Can Immersive Type of Virtual Reality Bring EMG Pattern Changes Post Facial Palsy?

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***Abstract*—The loss of facial expression via facial paralysis is a devastating condition, both functionally and aesthetically. However, given the life-long plasticity of the brain one could assume that recovery could be facilitated by the harnessing of mechanisms underlying neuronal reorganization. Currently it is not clear how this reorganization can be mobilized. Novel technology based neurorehabilitation techniques hold promise to address this issue. In this paper an immersive Virtual Reality (VR) based system is presented that is based on a number of hypotheses related to the neural structures targeted for recovery/reorganization, the structure of training system, and the role of individualization. The purpose of this paper is to examine the effects of an immersive type virtual reality (VR) intervention on activation of facial upper quadrant muscles following facial palsy in comparison with a control program. The key components of an immersive Virtual Reality (VR) based system and its effectiveness on facial palsy rehabilitation has been described in the form of experimental findings. Experimental trial was performed on an individual with facial upper quadrant muscles weakness due to facial palsy in a crossover study methodology with and without VR. EMG patterns from the facial upper quadrant muscles were recorded and analyzed for results. This trial has plotted a positive relationship between VR and facial upper quadrant muscles activation following a neurological impetus. The results reported here also show a consistent transfer of movement kinematics between physical and virtual tasks. EMG analysis has shown progressing improvement in the muscle activation in response to the challenging and impulsive activities in the virtual environment provided by the immersive VR devise.**

Keywords—Facial palsy; Virtual Reality; EMG-based measurements; Impulsive impetus

I. Introduction

Human facial expression is a rich source of information about a person’s psychological, emotional, neurologic, and physiologic state. The loss of facial expression via facial paralysis is a devastating condition, both functionally and aesthetically. Peripheral facial palsy is a lesion in the seventh cranial nerve. This is clinically distinguishable from central palsy because of the involvement of the facial muscles surrounding the eye. In peripheral lesions, the frontal branches of the facial nerve are impaired, whereas in central lesions the forehead can still be innervated due to an ipsilateral and contralateral central innervation of the forehead [1]. The incidence of facial palsy is between 23 to 35 cases per 100 000, affecting both genders with peaks from 30 to 50 and 60 to 70 years old [2]. Moreover, with inappropriate treatment, patients may suffer from incomplete recovery and presented contracture, hyperkinesis or synkinesis; the latter can vary between 17% to 42% [3]. Despite the significant impact that facial paralysis has on quality of life and daily function, there is no reliable, accepted method for activation and measurement of facial movement.

Virtual reality (VR) has now emerged as a promising tool in many domains of therapy and rehabilitation [4-7]. Continuing advances in VR technology, along with concomitant system-cost reductions, have supported the development of more usable, useful, and accessible VR systems that can uniquely target a wide range of physical, psychological, and cognitive rehabilitation concerns and research questions. What makes VR application development in the therapy and rehabilitation sciences so distinctively important is that it represents more than a simple linear extension of existing computer technology for human use. VR offers the potential to create systematic human testing, training, and treatment environments that allow for the precise control of complex, immersive, dynamic 3D stimulus presentations, within which sophisticated interaction, behavioral tracking, and performance recording is possible. Much like an aircraft simulator serves to test and train piloting ability, virtual environments (VEs) can be developed to present simulations that assess and rehabilitate human functional performance under a range of stimulus conditions that are not easily deliverable and controllable in the real world. When combining these assets within the context of functionally relevant, ecologically enhanced VEs, a fundamental advancement could emerge in how human functioning can be addressed in many rehabilitation disciplines.

Studies concerning motor strokes have consistently reported an initially disrupted functional connectivity between affected motor areas [8, 9]. One recent study demonstrated changes in cortical activation during a motor task after the onset of Bell palsy [10]. Animal studies have demonstrated primary motor cortex (M1) map reorganization after the transection of the facial nerve [11, 12]. No prior study investigated the effectiveness of VR on facial palsy in the human brain. The purpose of this paper was to examine the effects of an immersive type of virtual reality intervention on activation of facial upper quadrant muscles following facial palsy in comparison with a control program. A person with facial upper quadrant muscles weakness due to facial palsy (3 month post initial insult) was selected for a crossover study with and without VR. In the first phase she was given an eye brow elevation exercise program in front of the mirror for five days with thirty repetitions for a day. EMG from the facial upper quadrant muscles was recorded during the exercise and the same was used to count the receptions. She was given rest for five days and then was allowed to interact with the VR interface. The immersive type of VR was applied through a portable head mounted devise which generates unpredicted and challenging impulsions that is capable of activating the muscles around the eyes including frontalis. The EMG activities where taken before and after the interventions for comparison and analysis.

II. Brain Plasticity

Human brain is one of the most exciting subjects of research and understanding how it works has completely transformed the research paradigms in the fields of neuroscience. An intriguingly dynamic organ, the brain keeps on making a large number of changes in its neural maps referred to as brain plasticity, which ultimately results in behavioral and functional changes in brain's operability. Recent research has shown that brain plasticity and behavior can be influenced by a myriad of factors, including both pre- and postnatal experience, drugs, hormones, maturation, aging, diet, disease, and stress [13]. While the plasticity is quite useful for clinicians in terms of understanding normal and abnormal behaviors, their mechanism is of a greater interest to procedures in which the brain plasticity can be induced in patients with functional disabilities.

According to a well-established protocol [14], the mechanisms which lay in the improvement can be attributable to the following factors:

1) *Enhanced Ecological Validity; the degree of relevance or similarity that a test or training system has relative to the "real" world, and in its value for predicting or improving "everyday" functioning.*

2) *Stimulus Control and Consistency that Supports Repetitive and Hierarchical Delivery.*

3) *Real-Time Performance Feedback.*

4) *Cuing Stimuli to Support "Error-Free Learning"; stimulus features that are not easily deliverable in the real world can be presented in a Virtual Environment to help guide and train successful performance.*

5) *Self-Guided Exploration and Independent Practice.*

6) *Interface Modification Contingent on User's Impairments to Support Access to Rehabilitation.*

7) *Complete Naturalistic Performance Record,*

8) *Safe Testing and Training Environment which Minimizes Risks due to Errors*

9) *Gaming Factors to Enhance Motivation; the integration of gaming features into a VE has been reported to enhance motivation in adult clients undergoing physical and occupational therapy.*

10) *Low-Cost Environments That Can be duplicated and distributed.*

Using external influences for neuro plasticity has been a way of many psychological treatments. This includes medicines, physiotherapy, repeated movement therapy, assisted movement therapy, and other psychological treatments. In this work, it is proposed that VR can be used to insight these impetuses in order to enable the plasticity process. VR rehabilitation is still in an early phase of development characterized by successful "proof of concept" systems, encouraging initial research results, and a few applications that are finding their way into mainstream use and clinical practice.

III. Proposed Technique

In this work a hybrid technique is proposed that utilizes the powerful Virtual reality (VR) interface with external impulsive impetus that triggers the brain cells into plasticity. The evaluation is done through EMG based muscular movements. The use of EMG based muscular detection systems is not very common still and a lot of work is being done in various aspects of the technique. However, the non-clinical application with data fidelity analysis has been looked at from signal processing perspectives for using the EMG data for Human Computer Interactions (HCI) [15]. Figure 1 shows the overall block diagram for the proposed system. The VR system can be designed using any low-cost Head-mounted Device (HMD) that can excite the user into using the frontalis muscles as dictated by the VR environment produced in the HMD. As the eye tries to follow the specific type of impulsive movements seen in the HMD view screens, the muscular movements can be detected by a set of three EMG sensor probes placed just above the eyebrow with reference probe being on the cheek near the ear. The main idea of the presented work is the fact that sudden impetuses given to the brain can re-map the affected pathways due to strong excitations within the neuro-channels.

A. The VR Environment Description

A simple application has been developed using Vizard Virtual Reality Software Toolkit [16] in order to create the desired environment. The interface used is a Head-mounted-device (HMD) which is essentially an extension of the monitor of the PC which gives a more immersive sensation to the user. The program produces one random white colored ball in a black background in such a way that it appears moving towards the viewer and appears to fly over or to the sides of the eyes of the user.

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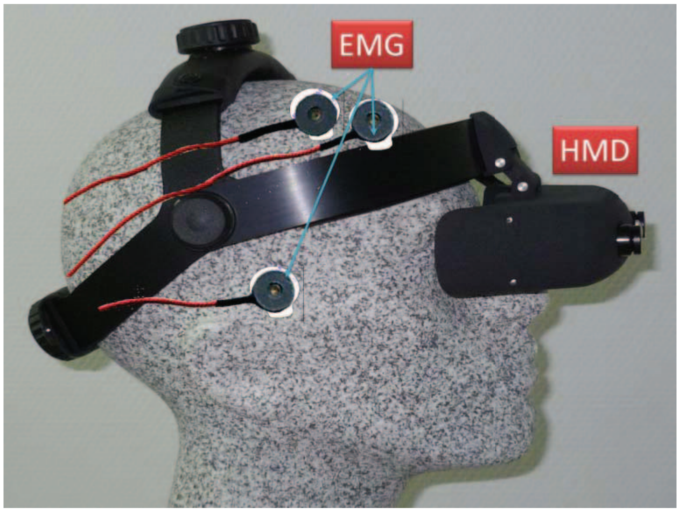


Fig.1. Proposed experimental setup for impulsive impetuses to the brain with EMG based evaluations

B. The VR Environment Description

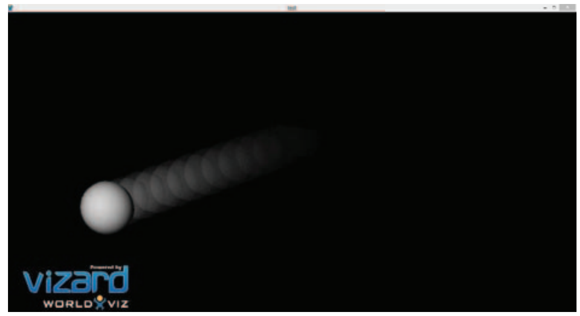
A simple application has been developed using Vizard Virtual Reality Software Toolkit [16] in order to create the desired environment. The interface used is a Head-mounted-device (HMD) which is essentially an extension of the monitor of the PC which gives a more immersive sensation to the user. The program produces one random white colored ball in a black background in such a way that it appears moving towards the viewer and appears to fly over or to the sides of the eyes of the user.

One ball is generated to be continuously moving from the center to either the left or right side of the screen. There are three main parameters of ball movement: direction, angle and speed. The direction of movement and its angle is assigned to the ball in a random manner. However, the speed is fixed to a certain value during the whole test. **Error! Reference source not found.** show screenshots of the application while the ball is moving in both directions.

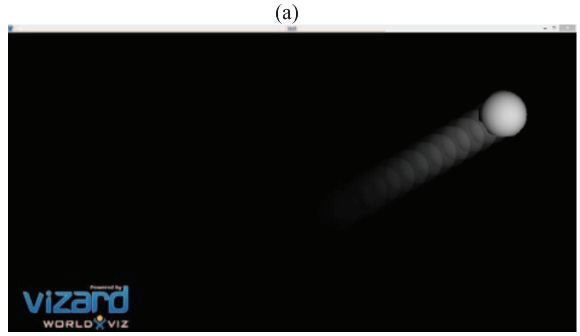
This specific setting was designed for the case being presented in this work in which case, the targeted muscle was the frontalis muscle which can be easily excited by the eye movement looking high above or to extreme sides. Similar applications can be appropriately generated further in order to excite specific muscles. For instance, for quick impulsive hand movements applications such as catching a ball or to stop a falling object, or blocking a punch, etc… can be easily made.

C. Hardware Details

The HMD system in Figure 1 is further added upon with the EMG signal acquisition system comprising of standard 3-EMG probes, one signal amplifier module [17] and a standard low-cost Data Acquisition module (NI USB-DAQ 6008) [18] into the main application environment of LabVIEW [19].



(a)



(b)

Fig.2. Screenshots of ball movements from the VR program

Figure 3 shows this experimental hardware. In its very basic form, this system does not cost more than a few tens of dollars and can be further reduced in cost by using alternate DAQ device. In LabVIEW, the main functionality is related to a continuous sampling and storage of the data coming from the EMG amplifier module. Essentially, any data-logging system can perform this task. The obtained data files are then analyzed against the actual true impetuses given to the patient in terms of ball movements. Similar actions are compared before and after the VR based exercise sessions to see the improvements.

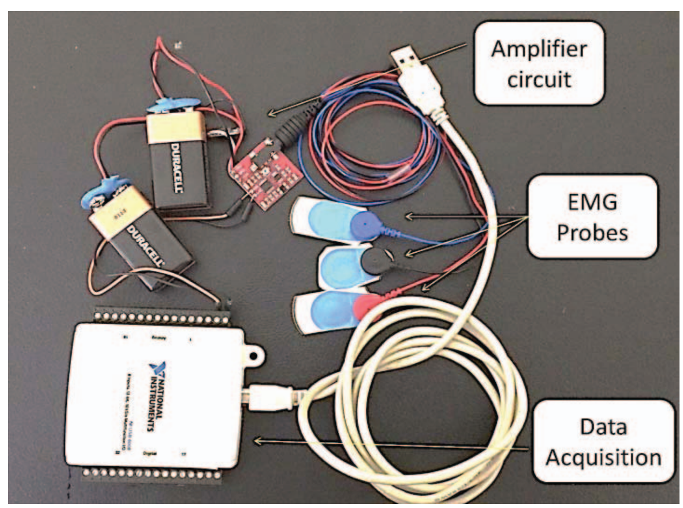


Fig.3. The experimental hardware used in this work. The DAQ module was connected to the PC using USB port

IV. TESTING AND RESULTS

A person with frontalis weakness due to Bell/s palsy was selected for a crossover study with and without VR. In the first phase the subject was given an eye brow elevation exercise program using the ball-following routine with the HMD system for five days with thirty repetitions for a day. EMG data from the frontalis muscle was recorded during the exercise and the same was used to count the receptions. The subject was given rest for five days and then was allowed to interact with the VR interface again and then a new set of readings were obtained. The immersive type of VR was applied through a portable head mounted devise which generates unpredicted and challenging impulsions that is capable of activating the muscles around the eyes including frontalis. The EMG activities where taken before and after the interventions for comparison and analysis. It should be highly emphasized at this point that the ball-movement routines generate extremely realistic ball throw actions from the center of the scene in any direction (left or right of the eyes either going up or down). Since the pattern of these movements is not known, the brain tries to push its channels into grasping any similarities present therein by forcing the inactive muscles into some movements. We do believe that if this is continued for a given period of time, the same forcing implemented by the brain could become permanent (plasticity) and the normal actions of the muscles will be restored, although, now they are being controlled by a different part of the brain as they were before the paralysis happened.

The above mentioned data was collected and analyzed with the actual ball movements as the truth class. Due to the randomness in the program, it was quite a bit of work before somewhat similar pattern was identified and data was compared based on that. Figure 4 shows such a comparison. The actual movements of the ball were not 'exactly' the same but somewhat similar. The main difference was in the delay between the balls which was also random. The directions were similar as far as coarse Left or Right was concerned. However, their angles were not quite the same due to the randomness, although they were quite closed to one another. Thus, a somewhat fair analysis in terms of comparison became possible and that is presented below.

In order to perform quantitative analysis on the above data, following statistical features were calculated:

1) Mean Energy: This was selected in order to see over all muscular effort being put in a window of 10000 samples from each signal (x).

a) Calculated as $F1 = \sum_{k=0}^{n} x^2$

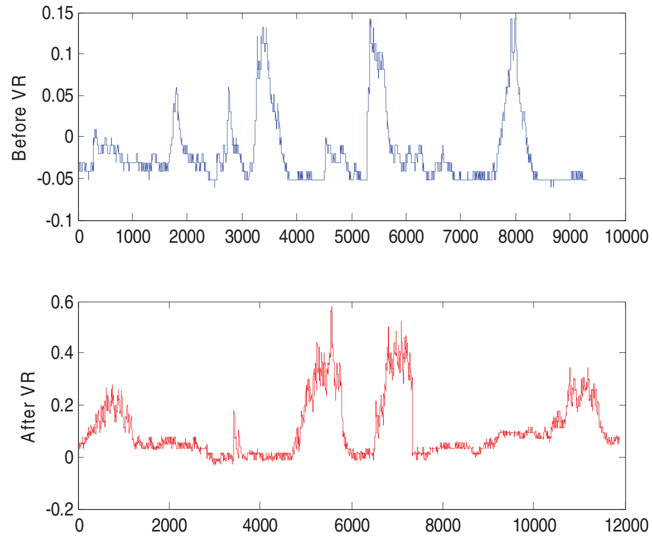


Fig.4. EMG data from the two experiments. Before starting the VR based exercises (above) and after doing the exercises for a week (below) for a similar pattern showing Left-Right-Right-Left-Left-Right-Left pattern

2) Variance: This was selected so that an estimate can be made in terms of the speed of the muscular movement can be made since a larger variance would mean a slower response for a given period of time.

a) Calculated as $F2 = \sigma = \frac{\sum_{k=0}^{n}(x_k-\mu)^2}{n-1}$

3) Skewness: This was selected since it can provide a measure of symmetry. A less symmetric value will have a higher Skewness.

a) Calculated as $F3 = \frac{\sum_{k=0}^{n}(x_k-\mu)^2}{(n-1)\sigma^3}$

4) Kurtosis: This was selected so that a response speed estimate can be obtained in terms of attaining peak values. A higher value of kurtosis represents a peaked data while a smaller value would represent a flatter data.

a) Calculated as $F4 = \frac{\sum_{k=0}^{n}(x_k-\mu)^2}{(n-1)\sigma^4}$

5) Histogram: This measure was selected in order to get an estimate of whether a set of peaks represent erratic pulses or a smoother distribution representing a more controlled movement of the muscle.

An average of several 10000-samples windows is shown in Table 1 and Figure 5.

TABLE I. STATISTICAL FEATURE VALUES FOR THE EXPERIMENTS

	Before VR	After VR
Mean Energy	19.7770	276.9466
Variance	0.0018	0.0126
Skewness	1.9437	1.4045
Kurtosis	6.2106	4.2700

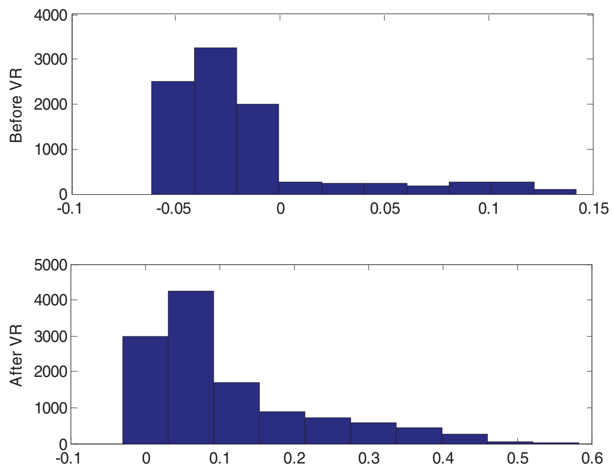


Fig.5. Histograms for the case shown in Figure 4. (above) before applying VR-based exercise, and (below) after the exercise was done

As can be seen that the post-therapy values comply quite nicely with the ideal standards mentioned above. The positive result obtained in the activation of frontalis muscle compared to a control program encourages for higher quality trails to prove its efficacy so that it can be a valuable adjunct in rehabilitation of various neurological dysfunction where one have to focus more on selective movement or muscle facilitation. The rationale behind this improved muscle performance may be beyond the scope of this paper. But an attempt to outline the possible mechanisms is conceivable.

Here we propose VR as a specific paradigm for movement facilitation that is currently applied generally for neurorehabilitation. We believe that this concept will smoothly generalize to address other deficits of the skeletal-motor system resulting from CNS lesions and possibly more. We are currently developing new training protocols for rehabilitation in clinics and for continuous long-term at home diagnostics and training that will allow us to directly validate these assumptions. We believe that the amalgamation of relevant features of the VR makes it a valuable rehabilitation tool. The impact of VR is currently the focus of studies with both acute and chronic patients and preliminary results support this belief.

V. CONCLUSION

The Virtual Reality technology used in this trial may be a stepping stone for further higher quality studies and to implement training protocols in order to provide neurorehabilitation training that allows for a gradual and individualized treatment neurological dysfunctions. we expect that this study may facilitate longitudinal clinical studies with specific muscular and movement dysfunctions in both acute and chronic stages. These results will be useful for creating new virtual reality software applications that will encourage activation of facial muscles following a neurological impetus.

A novel VR based paradigm for neurorehabilitation has been introduced in this paper, which combines specific rehabilitative principles to provide a personalized and automated training following facial palsy. This study may facilitate longitudinal clinical studies with specific muscular and movement dysfunctions in both acute and chronic stages.

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