Analyzes of Influencing Factors to the Sensorimotor Training
Technical Support Systems in the Physiotherapy

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Keywords: Sensorimotor Training, EMG Data, Technical Support Systems.

Abstract: The popularity of the sensorimotor training is still growing. Nonetheless, the training is not yet fully investigated. Information given by the manufacturers, in the literature and the experience of physiotherapists will form the basis of physiotherapeutic interventions. For an integration of evidence based decision making a change in the approach of the therapy planning is needed. This can be achieved by the use of technical support systems. Therefore, the behavior of 32 test persons was investigated. Within two different setups several investigation scopes were analyzed. One scope was the influence of the laterality to the muscular activity during the training on the exerciser. Furthermore, the effects of the different equipment with regard to the information of the literature and the manufacturers were analyzed. Additionally, a detailed investigation of the muscular activity during the realization of tasks given by the physiotherapist was made. Also, a survey regarding the muscular strain during the training as well as the acceptance of the sensors was fulfilled. Finally, factors which have an influence on the progress of the training were identified and analyzed. The benefit and the necessity of technical support systems in the sensorimotor training was shown.

1 INTRODUCTION

Across the health care professions the use of evidence is extensively promoted. The physical therapy profession goes along with this progress. One aim of the American Physical Therapy Association is that up to the year 2020 physiotherapists will use evidence in practice (Jewell, 2010).

The necessity of evidence is caused by a couple of reasons. On the one hand, there are many different ways to achieve an improvement within a special disease pattern. This variety of treatment options leads to a critical consideration of the therapy by the therapist and by the patient. Consequently, a detailed documentation of the therapy is needed. This documentation should contain essential information to provide evidence. This requirement can be achieved by the usage of technical support systems (Jewell, 2010; von Eisenhart-Rothe et al., 2007).

One therapy method, which is often used for prevention purposes, therapy, rehabilitation as well as for the improvement of the athletic performance is the sensorimotor training. Its huge popularity ensures that there is a great variety of equipment, which should support and improve the training. Despite its popularity, the training itself is not completely investigated until now (Rühl and Laubach, 2012).

Actually, the therapy planing is based on the following facts: the experience of the physiotherapist, the information given in the literature, the productinformation given by the manufacturers as well as on the possibilities in the physiotherapy practices. Depending on the information given by the manufacturer, the therapist is planing the usage of the equipment in the training. For example, the Balance Board should strengthen the musculature of the buttocks, the legs, the back and the abdomen (Sport-Thieme, 2012). Furthermore the literature documents additional effects. The first one is the improvement of the inter- and intramuscular coordination of the muscles of the feet and the legs. The second effect, staying with both feed on the Balance Board, is the enhancement of the stabilization in the region of the lumbar spine, the pelvis and the hip. Additionally, the optimization of the inter- and intramuscular coordination of muscles of the lumbar spine, the thoracic spine and

Thiers A., l'Orteye A., Orlowski K., Schrader K. and Schrader T..
Analyzes of Influencing Factors to the Sensorimotor Training - Technical Support Systems in the Physiotherapy.
DOI: 10.5220/0005093000450052
In *Proceedings of the 2nd International Congress on Sports Sciences Research and Technology Support* (icSPORTS-2014), pages 45-52
ISBN: 978-989-758-057-4

the cervical spine should also be a benefit (Bertram and Laube, 2008).

For the usage of evidence a more detailed look at the sensorimotor training is needed. The aim of the current study was to identify and analyze all kinds of factors which have an influence on the progress of the therapy. Therefore, the behavior patterns of 32 test persons were investigated during their training on the exercisers. Finally, the necessity and the benefit of using supporting systems in the sensorimotor training should be shown.

2 MATERIAL & METHODS

2.1 Measurements

The usage of Shimmer ™ measuring units is one approach for a noninvasive patient monitoring. Next to the mentioned feature of monitoring, the sensors assist diagnostics with their given functions. One of their benefits is the small form factor of the sensor. Additionally, the characteristic of wireless communication is a further advantage of the measurement units. The Bluetooth technology enables data to stream online and in real-time. All used sensors were a combination of a baseboard and a special daughterboard. For the current investigation the electromyogram (EMG) as well as the gyroscope daughterboards were used (Shimmer Research, 2011).

The EMG daughterboard allows the user to measure one channel of the electrical activity of a muscle. Furthermore the sensor also provides a preamplification of the EMG signal. Hence, the noninvasive method visualizes the whole activity of a muscle (Shimmer Research Support, 2012).

The gyroscope daughterboard consists of a single and a dual axis angular rate gyroscope and is able to measure three axis of angular velocity (Kuris, 2010).

2.2 Exercisers

Within the experimental setups the behavior of the test persons on three different exercisers was investigated. The first one is the Balance Board. The last two exercisers were two types of a special Rocker Board. The only difference is the direction of the deflection of the Rocker Board.

2.2.1 Balance Board

The Balance Board is characterized by its multidimensional instability, figure 1. The exerciser offers different fields of application. The Balance Board supports the strengthening of the musculature of the buttocks, the legs, the back as well as the abdomen (Sport-Thieme, 2012). The dimensions of the Balance Board are given in table 1.

2.2.2 Rocker Board

One feature of the Rocker Board is its one-dimensional instability, figure 1. The board can be used in two different ways. It offers either a forward-backward or a left-right instability. The Rocker Board is made to train the coordination, the stamina, the strength as well as the motor skills (Bad-Company, 2013).

In case of the left-right deflection it requires special movement patterns performed by the extension and the flexion of the knee joints. In contrast, the forward-backward deflection demands the reaction of the ankle joints.

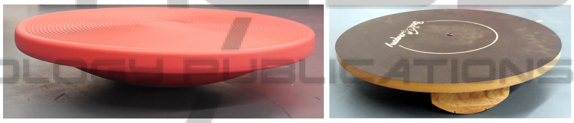

Figure 1: Balance and Rocker Board.

Table 1: Dimensions of the Exercisers.

	Balance Board	Rocker Board
Height	9.0 *cm*	7.5 *cm*
Dimension	41.5 *cm*	45.0 *cm*
Deflection	$\sim 18°$	$\sim 16°$
Material	Plastic	Wood
Surface	smooth	smooth and firm

2.3 Experimental Setups

The investigation obtains its data from two different experimental setups. The data from the first setup originates from a previous study (Thiers et al., 2014). The collected data prove the assumption that the training on an exerciser with a multidimensional instability causes a higher muscular activity than the training on an exerciser with an one-dimensional instability (Grifka and Dullien, 2008). The second setup was developed to have a closer look at the sensorimotor training. Additionally, the effects of the interventions given by the physiotherapist were analyzed.

To develop an user-oriented experimental setup the design of both studies was made in cooperation with experienced physiotherapists of a medical school. One requirement of the physiotherapists was the transferability of the setups into a training, which can also be performed by patients. Hence, this causes the drop out of the maximum voluntary contraction measurement. Alternatively, the normalization of the data was made by a reference measurement in front of the exerciser.

2.3.1 Setup 1

The first setup includes the data of 13 test persons. All of them were young and healthy students. For participating in the study all test persons have to gave their written consent.

The first setup comprised of three different parts. The first one was the test of the laterality of each proband. The second part contains measurements on the three exercisers. Finally, a survey regarding the acceptance of the sensors was made.

The investigations of the laterality were made by multiple tests. At the beginning six tests for the determination of the handedness were made. For instance, the hand which opens a bottle was identified. For the investigation of the dominance of the feet, ten different tests were made. For example, the establishment of the takeoff leg and shooting foot. Finally, a scales test was made. For this reason the test person has to stand with each leg on one scale. The distribution of the bodyweight on the two scales was documented.

For the second part of the setup two different types of Shimmer^{TM} measurement units were used. A pair of gyroscope sensors were centrally placed on the different exercisers. On the one hand this placement enables to synchronize all recorded data and on the other hand the intensity of deflection of the exercisers was documented. For the verification of the assumption that a higher muscular activity is achieved when using exercisers with a multidimensional instability compared to the training with exercisers with an one-dimensional instability (Grifka and Dullien, 2008), the EMG data of four pairs of muscles were recorded. The voltage values of the M. tibialis anterior, the M. soleus, the M. vastus lateralis as well as the values of the M. biceps femoris of both body sides were measured. The skin preparation and the placement of the electrodes followed the recommendations of the SENIAM project (SENIAM project, 2012).

The test persons had to perform the test sequence for each of the three exercisers. One iteration of the test sequence comprised a reference measurement in front of the exerciser with a duration of 15 s as well as a measurement on the equipment. This part of the procedure consists of four consecutive phases of changing difficulty, table 2. All phases have in common, that they were characterized by symmetrical requirements to both body sides. All recordings have been done without shoes. The subjects stand on both legs for the whole time. In addition, the instructions and the supervision of the correct execution were made by an experienced physiotherapist.

The last part of the setup was a survey regarding the subjective impressions of the training and the acceptance of the sensors. The questions regarding the subjective impressions comprised the content of the degree of the felt strain in general and in special body areas. Additionally, the supervisor documents her impressions, too. The following topics were addressed by the questions of the sensor acceptance (examples): if wearing the sensors caused restrictions during the execution, if wearing the measurement units induced an unpleasant feeling, if the test persons would use the technology again as well as the usefulness and applicability of the sensors in everyday life. The options for the answers were the choice of yes/ no as well as free text.

Table 2: Setup 1 - Test procedure.

Phase	Task	Duration
1	Eyes open	30 s
2	Eyes closed	30 s
3	Throwing a medicine ball	60 s
4	Eyes open	30 s

2.3.2 Setup 2

19 healthy and young students took part in the second setup. The participants were not the same than in the first trial.

The second setup also consisted of three different parts. These parts were executed subsequently: determination of the laterality, measurement on only one exerciser and the survey regarding the acceptance of the sensors. The first and the last part were identical to the first setup.

On the contrary, the second setup only investigated the behavior of the test persons on one exerciser, the forward-backward Rocker Board. The test sequence was composed of a reference measurement in front of the exerciser and a measurement on the exerciser. The overall duration of the training on the Rocker Board was eight minutes, table 3. The first phase had a duration of 60 s and during that phase the test person should get familiar with equipment. The second and the third phase were characterized by the intervention of the physiotherapist. She requested the subject to either focus on the right or left body side. Immediately after that, their was again a phase without any intervention. The aim of the fifth phase was an individual intervention by the physiotherapist. She gave different instructions regarding the stance and the posture as well as the performance.

The final phase should document, if the subjects have adopted the behavior of the previous phase or not. For a detailed investigation the deflection of the Rocker Board and the muscular activity were recorded. The EMG values were derived from both sides of the M. peroneus longus, the M. tibialis anterior and the M. vastus lateralis. Again, the skin preparation and the placement of the electrodes followed the recommendations of the SENIAM project (SENIAM project, 2012). The measurements of both setups had also in common, that the test persons had to stand the whole time without shoes on both feet. The study was supervised by an experienced physiotherapist.

Table 3: Setup 2 - Test procedure.

Phase	Task	Duration
1	Without Intervention	60 s
2	Right Intervention	30 s
3	Left Intervention	30 s
4	Without Intervention	120 s
5	Physiotherapists Intervention	120 s
6	Without Intervention	120 s

2.4 Data Analyzes

Before starting the signal processing, the data sets were synchronized. The first step of signal processing was the application of a notch filter to EMG data with a blocking frequency of 50 Hz. Secondly a fir band-pass filter was applied to the data (Merletti and Parker, 2004). Afterwards, the normalization of the EMG data took place. Therefore the average muscular activity when staying in front of the exerciser was calculated and used as normalization value. Subsequently, the absolute values of the measurement on the exercisers were transformed into relative values by using the normalization value. Finally, all EMG values were presented as a percentage value of the stance.

The next step regarding the EMG processing implies the full-wave rectification of the EMG data (Merletti and Parker, 2004). For the evaluation of the muscular activity in the time domain different statistical parameters were calculated. For instance the maximum and mean values for the whole signal over a time window of 512 ms (Gu et al., 2010). These statistical parameters were evaluated within further calculations. Namely, on the one hand the course of the maximum values over time was documented. On the other hand the mean value of the maximum voltage values for each phase as well as for the complete procedure were calculated. Besides that, the accumulated EMG activity (iEMG) was analyzed. Therefore, the EMG was integrated over time. Consequently, the total accumulated activity was computed by the calculation of the area under the EMG for a chosen time period (Robertson and Caldwell, 2004; Medved, 2000). This calculation was performed for each phase as well as for the complete test procedure. For a more detailed investigation, the course of the iEMG over the time was calculated and plotted.

3 RESULTS

3.1 Setup 1

Figure 2 provides an overview of the overall muscular activity of all test persons during the complete test procedure on each exerciser.

The complete accumulated EMG activity during the individual test sequences of each test person were computed. The data were normalized for each subject. Therefore, the muscle with the highest strain during all trials of each person was identified. This muscles represents 100 %. The values of the remaining muscles of the different trials were presented in relation to the 100 %. This data was collected for all of the 13 subjects. Finally, the whole data was averaged and visualized in figure 2.

The investigation of the EMG data had revealed, that it is useful to distinguish between the process of the compensation of the instability caused by the exerciser and the process of the maintenance of the body stability. The first part is mainly realized by the musculature of the lower legs. However, the maintenance of the body balance is linked to the stability of the knee joints. Due to that, the musculature of the thigh has to produce the major part of the performance. Accordingly, the patterns of the M. biceps femoris and the M. vastus lateralis show for all of the three exercisers a similar intensity.

On the basis of this approach, the evaluation of the musculature of the M. tibialis anterior and the M. soleus shows individual results for the equipment. The instability caused by the different Boards is mainly compensated by the ankle sprains. Consequently, a higher intensity of the instability induces a higher muscular activity. One assumption in the literature is, that an exerciser with a multidimensional instability requires a higher muscles strain in comparison to an exerciser with an one-dimensional instability (Grifka and Dullien, 2008). This assumption can not be validated by the measured EMG activity in this study. Both types of the one-dimensional Rocker

Board have produced a higher strain in the musculature of the lower legs. Consequently, in this case the Rocker Board has a comparatively higher degree of difficulty.

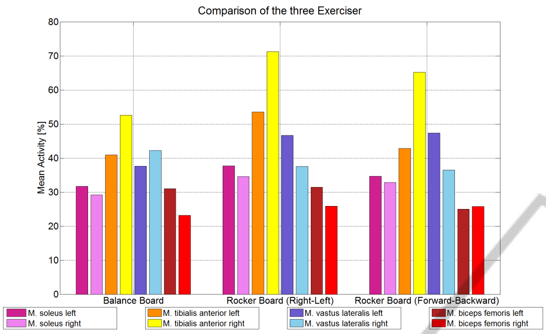

Figure 2: Comparison: Exerciser.

3.2 Setup 2

3.2.1 Intervention: Right/ Left

One type of intervention is to advise the patient to focus on one special body side. During the second phase the physiotherapist instructed the subjects to focus on their right body side. Immediately afterwards, in the third phase the task was to burden especially the musculature of the left body side.

The accumulated EMG activity was computed for the duration of both phases separately. The data were normalized. The muscle with the highest strain represents the 100 %. The remaining muscles were set in relation to the 100 %. The data of all test persons of setup two were collected and summarized in the boxplots of figure 3.

The upper graphic of figure 3 shows the intervention data for the M. peroneus longus. The visualization figures out, that the realization of the right intervention is made in a more correct way. Accordingly, the range of the boxplots is smaller during the right intervention. Notwithstanding the left muscle is more active during the left phase. In contrast, the results of the M. tibialis anterior show a different outcome. During both phases the right muscle is the more active one. Nonetheless, the median of the left muscle raises during the phase of the left intervention. In contrast, the right one is nearly the same. The most successful realization of the requirement to focus on one body side was documented for the M. vastus lateralis, lower graphic in figure 3. The measured activity during each phase corresponds to the expected ratio of the body sides. There is a clear difference of the amount of activation of the left and right muscles during the individual phases.

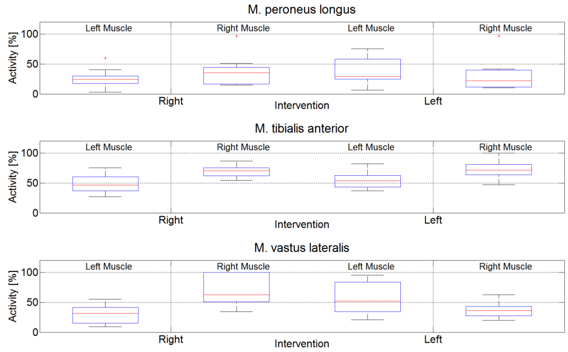

Figure 3: Intervention Right-Left.

3.2.2 Intervention: Physiotherapist

The fifth phase of the measurement on the Rocker Board comprised the intervention of the physiotherapist. Figure 4 represents the muscular activity of one test person during this phase.

The physiotherapist analyzed the behavior of the test person on the exerciser and gave immediate instructions for a better behavior. The current figure documents six instructions, red lines in figure 4. The first and the second intervention addressed the position of the pelvis. The physiotherapist advised the test person to rotate the left part of the pelvis into the front. The expected reaction in the muscular activity was an increase in the intensity of the EMG values of the left body side. Except the M. tibialis anterior, there were no changes in the EMG values of the left body side recorded. Especially after the repetition of the instruction, the left M. tibialis anterior increased its activity. The same effects were documented for the right side of the muscle. Within the third intervention the order was to lean the torso to the right. Again, the physiotherapists expects more activity in the EMG values of the right body side. Both muscles of the lower leg showed a slight activation. In contrast, the activity of the right M. vastus lateralis stayed the same. Again, the documented EMG values only meet in a limited way the exceptions of the physiotherapist. The instruction to improve the flexion of the knee joints was given during the fourth intervention. The realization of this task could only be occupied by the increased activity of the right M. vastus lateralis and the right M. tibialis anterior. Both muscles had fulfilled the expectations. In contrast, this result was not achieved by the left side. The physiotherapist addressed this instruction again for the left knee joint during the fifth intervention. Only the left M. tibialis anterior showed higher voltage values. The participation of the left M. vastus lateralis is needed for a correct flexion of the knee joint. Unexpectedly, the right muscle side produced higher values. In contrast to the previous interventions, the last one was an improvement of the performance. The physiotherapist advised the test person to burden both body sides equally. The expectation was the compensation of the muscular activity. Although, the left M. tibialis anterior produced higher voltage values, the right body side was still the more dominant one. Referring to the EMG values, the test person was not able to fulfill the requirement completely.

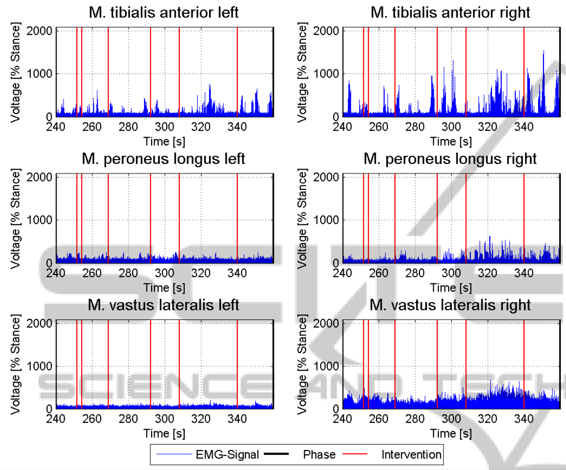

Figure 4: Intervention Physiotherapist.

3.3 All Subjects

3.3.1 Laterality

To determine whether there is a correlation between the laterality and the dominance of one body side in the muscular activity or not, different tests for the identification of the laterality were made.

The six tests for the handedness and the ten test for the dominance of the feet were analyzed separately. The first step comprised of the counting of the frequency, how often one body side was used within the test. The next step included the conversation of the frequency values from absolute values into percentage-values. Immediately afterwards, it was determined which body side was the dominant one. Within the actual investigation the concrete body side only plays a minor role. Only the percentage values of the dominant side of the hands and the feet were of interest. The difference between the two values was calculated. The results were visualized for each of the 32 (setup 1 and setup 2) test persons in the illustration of figure 5. The benefit of this calculation is to develop assumptions regarding the relationship of the dominance of the hands and the dominance of the feet.

A detailed look at the concrete dominance values shows that only five out of 32 subjects achieved 100 % while determining the intensity of the dominance of one hand. In contrast, no test person achieved 100 % regarding the dominance of one feet. This observation is supported by figure 5. Only 31.25% of the test persons have a more dominant body side regarding the feet than the hands (Test persons achieve a negative difference value). Additionally, it is obvious that there is a great variance in the plotted values. Hence, the intensity of the dominance of the feet is not directly linked to the intensity of the dominance of the hands. Furthermore, it is not possible to make general assumptions on how large the deviation of these two values might be for an individual subject.

The overall analyzes of the laterality data figures out, that by the majority of people the handedness tend to be more pronounced than the dominance of the lower extremities.

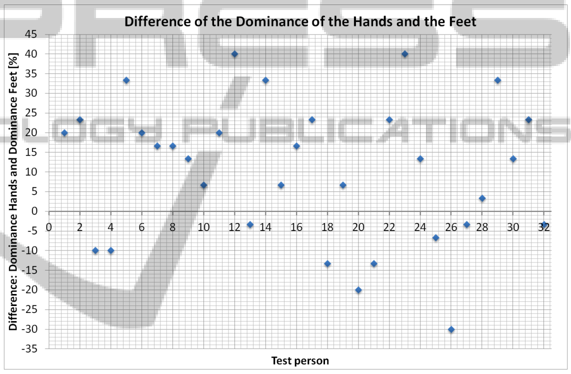

Figure 5: Laterality.

3.3.2 Subjective Impressions

All test persons had to comment the intensity of strain which they felt during the training. They had to choose between zero (nothing) and ten (very much exhausting). Depending on her point of view the supervisor also had to rate each training and had to document the level of strain for each test person independently. To evaluate if there is a correlation between the subjective impressions of the test persons and the impressions of the physiotherapist both ratings were paired and were plotted dependency on each other in graphic 6.

The investigation of the correlation revealed a covariance greater than two. Consequently, a positive correlation between the ranking of the test person and the ranking of the physiotherapist exists. The major outcome of figure 6 is, that there is rarely an accordance regarding the impressions of the physiotherapist and the impressions of the test persons. Only in 9.7 % of the training sessions an agreement was documented. In contrast, in 25.8 % of the sessions the test persons thought the training was more exhausting than the physiotherapist documented. In 64.5 % of the cases the test persons ranking of the strain was lower than the ranking of the strain of the experienced physiotherapist. Figure 6 visualizes the partially great differences in the ranking of the intensity of the strain during the trails. In one case, the physiotherapists impression was a ranking of ten. In contrast, the test person only documents a ranking of four.

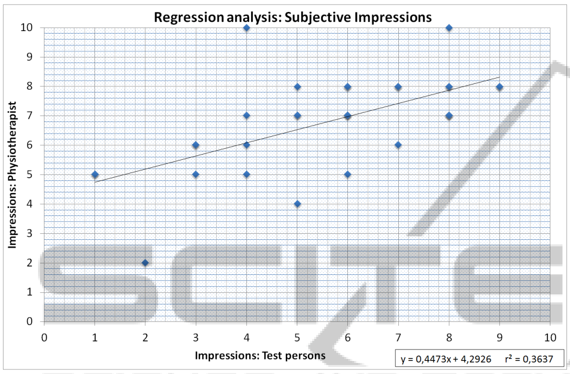

Figure 6: Subjective Impressions.

3.3.3 Acceptance

In addition to the survey of the intensity of the strain, the test persons had to answer a questionnaire regarding the acceptance of the measurement units. The results of this survey where documented in figure 7.

The first question discusses, if there are any restrictions during the execution of the trail when wearing the sensors. Three out of 29 test persons documented a restriction. The problem was the fixing of the sensors. To avoid a drop of the sensors, they were fixed with tape. In some cases the tape was too tight.

A similar result was achieved by the question, if the sensors caused an uncomfortable feeling. The tight fixation was a problem. Furthermore, the placement of the sensors at the M. vastus lateralis and the M. biceps femoris in setup one was slightly difficult. For some test persons it caused some problems to sit on a chair during the pauses in a comfortable way.

Only one out of 32 test persons would not use the measurement units again. Unfortunately, the person does not document a reason for this decision. One explanation for the fact, that nearly all persons agree to the question, might be, that they see the benefit of the sensors.

100 % of the test persons have answered the question, if they see a benefit in the usage of the sensors, with yes. Additionally, there was the possibility to give a more detailed answer. Most of them recognized the benefit in the fields of documentation of the training and the opportunity to have a detailed look at the behavior of the muscles.

One question addressed the usefulness of the transferability of the technology into physiotherapists everyday life. More than 80 % gave a positive feedback. A few test persons mentioned that it would be more useful for training and rehabilitation of patients, who were competitive athletes.

The greatest deficit of the current technology is that the application of the sensors took so much time. Therefore, the transfer of the technology into everyday life is difficult.

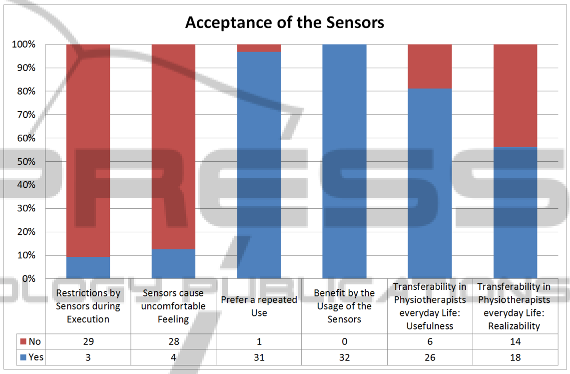

Figure 7: Acceptance of the Sensors.

4 DISCUSSION

The current study reveals different findings. The first setup points out, that each Board requires different skills of the test persons. Additionally, the assumption of the literature, that exerciser with a multidimensional instability cause a higher muscle strain than the one with an one-dimensional instability (Grifka and Dullien, 2008), could not be proven. Furthermore the distribution of the muscle activity of the individual muscles of the lower extremities figures out, that the body stability is maintained by the musculature of the upper legs. In contrast, the muscles of the lower legs try to compensate the instability caused by the exerciser.

This finding is also supported by the outcome of the investigation of the muscle behavior when the test persons were asked to focus on a special body side. The analyzes shows the clearest realization within the EMG values of the M. vastus lateralis. This is associated to the procedure, that in most cases the test persons move their body's center. The M. vastus lateralis is one of the muscles, which participates especially in the maintenance of the body stability. Consequently, the shift of the body's center has effects to the muscular activity. The muscles of the lower legs mainly participate in the process of the compensation of the instability of the exerciser. The task to focus to one body side is subordinated.

The detailed exemplary investigation of the physiotherapist reveals, that the subjects were able to understand instructions. However, sometimes their way to fulfill the tasks differs from the expectations of the physiotherapist. Unfortunately, it is not always possible to identify these differences without any technical support. An additional argument for the usage of technical support systems is given by the varying ratings regarding the difficulty of the exercises.

The last major finding of the investigation is the acceptance of the sensors. Although a few improvements of the technical arrangement should be made, the test persons were open-minded and would use the sensors again.

5 CONCLUSION

The investigation of the different questions regarding the sensorimotor training figures out, that technical support systems are a good opportunity to improve the quality of the training. It is not possible to make general assumptions regarding the effects of the individual exerciser. Each patient has its own characteristics and procedures to handle the given challenges. Therefore, it is necessary to analyze each test person, depending on his behavior, one exerciser could be chosen.

Next, the laterality of the test persons should be analyzed. The dominance of one body side is depending on the socialization and on other factors like sports. If the subject prefers bilaterally sports the dominance will be less significant or its behavior is correlating with situations which were typical for the sport. This laterality influences the behavior on the exerciser in general and the realization of special tasks given by he physiotherapists. Unfortunately, it is not always possible to give an objective evaluation of the quality of the execution of the patient. Aggravating this situation, the impressions of the patients does not always correlate with the physiotherapists impressions or the measured muscle activity.

To sum up, there are many factors which influence the quality of the sensorimotor training. To improve the efficiency and to objectively document the effectiveness of the training the usage of technical support systems would be a benefit.

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