controlled only the rotation and thus avoiding collisions with the VR objects. In the study the A/P tilt had no effect. Each subjects participated in assessment under two different conditions on the same path in the same VR environment:

1. Collisions with virtual objects. The subjects' task was to avoid virtual obstacles and enter the building at the end of the virtual path.

2. Haptic feedback at the onset of the collision with virtual object. In fact the subjects could ”feel” the object; i.e. the strength and the direction of the haptic floor movement was proportional to the collision law. The direction of the haptic floor movement was defined with direction of movement in the VR world and the angle of impact (Fig. 2), but the strength of the perturbation (haptic floor acceleration/velocity profile) was the same regardless of the angle of collision or weight of the subject due to the study conditions.

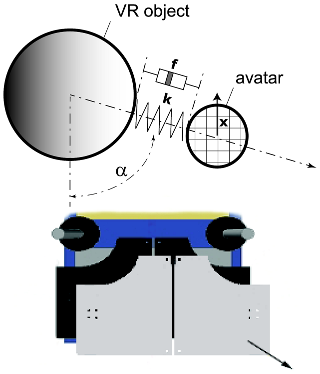

Fig. 2. The haptic floor provide biofeedback .

In both conditions the activities of left side muscles (TA, SOL, GAS, SEM, RF, TFL, ESI) were assessed and for condition 2 synchronized with the haptic floor translation. We assumed that EMG activity in healthy young adults was symmetrical and that assessment on the left side only would satisfy the requirements [10]. The task in both conditions lasted for 80 s and was repeated 3 times for each participating subjects.

D. EMG and CoG data analysis

From recorded data a CoG and its latency from the onset of collision with VR object was calculated. Similar procedure was taken with the recorded raw EMG. We applied a bandpass filter 30-250 Hz [11] and tried a full rectification of the signal. However, the rectification often removed the sharp peak in EMG, therefore raw EMG was helpful in precise identification of latencies. Therefore a raw EMG latencies were calculated for both conditions; 1. from the onset of collision with VR object only and 2. from the onset of haptic floor horizontal translation.

III. RESULTS

The following EMG latencies were found at collision with the VR object at the front-right side (rebound to the back-left direction): 1. only with VR feedback (Fig. 3): TA - 1834 ms, SOL - 294 ms, GAS - 444 ms, RF - 244 ms, SEM - 153 ms, TFL - 994 ms, ESI - 144 ms. 2. with VR and Haptic floor feedback (Fig. 4): TA - 202 ms, SOL - 92 ms, GAS - 162 ms, RF - 262 ms, SEM -112 ms, TFL - 712 ms, ESI - 151 ms.

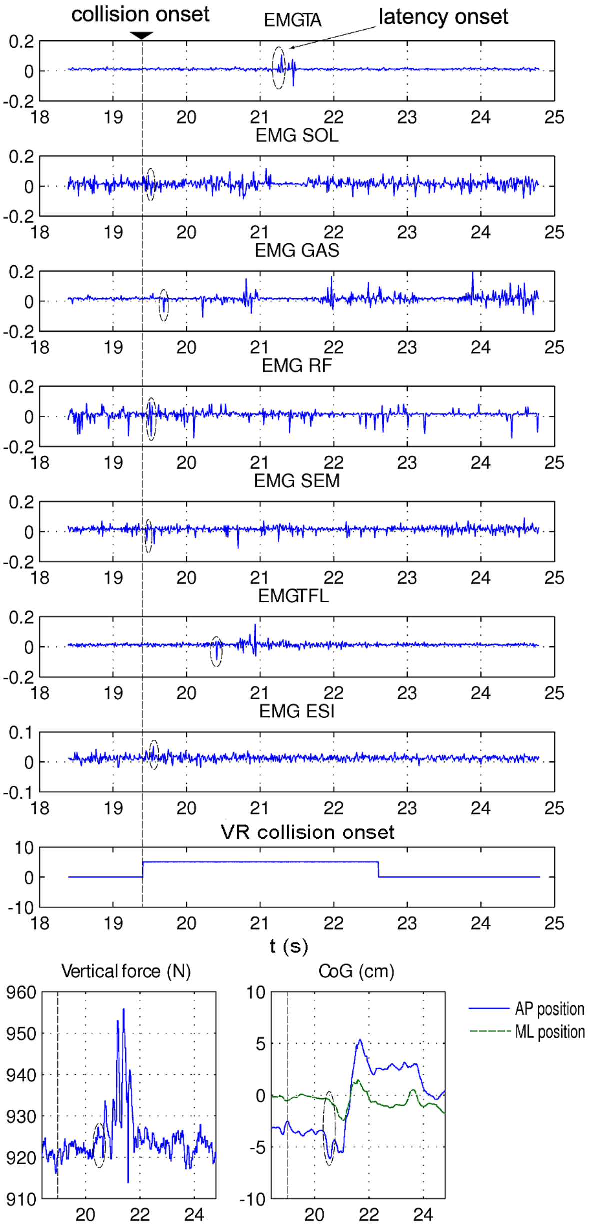

Fig. 3. EMG and CoG responses at collision with VR object (back-left) for the typical participating subject. The onset of collision (trigger) is marked with dashed vertical line and latencies for each muscle also.

In the Fig. 3, the vertical force graph demonstrates that the latency from the onset of the collision with VR is rather high (954 ms). Also the CoG graphs shows almost no change for the first 500 ms. When haptic floor feedback was applied (Fig. 4), a subjects' response to the collision was very prompt; 153 ms latency which is only 16 % of the latency without haptic feedback. Additionally the Fig.

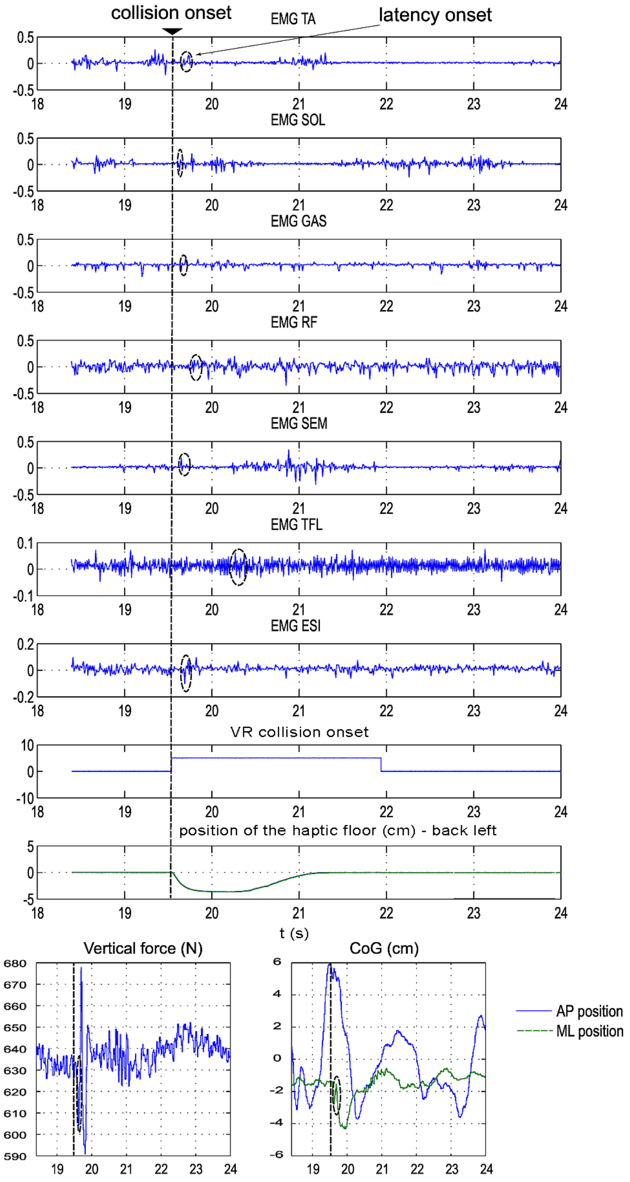

Fig. 4. EMG and center of gravity (CoG) responses at collision with VR object with the presence of haptic floor feedback (back-left) for the typical participating subject. The onset of collision is marked with dashed vertical line and latencies for each muscle also. Additionally the position of the haptic floor is shown. Bellow are the vertical force and CoG latencies.

4 includes the position of the haptic floor at the horizontal translation to the back-left direction.

IV. DISCUSSION

Most of the differences in EMG latencies at collisions occur simply because of the fact that the majority of the subjects do not react dramatically at the onset of collision with the VR object. The recorded muscle activities at the proximal muscles (RF, SEM, ESI) demonstrated also action before the collision. However, when haptic floor was in operation, the distal muscles or the ankle complex muscles (TA, SOL, GAS) took the major role in stabilizing the tibia and compensating for the imbalance of the body. One may notice that when haptic floor was applied, the plantar flexor muscles and the TA had very similar latencies to the vertical force and CoG. These findings are also in line with published studies, reporting on correlation between EMG and COP, particularly TA and COP latency [11].

V. CONCLUSIONS

The outcomes of the assessment demonstrated that inclusion of haptic floor in the balance training telerehabilitation system can effectively increase the subjects' dynamic contribution and thus enhance the telerehabilitation balance training to postural response experience. Speculatively saying, with appropriate mathematical algorithm we might be able to estimate to directional improvement of postural responses remotely without having to see the patient in-person.

There are numerous studies that can confirm our findings and the significant contribution of the haptic floor to the VR balance training experience. However, to make any conclusion with postural response telediagnostics a more extensive research including a comparison [12] with clinical data is necessary. Besides, for the time being the haptic floor may present an excessive investment in the telerehabilitation equipment.

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