PhysioSonic - Evaluated movement sonification as auditory feedback in physiotherapy

Katharina Vogt[1], David Pirrò[1], Ingo Kobenz[2],
Robert Höldrich[1], and Gerhard Eckel[1]

1 - Institute for Electronic Music and Acoustics,
University of Music and Performing Arts Graz, Austria
2 - Orthopaedic Hospital Theresienhof, Frohnleiten, Austria
vogt@iem.at, pirro@iem.at, hoeldrich@iem.at,
kobenz@theresienhof.at, eckel@iem.at

Abstract. We detect human body movement interactively via a tracking system. This data is used to synthesize sound and transform sound files (music or text). A subject triggers and controls sound parameters with his or her movement within a pre-set range of motion. The resulting acoustic feedback enhances new modalities of perception and the awareness of the body movements. It is ideal for application in physiotherapy and other training contexts.

The sounds we use depend on the context and aesthetic preferences of the subject. On the one hand, metaphorical sounds are used to indicate the leaving of the range of motion or to make unintended movements aware. On the other hand, sound material like music or speech is played as intuitive means and motivating feedback to address humans. The sound material is transformed in order to indicate deviations from the target movement.

PhysioSonic has been evaluated with a small study on 12 patients with limited shoulder mobility. The results show a clear benefit for most patients, who also report on PhysioSonic being an enrichment of their therapeutic offer.

1 Introduction

Body movements do not cause other feedback than given by the proprioception, the usually unconscious perception of movements and spatial orientation. Additional feedback is helpful in different disciplines of motor learning and physical exercise. In training, sports men and women or patients of orthopaedic rehabilitation are usually limited to visual feedback. Acoustic feedback has been used, but was limited to partial data or indirect measurements until recently, when real-time full-body tracking became possible.

An optimal learning and training process depends on the permanent comparison of an actual value to the desired value, in the sense of a closed-loop feedback. In learning of motor skills or re-learning them in the course of rehabilitation, the learner or patient needs information on his or her distance to a (therapy) goal and on the quality of the movement. This feedback can be inherent information, intrinsically coming from the human proprioception. But athletes or rehabilitation patients often require augmented, extrinsic feedback, which is usually given by the patient or the therapist. The learner then needs to know about quantitative and qualitative movement features the knowledge of results vs. the knowledge of performance. With this background it is possible to compare the actual to the desired value, and achieve a continuous performance increase. The therapy tool as presented in this paper allows the patient to access both information channels, the knowledge of results and the knowledge of performance. The feedback is in real-time, exact and without the subjective filter of the therapist or trainer.

In this paper we describe a sonification system for auditory feedback of different movements of the human body. We will shortly summarize the state of the art and outline the novelties in our approach. A technical and medical background will describe the system in more detail for an application in physiotherapy. Shoulder patients have difficulties in lifting their arms laterally in the coronal plane. For this context, several training scenarios have been developed. A pilot test was performed, where the training gain of our sonification system was tested.

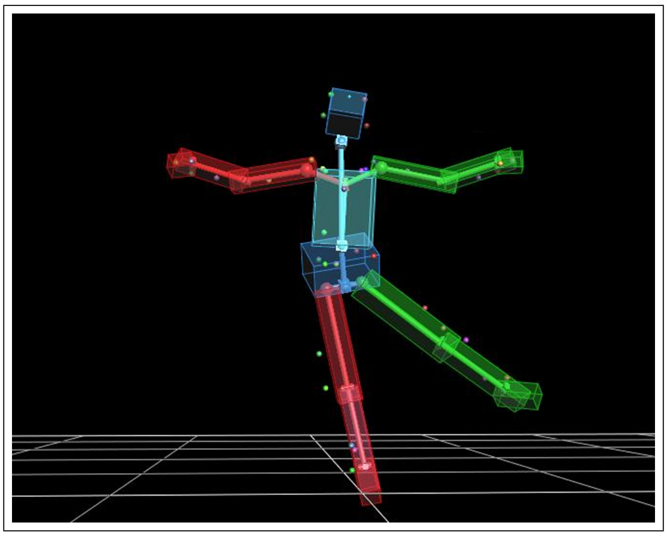

Fig. 1. *Example of a full-body tracking, used in EGM [22] project at the IEM.*

2 State of the art

We found different applications of sonification of movement data. Some focus on sports and physiotherapy, some serve as a basis for artistic research. Next to pure sonification approaches, the International Society for Virtual Rehabilitation [2] does research on virtual reality assisting in rehabilitation and for disabled people. See also the end of this section.

In sports, approaches to sonification vary largely. There is, e.g., a training system to learn the perfect golf swing supported by auditory feedback [3], [20]. Sonification is also used to analyse the dynamics of individuals interacting in a sport's team [18].

Several sonifications based on human motion data in sports were conducted by Effenberg et al., see [12].

In physiotherapy, one approach was the sonification of EMG (Electromyography), data on the electric potential of muscle cells [21].

A direct motion-sonification system is AcouMotion [14], thought for application in various disciplines from sports to physiotherapy. An accelerometer is used, for instance representing a virtual racket, allowing for training of *blindminton*, a game for people with visual impairment [16]. In a different application, a pilot study was conducted on the learning effects of people throwing a virtual object, when the thrower was supported with visual or auditory feedback or both. The latter lead to best results [17]. The change of proprioception of the test persons has been refered to augmented reality in this context [25].

Within the SonEnvir project [4], the movement of juggling clubs in relation to a juggling person was tracked with a motion tracking system and sonified in real-time [9]. The goal was to provide an additional feedback for the juggler and elaborate a multimedia performance. The same tracking system is used in the research project EGM - Embodied Generative Music [22]-, where the dancers are tracked directly. An interactive sonification of these movements allows to study the change of the proprioception of the dancers exhibited with new auditory feedback. Also, aesthetical interrelations between sound and movement is object of research in the project.

In MotionLab [13], kinematic data of a walking person is gathered with a motion tracking system and deduced quantities, as the expenditure of energy calculated. These data are sonified in order to analyse the movement. At Stanford university, motion tracking is used in different contexts ranging from dance and instrument playing to sports in a multidisciplinary course [5].

In general, the linking of movement to sound or other modalities is captured by the concept of aesthetic resonance in virtual rehabilitation. It is applied in a variety of cases, and can be classified as musculo-skeletal, post-stroke and cognitive Virtual Rehabilitation [11]. Classical rehabilitation, on the one hand, has disadvantages: it is repetitive, thus sometimes boring, provides few and often subjective data, is costly as a one-to-one treatment and it cannot be monitored at home. Virtual rehabilitation, on the other hand, has as a major advantage economy of scale. Furthermore, it is interactive and motivating and provides objective and transparent data. The main drawbacks, as cost-intensive equipment and disturbance of interfaces, that have not been developed for a therapeutic application, become less and less important with technological development.

The proceedings of the International Conference on Disability, Virtual Reality and Associated Technologies gives testimony of a growing number of applications in this field. As one example focussing on sound [10], the EU project CARESS [1] studied the interaction of children of various ability and disablity with sound.

3 PhysioSonic

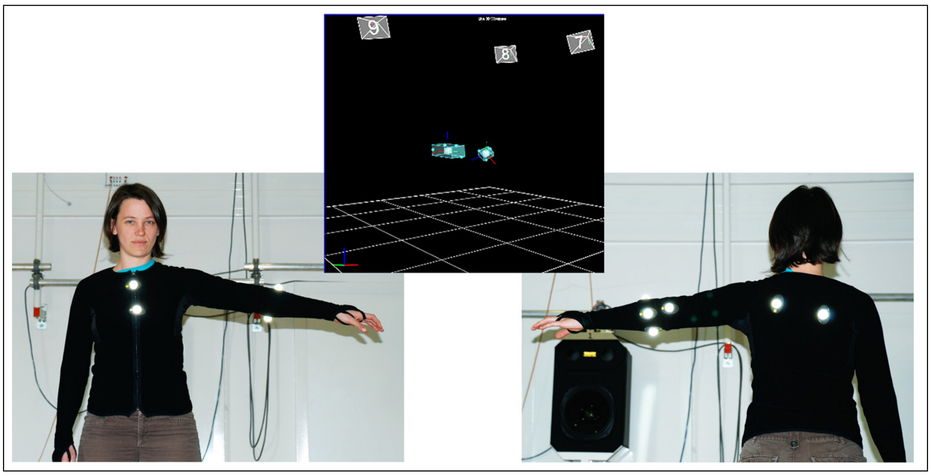

Fig. 2. *The placement of 8 markers: 4 define the thorax and 4 the arm. The tracking system calculates location and rotation of each object. The screenshot shows the tracked markers grouped as these objects by the software. The numbers on top refer to some of the cameras.*

Many of the pure sonification approaches refered to in section 2 use abstract sounds. Their meaning has to be learned by the subjects or the sonification is only meant for movement analysis by trained staff. Usually, the exact repetition of a movement leads to the exactly same sound. In a training context, this may cause fatigue or annoyance of the listener.

In PhysioSonic, we focus on the following principles:

- The tracking is done without a disturbance of the subject, as markers are fixed to an overall suit or the skin directly (and the subject does not, e.g., have to hold a device).
- In collaboration with a sport scientist, positive (target) and negative (usually evasive) movement patterns are defined. Their range of motion is adapted individually to the subject. Also a whole training sequence can be pre-defined.

– The additional auditory feedback changes the perception including the proprioception of the subject, and the movements are performed more consciously. Eyes-free condition for both the subject and an eventual observer (trainer) free the sight as an additional modality. In addition to the target movement, pre-defined evasive movements are made aware.
– We sonify simple and intuitive attributes of the body movement (e.g., absolute height, velocity). Thus the subject easily understands the connection between them and the sound. This understanding is further enhanced by using simple metaphors: e.g., a spinning-wheel-metaphor keeps the subject moving and thus *'pushing'* the sound; if the subject does not accumulate enough *'energy'*, the looping sound of a disk-getting-stuck metaphor is used.
– The sounds are adapted to each subject. Music and spoken text that are used as input sounds can be chosen and thus enhance the listening pleasure. Also, the input sounds change over time and have a narrative structure, where the repetition of a movement leads to a different sound, thus avoiding fatigue or annoyance. (Still, the sonification design is well defined, and the quality of the sound parameters changes according to the mapping.)

3.1 Technical background

Our sonification system was developed at the Institute of Electronic Music and Acoustics in Graz, Austria, in the CUBE [27]. Next to full audio equipment, this space is wired up with the VICON motion tracking system [7]. It allows spatial resolution in the millimeter range and a temporal resolution and reaction time below 10 ms: therefore the high quality of the tracking ensures that all relevant aspects of the body movement will be captured. This is the key feature that allows us to use this data to drive the sound synthesis and sound manipulation.

Fig. 3. *Infrared camera of the VICON motion tracking system.*

The 15 infrared cameras (see Fig.3) which are part of the system are sampled at 120 frames per second and are equipped with a ring of infrared emitting leds. They are installed at ca. 3 meters height in order to provide a homogeneous tracking quality within a volume of approximately 6 meters diameter and 3 meters height. In this space, every object or person with infrared reflecting markers is clearly visible to the cameras.

The video data coming from the cameras is collected by a data station and then processed in the VICON software which reconstructs the coordinates and orientation of the objects, representing different parts of the body.

The system has now also been installed at the Orthopaedic Hospital Theresienhof in Frohnleiten, Austria. The hospital has an own tracking system with 6 cameras.

In the example that will be described in Sec. 4, we worked with a specifically designed marker set which defines single objects tracked in the space (see Fig. 2). But the system allows also a full-body tracking mode in which the software reconstructs the whole skeleton of the test person providing 19 reliably tracked body segments from head to toe using inverse kinematics fitting in real-time (see Fig.1). The tracking data, including position and orientation data either in absolute or relative form, is then streamed via the *Vicon2OSC* [8] program developed at the IEM to a SuperCollider[6] client. Developing the mapping of the tracking data to the audio synthesis control parameters, we make use of SuperCollider classes and operators that handle tracking data and were implemented in the context of the EGM [22] project.

The system allows a very detailed continuous temporal and spatial control of the sound produced in real time. We establish thereby a closed-loop feedback between the subject's movements and the sound produced.

3.2 Generic model for movement sonification

A block diagram of the sonification is shown in Fig. 4. A specific example of the sonification design for shoulder rehabilitation is described in Section 4.4. A movement model is defined, assessing movement patterns and an optional training sequence. Sound material and synthesis are chosen. The movement model is adjusted individually and used to evaluate the data of the tracking system. This data is used for parameter mapping, the samples are transformed, sound is synthesized and/or spatialized.

Development of movement and sonification models. For a certain training goal, *positive* (target) and *negative* (evasive) movement patterns are defined. Optionally, also an evolution over time can be specified, supporting a training sequence. Sounds are classified as motivating or inhibitory. The sound synthesis is defined and sound samples, music or speech files, are loaded.

Individual Adjustment. The model parameters are adjusted to the subject (stationary position, range of motion, training goal, etc.). The aesthetic taste of the subject is taken into account in the sample selection.

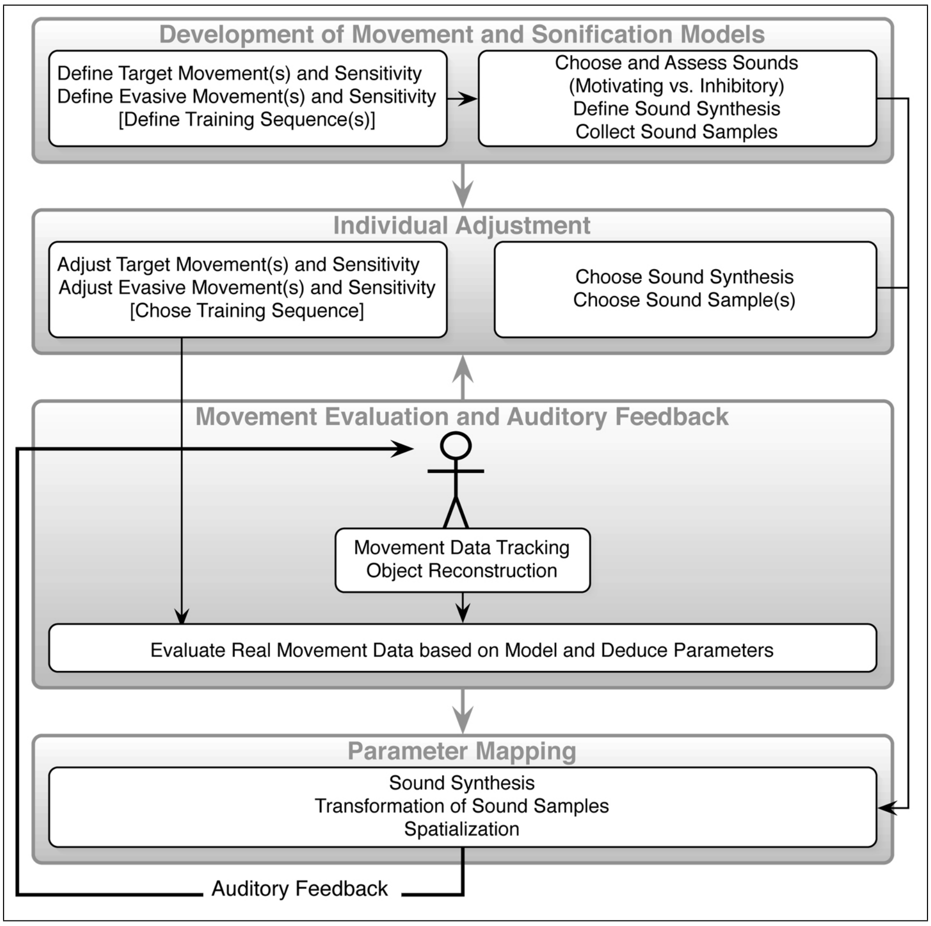

Fig. 4. *Block diagram of the project design.*

Movement evaluation and auditory feedback. The motion tracking system captures the movement data, and reconstructs the body parts as objects, using a body model, in real-time. This data is evaluated on the basis of the movement model, defined above. Inside the individually adjusted tolerance range, any deviation is ignored. Outside the range, the samples are sonified or sounds synthesized according to the parameter mapping (see below). Auditory feedback in real time enables the subject to correct the movement.

Parameter mapping. The mapping uses the sound material and transforms them or generates sounds according to the evaluated data. The sound samples are transformed by filtering or playing at a different rate. Sounds are synthesized depending on the data. Finally, a spatialization of both, sound samples and abstract sounds, gives additional cues.

4 Example: Shoulder

4.1 Medical background

From a series of tests we know that movement analysis of the upper extremity by means of 3 dimensional kinematics is a very exact and objective method to quantify the joint angles of wrist, elbow or shoulder [15], [24]. Correspondingly, monitoring the functional ranges of upper limb activity could become a very important method to evaluate the improvement of a physical therapy.

The study presented in this paper describes a new way to transform the results of 3D movement analysis of the shoulder joint kinematics into a special feedback which can be used to correct false postures or coordinate a therapeutic exercise for the shoulder joint.

Injuries or surgical treatments of the shoulder joint nearly always induce essential conservative treatment or physical therapy in order to regain the normal range of motion and muscle power. A limited range of motion or reduced power comprise the danger that a patient tries to compensate this lack of shoulder mobility by means of thorax movements. For example it can often be detected that patients try to lean their upper body laterally to increase their space within reach if the abduction of the shoulder is limited. Also, a backward leaning of the upper body is implemented in order to increase the radius in case of a limited flexion.

To avoid these undesirably compensatory activities the patient needs exact instructions what to do and how to practice. In most cases the patient does not know how much his physical exercise differs from the guideline. The system presented here gives a feedback to the patient if the exercise is accomplished precisely and corresponds with the guidelines. The new system offers a very effective control for the training of the shoulder joint.

4.2 The shoulder joint: Anatomy and movements

The human shoulder is a very complex system in which many joints are involved: The glenohumeral joint, the acromioclavicular joint, the sternoclavicular joint and the scapulothoracic joint. Normally we have only two joints in mind if we refer to movements: the scapulothoracic and glenohumeral joint.

The shoulder joint or glenohumeral joint is a ball-and-socket joint. The bones entering into its formation are the head of the humerus and the shallow glenoid fossa of the scapula. The joint is protected by an arch, formed by the coracoid process, the acromion, and the coracoacromial ligament.

The humeral head is attached to the glenoid cavity (scapula) by the help of a group of muscles, the rotator cuff. Complementarily, these muscles stabilize the joint in all positions and support other muscles (synergist). We are talking about the supscapularis, infraspinatus, supraspinatus and teres minor.

Additionally other muscles enable movements in the glenohumeral joint: teres major, subcapularis, deltoid, biceps femoris, triceps femoris, corachobrachialis.

Muscles moving the scapula are trapezius and rhomboids e.g. Pectoralis major and latissimus dorsi both move the scapula as well as the humerus.

Scapular and the glenohumeral muscles enable the patient to fulfill a range of different movements:

- to lift his arm laterally (movements in the coronal plane, abduction-adduction)
- to move the arm forward (movements in the sagittal plane, flexion-extension)
- to rotate the arm around the long axis of the humerus (movements in the transverse plane, medial-lateral rotation).

There is no doubt that the quantification of these complex joint movements by means of a 3D analysis system is very difficult.

According to Rab [23] in our simplified biomechanical model which serves as the basis for this study the shoulder complex is reduced to the movement of the humerus in relation to the thorax.

4.3 A special movement: The abduction

What is the therapeutical profit of this new system?

According to Kaspandji [19] the abduction can be split into 3 phases:

- Within the first phase the arm is abducted from the neutral position to 90 degree abduction. Deltoideus and supraspinatus are mainly responsible for the work. The end of this phase is the contact between tuberculum major and the scapula which limits the movement. If this abduction is combined with a small anteversion of about 30 degree the arm follows a physiological track [26]. This guideline could be transmitted to the patient by acoustic feedback. If the patient sticks exactly to the rules his effort can be controlled by the system. As a result it is possible to train certain muscles in special ranges. Resistance can be added according to demand.
- Within the second phase (from 90° to 150°) the scapula must move additionally to guarantee the aspired abduction. Trapezius and serratus anterior can be trained in this phase because they are responsible for the scapula movement.
- In the last phase of abduction (150° to 180°) the thorax has to move to the contralateral side. If this movement is detected within phase I or II it could be signalled with the help of the feedback system. The signal should encourage the patient to increase the space within reach by an enhanced movement of the shoulder joint.

A series of informal analyses proved that the new system is an excellent means to guide patients during their training program. By the help of acoustic feedback the patient practises within the allowed extent of abduction and does not exceed beyond the desired range of motion. A pilot study will be set up to judge on the efficiency of this new training method vs. traditional ones.

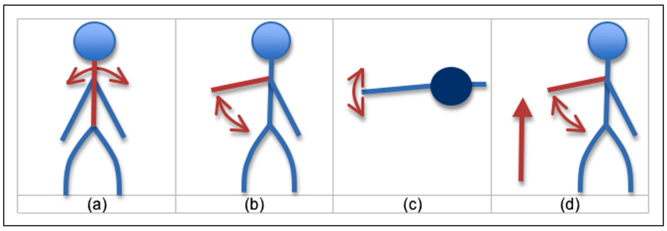

Fig. 5. *Relevant movement patterns.*

4.4 Sonification design and metaphors

As discussed in the previous sections, in orthopaedic rehabilitation patients train shoulder abduction and adduction. In the training sequences it is important that the subjects do the required movements without inclining the thorax too far (see Fig.5a). Another requirement is that the movement is done laterally in the coronal plane, also inside a certain range of tolerance (see Fig.5c, seen from above). Given these constrains we concentrated in designing two specific training scenarios.

1. In the first one the elevation range of the arm is divided into a number of previously defined subject-specific ranges. The aim for the patient is to reach each of these ranges in sequence (see Fig.5b). The therapist may adjust the posture with the patient and give him/her a feeling of the right position.
2. In the second training sequence the patient is required to repeat the abduction and adduction of the arm continuously within a pre-defined velocity range and possibly also reaching a specific minimal height (see Fig.5d). Thus s/he can perform a training independently.

In order to capture the movements' features that are relevant in these two scenarios we used 8 markers grouped in 2 sets defining 2 different objects (see Fig.2). Thus from the motion tracking system we receive position and rotation information of thorax and arm. The first allows us to detect whenever the patient tilts the thorax and in which direction. The arm position and orientation give us the possibility to compute the elevation of the arm relative to the thorax. Furthermore, we use the azimuth value of the arm to show whenever the movement of the patient leaves the required plane for the exercise. For all different movements, ranges of motion are defined with a certain tolerance region in which deviations are ignored. All data is relative, thus independent of the absolute position in the room.

Training 1 - Wood scenario. As described above, in the first training sequence, we divided the elevation range of the arm into slices. To each of these slices corresponds a particular sound sample which is then looped. When the patient moves the arm higher or lower into another elevation range another sound is triggered. We experimented with this setup using natural sound textures. The lowest range corresponds to the sound of a rustling leaves, in the next slice we find animal sounds, croaking frogs, grunting pigs and chirring crickets, then birds' songs and, in the highest range, the sound of the wind through the trees (see Fig.6). This sound was chosen, because it allows a very intuitive estimation of the height of the arm, and motivates the patient to *reach*, e.g., the birds. Also it reminds to a wooden surrounding, which is quite the contrary to a sterile clinical environment, and thus makes the training situation more pleasant.

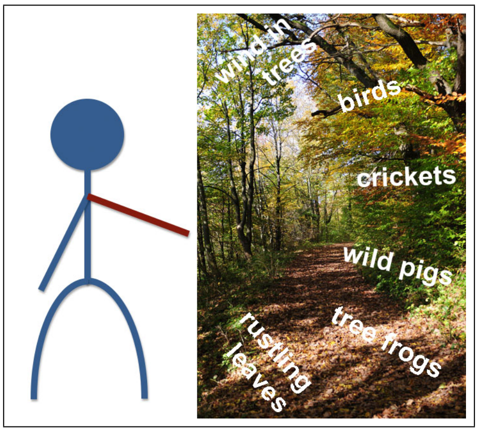

Fig. 6. *Training scenario 1: Forestal wildlife as a pleasant and simple metaphor to absolute heights of the arm. The different animal sounds overlap and give a continuous impression.*

Training 2 - Music scenario. In the second setup we compute the velocity of the elevation and we then use this parameter to control a reproduction of a sound file. In this case we used longer sound files containing either music pieces or texts. If the patient's movement falls below a certain mean velocity, the reproduction will get stuck, looping the last few seconds of the recording. This metaphor is very intuitive, mimicking a disk getting stuck. But if the patient's arm velocity is faster than this threshold the sound file will be reproduced normally allowing to hear it to the end.

Another metaphor that we want to implement is the spinning wheel: if the sound is not pushed enough, e.g. by reaching a pre-defined height, the playback slows down, i.e., the pitch is lowered, and the sound eventually stops.

Evasive movements - thorax inclination. Looking at the evasive movement of the thorax (see Fig.5a), first we decided to use synthesized white noise to sonify the inclination. The volume of this noise is coupled to the computed displacement and thus becomes louder when bending away from the correct position. The direction of the displacement (front, back, left, right) is taken into account by the spatialisation of the sound i.e. having the produced sound come from a loudspeaker placed in the same direction as the evasive movement. That means when bending forward the noise will come from a loudspeaker placed in front of the patient. Next to simple masking white noise, we used a creaking sound as a metaphor to underline the negative quality of the evasive movement. Noise or creaking can be chosen (or muted) and are then played together with the training scenarios.

Evasive movements - arm evasion. Finally we take into account the case in which the patient's arm leaves the optimal movement plane we defined above (see Fig.5c). When the arm moves more to the front or to the back of the patient, the sounds produced according to the elevation or velocity of the arm will be strongly filtered thus becoming more unrecognizable the farther the arm is from the desired movement plane.

All metaphoric sounds and sonification designs described above allow to hear the correct sound only with the correct movement. Else, the music or text files are masked (by noise or creaking), filtered, get stuck and loop, or slow down and loose their pitch. All this destroys the original *gestalt* and is very easy to perceive also for non-trained people.

Both the music and text files and the ambient sounds can be chosen by the patient. Until now, we provide a set of different music styles ranging from J.S. Bach to Paolo Conte, as well as texts from Harry Potter to Elfriede Jelinek. In a later stage, the patient shall have the opportunity to bring his or her own favorites along to the therapy.

5 First evaluation

A first study on the practicability of PhysioSonic was conducted in the orthopedic hospital Theresienhof. It investigated the influence on augmenting the shoulder abduction with in the same time stabilizing the thorax in the frontal plane. The compensatory movement of the upper limb should be avoided. The focus of the study was set on the practicability of the software package from the point of view of the therapist and the acceptance by the patients.

5.1 Test persons

12 in-patients of the hospital took part in the study, out of which were 5 women and 7 men. These had indicated in their admission the enhancement of mobility of the shoulder joint as primary therapy goal. Criterion for exclusion of the study were situations of structurally limited mobility of the shoulder joint because of muscle or tendinous contractures or a restrained mobility caused by neuronal damages. Also patients with reduced hearing ability and lack of compliance were not taken into account.

The average age was 55,2 years (standard deviation 8,9 years). The diagnoses in particular: 4 total ruptures of the rotator cuff, 3 ruptures of the supraspinatus tendon, 2 fractures of the humerus and 1 inverse shoulder prosthesis delta.

The average of the postoperative interval of these patients was about 89,4 days (std.dev = 49,9 days). 2 patients with a shoulder impingement syndrome were treated conservatively.

All patients had a higher passive mobility in the shoulder joint than the active range during therapy.

5.2 Methodology

Before and after the PhysioSonic training the active mobility of the shoulder joint was recorded with the VICON motion tracking system. For each patient, the maximal abduction, maximal flexion and the maximal outward rotation was measured before and after PhysioSonic (pre- and post-measurement). A comparison of these results was done to measure the outcome of Physiosonic. This allowed to compare the mobility in the shoulder joint. For calculating the dynamics, the upper limb model following Oxford metrics was used (see Fig. 7).

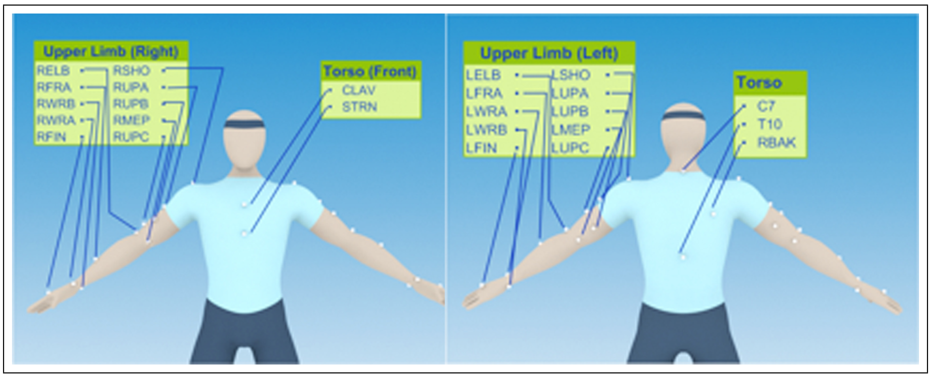

Fig. 7. *Marker placement of the upper limb model (Oxford metrics).*

After the pre-measure the marker setup was reduced: two rigid segments were marked: thorax and upper arm (see Fig. 8). The relative movement between these segments and their absolute location and orientation in space are the basics for PhysioSonic (see section 4.4). The placement of the markers is described in detail in the following table:

Definition of the markers for PhysioSonic.		
THORAX Segment:		
Marker Label	Definition	Marker Placement
THO	Thorax Origin	Processus Xiphoideus
TH1	Thorax M1	Jugular notch manubrium
TH2	Thorax M1	Processus Spinosus C7
TH3	Thorax M1	Processus Spinosus TH10

ARM Segment:

Marker Label	Definition	Marker Placement
ARO	Arm Origin	Epicondylus lateralis
AR1	Arm M1	On the lateral upper arm
AR2	Arm M2	Epicondylus medialis
AR3	Arm M3	Most prominent part of the olecranon process

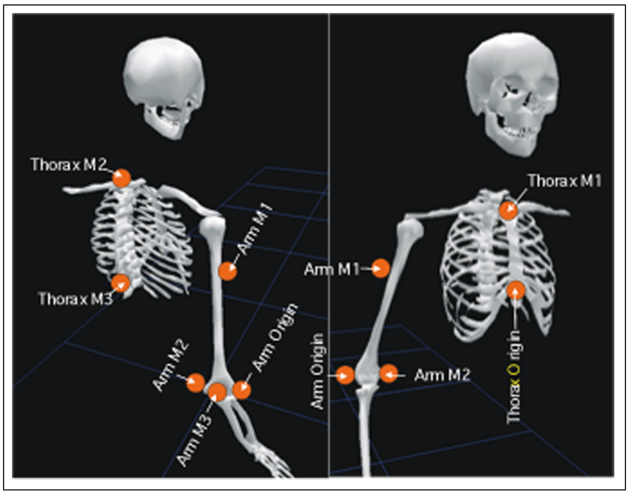

Fig. 8. *Marker placement for PhysioSonic.*

The patient then was explained the different acoustic feedbacks of PhysioSonic and how to control them. The sensitivity of the thorax parameters was adjusted to each patient with a short training. Then, the music scenario was played for continuous training, followed by the wood scenario played for 3-5 times. In the wood scenario, the parameter for the arm's elevation range was re-adjusted several times in order to find a goal range that leads to a performance increase. Then the training in the music scenario was repeated.

Finally, the measuring marker setup was re-set for the post-measurement. The placement of the markers had been color-marked in order to achieve an identic measuring situation.

The time for the pretest, the PhysioSonic therapy and the posttest was about 30 minutes, the evaluation of the data not included. Using only PhysioSonic for therapy without data analysis took about 15 minutes. Therefore, as mentioned, a very simple marker setting was used (see Fig. 8).

5.3 Results

Study indicators were the stability of the upper limb and the change of abduction range in the shoulder joint. The use of acoustic feedback for movements of the arm in the sagittal plane was neglected, as all patients showed no significant deviations and conducted the movement in the right way.

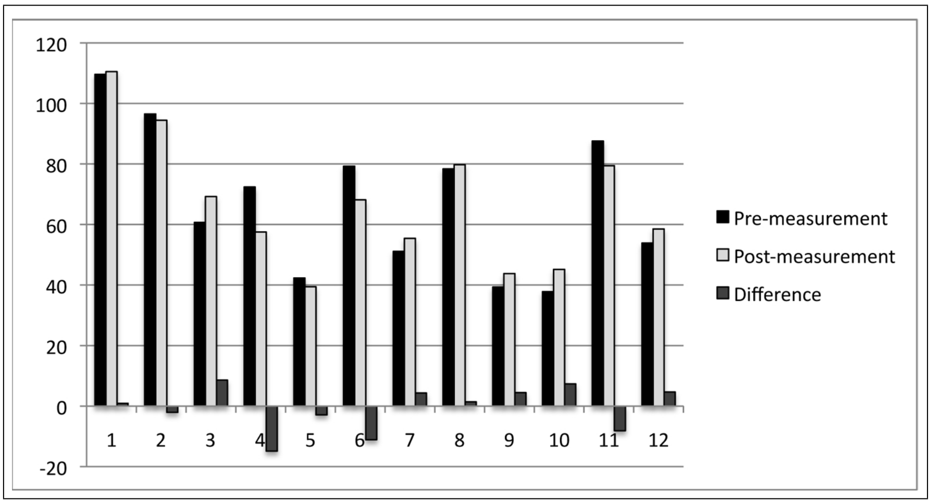

Fig. 9. *Shoulder abduction before and after the therapy with PhysioSonic.*

Figure 9 shows the shoulder abduction range before and after the PhysioSonic therapy, and the difference between the two. 7 out of the 12 test persons showed an increased abduction after PhysioSonic (58,3%). The mean improvement was 4,5°. Figure 10 shows the verticalization of the thorax before and after the PhysioSonic training and their difference. In the post-measurement, 8 out of 12 patients (66,6%) showed an optimized, thus reduced, evasive movement of the upper limb to the contra-lateral side.

5.4 Discussion and additional results

The application of PhysioSonic in the rehabilitation as described above leads to the discussed increased performances and optimizations. The observed worsening of the abduction for 3 patients can be explained by an overload of the relevant musculature. This shows, that PhysioSonic can lead to a muscular demand that excesses the subjective optimal load limit, and thus reduces the mobility. The reduced verticalization of the upper limb with 3 patients can also be explained by this effect.

Additionally to this study, two patients have used PhysioSonic at their own request several times a week during their stay at the hospital. A clear amelioration of mobility and strength in the shoulder joint could be observed with both of them. Still, a mono-causal assignment can neither be referred to PhysioSonic nor to other therapeutic measures alone.

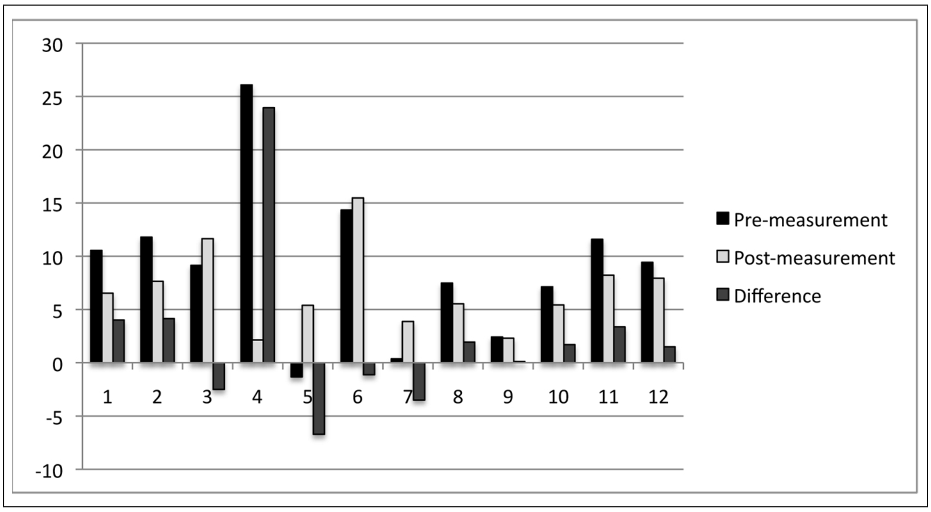

Fig. 10. *Verticalisation of the thorax using Physiosonic.*

With single patients, further implementation options of PhysioSonic were tested. During the music scenario, the arm movement was influenced transversally leading to a force distracting from the desired movement plane. The additional muscular activity necessary to stay within the reference plane constituted a therapeutic measure. The specific invigoration can be optimally detected with PhysioSonic and controlled with different resistances. Furthermore, in the music scenario, the initial position was varied to activate other regions of the abductors of the shoulder joint. Thus the starting position approached more and more the (actively) maximal abduction. This convergence on the one hand reduces the movement range and leads to a different muscular activity on the other hand. Furthermore free weights were adapted at the wrists of the patients to increase the resistance and to motivate them.

6 Conclusions and Outlook

The present paper describes a new concept for the sonification of motion data. The data is gathered by a real-time motion tracking system with high spatial and temporal resolution. Simple movement attributes and sounds guarantee the understanding of test subjects, who are neither specialists in training nor in sonification. In an example, we implemented a training system for shoulder patients, who have difficulties in raising their arms laterally. Motivating sounds encourage the patient. These sounds have narrative structure, which shall lead to further motivation in a training context. Music and texts can be chosen and thus follow the aesthetic preferences of the patient. Negatively defined sounds are inhibitory or mask the other sounds. They are linked to evasive and often unconscious movements and will be avoided by the patient.

We implemented several training scenarios of the lateral abduction and adduction of the arm for orthopaedic rehabilitation. The system has been set up at the hospital Theresienhof in Frohnleiten, Austria. A pilot study is in preparation that will evaluate the sonification designs and the efficiency gain in the training.

PhysioSonic was throughout accepted positively with the patients and enriched the therapeutic offer according to their statements. The use of auditory feedback was completely new for all of them, which lead to high motivation in the conduction of the movement. For the therapist, PhysioSonic is an easy to handle tool. It has various application options that allow using it in practice for different goals. Still, modifications in the software are necessary to extend PhysioSonic to a variety of possible other movements and human joints. These modifications are under development.

7 Documentation and Acknowledgements

Videos of the described system can be found at
https://iem.at/Members/vogt/physiosonic.
A short television report *in german* can be found at
http://steiermark.orf.at/magazin/immergutdrauf/wissen/stories/335626/

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