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PREVENTION & REHABILITATION: Case Report

The role of EEG and EMG combined virtual reality gaming system in facial palsy rehabilitation - A case report

Uvais Qidwai [a], M.S. Ajimsha [b, *], Mohamed Shakir [c]

[a] KINDI Lab for Computing Research, Department of Computer Science & Engineering, Qatar University, Qatar
[b] Department of Physiotherapy, Hamad Medical Corporation, Qatar
[c] Learning and Development, Qatar Airways, Qatar

A R T I C L E I N F O

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A B S T R A C T

Background: The recovery rates for facial palsy are usually excellent; however, regularly patients present with problems with their fine facial movements that affect their emotional expressions.
Objective: To discover the viability and ease of using an Electroencephalogram (EEG) and Electromyography (EMG) combined Virtual Reality (VR) gaming system – the 'Oculus Rift' device in the evaluation and rehabilitation of facial palsy.
Design: Single case study.
Patient information: A young 23-year-old female with facial palsy.
Clinical findings: Most of the patient's facial features were re-established within the recovery time frame, except for her right forehead and eyebrow movements.
Intervention: A 10 day exercise program (Day 2–11) with an immersive virtual reality device, which randomly shoots virtually animated white balls in an unpredictable and testing pattern.
Outcome measures: EEG and EMG patterns corresponding to the facial upper quadrant were taken at baseline, post-intervention, and at follow up.
Results: EMG and EEG investigation revealed a progressive improvement in the muscle activation in response to the impulsive and unpredictable activities in the virtual environment provided through the immersive VR device.
Conclusion: The case report found a positive relationship between VR, facial upper quadrant EMG activation and EEG pattern changes following the intervention.

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1. Introduction

Human facial expressions provide a wellspring of data about a person's psychological, emotional and neuro-physiologic status. An inability to form facial expressions is an upsetting condition, both functionally and aesthetically. Peripheral facial palsy occurs as a result of a lesion in the seventh cranial nerve (Lorch and Teach, 2010). This is clinically distinct from central palsy in light of the inclusion of the facial muscles encompassing the eye (Peitersen, 2002). In peripheral lesions, the frontal branches of the facial nerve are impaired, though in central lesions the forehead can still be focally innervated ipsilaterally and contralaterally (Beurskens and Heymans, 2004).

Facial palsy is a relatively common condition that affects people across the age and gender spectrum, with an incidence rate ranging from 11.5 to 53.3 per 100,000 in different populations (Brandenburg and Annegers, 1993; Katusic et al., 1986; Monini et al., 2010; Rowlands et al., 2002; Tsai et al., 2009). The lifetime prevalence rate fluctuates because of the great prognostic variables, and ranges from 500 to 800 cases per 100,000 people aged 15 years or older (Yetiser et al., 2003; Savettieri et al., 1996; Rowlands et al., 2002).

Over 80% of patients with facial palsy recover to a satisfactory degree; however, roughly 17% of patients display mild dysfunction (UMMC). With inappropriate treatment, patients may suffer from inadequate recovery and contracture, hyperkinesis or synkinesis; the latter can vary between 1.7% and 42% (Shafshak, 2006). In spite of the considerable effect that facial palsy has on quality of life and daily function, there is no solid, established strategy for estimation and activation of facial movements.

* Corresponding author.
E-mail address: ajimshaw.ms@gmail.com (M.S. Ajimsha).

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Virtual reality (VR) has now emerged as a promising tool in many domains of therapy and rehabilitation (Weiss and Jessel, 1998; Glantz et al., 2003; Zimand et al., 2003; Rizzo et al., 2004). Advances in low cost VR technologies have reinforced the development of more functional, convenient and accessible VR systems that can target a wide range of physical, psychological and cognitive rehabilitation concerns and research questions. Current VR systems offer methodical human testing, training, and rehabilitation through precise control of complex, immersive, dynamic 3D stimulus presentations with endless opportunities for refined interaction, behavioral processing, tracking, and outcome measurements. When combining these assets within the context of functionally relevant, ecologically enhanced Virtual Environments (VE), fundamental advances could be made to address the rehabilitation of human functions across many disciplines (Merians et al., 2006).

Despite the fact that the recovery rates following an onset of facial palsy are very high, patients often complain about their inability to execute certain fine movements such as eyebrow elevation, frowning, and so forth; expressions often associated with specific emotions. In a study by Coulson et al. (2004) 50% of facial palsy patients found themselves less effective in the facial expression of emotions. This area is often neglected in patient care but is an important factor as far as quality of care is concerned. To enhance management of emotional expression in patients with facial paralysis, a broader approach is recommended, linking the rehabilitation goals with patient-centered outcomes. We believe that the VR system has a positive effect on this aspect by considering a noteworthy issue which has been largely neglected in mainstream care until recently. A detailed web search failed to identify studies on VR and facial palsy and the use of EMG and EEG as outcome measures.

1.1. Patient Information

The procedure outlined in this report was tested on a young female subject of 23 years old with facial palsy that occurred approximately 6 months prior to the therapy.

1.2. Clinical findings

Most of the facial features had been restored during the recovery period, except her right forehead and eyebrow movements, thus affecting her facial expression. This was the patient's primary concern.

1.3. Intervention

Following ethical approval granted by the Medical Research Center of Qatar University and informed consent from the patient; a 10-day exercise program was introduced through the 'Oculus Rift' immersive VR headset. A software program that can arbitrarily shoot virtually animated white balls in an unpredictable and challenging pattern was created for this purpose. The aim was to virtually activate facial upper quadrant muscles including the frontalis muscle. The patient's task was to actively follow the moving balls in a 'flyover' fashion with random speed, frequency and direction (medial or lateral deviation) in the VR environment. The exercises were paced with a 30s gap for every 1 minute of VR training, to produce an overall 5 minutes of cumulative training per day. The training was conducted in the morning straight after waking, under the supervision of a research team member in the patient's home. A dosage of five minutes of VR training for 10 days (day 2–11) was decided in order to keep the dosage as low as possible for an effect so that future dose-response studies could be attempted. The participant's feedback and adverse events, if any, were recorded. Before the study, an activity chart for the patient was prepared for a month, with a daily activity frame to be followed during the case study time. This was done in order to avoid any possible extra stimulation to the patient's facial muscles other than the routine work. The patient was advised to avoid computer games, facial exercises and activities which might cause emotional changes during the study time.

EEG signals from the concerned area of the brain (contralateral M1) and EMG patterns of the facial upper quadrant muscles were recorded as the outcome measures on the first day (baseline), 12th day (post-test) and a month after post-test (follow-up) of the test by using the Emotiv EEG headset, EMG sensors, and by incorporating progressive measurement technology. Both the EEG and EMG signals of the patient were stored in the computer via data acquisition process. The acquired signal was then analyzed using MATLAB in order to follow trends in the improvement, stage after stage with the VR device. To further understand the improvement in the patient's condition, the EMG was modified slightly to change the level so as to fit near the eye muscle zone.

1.4. The VR environment description

In this work a hybrid technique was proposed that utilized the powerful VR interface with the external impulsive impetus, based on an assumption that it could trigger some neuroplastic changes in the brain. The evaluation was made through EMG and EEG analysis. The use of EMG-based muscular detection systems and EEG patterns is uncommon in this area, but its use in Human Computer Interaction (HCI) studies was used as the reference (Qidwai and Zahid, 2014). The proposed platform could be a very valuable research tool since it could enhance the study of patients with neurological dysfunction and its effect on the recovery period.

The system (Fig. 1) consists of three segments:

a. Virtual system
b. Data acquisition system
c. Data processing unit.

The purpose of the virtual system was to sense and act in a virtual environment. This system consisted of 3 subsystems: the Oculus Rift headset, an EEG sensor and an EMG sensor (Fig. 1). These devices/sensors were used to simulate and monitor simultaneous EEG and EMG activities of the patient's brain. As the user's eye tried to follow the specific type of impulsive movements seen in the Oculus Rift device, the muscular movements were detected by a set of three EMG sensor probes placed just above the eyebrow with a reference probe placed on the cheek, near the ear. An EEG probe was applied to the scalp to pick up the EEG signals. The signals from the EEG and EMG sensors were then acquired using the data acquisition device. This signal was fed to the algorithm which detected changes in the patient over time in both real-time and offline mode. Once the data were processed by using fuzzy logic, human heuristics, and data mining analysis, the system was able to plot the trend of changes or deviations of the measured parameters. These data were then stored for further analysis.

This device used a three Degrees of Freedom head tracker that is normally 250 Hz with a special algorithm embedded in it; the tracker latency was less than 20 ms - a vital issue due to the dependency of virtual reality's realism in response time. This device used a combination of 3-axis gyros, accelerometers, and magnetometers, which made it capable of absolute (relative to Earth) head orientation tracking without drift. A dial on each side of the headset allowed adjusting each display closer or further away from the eyes. The development kit also included interchangeable lenses that allowed simple dioptric correction.

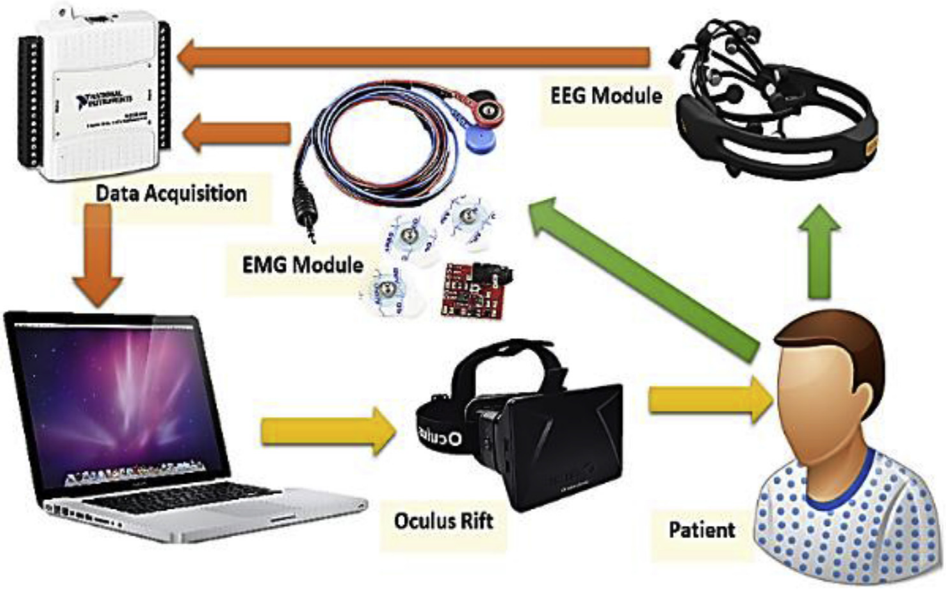

Fig. 1. Overall block diagram of the System.

The software User Interface (UI) for the Oculus Rift used the Python programming language. The main task of this software was to animate a white moving ball which moves towards the patient from different angles so that they can track the ball moving along. In this way, the signal was acquired and it was possible to evaluate the EEG and EMG signals from the client in real-time. Initially, the ball was positioned in the center of the screen. Then, it was moved either left or right continuously for a certain amount of time. The movement of the ball was controlled by three main parameters: direction, angle and speed. The first two parameters were set randomly with a predetermined seed value in order to preserve the same pattern. However, the speed remained fixed during the test. Fig. 2 shows some of the screenshots of the interface.

Whenever there was eye movement activity to trace the balls generated by the Oculus Rift, the EMG sensor picked up the activity in real-time and was synchronized with the EEG activity of the brain. In the system, EMG data were used for classification of prehensile EMG patterns. After feature extraction, the adequate control signals were generated, and these acted as a classifier for the algorithm. The device captured the EMG signals from three skin surface electrodes. The EMG sensors were used directly with a data acquisition device. The bioelectrical activity inside the frontalis muscle of the client was detected with the help of these electrodes.

The second type of measurement was done using EEG probes. An 'Emotiv EPOC EEG' research headset was used to acquire the EEG signals in this case study setup, in order to identify specific signatures for particular emotions, feelings or commands in real-time to classify those brain patterns. The advantage of this system was that all the filtering and preprocessing was done by the main sensory unit, the Emotiv headset, and the accompanying software interface. Fig. 3 shows the user interface for this system featuring various sensor probes as they were placed in pre-defined places on the skull, and corresponding EEG waveforms.

The tapped signals in different condition sets were exported to an excel file and sent to the DAQ data analysis in LabVIEW software and the development platform. This simple Virtual Instrument is shown in Fig. 4.

The measurement of EMG and EEG data was taken on the 1st day (baseline), 12th day (post-test) and a month after post-test (follow-up) by using the Emotiv EEG headset and EMG sensors. The tests were conducted at specific times (immediately after waking), with the same experimental settings and with the same variables in the virtual environment (VE). The testing comprised of 3 phases. Phase I was the reading taken with the patient's eyes closed while inside the headset for a duration of 10 seconds. In phase II, the patient kept her eyes open but without following the random balls in the VE. The duration was again 10 seconds. Phase III was for 30 seconds where the patient had to actively follow the random balls in the VE along with attempted eyebrow elevations. The three phases were separated by a gap of 1 minute each. The readings were then analyzed for results.

1.5. Data analysis

The challenges in analyzing the acquired data were primarily the comparison of different type of source signals. We have utilized multiple procedures to minimize these discrepancies, so that the readings of EEG and EMG could be aligned as perfectly as possible.

An attempt was made to provide a 'constant testing environment' for the patient. This included the test time, duration, sleep time, computer usage etc, to ensure that the modifiable external factors in the tests were either standardized or controlled to a certain extent so that the artifact readings were similar and thus cancelled in successive tests.

1.5.1. Quantitative measures

Once the EMG and EEG signals were isolated, comparisons were made in terms of improvement or changes in the responses. The task measured the EMG and EEG patterns in the predefined time to note any changes which were attributed to a positive outcome compared to the activity before the treatment.

The simplest form of the comparison analysis examined signal magnitudes. An increase in the pulse magnitude indicated an improvement in the signals. This was calculated for both EEG and EMG waveforms using the following general formula:

$$PI = \frac{P_k - P_{k-1}}{P_k} \times 100\%$$

where PI is the Pulse Increase in the corresponding peaks (P_k) at

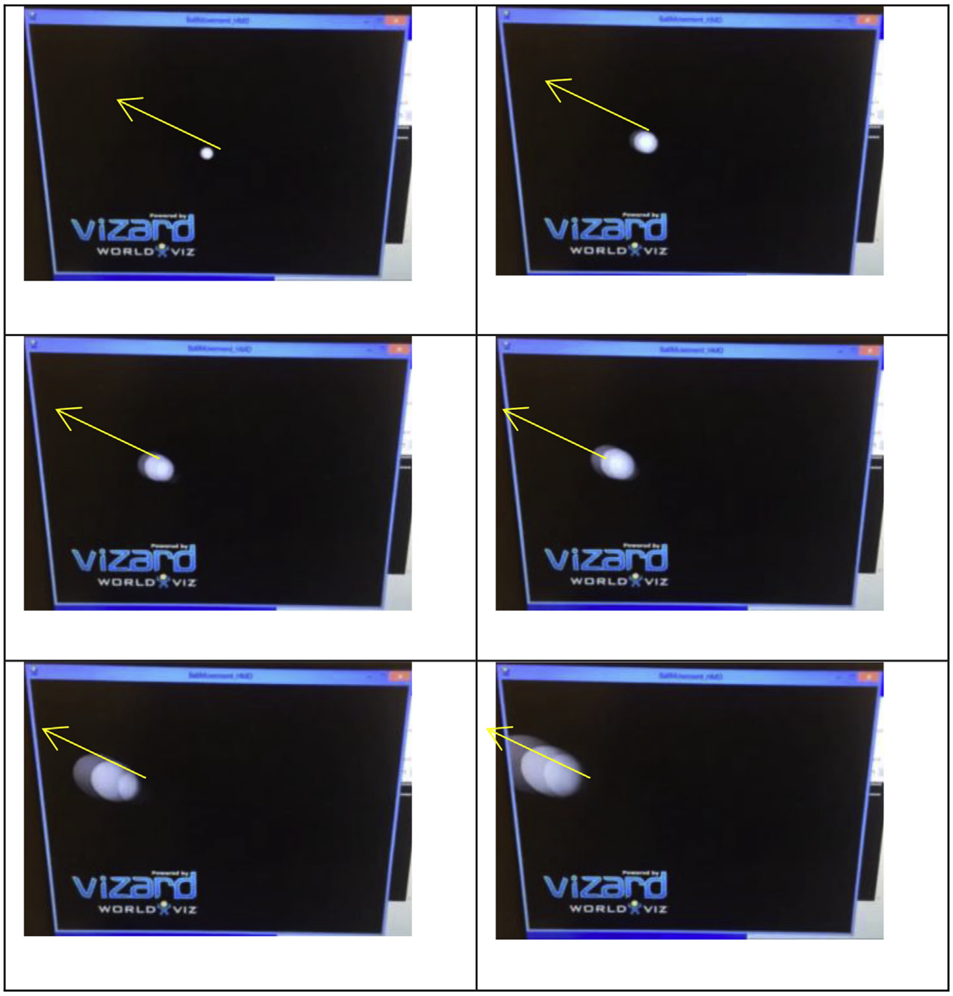

Fig. 2. Various frames of the captured video. The sequence (top left to bottom-right) shows a sudden moving ball in the direction indicated by the arrow.

instance k and (P_{k-1}) at instance k-1 respectively.

A comparative analysis was done by using the percentage change measures by:

$$PC_m = \frac{PI_m - PI_{m-1}}{PI_m} \times 100\%$$

where PC_m is the Percent Change in the relative pulse increase. To normalize EEG and EMG, overall amplitude has been changed by a fixed amount to reach a target level. It did not affect the dynamics of the waveform but simply changed its amplitude. This helped to classify the signal easily.

2. Outcome

After 10 days of therapy in which the random, impulsive 3D patterns were used to retrain muscle activity in the forehead, the patient was able to move the affected muscle with more control, at will. The same conclusion was obtained through the quantitative analysis of the EMG as well as EEG measurements. From the EMG signals, an average 65% increase was observed by applying Equation (2) to various positive peaks and then averaging them out. For the EEG patterns, it was quite evident that the major change was observed at contralateral probe F7 which probably corresponds to the contralateral M1 area, the area that controls the facial expressions that this study focused on (Korb et al., 2008).

As can be seen from Fig. 5, initially there was not much improvement for similar activities in the F7 area. This figure shows the three EEG readings, and Fig. 6 shows the corresponding EMG waveforms. However, the post-test reading revealed a substantial change which persisted even in the follow-up.

The overall gain in the amplitude of response from first to third reading was approximately 92%, strongly suggesting that the procedure was able to produce positive changes in the muscular and neuronal activity of the affected region and its surroundings. This was an assumption based on the current finding, but to prove this definitively higher quality studies with more sophisticated systems are recommended. The low cost and portability were an added advantage of this technology.

3. Discussion

This case study explains in detail a VR specific paradigm and its methodology for movement facilitation that can be applied for neuro-rehabilitation. The rationale behind this improved muscle performance may be beyond the scope of this paper. Nevertheless, an attempt was made to outline the possible mechanisms by exploring the current literature.

Klingner et al. (2012) measured the alterations of brain structure and functional connectivity during facial palsy by MRI and found morphometric alterations in the M1 area contralateral to the

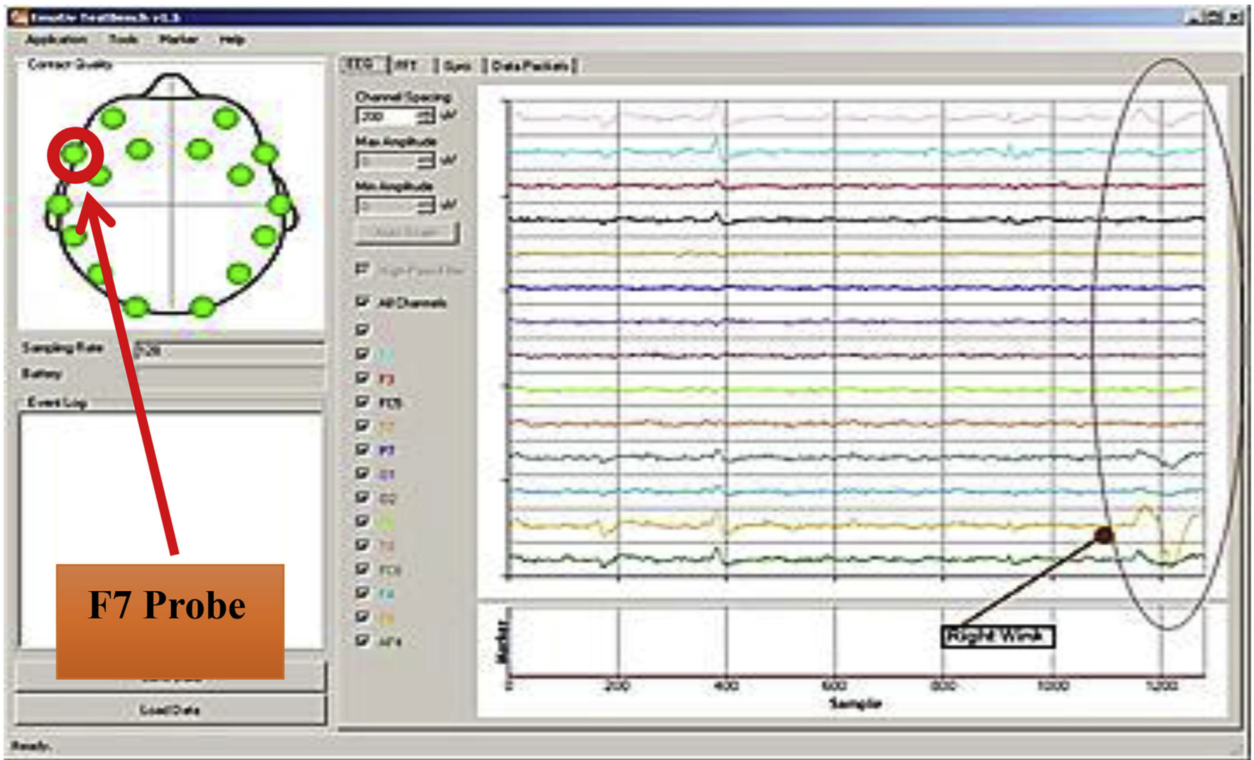

Fig. 3. EEG Data Acquiring software shows the activity of right eyeball movement using the EPOC Research SDK. The main EEG readings were taken from F7 probe as indicated by the circled and marked area.

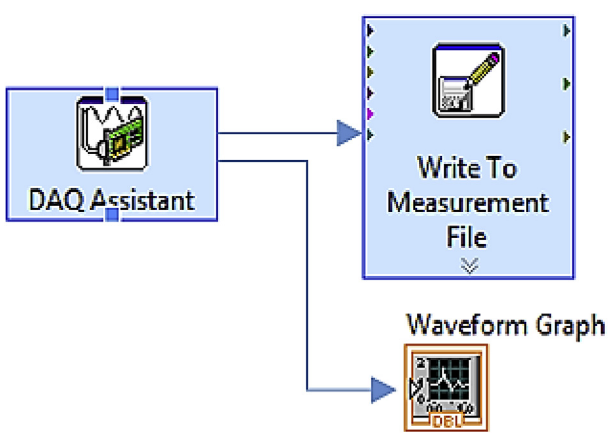

Fig. 4. Data acquisition VI in LabVIEW-Block diagram.

paretic side. He concluded that the recovery from facial nerve palsy was complemented by cortical reorganization. In another study, Svensson et al. (2006) found that one hour of tongue-task training was positively associated with corticomotor excitability. Multiple animal studies also revealed the same with motor skill training (Sessle et al., 2007; Sessle et al., 2005; Martin, 2009). Thus, it is evident that rehabilitation training can bring about cortical structural changes following facial palsy.

Most of the literature on M1 neuroplasticity and motor control suggests the latter possibility and supports the view that M1 neuroplasticity reflects dynamic, adaptive constructs responsive to changes in the sensory environment (Muellbacher et al., 2001; Ioffe et al., 2004; Koeneke et al., 2006). A VR program with an unexpected and challenging environment can provide such dynamic stimulation for optimum cortical plasticity, which may be the reason behind the improvement shown in the EMG and EEG analysis.

Here we propose VR combined with EMG and EEG sensors as a specific paradigm for movement facilitation following facial palsy. The introduction of low-cost VR, EMG and EEG devices can redefine the process of neurorehabilitation and more objective measurement options to record the progression/regression. 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, home and hospital-based testing 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 many studies and preliminary results support this belief (Cameirao et al., 2008, 2009).

Using external influences for neuroplasticity has formed an approach used in many psycho-physical treatments (Kempermann et al., 2000; Joseph, 1999). This includes medicines, physiotherapy, repeated movement therapy, assisted movement therapy, and other psychological treatments. It can be proposed that the combined use of VR, EMG and EEG can facilitate the rehabilitation process and divulge the neural and muscular changes associated with it. 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.

The novel virtual reality technology combined with EMG and EEG used in this report may be a stepping stone for further higher quality studies and the implementation of training protocols to provide neurorehabilitation training that allows gradual and

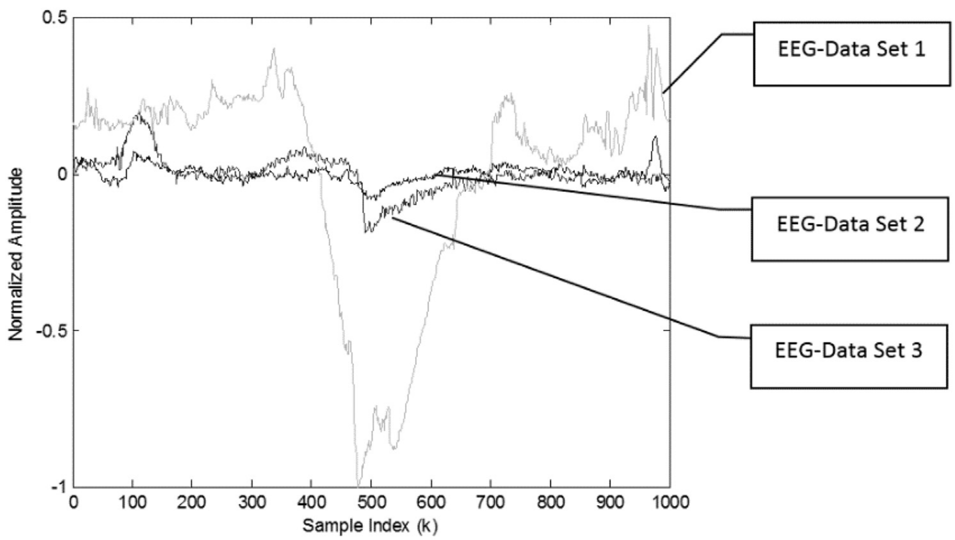

Fig. 5. EEG waveforms from the three tests, (Data Set 1[pre-test], 2[post-test] & 3[follow-up]).

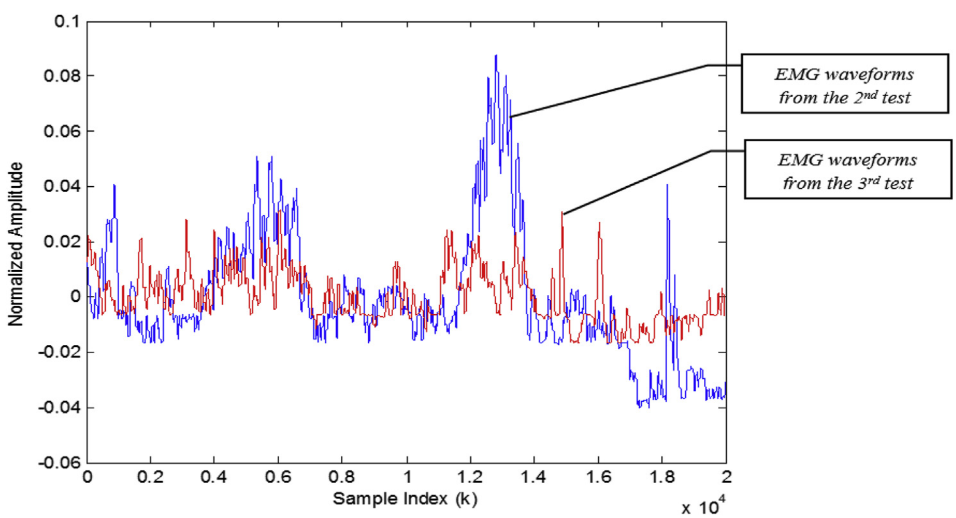

Fig. 6. EMG waveforms from the 2nd and 3rd tests, (Red and Blue respectively). The original signal before the start of therapy was almost non-existent. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

individualized treatment for neurological dysfunctions. These results would be useful for creating new virtual reality software applications that will encourage activation of facial muscles following a neurological impetus.

The tested device was able to provide a customised and automated training following facial palsy adhering to the principles of neurorehabilitation. We expect that this study may facilitate longitudinal clinical studies with explicit muscular and movement dysfunctions in both acute and chronic stages.

Conflict of interest

- o All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.
- o The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript

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