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Lower-extremities training in virtual reality augmented by sound and sensory electrical stimulation

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Aim

The use of virtual reality in rehabilitation studies and applications has been increasing steadily over the last decade.[1] It engages the subjects' biofeedback which augments the rehabilitation process and adds to the improvement of the rehabilitation results. The most common modality of the virtual environment is visual; however it has been shown that the feeling of presence increases when visual information is complemented by other modalities, such as sound, electrical stimulation, or vibrations.[2] In the present study we propose the setup using visual, auditory, and sensory electrical stimulation. An investigation was performed, engaging these modalities in different combinations in order to investigate the contribution of their particular influence on the level and the quality of adaptation to the virtual environment.

Methods

The visual feedback was provided by a virtual mirror [3] – a large screen in front of which the subject performs the lower-extremity movements while observing two superimposed figures in a three-dimensional virtual environment: the real time virtual self and the pre-programmed virtual instructor (Figure 1). The latter is visualized as a yellow semi-transparent figure whereas the real-time representation of the subject is rendered as a grey solid figure of the same size and shape. An infrared camera and markers were used to track the human motion. The subject is instructed to follow the movements of the virtual instructor as accurately as possible by visually minimizing the differences between the virtual self and virtual instructor. We used stepping-in-place (SIP) reference pattern [4] which has a rather long medical history and can be described by the same spatial and temporal parameters as gait. A one-minute task with changing cadence and joint angles of the SIP was presented to the subjects to perform and repeat with and without the auditory and sensory electrical stimulation present. The cadence values were 60, 90, and 120 beats per minute, whereas the reference hip angle values alternated between 45° and 90° (Figure 2). Short and clear whistle sound signals and cutaneous electrical stimulation of the skin over the soleus muscles were added to provide the exact timing of the heel-off moment. The frequency of the sensory electrical stimulation was set

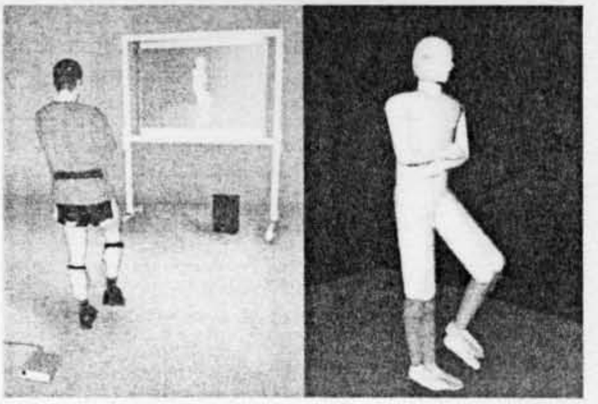

Figure 1. — Virtual mirror.

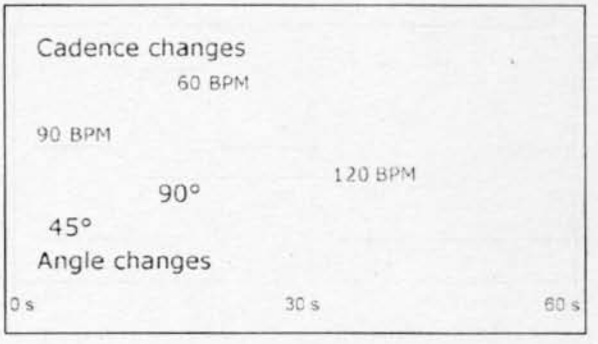

Figure 2. — Cadence and angle perturbations within the task.

to 100 Hz, with pulse duration of 3 ms. Both duration of the pulse train and sound signal was 200 ms. The amplitude of sound and electrical stimulation was adjusted to make it clear but below uncomfortable levels. We observed the ability of the subjects to adapt to the reference using different combinations of the employed modalities as shown in Table I. The study was performed among 9 healthy male adults (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

The results include maximal hip and knee angles, swing-phase duration and stepping-in-place period duration in each step to enable the analysis of spatial and temporal adaptation to the reference movements. Figures 3A,B show spatial adaptation for the 4 modes listed in Table I, whereas Figures 3C,D show temporal adaptation. The spatial errors of the subject's performance were calculated as a mean absolute error of maximal angle values of all steps during the course of the task performance. Temporal errors were calculated as a mean absolute error of all steps during the task performance. Bold lines indicate the median error values with

Table I. — Combinations of visual and auditory modalities, and sensory electrical stimulation.

	Virtual Instructor	Visual Reference	Sound	Electrical Stimulation
Mode 1	✓	✓	✓	-
Mode 2	✓	✓	-	✓
Mode 3	✓	-	-	✓
Mode 4	✓	-	✓	-

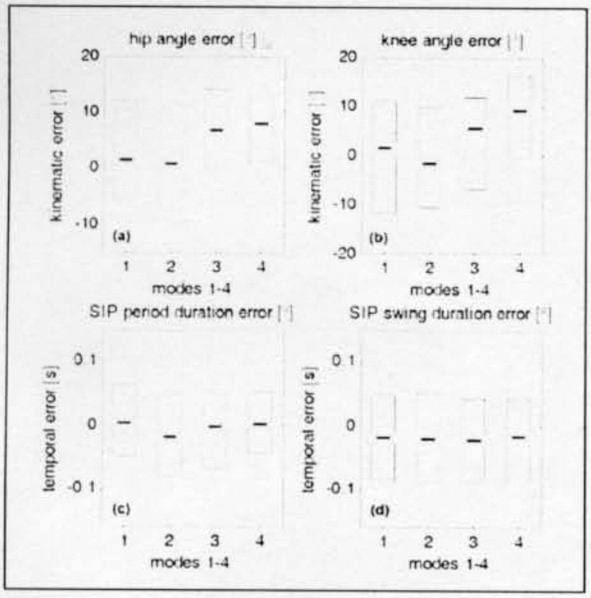

Figure 3. — Spatial (A,B) and temporal (C,D) adaptation of the subjects for all tasks.

boxes representing the 25th and 75th percentile values among the group of subjects.

Conclusions

In our previous study [3] it was found that healthy subjects can adapt to the virtual mirror quickly; however, spatial adaptation was generally achieved sooner than temporal adaptation, especially at faster cadences. This phenomenon suggested the use of further modalities in the virtual environment to enhance the feedback and improve temporal coordination. Including sound and sensory electrical stimulation in the present study in fact improved temporal adaptation of the subjects; without sound or sensory electrical stimulation, subjects had needed several steps to adapt temporally, whereas with these two modalities included, one or two steps following the perturbation were sufficient. However, no significant differences between auditory signal and sensory electrical stimulation were observed. Moreover, it was found that spatial adaptation was more accurate when visual feedback was present (modes 1 and 2) but error variance was greater compared to visual reference only (modes 3 and 4). No significant differences among the modality combinations were observed in temporal adaptation. The results suggest using the visual biofeedback to improve spatial adaptation and the addition of sound or electrical stimulation to improve the temporal adaptation in the further studies or medical applications with the virtual mirror. Sound should be preferred over sensory electrical stimulation since it is much easier to facilitate the desired signals with. Further studies should also investigate other feedback modalities and combinations, especially haptics.

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The effectiveness of locomotor therapy using robot-driven gait orthosis system in acute stroke patients: a randomized controlled trial

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Aim

Locomotor therapy by treadmill with partial body weight support is evolving as a promising new approach to improve gait ability for severely impaired neurological patients.[1] Using a robotic-driven gait orthosis system (LokomatTM) instead of the regular training has several advantages mainly that it enables more repetitive practice of complex gait cycles.[2] In this prospective, randomized controlled pilot study we evaluated the effectiveness of early locomotor treatment using the LokomatTM system on the functional motor outcome of acute stroke patients.

Methods

This was a non-blinded prospective, randomized, controlled study that included 56 acute stroke patients. Twenty-nine patients were treated by robotic-assisted gait training (RAGT) and 27 were treated by regular physiotherapy. RAGT treatment was administered [3] times a week for 30 minutes,