Investigation of the Sensorimotor Training
Analyzing Exercisers with One-dimensional and Multidimensional Instability

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Abstract: The importance and the attractivity of the sensorimotor training is still growing. Up to now the impact of the training on the body is not yet fully investigated. Hence, nowadays the planning of the therapy is mainly based on the experiences of the physiotherapist and on the conditions of the practice. For the development of the therapy the physiotherapist is supported by manufacturer's information about the exercisers as well as by general assumptions regarding the sensorimotor training. For the validation of this information two setups were investigated. In the first part, the behavior of two students was studied on three exercisers. Here the EMG data and the motion data were analyzed. In the second part, the behavior of the left and the right body side was analyzed for 16 subjects. The study revealed that the major work for the maintenance of the equilibrium is done by the distal musculature. Furthermore, it was shown that there is a different behavior of the musculature at both body sides. Additionally, it has been proven that each test person had an individual behavior on the exercisers. Consequently, it would be hard to make general assumptions regarding the impact of the training on the body.

1 INTRODUCTION

The sensorimotor training offers a great variety of application fields as well as a lot of different exercisers. Hence, it is going to be more and more attractive. Nevertheless, the training itself is not completely investigated until now (Rühl and Laubach, 2012).

In the physiotherapists practice the training is especially used for prevention, therapy, rehabilitation as well as for the improvement of the athletic performance (Häfelinger and Schuba, 2010).

Firstly Dr. Vladimir Janda noticed that regarding the control of human movement there is a direct correlation of the sensory and the motor system. He pointed out that both systems react as one and that changes in one system also lead to reactions in the other system. He also introduced the term "sensorimotor system". His studies showed that the proprioception, also known as depth sensitivity, is the most significant aspect for the coordination of movement. As part of his investigations he developed the sensorimotor training (Page, 2005; Lukas et al., 2011).

Besides that the motor unit activity is also a keyword of the sensorimotor training. Motor unit activity comprises the terms of reflexes, controlled voluntary movements as well as rhythmic and cyclical motion patterns. The overall process of the coordination of the movement is a complex process. Consequently, the success of the training depends mostly on the correct and professional execution of the training (Lukas et al., 2011).

The growing popularity of the sensorimotor training causes a huge range of different exercisers for supporting. The great amount of different exercisers and the fact that the sensorimotor training, especially the therapy planning is not fully investigated, make the execution of an effective training quite difficult.

Nowadays the application of the exercisers as well as the planning of the whole therapy is mainly based on the experiences of the physiotherapist and of the given possibilities in their practice (Rühl and Laubach, 2012). The information about the exercisers published by the manufacturers or in the literature may have an influence on the planning of the training. For example, the Balance Board should strengthen the musculature of the buttocks, the legs, the back and the abdomen (Sport-Thieme, 2012). The maintenance of the equilibrium on the Balance Board should

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have different effects. The first effect 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. The last effect is the optimization of the inter- and intramuscular coordination of muscles of the lumbar spine, the thoracic spine and the cervical spine (Bertram and Laube, 2008). Another example says that the beginners should use an exerciser like the Rocker Board. Rocker Boards have a one-dimensional instability. The principle behind: the higher the instability the more the musculature has to stabilize (Grifka and Dullien, 2008).

In summary there are the following problems regarding the planing of the sensorimotor training:

1. Great variety of exerciser
2. Assumption of the expected trainings effects of the exercisers are based on:
   (a) the manufactures informations
   (b) the literature
   (c) the physiotherapists knowledge
3. It is difficult to verify the expected trainings effects

For the analyzes of the sensorimotor training, especially regarding the first two items, an investigation of the effects of three different exercisers was made. Thereby two exercisers with a one-dimensional and one exerciser with an multidimensional instability were compared.

2 MATERIAL & METHODS

2.1 Measurements

The Shimmer^{TM} measuring instruments are small wireless sensors. The Bluetooth technology enables to stream the data online and in real-time. The used sensors were a combination of the baseboard and different daughterboards. The used daughterboards were the electromyogram (EMG) as well as the gyroscope sensor (Shimmer Research, 2011).

The EMG module allows the one channel measurement of the electrical activity of a muscle. Providing pre-amplification of EMG signal the non-invasive method represents 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 angular velocity (Kuris, 2010).

2.2 Exercisers

2.2.1 Balance Board

The Balance Board is an exerciser with a multidimensional instability, figure 1, which offers different fields of application. The height of the exerciser is 9 *cm*. The Balance Board supports the strengthening of the musculature of the buttocks, the legs, the back as well as the abdomen (Sport-Thieme, 2012).

Figure 1: Balance Board.

2.2.2 Rocker Board

The Rocker Board is characterized by its one-dimensional instability with a height of 7.5 *cm*, figure 2. The exerciser 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).

The left-right deflection requires movement patterns performed by the extension and the flexion of the knee joints. In contrast, the forward-backward deflection aims for the reaction of the ankle joint.

Figure 2: Rocker Board.

2.3 Experimental Setups

During the investigation two different setups were analyzed. The main part of the analyzed data is originated in the first setup. The second setup derived from a previous study (Thiers et al., 2013b) and was added for statistical analyzes. The first setup is meant to prove the assumption that the training on the exerciser has got some effects on the whole body. The aim of the second setup was the investigation of the participation of both body sides during the sensorimotor training (Thiers et al., 2013a).

Supporting the objective to develop a user-oriented experimental setup the design of the study was made in cooperation with experienced physiotherapists of a medical school. The requirement to develop a test procedure which can also be executed with patients causes the drop out of the maximum voluntary contraction measurement. Instead of the MVC normalization a reference measurement in front of the exerciser took place.

2.3.1 Setup 1

The first setup comprised of two young (age under 30 *years*) and healthy students. Both subjects were not familiar with the exercisers. An equal distribution of the sexes was given.

For the investigation two different types of Shimmer^{TM} measurement units were used. A pair of gyroscope sensors were centrally placed on the different exercisers. For the verification of the assumption that the training on the exercisers has effects to the whole body the sensors were placed at five different muscles along the body. The following five muscles were recorded: the M. tibialis anterior, the M. vastus lateralis, the M. gluteus maximus, the M. erector spinae (longissimus) and the M. trapezius. All test points have been measured on the right and on the left body side. Ag/AgCl surface electrodes were applied at the skin. The skin preparation as well as the placement of the electrodes considered the recommendations of the SENIAM project (SENIAM project, 2012).

The test persons had to perform the complete test sequence for each of the three exercisers. The subjects stand on both legs for the whole time. One test sequence comprised of a reference measurement in front of the exerciser with a duration of 15 *s* as well as of a measurement on the equipment. This part of the procedure was divided into four consecutive phases of changing difficulty, table 1. All phases were characterized by symmetrical requirements to both body sides. All recordings have been done without shoes. The instructions and the supervision of the correct execution were made by an experienced physiotherapist.

Table 1: 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

The second setup involved 16 healthy subjects of the medical school and the university. Two test persons of the original study were not included. The selection criterion, the subjects have to be a right-hander was not full filled. The test persons ranged from 20 *years* to 53 *years* in age. One half of the test persons was familiar with the used exercisers.

For the current investigation only the data of the Balance Board is of interest. Again, different sensors were used. Nevertheless, only the EMG data of the left and right M. tibialis anterior were important for the current analyzes. The skin preparation and the placement of the electrodes followed the recommendations of the SENIAM project (SENIAM project, 2012).

The exercises were characterized by standing the whole time on both legs and symmetrical requirements to the body sides. In this setup one test sequence consists of a reference recording in front of the exerciser and the measurement with five different phases on the Balance Board. Four of the phases were identical to the phases of the first setup. Consequently, only these four phases were considered in the analyzes of the behavior of the left and right body side. Again, all test persons have not worn shoes.

2.4 Data Analyzes

Firstly the EMG data was notch filtered with a blocking frequency of 50 Hz. Secondly a band-pass filter was applied to the data (Merletti and Parker, 2004). The next step comprised the normalizations of the EMG data. The calculation of the average muscular activity when staying in front of the exerciser was used as normalization value. Subsequently, the absolute values of the measurement on the exercisers were transformed into relative values by using the normalization value. Consequently, the values were presented as percentage of the stance.

The signal processing also implies the full-wave rectification of the EMG data (Merletti and Parker, 2004). The evaluation of the data in the time domain includes the calculation of different statistical parameters. The maximum and mean values were computed for the whole signal over a time window of 512 *ms* (Gu et al., 2010). These values were used for further calculations. 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 was calculated. Next to the mean and the maximum of the EMG the accumulated EMG activity (iEMG) was evaluated. 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. Furthermore, the course of the iEMG was documented by the summation of the iEMG over the time.

The transformation of the EMG signal from time into frequency domain was achieved by using the Fast Fourier Transformation over signal segments of 512 ms (Kaplanis et al., 2009; P. Grimshaw and Fowler, 2006). This transformation allows the computation of parameters in the frequency domain. The total power is described as the accumulation of the power density spectrum (SPD) of the whole frequencies (f), equation 1 (Kaplanis et al., 2009).

$$E_{totalPower} = \int_0^\infty S_{PD}(f)df \tag{1}$$

The parameter is used as an indicator for muscle fatigue. An increase of the total power indicates that the muscle is fatigued.

In addition to the EMG data the gyroscope data was also analyzed. The motion data was low-pass filtered. Afterwards the direction of motion as well as the current deflection was computed.

3 RESULTS

The accumulated EMG activity was calculated for each muscle and for each exerciser. For the comparison of the participation of the individual muscles the one with the highest activity value was declared as 100 %. All other activity values of the remaining muscles were set in relation to the 100 %.

Figure 3 shows the course of the accumulated EMG activity of the M. tibialis anterior and the M. vastus lateralis for both body sides of test person two on the left-right Rocker Board. In this case the 100 % were achieved by the right M. vastus lateralis. This observation goes along with the expected relationship of the participation of the individual muscles. The left-right Rocker Board especially requires the flexion and the extension of the knee which is among other things realized by the M. vastus lateralis.

Another outcome of figure 3 is that both sides of the M. tibiales anterior perform less work than the right M. vastus lateralis. It is also shown that the left muscles only carry out half of the activity compared to the right side. Additionally, it can be seen that with the beginning of the second phase the values of the EMG activity as well as the difference in the amount of the activity between the two muscles increases. Both muscles have in common that the difference in the amount of the activity level raises over time.

This behavior was analyzed in the context of the direction of motion. However the distribution of the direction does not depend on the overall time the board moved to right is similar to the overall duration of the left movements. Hence, the dominance of the right musculature depends not on the supremacy of one direction of motion.

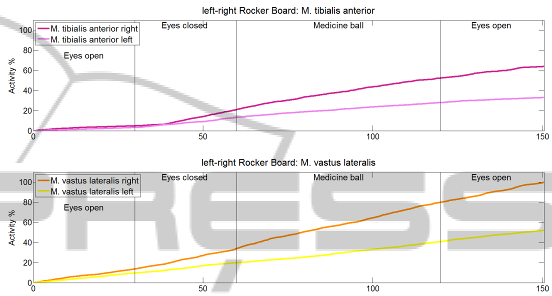

Figure 3: Left-right Rocker Board - Accumulated Activity (TP 02).

Figure 4 visualizes the average maximum values for each phase for each muscle when test person two used the Rocker Board (left-right). The first finding is, that during the initial phase nearly for all muscles the lowest values were documented. Although, the first and the last phase require an identical task, the measured values of the last phase were higher. This highlights that there is a slow relaxation of the muscle activity.

The second finding is, that the highest values were always reached by the distal musculature. Especially, for the left and right M. gluteus maximus and the left and right M. trapezius descendens relatively low voltage values were documented.

The highest values for nearly all muscles can be seen during the third phase “Medicine ball”. The catching and throwing of the ball causes an additional, external stimulus which influences the maintenance of the balance. Furthermore, the execution of this motion sequence requires the left and right M. erector spinae. Consequently, for a higher participation of the back muscles an external stimulus is needed. This also supports the assumption that the major part of the work for the maintenance of the equilibrium is done by the distal musculature and that for a participation of the proximal musculature an external stimulus is required.

Another outcome of figure 4 is that in most cases the higher voltage values were reached by the right body side. In particular, the difference between the documented values of the left and right body side of the leg muscles supports the assumption that there is a dominance of the strain in the right body side although a symmetrical requirement to both sides is given, again.

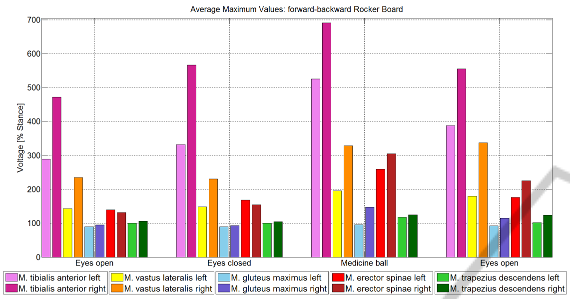

Figure 4: Forward-backward Rocker Board - Average Maximum Values (TP 02).

Figure 5 shows the course of the average maximum values as well as the course of the total power of the left and right M. gluteus maximus of test person one during the usage of the Balance Board.

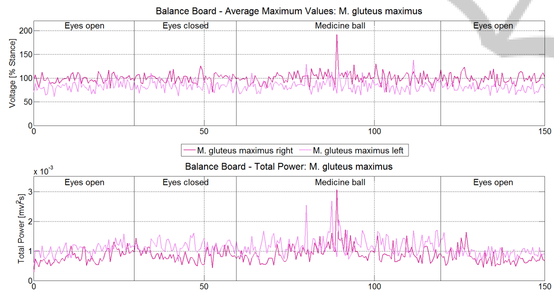

Figure 5: Balance Board - Average Maximum Values and Total Power (TP 01).

On the one hand the illustration points out that the right body side is generating higher voltage values over the whole time. On the other hand, it can be seen that nearly for the whole time the values of the left muscle show an amount of under 100 %. This means that the left muscle is producing lower voltage values during the measurement on the Balance Board than during the reference recording in front of the exerciser. On the contrary, the voltage values of the right M. tibialis anterior were between 200 and 2000 %. This finding is a reason to assume, that the accessory muscles, like the ischiocrural muscles, are mostly responsible for the maintenance of the functions of the M. gluteus maximus.

The lower section of figure 5 shows the course of the total power of the left and right M. gluteus maximus. Fatigue is defined in muscle physiology as a state when a subject can no longer maintain a required force (Merletti and Parker, 2004). Hence, the maintenance demands an increasing recruitment of motor units (Lukas, 2000). Although, the left M. gluteus maximus produces lower voltage values, the total power of the left muscle is nearly the whole time higher than the total power of the right body side. Consequently, the left muscle had recruited a higher number of motor units despite the lower voltage values.

The illustration 6 provides a brief overview of the complete muscular activity of each muscle on each exerciser for both test persons. The muscle with the highest strain from both subjects represents the 100 %. The values of the remaining muscles from both test persons were presented in relation to the 100 %.

The complete muscular activity for test person one for each muscle and each exerciser is documented in the upper part of the figure 6. The 100 % were achieved by the right M. tibiales anterior during the execution of the trial on the forward-backward Rocker Board. Furthermore, the second highest value was achieved on the same exerciser but in this case by the left M. tibialis anterior.

The figure also points out that the strain of the individual exercisers aims to different muscles. Using the Balance Board mostly burdens the left and right M. vastus lateralis. In contrast, the M. erector spinae shows for both body sides the highest values on the left-right Rocker Board. As already mentioned the forward-backward Rocker Board shows the highest strain in the M. tibialis anterior. Nevertheless, the first and last exerciser have in common, that the distal musculature shows the highest values. The ranking of the overall strain of the three exercisers shows the order (highest strain first): forward-backward Rocker Board, Balance Board, left-right Rocker Board.

The values of the complete activity of all muscles on all exercisers of test person two are presented in the lower part of figure 6. Test person two obtained the highest values with the right M. vastus lateralis on the left-right Rocker Board. The overall comparison of the three exercisers shows that the Balance Board seems to be the smallest challenge for the test person. In contrast, the highest complete strain was achieved by the left-right Rocker Board. The various forms of the Rocker Board required different muscles. The left-right Rocker Board has the highest effort in the right M. vastus lateralis. On the contrary, the right M. tibialis anterior shows the highest values during the usage of the forward-backward Rocker Board. Again, all exercisers have in common, that the highest values were documented for the distal musculature. The difference of the amount of the activity of the leg muscles on the individual exercisers is greater than the single values of the M. gluteus maximus, M. erector spinae and the M. trapezius descendens.

The illustration also figures out, that on each exerciser all muscles, except the M. trapezius descendens, show the highest values for the right body side. All exercisers have in common, that the EMG activity of the test person differs. Although the test persons used the same exercisers and had to handle identical tasks the individual requirements seem to be different.

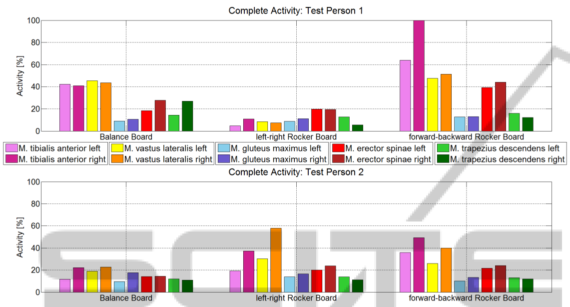

Figure 6: Activity - Comparison of the three exercisers.

The current figure 7 shows the deflection into the direction forward-backward. In the upper part of the figure the deflection for the Balance Board is shown. The course of the forward- backward Rocker Board is shown in the lower part of the figure.

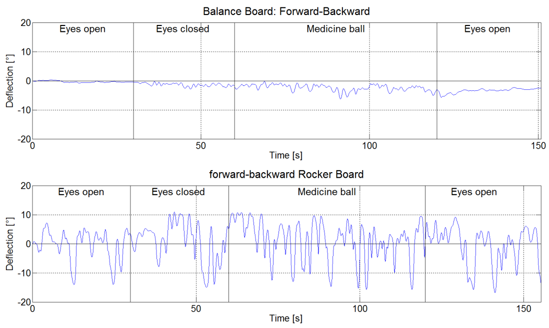

Figure 7: Balance Board and forward-backward Rocker Board - Deviation (TP 01).

The Balance Board shows no drift in one direction over the whole time. Only during the phase "Eyes closed" (Phase two) a drift can be seen. Immediately after the visual analyzers, the eyes, are turned on again, the drift is corrected. In the third phase greater deflections were measured, they are caused by the additional difficulty induced by the external stimuli of the medicine ball. On the whole, the course is characterized by small and short deflections around the baseline.

The course of the forward-backward Rocker Board only shows slight differences during the individual phases in the amount of the values of the deflection. In the first and second phase a short and small drift was documented. In both cases the drift is correct after 15/ 20 s. The comparison of the strength of the deflection from the forward-backward Rocker Board to the intensity of the forward-backward deflection of the Balance Board shows differences. The intensity of the deflection of the Rocker Board is much greater than the intensity of the Balance Board.

Figure 8 serves the comparison of the left-right relation of the M. tibialis anterior on the Balance Board. Therefore the average maximum voltage values of 18 test persons (two from setup one and 16 subjects from setup two) were summed up in the box plot.

The figure points out, that the highest voltage values were produced by the right M. tibialis anterior during the second phase "Eyes closed". One additional finding of the right body side during this phase is, that it has the largest range between the maximal and the minimal values. This may mean that the individual persons react in different ways to the elimination of the visual analyzer. The behavior of the test persons depend on their age, their balance skills, their muscles, their motor and coordination skills and so on. This influential factors cause, that for some people the consequences regarding the maintenance of the equilibrium are greater than for others. The figure 8 also brings out, that in the overview of all test persons the right side is the dominant body side for all considered scenarios. On the one hand, every time the median value is higher on the right side of the M. tibialis anterior. On the other hand, the 75 th percentile is also always greater on the right body side. In addition, the left body side has always the lowest minimum values (25 th percentiles).

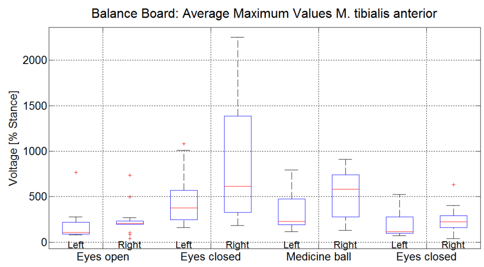

Figure 8: Comparions of the average maximum voltage values of both body sides.

The current box plot of figure 9 shows the average maximum voltage values of the test person from both setups for the M. tibialis anterior and the M. gluteus maximus. On the one hand the measured values again document that the major part of the work is done by the distal musculature. The median value of the M. tibialis is up to four times higher than the median value of the M. gluteus maximus. The documented values of the M. gluteus maximus correspond to the activity values during the reference measurement in front of the exerciser. Consequently, it is shown that the continuation of the muscular activity up to the proximal musculature has only a small extent because the demand to the musculature is slightly higher than in demand in front of the exerciser.

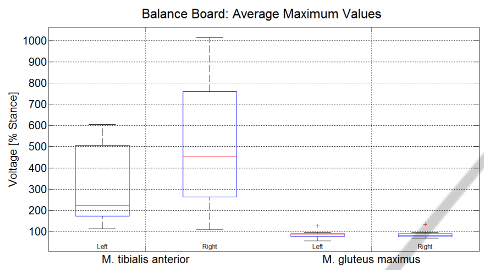

Figure 9: Comparions of the average maximum voltage values of M. tibialis anterior and M. gluteus maximus.

For further statistical analyzes the "Chi-squared" test was performed for the 18 test persons from setup one and setup two when using the Balance Board. The statistical investigation was made for the average maximum values for the left and right M. tibialis anterior. Therefore a comparison of the voltage values of each test person was computed. For each subject a decision which body side reached the higher values was made. The evaluation was fulfilled for each phase and for the overall measurement. Consequently, the H_0 hypothesis, that there is no dependency between the maximum values and the body side, was rejected to significance level of 5 %.

4 DISCUSSION

The experimental study points out four important findings. Firstly, the assumption that the muscles of nearly the whole body were involved in the process of the maintenance of the equilibrium on the exercisers could not be proofed. Secondly, there is a different behavior regarding the left and right musculature. The third finding is, that it is not possible to make a general assumption, that exercisers with a one-dimensional instability are easier to handle than the exercisers with a multidimensional instability. The last finding is, that each test person shows an individual behavior on the exercisers.

The analyzes of setup one showed, that the major part of the work for the maintenance of the equilibrium is done by the distal musculature. To achieve a higher participation of the proximal musculature an external stimuli, like catching and throwing of a medicine ball is needed. Especially, for the left and right M. gluteus maximus low voltage values were documented. This observation leads to the hypothesis that the ischiocrural musculature takes the job of the M. gluteus maximus.

The study of the voltage values of the left and right body side was carried out for both setups. The investigation of setup one showed that in most cases the right musculature achieved the higher voltage values. In particular, the distal musculature of the left and right body side often shows great differences between the maximum voltage values as well as between the accumulated EMG activity. This finding was supported by the statistical analyzes of the maximum voltage values for subjects of setup one and two.

Both, the EMG data and the motion data of the three exercisers, showed, that it is not possible to determine the difficulty of an exerciser by one- or multidimensional instability. The exercisers with the one-dimensional instability were in both cases the one with the greater deflection and the greater voltage values. However, both test persons from setup one achieved the highest values on different Rocker Boards.

The overall finding is, that it is not possible to make general assumptions about the usage as well as about the effects of the exercisers. This is due to the fact that the test persons showed an individual behavior on the equipment.

5 CONCLUSIONS

The investigation of the three exercisers reveals that it is necessary to analyze the sensorimotor training more detailed. It is not enough to take the manufactures information, the literature as well as the practical knowledge in consideration. Rather the results show that the application and the corresponding effects of the exercisers depend on the behavior of the subject. One solution for the improvement and the verification of the training is the application of wireless sensors. The usage of wireless sensors is a helpful instrument to analyze the behavior of different subjects on the exercisers. Consequently, the physiotherapist has to consider the characteristics of the patient in the planning of the therapy. Furthermore, the use of wireless sensors are a very good way to document the development and the results of the therapy. The physiotherapist are able to control the changes of the behavior of the muscles.

A second point for an effective planning of the therapy is excellent knowledge about the exerciser. In the majority of cases the product descriptions include information of the material, the height, the diameter and sometimes the angle of deflection. All analyzed exercisers have similar values regarding the height, the diameter as well as the angle of deflection. Nevertheless, the test persons showed different activation patterns. This leads to the recommendation that the product descriptions should include additional information, for example about the own weight of the exerciser or information about the special characteristics of the supporting surface.

The current results can be extended to a more detailed investigation of the behavior of the muscles in dependency of the movement on the exerciser and with a greater number of test persons. With the help of the mobile sensors it is also possible to give an immediate feedback for the correction of the dominance of one body side. This different behavior of the body sides will be analyzed more detailed in further studies. In this context we will also analyze whether the dominance of the right side is caused by the fact that the test persons were all right handed.

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