Emotional stimulation during motor exercise: An integration to the holistic rehabilitation framework

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Abstract— **Over the recent years, plenty of studies have been carried out concerning disabilities and rehabilitation. However, very few of them have focused on proposing or creating a holistic framework meant to maximize the merits of rehabilitation treatments. More importantly, an even smaller number has taken into consideration the immense impact of emotions and the crucial role they display concerning patients' performance during rehabilitation. The purpose of this study is to examine and highlight the direct connection of patients' performance quality with an artificially induced positive or negative emotional state. For that reason, we conducted an experiment regarding the convergence of emotions with the motor exercise. Specifically, our study was conducted with 45 participants and the GAPED database was employed as an emotional classifier. The effect of the visual stimulus was combined with a simple bicep exercise which introduces the motor element in our study. Statistical analysis of the yielding EMG & Acellerometer signals demonstrated a considerable difference in the quality of the physical activity of each subject induced by different emotional triggers. As a result, it is pivotal to integrate a holistic approach to rehabilitation in future clinical trials, aiming to reinforce the patient involvement and engagement process and thus the efficacy of the treatment.**

I. INTRODUCTION

Rehabilitation is an apt description of all tasks and assistive devices or environmental adaptations involved in neutralizing the effects of occurrences such as a stroke, an injury, traumas, diseases (e.g. multiple sclerosis), disorders or other circumstances, such as genetic disposition affecting physical or cognitive abilities [1], [2]. Rehabilitation is the term covering multiple types of medical or physical tasks a therapist can choose from or combine to counteract the negative results of the above-mentioned instances by developing, improving or regaining maximum functioning [1]–[4].

Even though statistics are specific when it comes to disabilities with around 15% of the world's population living with some form of disability [2], very little data can be found on the effectiveness of rehabilitation the main reasons being the lack of rehabilitation professionals and the deficiency in providing this service to people with disabilities [5]. Data has shown that only 26-55% of people in four Southern African countries receive medical rehabilitation [5] making it extremely difficult to come to valid conclusions on how best to apply rehabilitation, when and with what results. According to the WHO disability report, rehabilitation programs may be lacking in coverage, effectiveness and efficiency and need to be reviewed [5]. Reports on disability show a 12.8% increase in the US [6] and interest in the healthcare system of developing countries has produced an increase in data in regards to disability and the rehabilitation process; for example, in South Africa or Uganda the incidence of clubfoot is 1.2 per 1000 live births with treatment leading to positive outcomes in 98% of the cases after the implementation of the 'Ugandan Sustainable Clubfoot Care Project'[5]. This increase leads to the conclusion that the needs and unmet demands in the rehabilitation field will increase as well [5].

The need for a better rehabilitation strategy has led to the emergence of new evidence-based concepts that include systems biology combined with several types of interventions, such as meditation or mental and physical training [7]. Other research has found that cross-disciplinary collaborations forming an integrated strategy, as well as the formation of multidisciplinary or interdisciplinary teams are a more effective approach, and this approach has become a central tenet in high-quality rehabilitation [7], [8]. Thereby, the concept of a holistic framework has emerged to improve the efficiency of the treatment through a dynamic therapist-patient relationship, enhance the individual's self-management and decision-making skills to increase engagement, and also increase the desire to access assistive technologies, thus reducing visits to rehabilitation institutions and minimizing the cost of the entire program [9]. Literature defines holistic rehabilitation as "the combination of physical, psychological, social, emotional, and motivational rehabilitation" [9], which is in alignment with the principles of the International Classification of Functioning, Disability and Health (ICF) [10] proposed by the World Health Organization [2]. This is also referred to as the holistic bio-psycho-social rehabilitation model, and it supports the need for the individual to be involved in order for the rehabilitation to be effective [9].

However, even if cost and accessibility seem to be the leading causes of the high dropout rate [2], [8], [11] another key reason for that has been the absence of a holistic

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framework in most rehabilitation programs. To date, what have been measured in rehabilitation are the individual's impairment level, individual activity and participation outcomes [5]. This focus simply enhances the creation of activity-based programs, and even though engagement over the past few years has been an important feature in recent studies, the outcomes stated make no reference to the emotional state of the patient, or the mental consequences of their trauma and the influence it has on the treatment process. Engagement focuses more on providing a gamified methodology, in order to keep patients focused on therapy, rather than focusing on the impact of individual emotions and how they are demonstrated through behavioral patterns during therapy. Indeed, exercise has been researched as a successful form of intervention in most neurological disabilities such as Parkinson's Disease and in TBI (Traumatic brain injury) [12] and in disabilities caused by injury. In most cases, the emotional response to injury or the emotional rehabilitation have been researched, primarily leading to the application of rehabilitation in two distinct phases, that of emotional rehabilitation and then of physical rehabilitation [13]. The study of triggering emotion while the patient is performing an activity to record how various emotions affect the outcome of rehabilitation is what we decided to focus on. More specifically we aim to examine specific emotions and how these may affect, and to what extent, the rehabilitation process.

Consequently, in this study, our hypothesis is to find correlations between the execution of the motor-exercise and the emotional state of the patient during the session. In particular, we worked with a number of volunteers and separated them into groups. During the rehabilitation sessions, each group was presented with different visual stimuli while performing a specific motion enhancement task. Simultaneously, physiological signals of the participants were measured to find those possible connections. In this study, we observed the aforementioned hypothesis by executing a one-arm concentration (bicep) curl and focusing on strengthening the Upper-Limb. This exercise was chosen from the Taxonomy of Tasks [14], [15] as a key motor-training exercise. The Taxonomy defines such exercises which help patients in rehabilitation perform a specific task that would improve their motor status.

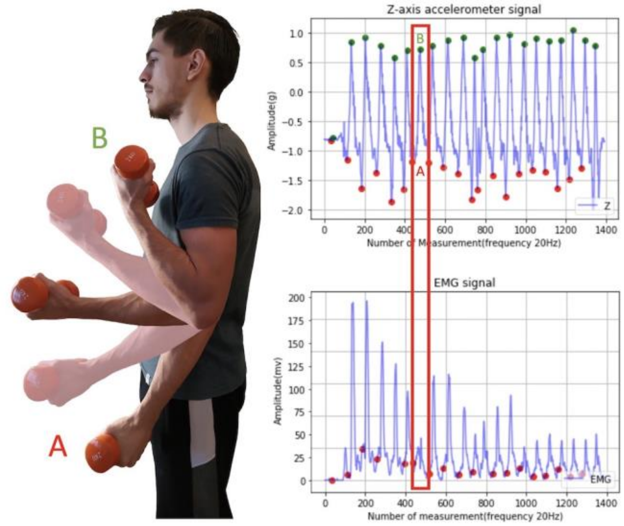


Figure 1: (a) – left: The bicep exercise demonstration, where Point A is the lowest point and Point B is the highest point. (b) – right: On the top is the Accelerometer signal, on the bottom is the EMG signal. The red rectangle demonstrates a full curl which corresponds to one full exercise curl.

II. System Description & Materials

A. Exercise

The exercise we chose for this study was the one-arm concentration (bicep) curl with 2Kg dumbbell. More specifically, in order to complete a full curl, the participant must initially have the arm pointing downwards and parallel to the body (Point A) according to (Figure 1-a), then move their arm in an upward motion until the forearm touches the bicep (Point B) according to (Figure 1-a), and finally return their arm to the initial position by moving it downward from (Point B) to (Point A).

B. Hardware & Software

The hardware used for monitoring the exercise is: An iMac desktop computer (CPU: Intel i5, RAM: 8GB, Video Output: HDMI 1.3 Ports: 3x USB 3.0), an Arduino Uno, a MyoWare

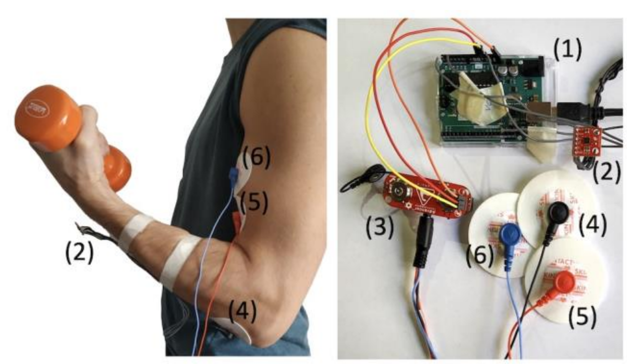


Figure 2: Hardware's placement on the user (a) – left: The placement over the participant. (b) – right: The Hardware used.

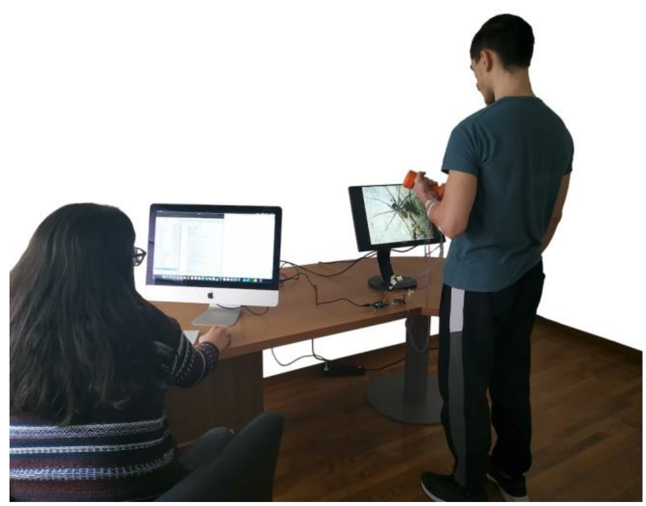


Figure 3: Demonstration on how the simulation is executed. The participant on the right side observes the monitor with emotionally charged images while executes the exercise and a prober on the right records the measurements.

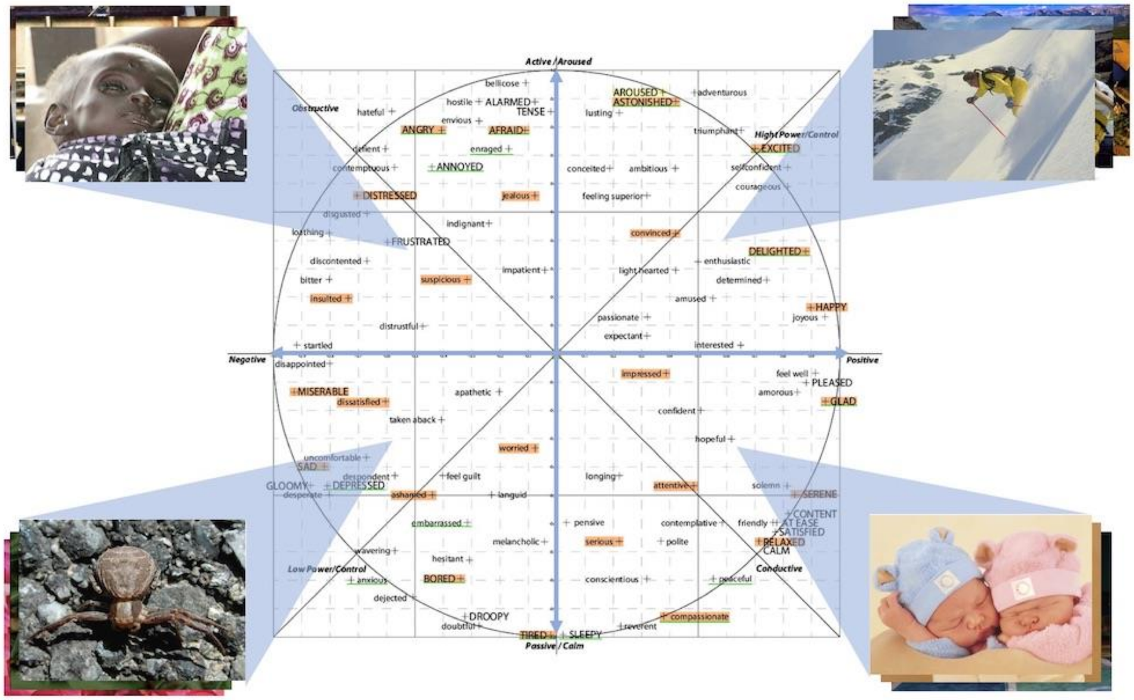


Figure 4: Circumplex Model of Affect. The 4 quarters with the pictures 4 emotion categories by the GAPED Database.

Muscle Sensor and a SparkFun Triple Axis Accelerometer Breakout (Figure 2). The electrodes of the Muscle Sensor are placed on the participant's bicep with the assistance of a gel depending on whether they are right- or left-handed (Figure 2-a). Concurrently, the Accelerometer is placed on the outside of their wrist on the same side as the Muscle Sensor (Figure 2-b). We used an Arduino licensed software as the measurement collection program (at 20Hz), and Python for data acquisition via the computer's USB 3.0 portal. The Arduino software communicates with the Accelerometer through the I2C protocol, whereas the Muscle Sensor's data is collected from Analog Pin A0; every fifty milliseconds we extract the data from both sensors and transmit them to our Desktop Computer. To process the data collected, we used a program called JupyterLab.

C. Monitoring

To observe the progress of the exercise, we used an Accelerometer and then evaluated the motion acceleration on the vertical z-axis. When the wrist is in Point A, the Accelerometer produces rates close to -1.5 (Figure 1-b), whereas in Point B its rates are approximately around 1. In Point A the absolute value of acceleration is bigger than the absolute value of acceleration in Point B. In Point A the acceleration of gravity is summed up with the acceleration of the arm. In Point B the gravity force is opposite to the acceleration of the arm. As far as the intermediate situations are concerned, where the arm rises and falls correspondingly, rates range between -1.5 and 1. With the assistance of the A accelerometer, we can monitor a full curl, and consequently divide the measurements taken from this curl into peak/valley segments. This distribution in segments (windows), along with the measurements from the Muscle Sensor, provides us with precise information on muscle force per full bicep curl.

D. Emotional Stimulation

In order to emotionally stimulate the participants, we displayed several images for them on a screen while they executed the exercise (Figure 3). The images used were taken from the 'Geneva Affective Picture Database' (GAPED), which relies on the Circumplex Model of Affect. The circumplex model of affect proposes that all affective states arise from cognitive interpretations of core neural sensations that are the product of two independent neurophysiological systems. This model suggests that emotions are distributed in a two-dimensional circular space, containing arousal and valence dimensions. The x-axis (horizontal axis) of the model is the continuum between emotions considered as pleasant and unpleasant, like happiness and sadness respectively. The y-axis (vertical axis) is the continuum between high and low arousal. In this model, an emotional state can be represented as either arousal or valence, or as a combination of arousal and valence levels (Figure 4).

The reason we chose and relied our database on GAPED is because it is an open and well employed database that everyone can have access to. The images classified in this database are characterized by great estimates and can stimulate their corresponding emotional response [16].

Our study focused on four groups of emotions, which can be found on every 4th quarter of the perpendicular bisector, so that a significant distinction between them is apparent. Specifically, we chose the following groups: a) Group 1, located on the top right-hand quarter which involved emotions such as Excitement and High Power; this group presented increased levels of both Arousal, and Valence as well, b) Group 2, located on the bottom right-hand quarter, which involved emotions such as Serenity and Tranquility; this group presented increased levels of Arousal but decreased levels of Valence instead, c) Group 3, located on the bottom left-hand

Figure 5: On the left is the EMG means from all the participants in each group, the values are measured to mV and the data are normalized. On the right is the dtCycle from the Accelerometer from all the participants in each group, the values are measured in multiples of 0.05 seconds.

quarter, which involved emotions such as Depression and Low-Energy levels; this group, on the other hand, presented decreased levels of both Arousal and Valence, and finally d) Group 4, located on the top left-hand quarter, which involved emotions such as Obstruction, Fear or Horror; group 4 presented decreased levels of Arousal but increased levels of Valence instead.

III. Method

For the purposes of our study, 45 men aged between 20 and 30 years old without any physical disabilities participated in one session trial; they varied from 1.68cm to 1.89cm tall and weighed between 65kg and 92kg. Due to the fact that the study of muscular activity can be altered by factors such as sex and body structure and strength [17], [18], only male participants with as few physical and physiological differences as possible were selected. Our main priority was to ensure a uniformity in our experiments and evoke specific behavioral responses excluding as many parameters as possible. All participants were recruited within the campus of the National Technical University of Athens, Greece. Each one of them participated in a 3-minute one session trial. Sessions took place at the premises of the Biomedical Engineering Laboratory of the National Technical University of Athens. During each session, participants had to perform the aforementioned bicep exercise 20 times, while several emotionally-charged pictures were displayed for them on a screen. This trial was approved by the Ethics Committee of the National Technical University with protocol number #7238.

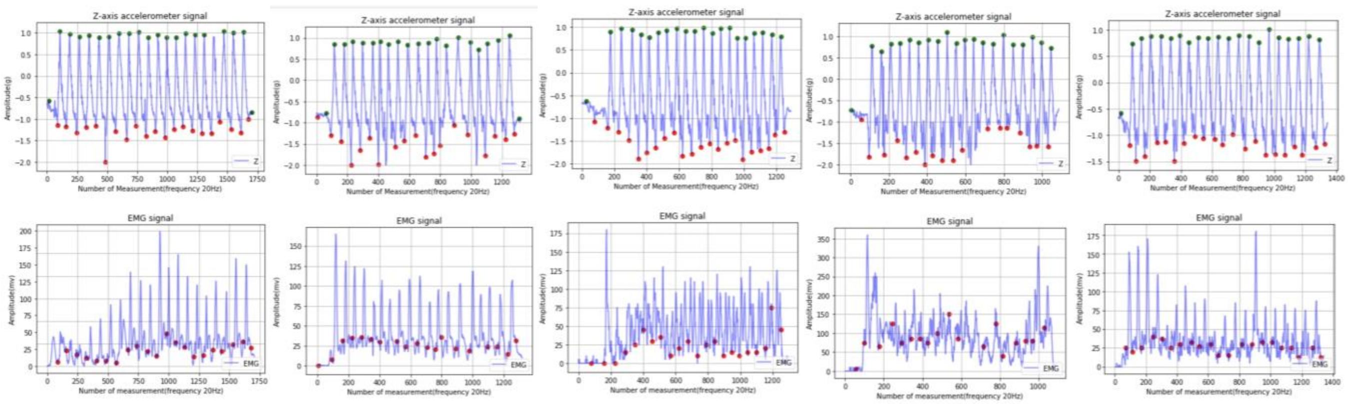
We divided our 45 participants and randomly placed them into 5 groups of 9 people. All of the participants, regardless of their group, executed the same exercise. The only difference was the pictures that were used, which conformed to the rules of the aforementioned circumplex model. More specifically, group A was presented with pictures from Group 1 (emotions of Excitement & High Power). Group B was presented with pictures from Group 2 (emotions of Serenity & Tranquility). Then, group C was presented with pictures from Group 3 (emotions of Depression & Low-Energy levels). Similarly, group D was presented with pictures from Group 4 (emotions of Fear & Horror). Finally, group E was not presented with any pictures; they simply executed the exercise.

A significant prerequisite for our experiment was that participants had to refrain from any intense physical exercise two days prior to their session. Moreover, participants were asked to avoid alcohol or caffeine 5 hours and smoking 1 hour prior to trial, and this due to the fact that those factors could affect the mental condition and the physical performance of the participants during the session [17]. Before each session, users were informed about the purpose of our experiment as well as instructions on how to perform the exercise correctly. In particular, the exercise they were requested to execute was the aforementioned bicep exercise. Participants were instructed to move their limb in a steady rhythm and avoid excessively quick (i.e. less than 2 second per each exercise curl) and slow (i.e. more than 5 seconds per each exercise curl) movements. Apart from this guideline, no further instructions were given about the timeframe of each exercise curl, since our main concern is to examine participants' reaction times and their physiological behavior based on emotionally laden stimuli. Finally, at the beginning of every session, participants had to complete 2 sets of repetitions, in order to familiarize themselves with the motion, and also for us to ensure that the sensors were working properly and producing the right measurements.

IV. Data Analysis

Because individuality is a big issue in EMG signals, we used a normalization technique before proceeding to feature extraction and its subsequent analysis. Regarding the muscle measurements, extrinsic and intrinsic factors have been found to affect the amplitude characteristics of the raw EMG, which were acquired by using surface electrodes. These factors include electrode application, perspiration, temperature, muscle length, cross talk from nearby muscle activity and subcutaneous fat thickness [20]. To achieve comparable measurements of muscle activity between different individuals and different time intervals, the EMG signal should be normalized [18]. In this study the normalization process was accomplished with the use of peak dynamic method, in which we acquire the max peak value of the EMG signal and then we divide this signal with the max value [19], [20]. Thus, we end up having normalized signals the values of which are between 0 and 1 (Figure 5). After completing the collection of data from all 45 participants and having normalized their corresponding EMG signals, we extract one feature and that is the mean value of each normalized EMG signal.

Whereas from the Accelerometer we obtained the mean value of duration per full curl (dtCycle) measured in multiples of 0.05 seconds (for example, if a participant has dtCycle = 70 then $70 * 0.05$ seconds = 3.5 seconds, so this participant has an average duration per full curl 3.5 seconds). As we mentioned in System Description, as full curl we define the



(a) (b) (c) (d) (e)

Figure 6: One randomly selected participant from each group. On the top are the Accelerometer graphs on the bottom the EMG graphs respectively from each group. Accelerometer horizontal axis: "Number of Measurements (frequency 20Hz)". Accelerometer vertical: "Amplitude (g force)". EMG horizontal axis: "Number of Measurements (frequency 20Hz). EMG vertical axis: Amplitude (mV). (a) group A (emotions of Excitement & High Power). (b) Group B was presented (emotions of Serenity & Tranquility). (c) group C (emotions of Depression & Low-Energy levels). (d) group D (emotions of Fear & Horror). (e) group E (no emotion stimulation).

time needed to move from point A to point B and then back to point A. The data we collected from users Accelerometer are presented in Figure 5.

For the statistical analysis, repeated muscle measures were compared with ANOVA among the 5 groups with alpha level set at a=.05. As far as muscle measurements are concerned, there was a significant difference among those 5 groups $F(4,40) = 13.302, \mathrm{p} < .001, \mathrm{n}^2 = .56$. The Post Hoc (Tukey) testing revealed significant differences between group A (Mean = .38 mV, SD = .051) and group D (Mean = .40 mV, SD = .036) compared to group B (Mean = .28 mV, SD = .040), group C (Mean = .29 mV, SD = .046) and group E (Mean = .30 mV, SD = .043). In particular, participants from groups A and D, demonstrated higher muscle force compared to those of groups B, C and E. Group A presented a 4% higher muscle force compared to the average of groups B, C and E, while group D presented a 5% higher muscle force compared to the average of groups B, C and E.

Regarding the Accelerometer and the dtCycle factor, there was also a significant difference among the 5 groups $F(4,40) = 37.62, \mathrm{p} < .001, \mathrm{n}^2 = .79$. The Post Hoc (Tukey) testing revealed significant differences between group A (Mean = 76.91, SD=3.47) and group B (Mean = 73.68, SD = 2.93) compared to group C (Mean = 66.54, SD = 4.29), group E (Mean = 63.33, SD = 3.90) and group D (Mean = 58.36, SD = 3.39). Participants from groups A and B took the longest average time to execute one curl compared to those in groups C and E, who took a shorter average time per curl; participants from group D took the least time in all of the groups to execute one curl. Group E demonstrated a 22% quicker execution compared to the average of groups A and B. Also, group D demonstrated a 10% quicker execution compared to the average of groups C and E. Finally, the average of groups C and E demonstrated a 13% quicker execution compared to the average of groups A and B.

The signal screenshots can be seen in Figures 6 a, b, c, d, e after a random selection of participants from each of the groups respectively. As we can observe in Figure 6-a, there is stability in the intensity of the exercise and the execution time comparing to Figure 6-d in which it is not clear when the muscle stretches and when is relaxes. The range of motion is clear in Figure 6-a, whereas in Figure 6-d the range of motion is interrupted, and the execution time is faster due to the muscle being in constant contraction status with minimal relaxation points. In Figure 6-b, we observe low intensity and slow motion, while in Figure 6-c, we observe low intensity as well but with a slightly faster motion in relation to that of Figure 6-b. Finally, we observe a stable yet faster pace of execution in Figure 6-e comparing to that of Figure 6-a.

V. Discussion

The hypothesis that emotions can trigger certain behavioral reactions that could be characterized as patterns was verified. Specific correlations between the execution of the motor exercises and the emotional states triggered in the participants during the session were demonstrated by measuring physiological signals. In particular, participants in group D, who were exposed to images classified as ones that evoke horror or fear, completed the tasks with higher muscle force and speed of motion. Participants in group A, who were exposed to images classified as ones that evoke emotions related to excitement, power and control completed the exercises with high muscle force at a steady pace, whereas group E, which performed the exercises in a typical environment without any controlled external stimuli demonstrated similar measurements to those obtained from groups B and C. However, on average, participants in group C executed the exercise circuit slightly faster than those in group B. In contrast to the measurements obtained from groups A and D, data gathered from groups B and C show a relatively lower muscle force that is directly related to the clam and low-energy emotion triggered by the respective images. It is thus concluded that emotions play a significant role in the execution of motor exercises.

One key observation is that the differences produced by the emotionally-charged image used to stimulate an emotional reaction are relatively slight and not as intense. Given that the number of images that the participants were presented with was small and that the emotions were momentarily induced for a short period of time, we discuss the possibility that emotions induced by a more immersive technology such as a VR environment will seem more real and more intense thus possibly producing more significant differences in the execution of an exercise or task used in rehabilitation programs.

Rehabilitation types are dependent on the cause or outcome of the injury. Depending on the extent and stage the patient is at, the therapist will choose the most appropriate combination of rehabilitation types [9]. This study did not focus on cognitive rehabilitation as a stand-alone therapy but on motor rehabilitation. For the sake of clarity and specificity, this study focuses on motor skill testing –i.e. motor rehabilitation. The system was tested on healthy participants and not on actual patients. The primary focus was the performance of motor movement to investigate the role of emotions present during this task. The reason we decided to work with healthy participants instead of patients was that patients would possibly be experiencing emotions inflicted by the cause of injury, thus not allowing us to ensure precise physiological and, consequently, emotional measurements. Taking into consideration the fact that we did not test the system on patients, we propose that, in the future, this system should be tested on real patients, leaving room for the emergence of different behavioral patterns after the patients are exposed to triggers adapted from the circumplex model.

Even though one of the most common muscle activity measurement techniques is before, during and after muscle fatigue [21]–[25] this study did not request from participants to perform the tasks using maximal force or power. Rather, it is focused on performing the exercise in conditions where the participant remained comfortable. In the future, the system can be tested on patients who have reached muscle fatigue point and expose them to emotional triggers, so as to observe and evaluate their progress and how all of the aforementioned facts influence patients' performance.

A limitation to our study is that our sample consisted only of men with similar age and physiological characteristics there were no women or older/younger people involved in the experiment. The reason behind that is our goal to have as similar characteristics as possible, in order to focus more on differences between groups based on similar measurements. Essentially, even though it outlines sufficiently the potential of our system to recognize different behaviors, it limits the range of knowledge obtained from results. Therefore, it is essential that we also focus on other groups with different characteristics and discover more behavioral patterns. Thus, we would like to include more people of different sex and social groups and collect more diverse data on their behavior during rehabilitation sessions.

Another limitation that is worth mentioning is the fact that we extracted only one feature from the EMG sensor and one from the Accelerometer. Our goal in this study was to investigate whether there is a detectable difference in physiological behavior of participants based on different stimuli. In future studies we envision to find more features that will help us analyze thoroughly the signals' performance along with the contribution of each exercise curl and finally identify specific behavioral patterns for each emotional stimulus. The inclusion of additional electrophysiological sensors, such as the ones that measure heart rate, electrodermal activity and respiration will strengthen our findings and help us elucidate the impact of the emotional factor in physical exercise as part of physical rehabilitation.

At the same time, in our study we chose the effect of a visual element and particularly the introduction of image as an emotional inducer. Since emotions are considered a complex and high-level cognitive mechanism, we examined very carefully our choice of emotional stimuli and took into account other means which might also evoke our desired responses, that are based on either audio, visual or audio-visual factors. For example, the feature of music is frequently employed as the most efficient way to generate unique emotions, especially when it aligned with a visual component [26]. Equally interesting is the use of more immersive tools as effective emotional stimulants. For example, the use of virtual reality systems has already proven to reproduce more vividly emotional stimuli compared to tv screens [27]. However, for our stated purposes, we chose only the visual stimuli.

Finally, it is crucial that we further discuss a technological issue we had to overcome; one of the greatest challenges we were asked to face during the development of the system was the muscle sensor electrodes placement. One of the major concerns regarding electrophysiological sensors is placing them appropriately. A possible faulty placement of the sensors could lead to obtaining unclear data, and thus incorrect measurements as well. The placement was in compliance with the Seniam guidelines. We selected the MyoWare muscle sensor (AT-04-001) on which we installed external electrodes. We used three electrodes: the REF (Black), the END (Blue) and the MID (Red). The REF electrode was placed on the flexor carpi ulnaris. The END and MID electrodes were placed on the line between the medial acromion and the fossa cubit at ⅓ from the fossa cubit in respect. We used alcohol to clean the skin and apply gel on the bicep, prior to the placement of the electrodes. Moreover, during the experiments, participants were asked to complete 2 sets of 10 repetitions before the actual session began, in order for us to double-check the placement of the electrodes. In fact, we had to remove the electrodes and place new ones instead in 23 of our sessions. Consequently, in future researches, more emphasis should be given to proper placement of the electrodes and biosensors, the correct collection of measurements, or the design of better electrodes and biosensors –since current systems are mostly used as 'black boxes' with 'opaque' implementation.

As a last note, we propose that researches focusing on the creation of systems, which include gamification to maintain or increase the patient's engagement in a rehabilitation program, should also include the emotion factor and the manner in which these emotions affect the outcome of completing a rehabilitation task so as to reduce dropout rates [8], [28]–[30].

VI. Conclusion

In this study we sought to find the effects of combining emotional stimuli with a simple motor task to propose a more integrated rehabilitation scheme that positively utilizes both, the subjects' physical condition and their emotional state. Specifically, a lot of emphasis has been placed on the impact of the various pre-existing emotions on the performance of patients during the physical exercise and not on the study of the patients' progress and adaptation within the emotional environment. In order to ensure the emotional outcome and find discernible differences, the use of powerful and impactful images was considered as a necessary way to induce extreme feelings. Our ambition is to include the emotional factor in future studies and develop an upgraded holistic version of the rehabilitation process that can be applied effectively to patients who suffer from debilitating motor disorders.

According to the World Health Organization Report on disability as well as similar studies [2], [8], [9], [31], [32] research should be carried out in establishing the holistic biopsychosocial and the multidisciplinary rehabilitation models in more studies, and assess their efficiency, especially since current programs –which exclude the significance of emotions– are not as promising [5]. Thereby, we would urge experts involved in creating rehabilitation systems as well as therapists to take into consideration the impact of emotions during therapy.

ACKNOWLEDGMENT

The graph from Figure 4 take based on the following publication "Asymmetrical Facial Expressions based on an Advanced Interpretation of Two-dimensional Russell's Emotional Model" [33].

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