Critical illness VR rehabilitation device (X-VR-D): Evaluation of the potential use for early clinical rehabilitation

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Received 30 March 2006; received in revised form 27 October 2006; accepted 14 November 2006

Abstract

We present a new critical illness VR rehabilitation device (X-VR-D) that enables diversified self-training and is applicable early in the rehabilitation of severely injured or ill patients. The X-VR-D consists of a VR program delivering a virtual scene on a flat screen and simultaneously processing commands to a moving chair mounted on a motion system. Sitting in the moving chair and exposed to a virtual reality environment the device evokes anticipatory and reactive muscle contractions in trunk and extremities for postural control. In this study we tested the device in 10 healthy subjects to evaluate whether the enforced perturbations indeed evoke sufficient and reproducible EMG muscle activations.

We found that particular fast roll and pitch movements evoke adequate trunk and leg muscle activity. Higher angular velocities and higher angles of inclination elicited broader EMG bursts and larger amplitudes. The muscle activation pattern was highly consistent between different subjects and although we found some habituation of EMG responses in consecutive training sessions, the general pattern was maintained and was predictable for specific movements. The habituation was characterized by more efficient muscle contractions and better muscle relaxation during the rest positions of the device. Furthermore we found that the addition of a virtual environment to the training session evoked more preparatory and anticipatory muscle activation than sessions without a virtual environment.

We conclude that the X-VR-D is safe and effective to elicit consistent and reproducible muscle activity in trunk and leg muscles in healthy subjects and thus can be used as a training method.

1. Introduction

Early intensive exercise in the bed bound phase of severely injured or critically ill patients (e.g. polytrauma, cardiac failure, critical illness PNP, spinal cord injury, head injury, stroke etc) is important as it facilitates functional reorganization of the brain and minimizes negative neural and muscular plasticity induced by bed rest and/or non-use of muscles. This specific category of patients suffer extensive physiological and mental effects, such as muscle wasting, muscle shortening, joint contractures, osteoporosis, heterotopic ossifications, decrease of heart–lung condition, reduction of vascular diameters, thromboembolic complications, skin pressure ulcerations, agony, depression and intensive care delirium (Robson, 2003).
Even in healthy subjects, bed rest will on itself induce muscle wasting (25% of the calf muscle and 14% in quadriceps muscle) and bone loss. This was found with computer tomography measurements in the Berlin 90 days Bed Rest study (Rittweger et al., 2005; Mulder et al., 2006). In critical care patients, the physiological effects are even more pronounced because of the frequent catabolic circumstances caused by infections, wounds and poor nutrition. The current situation with respect to exercise and training of this category of patients often exists of single daily physiotherapy sessions of approximately 20 min. Since we expect that this intensity of training is not sufficient to counteract the above mentioned negative physiological processes we developed a critical illness VR rehabilitation device (X-VR-D) that enables early intensive sensory motor training and can be applied early in the rehabilitation program of severely injured or ill patients. The device is constructed in a way that it enables stimulation of proprioception, equilibrium, vision and hearing. The stimuli are applied by a flight simulator-like device using a moving chair integrated with a virtual reality environment displayed on a flat screen. Sitting in the moving chair and exposed to a virtual reality environment the device evokes anticipatory and reactive muscle contractions in trunk and extremities for postural control. By using different motion and virtual reality programs the training is, diversified, and has self-training possibilities and is made challenging by using game like elements. The training program can be extended with interactive control so that the training program can automatically adjust the exercise level to the patient’s physical state. The possible functional gains of X-VR-D training in a broader perspective are: quicker mobilization and a better cardiopulmonal physical state with less dependency on pain killers, antidepressants and neuroleptics.

Our hypothesis for the study was: X-VR-D training evokes muscle activity in trunk and leg muscles, which is consistent among different subjects, in repeated sessions there is no habituation and display of VR enhances the muscle activity. To investigate this we examined the EMG muscle activation patterns in trunk and lower extremities in response to postural perturbations evoked by movements of the device.

Sessions with and without the display of a virtual space on the PC monitor were used to investigate whether there is different anticipatory and/or preparatory trunk and leg muscle activation when subjects are exposed to perturbations with visual information compared to sessions without visual information. The first condition can be compared with a situation as driving as a passenger in a car, the latter as driving in the same car with the windows blinded.

1.1. Study questions

1. Does the X-VR-D evoke muscle activity in trunk and leg muscles?
2. Is the muscle activity pattern consistent in different subjects?
3. Is there habituation of muscle activity in repeated sessions?
4. Is the muscle activation pattern of perturbation sessions with display of a virtual environment different from perturbation sessions without the display of a virtual environment?

2. Methods

The critical illness VR rehabilitation device (X-VR-D) (Fig. 1) consists of a chair mounted on a Rexroth Hydrondyne Micro Motion System (Boxtel, The Netherlands) and a flat screen placed in front of the subject sitting in the chair. With this system, perturbations can be delivered in six degrees of freedom in adjustable angular velocities and inclination angles (Fig. 2). A hydraulic power unit, a motion control cabinet, a motion computer and six hydraulic actuators support the motion platform. The motion commands are delivered by a virtual reality program designed by MCW studios in Rotterdam, The Netherlands, using Virtools. The motion computer converts these motion commands to six individual actuators underneath the chair. The VR program used in this study was created as a virtual spaceflight. The subjects sitting in the X-VR-D experience a situation as a flying passenger in a space vehicle through artificial objects placed in the virtual universe. The pitches, rolls and all other possible movements of the X-VR-D create the virtual feeling of flying. The chair component of the X-VR-D was developed in our group in collaboration with the Industrial Design Department of the Technical University in Delft, The Netherlands. The chair is adjustable to different sitting positions and subject sizes and contains safety sidebars. To maintain an upright sitting position, posture has to be actively controlled by different muscle groups. The sitting
position can be adjusted to the subject’s physical state. Very weak subjects can thus be placed in a half lying or deck chair position. Even subjects with complete loss of sitting balance can be placed in the chair using a hospital lift.

2.1. Study design

The efficacy of the X-VR-D as a possible early training method was evaluated in seven healthy volunteers (age 24–41) by measuring surface electromyography (EMG) in trunk and lower extremities muscles during a virtual spaceflight. The virtual spaceflight consisted of a 2 min motion program combined with a virtual space displayed on a flat screen. Each subject underwent one trial with six consecutive 2 min series of an identical spaceflight; three series with flying motions of the chair combined with a virtual space displayed on the monitor and three series with flying motions of the chair without display of the virtual space. The series with and without the display of a virtual space on the flat screen were randomly assigned to the test subjects. The subjects were instructed to sit upright during the spaceflight series. The randomization was used to investigate whether there is different anticipatory and/or preparatory trunk and leg muscle activation when subjects are exposed to a spaceflight with visual perturbations. The EMG pattern was consistent between the different subjects. The roll and pitch perturbations elicited also consistent RF and TF activities. Faster angular velocities and larger inclination angles evoked higher EMG amplitudes than low velocities and small inclination angles. The heave and surge perturbations did not evoke any reproducible EMG activity. Only the sudden fast starts of the heave and surge perturbation elicited a startle-like response in trunk and leg muscles. The combined perturbations such as pitch roll’s and yaw roll’s were associated with EMG activity in all trunk and leg muscles with a consistent temporal pattern.

Question 2. Is the muscle activity pattern consistent in different subjects?

The mean EMG response of the three space flight series with and without VR per test subject was calculated. These individual mean EMG patterns were used to calculate the group mean and are shown in Fig. 4. The EMG pattern was consistent between the different subjects. The rolls and pitches showed the best between subjects comparison. In the combined pitch roll and pitch yaw movements there were more differences in EMG bursts patterns related to the individual differences in postural control strategy.

Question 3. Is there habituation of muscle activity in repeated series?

To discriminate habituation from interseries variability we first reduced the possible effect of interseries variance by calculating the group mean EMG trace. The group mean of the first series was then compared with the group mean of the third series (Fig. 5). The general pattern of habituation was shortening of EMG bursts and the reduction of backgrounds EMG activity between the bursts in the third series compared with the first series. Some habituation did thus occur but however the general temporal pattern and amplitude of EMG was maintained.
Question 4. Is the muscle activation pattern of the series with display of a virtual environment different from space-flight series without the display of a virtual environment?

The difference between these two conditions was most obvious in the group mean EMG response of the first series without VR display compared with the group mean EMG.
The addition of a VR environment evoked more anticipatory and preparatory EMG bursts and the amplitudes of EMG bursts are larger.

4. Discussion

In this study we evaluated a new training device of the potential use for early clinical rehabilitation. For this purpose we first tested the device in healthy subjects to evaluate whether the enforced perturbations indeed evoke reproducible and sufficient muscle activation. Based on visual interpretation of EMG data in a descriptive study, we found indications that particular fast roll and pitch movements elicit active control of important trunk and leg muscles. Higher angular velocities and higher angles of inclination elicit increasing EMG responses. The muscle activation pattern was highly consistent between different subjects and although we found some habituation of EMG responses in consecutive series the general pattern was maintained and predictable for specific movements. The habituation was characterized by more efficient muscle activation strategies in response to perturbations and by more muscle relaxation during the rest position of the device. Furthermore we found that perturbations plus display of a VR environment evoked more preparatory and anticipatory muscle activation than the series without display of a VR environment. This finding indicates that when there is a challenging virtual environment this may have an extra training effect and is in this way an effective rehabilitation tool.

The X-VR-D is developed with the specific purpose to offer bed bound patients an adequate, early and intensive training. In healthy subjects’ activities of daily living produce enough muscle activity to stay fit. In bed ridden critically ill patients the situation is different. Here it is a matter of importance whether to have no or some muscle activity during the day. No muscle activity will lead to physical deterioration, X-VR-D induced muscle activity in these patients may counteract deterioration. VR technology has been advocated as a powerful tool for various forms of rehabilitation (Kenyon et al., 2004). So far, we did not find any devices in the literature neither with a comparable design nor purpose. The group of Sinkjaer published a Multipurpose Rehabilitation Frame designed for training balance during standing (Matjacic et al., 2000). Another example of a rehabilitation system for postural balance control using a bicycle and VR was published by a group of Korean engineers (Kim et al., 1999). However, these apparatus are not applicable for the critically care patients we focus at, and did not use the possibilities of VR to enhance muscle responses. There are some studies about postural strategies in sitting perturbations. These studies were not designed within the framework of a training method but were performed to investigate how posture is controlled in sitting (Zedka et al., 1998). Zedka et al. found in the pitch perturbations, symmetrical EMG bursts in back and abdominal muscles. In the roll perturbations they found reciprocal phasic EMG activity between the left and right back muscles. Grosso modo the same patterns as we found in the study presented here.

Our first careful conclusion is that the X-VR-D might be appropriate to be used as a training method. Furthermore, we found that test subjects experience the VR sessions in the X-VR-D as exciting and challenging. All subjects tolerated the training sessions without complaints or signs of
motion sickness. Even repeated sessions of the same flight remained pleasant and exciting. Although we realize that the muscle responses evoked by the X-VR-D are not that intensive to be used as an appropriate training in healthy individuals, for critically ill bed bound patients we expect that these X-VR-D sessions will have sufficient training impact. It may offer a valuable and varied training in a diversion of all possible (virtual) sceneries with a patient, distracted from daily routine, not realizing he or she is actually exercising. This opportunity may elude a new era wherein a hospital stay on a ward or intensive care unit may be less annoying with possible beneficial effects on pain, recovery and the patients general well being. The unrestricted possibilities of virtual environments, the eventual addition of gaming features and interactivity will enable thus a broad spectrum of challenging training possibilities. Our next step is to investigate whether the X-VR-D is tolerated, appropriate and safe in patients with critical illnesses.

Acknowledgements

We thank Martin van den Berg and the MCW studio’s in Rotterdam, The Netherlands, for their contribution in the development of the X-VR-D and specially the VR part of the project. We also thank Maarten Menheere and Dr. Richard Goossens of the Department of Industrial Design of the Technical University Delft, The Netherlands, for design, development and construction of the X-VR-D and Ronald Yntema and Rexroth Hydrodyne BV, Boxtel, The Netherlands, for kindly providing the Micro Motion System.

References


Rittweger J, Frost HM, Schiessl H, Ohshima H, Alkner B, Tesch P, et al.. Muscle atrophy and bone loss after 90 days’ bed rest and the effects of

Fig. 6. VR plus vs. VR minus: group mean EMG pattern of session with a virtual reality scenery displayed on a flat screen (VR+), and group mean EMG pattern of sessions without display of a virtual reality scenery (VR−). The perturbation program (schematic bar) is identical as in Fig. 3. ES: erector spinae; TF: tensor fascia latae; RF: rectus femoris.

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Please cite this article in press as: Van de Meent H. et al., Critical illness VR rehabilitation device (X-VR-D): Evaluation of ..., J Electromyogr Kines (2007), doi:10.1016/j.jelekin.2006.11.005