Investigation of the Sensorimotor Training using Wireless Sensor Networks

Analyzing Three Different Exerciser

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Abstract: The sensorimotor training method is more and more applied in therapy, rehabilitation, prevention as well as to increase performance. The training comprises of the practice of motor action and the improvement of the proprioception. The increasing demand for training has led to a growing range of training equipment. However, this can only be achieved when the training equipment is applied correctly. The application of the training equipment is influenced by two factors: the indiviual behavior when using the equipment as well as the subjective impression of effort by each patient, both of which can differ strongly. For the purpose of this study, 18 healthy test persons were recruited. The test comprised of each person having to use each device at various levels of difficulty. Physiological data measured by EMG and ECG as well as psychological data were collected. The study revealed that the equipment demands different levels of effort from the individual depending on the physical abilities. Furthermore, it was shown that changing tasks on the particular exerciser improved the effort of the test persons.

1 INTRODUCTION

Typical fields of sensorimotor training are the prevention of ankle sprains, the therapy of instability of joints, the rehabilitation of cruciate ligament injuries and the improvement of the athletic performance (Häfelinger and Schuba, 2010).
Reflexes, rhythmic and cyclical motion patterns as well as controlled voluntary movements can be summarized under the term motor activity. Besides the motor activity, the so-called proprioception, depth sensitivity, are the main characteristics of a sensorimotor training (Lukas et al., 2011).

The training's objectives include the regeneration and the activation of injured proprioceptors, the increase of their potential force and the reduction of the response time of the stabilizing musculature. Hence, the overall goal of the training is the improvement of the reception and the processing of information. In addition, the translation of the information into the targeted movement is necessary to guarantee the optimal execution of the movement. The positive health benefit of this training method has been verified in several scientific studies (Dohm-Acker et al., 2008; Lukas et al., 2011). Therefore, the market for sensorimotor training equipment is still growing.

To maximize training results a correct application of the equipment is paramount. Due to the different materials, functions and characteristics of the exercisers correct application might be challenging. An additional difficulty for the therapy planning is represented in the subjective impressions by the patients. When facing the same task, different opinions regarding the strain of the exercise tend to be expressed by the patients. In the following experimental study the mode of action of three different exercisers was analyzed. The research involved 18 subjects of different age and with different experiences.

2 MATERIAL & METHODS

2.1 Measurements

The Shimmer^{TM} measurements are wireless sensors

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with a small form factor. Using Bluetooth allows for online data streaming in real-time. Providing pre-amplification of EMG-Signal the non-invasive method represents the whole activity of a muscle using two or three channel data acquisition. Similar to the EMG signal, the ECG measures the electrical activity of the heart muscles with a two channel ECG. As the EMG data, the ECG signal is also pre-amplified (Shimmer Research Support, 2012b; Shimmer Research Support, 2012a).

2.2 Exercisers

To evaluate different sensorimotor training methods three different exercisers were chosen and evaluated under different aspects (fig. 1).

Figure 1: Balance Pad, Balance Board, Ortho Pad.

The Balance Pad offers multifaceted applications of the sensorimotor training. The Pad is made of a special foam. One characteristic is its damping property. Hence, the destabilization of the lower extremities is supported (Sport-Thieme, 2012a).

The top of the Balance Board is made of stable and reinforced plastic with a diameter of 40 *cm*. Here the aim is to strengthen the musculature of buttocks, legs, back and abdomen (Sport-Thieme, 2012c).
The Ortho Pad is a specific type of a teeter board. Its special construction offers a multi-axial balance training, as the patient has to handle a balance shift in at least four directions (Sport-Thieme, 2012b).

2.3 Experimental Setup

18 healthy subjects from the university and the medical school took part in the study. They gave their written consent to participate after being informed about the test procedure. Based on age and skills, a division into three groups was made. One group consisted of young students with no experiences in sensorimotor training. Group two comprised of students with comprehensive experience in balance training. Group three included all subjects over the age of 40 *years* irrespective of their experience with the exercisers.

During the research, two different types of Shimmer^{TM} sensors were used. For stress documentation the ECG sensor was placed on the anterior thorax for measuring the chest leads. During the data analysis, primary attention was paid to the muscular activity. The ECG was of secondary importance. To examine the muscular activity, sensors were placed on the right and on the left lower extremities and buttocks. The placement of the sensors was chosen due to the fact that injuries of the ankle joint are often treated with proprioceptive training and it is therefore of interest to look at the behavior of the M. tibialis anterior. This muscle supports dorsal flexion, supination and adduction of the foot (SENIAM project, 2012). To proof the assumption that the upper body areas participate in balancing motions, the EMGs of the right and the left M. gluteus maximus were also measured.

All subjects had to perform the same test procedure for all exercisers. The order of the training equipment was randomized for each test person. One test sequence comprised of a reference measurement (30 *s*) and the measurement while on the test equipment (210 *s*). The reference measurement was made on the floor while the subject was in rest. Immediately afterwards, the measurement on the exerciser took place. The test scenario consisted of five phases of varying difficulty. Each of the first two phases (standing on the exerciser with eyes open and eyes closed) lasted 30 *s*. The following phases, throwing a medicine ball and doing a cable pullover, had a duration of 60 *s* each. The final phase is identical to the first one regarding the task as well as the duration. After finishing the procedure on one exerciser the test persons were asked different questions regarding the handling of the equipment in general and which phase was the most exhausting one. All questions used an eleven-point answer scale (0 equals "no effort" to 10 equals "very high effort") except for the one inquiring about the most exhausting phase.

2.4 Data Analysis

The data analysis process startet with the normalization of the EMG data. The absolute values were transformed into relative values by using the data of the reference measurement. A notch filter with a blocking frequency of 50 *Hz* and a band-pass filter from 15 to 500 *Hz* were applied to the raw EMG (Merletti and Parker, 2004). In the next step, EMG signal processing required the full-wave rectification of the signal. In order to analyze the data in the time domain, different statistical parameters, such as mean and maximum were calculated. On one hand, the parameters were computed over an interval of three seconds. On the other hand, the parameters in each of the phases were calculated. Similar to the processing of the EMG signal, the ECG was also bandpass (0.05 *Hz* - 30 *Hz*) and notch filtered (Husar, 2010). The properties of the notch filter were identical to those of the EMG. Analyzing the ECG in time domain includes the calculation of the heart rate itself as well as the computation of statistical parameters of the heart rate.

3 RESULTS

The aim of the sensorimotor training is to improve the motor action and the proprioception. The training process should lead to a targeted use of the muscles. Therefore, it is to be expected that trained subjects have both, a smaller total amount and a shorter time in muscle activity. This effect is visualized in figure 2, comparing one untrained subject from group one with one trained subject from group two. Already in the phase “Eyes Open” the difference between the trained and untrained subjects is clearly illustrated. The trained person has lower voltage values across all phases. In addition it is visible that the subject of group two restored its balance faster and was able to keep the balance much better because there was temporarily nearly no muscle activity. Especially in the phases “Eyes Open” and ”Cable Pullover” the comparison of the individual EMG courses show a clear difference in the patterns. For example, in the phase “Cable Pullover”, the untrained subject has to apply more than double the muscle activity. A similar effect can be seen in the first ans last phase. In summary, figure 2 supports the assumption that trained persons can better preserve their balance and are also able to restore their equilibrium faster.

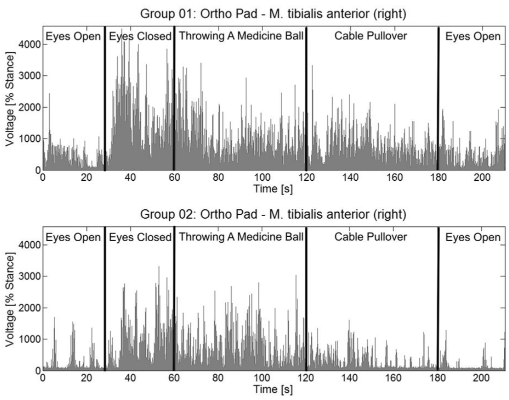

Figure 2: Comparison of one representative of group one and two.

Figure 3 documents the muscle activity of an untrained young subject on the various equipments. It is obvious that the three exercisers lead to different muscle activity patterns. Comparing the same phases with the three pieces of equipment revealed that each exerciser required different skills of the subject. Both, the Balance Board and the Ortho Pad demanded a high effort during the “Eyes Closed” phase. On the contrary, the comparison of the sum of the voltage values of the Balance Pad in this phase showed relatively low values. The third and the fourth phase illustrated regular muscle activity. At the start of both phases the voltage values were relatively high and long-lasting. The muscle activity correlated with the catching/throwing of the medicine ball and the pulling of the load in the phase “Cable pullover”. The comparison of the measured values of the Balance Pad and Board during the third phase showed that the average values for this subject were higher when using the Pad. However, the recorded impression of the subject showed the highest effort during the second phase. The categorization based on figure 3 generated the following ranking for the level of difficulty (lowest first): Balance Pad - Balance Board - Ortho Pad.

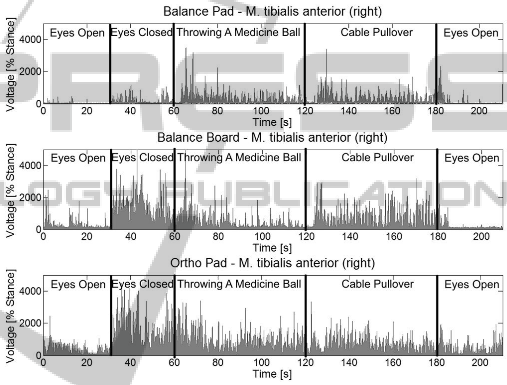

Figure 3: Comparison of the three exercisers.

The heart rate is used as an indicator for stress. Figure 4 shows the average heart rate during the five phases for each of the three groups. The test persons of group one have the lowest heart rate. In contrast to the other groups, the subjects of group one were familiar with the measuring instruments. The higher heart rate during the initial phase could have been caused by the tension of the subjects. This assumption is supported by the course of the heart rate of group two which is lower during the last phase than in the first one. The recorded course of the heart rate for group one follows a similar pattern than the one for group three, both increasing during the first four phases. In contrast, the heart rate for group two already decreases after the second phase. This confirms that training causes a learning effect and leads to the subjects starting to feel comfortable after an initial phase of adaptation.

The test persons’ subjective impressions when using the “Ortho Pad” are documented in figure 5. When analyzing the heart rate, the lowest stress level was recorded for group two while group 3 had the highest one. Comparing the test persons’ subjective impressions (figure 5) with the measured heart rate

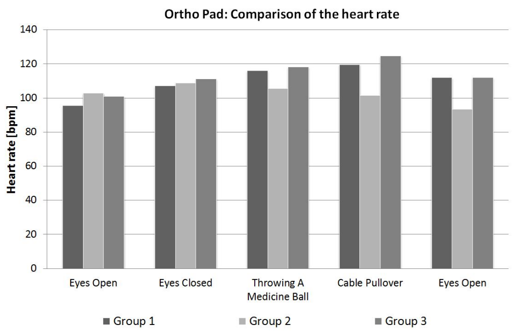

Figure 4: Comparison of the heart rate at the Ortho Pad.

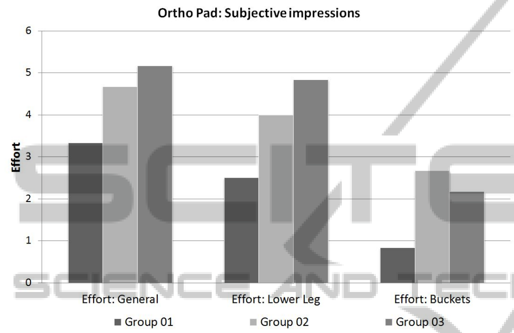

Figure 5: Subjective impressions after using the Ortho Pad.

(figure 4), only group three showed a direct link between the two.

4 DISCUSSION

The main finding of this study is that the correct application of an exerciser depends on several factors. The analysis of the EMG patterns from one subject using the three exercisers shows that the patterns are different with respect to the produced voltage values as well as the activation duration of each muscle. Hence, the analysis of the individual exerciser could be a tool for the optimal therapy planning. Despite identical tasks, the muscle activity patterns of the individual subjects differ strongly. This implies that the course of the muscle activity is also depending on the subjects' skills. Therefore, it is recommended to analyze the individual behavior of a patient at the various exercisers in order to plan his or her therapy effectively.

One possible application for the sensorimotor training is the fall prevention, especially for older patients. Depending on the physical fitness of these patients, a verification of the general effort could be useful.

The study further revealed a limited correlation between the subjective impressions of the test persons and the measured values. Therefore, the therapist should critically review the patient's comments.

5 CONCLUSIONS

The evaluation of the exercisers showed that different subjects can have different courses of movement when using the same equipment. Hence, mobile sensors could greatly improve the study of the individual interaction between a subject and the equipment in use. Furthermore, the sensors can assist with therapy documentation in general as well as the progress recording of a particular muscle.

A possible continuation of this study could be the measurement and analysis of the gyroscope data. In combination with the muscle activity pattern, the data can offer additional information about the way a patient is reacting to movements of the exerciser. Within this context, the calculation of the reaction time of the muscle could also be considered. Hence, it is possible to characterize the individual muscles needed to improve for example the instability of a joint.

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