Chapter 21

Aiding Movement with Sonification in “Exercise, Play and Sport”

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This chapter deals with several applications of sonification in the field of sport and movement sciences. A selection of authors from various sciences (e.g., Electronics, Music, Technology and Sport Science) illustrate a wide scope of multidisciplinary applications in aiding human movement using interactive sound. These applications can be allocated to the comprehensive field of “Exercise, Play and Sport” i.e., physical activity in its widest meaning.

Reference:


Media examples: http://sonification.de/handbook/chapters/chapter21
This chapter deals with several applications of sonification in the field of sport and movement sciences. A selection of authors from various sciences (e.g., Electronics, Music, Technology and Sport Science) illustrate a wide scope of multidisciplinary applications in aiding human movement using interactive sound. These applications can be allocated to the comprehensive field of “Exercise, Play and Sport” i.e., physical activity in its widest meaning. For this field, we distinguish health-promoting exercises in rehabilitation programs (e.g., movements in physiotherapy, therapeutic games), fun-related movements in entertaining games (e.g., playing computer or sports games) and performance-related movements in competitive sport (e.g., diagnostics and training).

Figure 21.1 illustrates the framework for this chapter and presents an arrangement of the sections by assigning the applications to the three areas “Exercise, Play and Sport”. Section 21.2 describes the use of sounds in measuring standardized movements in therapy and rehabilitation activities. Section 21.3 describes non-standardized movements based on open-skilled, situation-dependent and “fun-related” game activities within virtual spaces. Sections 21.4 and 21.5 take this further by linking sport with ‘play’ and ‘exercise’ respectively. Section 21.5 also examines the transfer of the enhancement processes in competitive sport to the field of motor rehabilitation.

In more detail, section 21.2 (by A. Hunt and S. Pauletto) demonstrates the multidisciplinary applications of sonification with the “Use of sound for physiotherapy analysis and feedback”.
The authors describe methods of sonification helping therapists to analyze the complex signals which originate from multiple EMG sensors on a patient’s body. Converting electrical impulses from muscles into sound enables therapists to listen to the muscles contracting when physical activity is carried out. An adaptation of the standard hospital monitoring system allows this sound to be generated in real time. This has several advantages over visual displays, the most important of which is that medical staff and patients have an eyes-free display, which gives real-time feedback on the quality of muscle activity and is thus a new analytical component in therapy.

Section 21.3 “Interaction with sound in auditory computer games” (by N. Röber) extends the applications of the interactive use of sound to fun-related actions in playing computer games. Computer games are constantly increasing in popularity, but audio-only computer games still occupy only a very small niche market, mostly for people with visual impairment. This section reflects the reasons for this, presents an introduction into audio-only computer games and provides an overview on the current state of the art. Using the genres of narrative adventures and interactive augmented Audiogames, this section discusses the techniques which are necessary to interact with - and to explore - virtual auditory environments. It also provides a detailed look at the important methods for scene sonification and 3D sound rendering, and ends with a glimpse into future developments.

Just as in traditional (visual) computer games, visual information is the leading afferent information for players to regulate their actions in sports games. As a consequence, access
to sports is particularly difficult for people with visual impairment. The field of Adapted Physical Activity explores new opportunities and enabling techniques to facilitate their participation. Section 21.4 introduces one approach to this task in “Sonification-based sport games and performance tests in Adapted Physical Activity” (by O. Höner and T. Hermann). This section relates to the previous one as it also reports on the use of a gesture-controlled audio system for playing non-visual, audio-only games. By contrast, the origins of these games are not computer games, but sports games such as badminton. Thus, the player is engaged in physically exhausting sporting activities and additionally gains audio-motor movement experience. Therefore, an Interactive Sonification System for Acoustic Motion Control (“AcouMotion”) provides a link between body movements and auditory feedback through interactive sonification. As well as covering the development of new kinds of (adapted) sports, this section also covers new perspectives on performance diagnostics applied to traditional sports played by people with visual impairment.

This leads on to the field of performance-related movements. Section 21.5 focuses on the performance enhancement in competitive sports in “Enhancing Motor Control and Learning by Additional Movement Sonification” (by A. O. Effenberg). It explains the processes of motor control and learning which are based on perceptual functions and emergent motor representations. In contrast to Section 21.2 (where sonification is used to enhance the knowledge about the functional state of a muscle), Effenberg uses movement sonification to induce a direct effect on motor behavior. The author presents a theoretical framework and empirical evidence for the assertion that the auditory system can be involved in the processes of motor control and learning. This is done by providing additional movement acoustics (‘movement sonification’) resulting in more accurate motor perception and a better motor performance. Finally, the functionality of movement sonification for closed skills in competitive sports is discussed and moreover perspectives for motor rehabilitation are pointed out.

All sections of this chapter have a similar structure. Each section consists of at least five fundamental parts, i.e., the description of (i) general and core assumptions of the research approach, (ii) the main user / target groups (e.g., specific needs of these people, particular advantages of using sound for these groups), (iii) technical systems used for aiding movements (e.g., concerning gesture or movement analysis, type of sonified data, auditory display), (iv) empirical (case) studies and (v) future directions (e.g., concerning further user groups, further application in other areas of Figure 21.1, technical improvements, perspectives and expansions of the core applications).
21.2 Use of Sound for Physiotherapy Analysis and Feedback

Andy Hunt and Sandra Pauletto

21.2.1 Introduction to EMG

EMG (electromyography) sensors detect the electrical activity associated with muscle movement. Electrodes on the skin’s surface pick up electrical signals from the muscles below, and the signals are usually digitized for storage and analysis. Physiotherapists typically use various computer programs to capture the data, perform some basic statistics on it and display it in a graphical form. When working in a real-time situation the therapist is often distracted from contact with the patient because of having to operate the (visual) menu system and studying the (visual) results. EMG signals are believed to be full of information about the muscle activity and it is hypothesized that this visual and statistical analysis does not exploit the full information contained in the data.

21.2.2 Traditional analysis of the raw signal

The work described here is concerned with portraying as much of the raw signal as possible to the therapists, because it contains many clues about the health, motion and condition of the muscles.

“[The analyst] should monitor the raw signal, even though other signal processing may be used, so that artifacts can be detected and controlled as necessary” [2].

Traditionally this monitoring work is carried out by visual inspection of a captured signal. The following section describes one example of how to use sound as a good alternative for monitoring the raw signal, and one that allows vital eye contact and focus with the patient to be maintained.

21.2.3 Designing sound to portray EMG signals

Initial experimentation was carried out using example data sets from patients at the Teesside Centre for Rehabilitation Sciences. A custom-designed Interactive Sonification Toolkit [3] was used to experiment with various methods of converting the EMG data into sound (sonification). This toolkit allowed researchers to take in multiple data sets, and try out a range of data-scaling and sonification techniques.

The design criteria for the sonification algorithm were:

1. It should portray an accurate analogue of the captured signal;
2. Sounds should be made in real time, in response to patient movement;

The work described in this section is a collaboration between the University of York Electronics Dept., and Teesside Centre for Rehabilitation Sciences (a partnership between the University of Teesside’s School of Health & Social Care and South Tees Hospitals NHS Trust). It was funded by EPSRC (Engineering & Physical Science Research Council), grant no. GR/s08886/0.
3. It should be **pleasant** to listen to (or at least not annoying);

4. Data should be audible when being analyzed at different speeds;

5. Signals from several EMG sensors can be listened to together.

The team’s first experiments involved **audification** - the direct conversion of data samples into sound. However the EMG data sampling rate is rather slow compared to the data rate needed for sound, so when analyzing a signal slowly there was not fast enough change in the signal to make it audible (sound example S21.1). Also, when multiple sensors are used the resultant signal becomes very noisy.

Progress was made using MIDI notes to represent the values from more than one sensor. For example in the following sound (S21.2) two sensors are heard, panned left and right in the stereo field. Although this led to a useful form of comparison between two related sensors, this form of continually re-triggered sound (caused by the sensor value reaching a new MIDI note threshold) proved tiring for the clinicians to listen to and was overly quantized in pitch.

The final choice of sonification method involved amplitude modulation; each EMG sensor was mapped to the amplitude of a different sine wave oscillator. The frequencies of the different oscillators were set in a harmonic relationship with each other with the intention of making the sound pleasing (more instrumental than noise-like). This method also provides a tone whatever the speed of playback. It also allows the modulation of several sensors simultaneously, fusing their varying inputs into one complex, but easily understood, resultant sound (sound example S21.3).

### 21.2.4 Gathering and processing the clinical data

The EMG sensors are connected to the existing clinical Biopac [4] analogue-to-digital converter (which allows file storage and visual analysis), and also into a computer running the sound mapping software (written in PD [5]). Figure 21.2 shows this set-up, with a patient about to perform a leg extension (with resistance from the machine). This produces bursts of complex sound which can be heard by all in the room. A short video example (S21.4) shows the system in action and the resultant sound. The traditional visual analysis is also available for comparison.

### 21.2.5 Clinical testing of the sonification system

An experiment was conducted to verify the system’s efficacy as an auditory display of the data. The sonification was found to be effective in displaying known characteristics of the data, comparing them to traditional analysis. Non-therapist listeners were able to gauge the condition of a client’s muscles just from the sound.

A listening test was set up so that 21 subjects (average age 29, and all studying or teaching engineering with sound) could listen to 30 sonifications created from EMG data. Each sonification was then scored, on a scale from 1 to 5, for the following characteristics: Overall loudness; Speed of the sound’s attack; Roughness; Presence of distinct pitches; Presence of structure in time. Loudness and attack speed are the variables that should vary with age and therefore they were clear candidates to test the validity of the sonification. The other
factors were included so that we could compare the effectiveness of the sonification with visual displays.

The data was gathered by Dr. John Dixon of Teesside University using the equipment in Figure 21.2, and from patients with a range of ages from 19 to 75. A testing interface was developed in Pure Data that was used to run the experiment and gather most of the experimental results automatically (see Figure 21.3).

Subjects were able to listen to each sonification as many times as they liked, and then scored the data according to the characteristics. Each subject received a different randomized order of sonifications so that any biases due to presentation order or layout were avoided.

### 21.2.6 Results

Though none of the experimental subjects knew anything about the ages of the participants they were listening to, the results showed a remarkable correlation between age and three of the scored parameters: attack speed, loudness and roughness (see Figure 21.4). For example loudness showed a significant negative rank correlation with age (non-parametric Spearman rank correlation factor $= -0.58$, significance test $p < 0.005$).

Thus a set of non-clinically trained listeners were able – by sound alone – to gain an insight into the age of participants and their muscle strength deterioration. Full details of the experiment are found in the proceedings of ICAD [6]. Further experiments have been carried out [38] which show that the same data is analyzed at least as well by sonification as by visualization as sonograms, and for some aspects (especially temporal changes) much better.
21.2.7 Conclusions and further work

Muscle monitoring is a complex activity and currently involves therapists in many hours of visual data mining to interpret data for use in the clinical environment. The sonification of EMG data allows the health-care professional to observe the patient rather than the screen, using an auditory signal which may be better qualitatively understood than (and may provide additional information to) the more traditional visual displays. This is an innovative approach and has the potential to change clinical practice.
21.3 Interaction with Sound in auditory computer games

Niklas Röber

21.3.1 Sound in Computer Games

The first games to be played on a computer were designed in the early 1960s and 1970s. These games were very simple, having only primitive graphics and almost no sound. Since then, games have evolved tremendously and attract a huge range of followers today. Currently, games are one of the major industries in computer science and a huge driving force in research and computer development. Computer games have always been about fun, enjoyment and competition and are nowadays also employed in applied sciences in the area of health related computer games [7] (see also section 21.4 on sonification-based sports).

The first largely available computer games were played on custom consoles, then on the Commodore and Atari computers and later moved to the PC platform. Compared to its contemporaries (the Amiga and Atari systems), the PC of this time was very limited in its sound synthesis and playback capabilities. This changed in the late 1980s when the first add-on soundcards were introduced. Today’s PC sound hardware is very well advanced, able to produce 3D sound and surround effects simulating virtual room acoustics, and in some cases even programmable through customized DSP\(^2\) algorithms.

Sound is important for every game genre, and a bad acoustic environment can ruin an otherwise perfect game. 3D sound has proven to be advantageous, especially for very realistic games such as 3D FPS\(^3\). Here it assists the player to detect the opponent acoustically. The simulation of room acoustics plays an important role, as it intensifies the game’s atmosphere and therefore the degree of immersion into the virtual game world.

Although sound hardware has not evolved as fast as graphics hardware, game audio has received a lot of attention in recent years, and the awareness of the capabilities of a good auditory design is present in both the developer’s and the player’s mind. Fast graphics hardware is employed for 3D sound rendering and a more accurate simulation of virtual room acoustics [8, 9].

21.3.2 Audiogames

Audiogames, also known as audio-only computer games, are played and perceived by auditory means alone. These games are often developed by, and for, visually impaired people. One of the first commercial audiogames developed was “Real Sound - Kaze no Regret” (1999), an audio adventure that was inspired by blind fans and available for Sega’s Saturn and Dreamcast consoles. In the following years, several genres from the visual game domain have been adapted as audiogames, including adventures, action and racing games as well as simulations and role-playing games. The differences in game-play between a visual and an auditory implementation can be quite substantial. Audio is very well suited for presenting narrative content, but even action games that rely on precise listening and fast user reactions

\(^2\)DSP - Digital Signal Processor
\(^3\)FPS - First Person Shooting games
are available. The community of blind people is quite active in this area and many of the old text-adventures are still being played by people with visual impairment as they can be easily read out by speech synthesis software. An overview of the different genres and games can be found at the audiogames.net website [10].

A real advantage of audiogames is that they are able to provide greater stimulation to the player’s imagination. This results in a higher immersion, similar to the experiences of radio listeners who often state that the “pictures look better on the radio”. Other advantages include an accessible game-play and a simplified development cycle. Difficulties occur within the game itself in the estimation of distances and the mapping of sounds to specific events.

Although there is a potentially big market available, most audiogames are still rather simple and far less complex than their visual counterparts. But a current trend is moving towards more complex and challenging games as well as to the concept of augmented and real-world game play. The most important rule in designing audiogames is to immerse the player in a high quality virtual auditory world and to use techniques that support and enhance this sensation. Crucial here is the design of the user interface and its integration within the game. In some games, including visual ones, problems occur due to poorly designed interfaces and menus that break the illusion of being immersed in a virtual world.

Following is a discussion of two quite well designed audiogames:

1. Terraformer\(^4\) is a so-called hybrid game. These are conventional audiovisual computer games that have been extended by certain sonification techniques to make them accessible for people with visual impairment. Hybrid games are quite common among audiogamers, as they are more attractive to a larger community, and sighted and blind people can play together. Terraformer is an action-adventure game and set on a foreign planet in a futuristic 3D world. The player’s task is to fight against rebelling robots, find missing pieces of technology, and re-establish the terraforming process. Terraformer received a lot of attention at the time of its release due to some novel game sonification techniques. The acoustic orientation and navigation is supported by 3D sound and the user has a sonar-like technique for room exploration that provides a rough perception of distances, as well as identifies objects in front of the player. Other sonification tools include an auditory compass and GPS, as well as a voiced computer system that provides various feedback paths from the game.

2. Seuss Crane: Detective for Hire\(^5\) is an audio adventure game in which the player is a detective who has to unveil a murder mystery. It is based on a radio play, in which the player chooses the locations to investigate, and after a while has to accuse someone for murder. The game has an interesting story and uses professional radio voices. Although the game does not rely on any visual information, the user interface is still in the form of a simple hypertext-like menu. It would have been nice to see this interface being represented using auditory means as well. Another drawback is that one has to follow a predefined sequence in order to get points and to solve the game.

The next section presents research on interactive auditory environments that extend and generalize the audiogames approach.

\(^4\)http://www.terraformers.nu/
\(^5\)http://radio-play.com/
Interactive auditory environments take audiogames one step further. They generalize the underlying ideas and combine the existing approach with common sonification and interaction techniques to form 3D auditory environments. Auditory environments can be thought of as being the acoustic analogue to a visual 3D game world. Applications exist not only in the areas of entertainment and edutainment, but also in the form of general auditory user interfaces and the development of tools to aid visually impaired people. It is imperative to have an intuitive and integrated design and the right balance between aesthetics and function.

The main components that characterize interactive auditory environments are:

- A 3D virtual scene/world described by a non-realistic auditory design.
- Intuitive sonification and interaction techniques to enable the user to explore, navigate, and interact with the environment.
- A narrative concept that focuses on an acoustic representation.

The following describes a research prototype that focuses on the implementation of such interactive auditory environments. The acoustic presentation that describes the scenery must have a non-realistic design, in which a realistic auditory representation is exaggerated and enhanced at certain points and also enriched with additional information. The auditory reality is not just augmented, but presented in a way that sounds’ perception is more intuitive and clear. This can be done by exaggerating certain acoustic effects, such as the Doppler effect, or by making silent objects audible. The additional information can be conveyed through auditory textures, earcons, beacons and other sonification means. The quality of the sound rendering itself should thereby be as high as possible, especially the 3D sound spatialization and the simulation of environmental (room acoustic) effects, as they directly assist the player in orientation and navigation.

For experimenting with the various sonification and interaction techniques, a framework has been designed for interactive auditory environments, which also serves as a platform to prototype user interfaces and simple audiogames. Figure 21.5 shows an overview of the system. It is based on OpenSceneGraph\(^6\) to manage the various 3D scenes and uses OpenAL/EAX\(^7\) for the sound rendering. The majority of sounds are spatialized using HRTFs\(^8\) and the simulation of room acoustics is implemented using OpenALs EAX/EFX system.

Although the orientation and navigation within the 3D virtual auditory environments is challenging, it can be greatly improved by incorporating the user’s (head-) orientation and movements. These motions are tracked using a Polhemus Fastrak\(^®\) that is controlled by the VRPN library\(^9\). The modeling of the 3D environment takes place in 3DStudioMAX\(^®\), from which the data is exported and integrated into the system as an extended XML file [15].

The sonification and interaction techniques are closely related and depend on each other: Sonification is used to transfer information from the scene to the user, while interaction is required to input the user’s changes into the virtual environment. Care has to be taken in

\(^6\)OpenSceneGraph - [http://www.opensg.org](http://www.opensg.org)
\(^7\)OpenAL/EAX - [http://www.openal.org](http://www.openal.org)
\(^8\)HRTF - Head-Related Transfer Function
the design of these methods, as they should integrate seamlessly. All techniques have to be implemented to perform in real time, otherwise the orientation and navigation would become extremely difficult. The tracking system allows the emulation of several listening and interaction behaviors, and therefore an easier and more intuitive orientation and navigation. It also permits an integration of basic gestures into the system, such as nodding or the drawing of symbols. A real advantage is the possibility of interacting within a spatial environment that allows the positioning of information and menus using a ring metaphor; sounds and interactable objects are thereby arranged in a ring 360° around the user. Additionally, a regular gamepad can also be used for user interaction.

The sonification techniques used can be divided into two different groups: the ones that are bound to interaction techniques, and the ones that solely sonify the scene without interaction. The first group consists of methods such as radar, sonar or an auditory cursor, in which the user probes and actively explores the environment and receives feedback through sonification. The second group describes the sonification of (non-interactive) scene objects and the auditory display of additional information using auditory textures, earcons, beacons and soundpipes [11, 12].
21.3.4 Designing interactive Audiogames

Example 1: Matrix Shot

One of the first experiments using this framework included spatial sonification and interaction techniques that led to the implementation of four simple action and adventure audiogames [11]. Figure 21.6 shows the principle and an action shot of the Matrix game, in which the player has to detect and avoid virtual acoustic bullets (see also the video example S21.5). We conducted several user tests to compare our implementations with other available audiogames, to investigate playability, usability as well as the quality of the sonification and interaction. Almost none of the participants had any prior experiences with audiogames, but everyone liked the idea and the simple concept of play. Initial difficulties occurred in the estimation of distances and the position of the virtual bullets. Very helpful was the later integration of 3D head-tracking, as it allowed the player an easier determination of the bullet’s position simply by rotating the head.

![Figure 21.6: Matrix Audiogame: a) Principle b) User Interaction.](image)

Example 2: Interactive Audiobooks

A second project was called Interactive Audiobooks and aimed to unify the interactivity of computer games with the narration of books and radio plays [13, 14]. The first attempt consisted of an auditory adventure game to research the possibilities of storytelling within an auditory presentation. The story and the game were simple, linear and non-adaptive, leaving the user every freedom to explore the 3D environment. This caused several problems, as one could easily get lost in the virtual environment. The spatial representation with free user movement was replaced by a story engine that only allowed a certain movement depending on the development of the underlying storyline. The implementation is based on the previously introduced 3D audio framework, but also employs a storytelling engine that allows a non-linear game play with a varying degree of interactivity. Now it is possible to either play parts of it as an audiogame, or just listen to the complete story as a radio play. The presentation of the story has many similarities to common adventure games, but some differences exist, especially with the interaction and the design of the user interface (see video example S21.6).
Example 3: Augmented Audiogames

For an implementation of so-called Augmented Audiogames, the system was made portable and extended by techniques to allow mobile head-tracking and user positioning [15]. Augmented auditory reality combines a real-world environment with an artificial auditory representation of this environment. The interaction and sonification is similar to other auditory displays, with the extension that the user can now freely walk around within the virtual scene. This narration in the real world largely increases the level of immersion, as more senses are addressed. The calculation of the player’s position is important, but as the scene is described acoustically, an accuracy of about 1m has proven to be sufficient. For the positioning, GPS is used when outside, and several WiFi hotspots within buildings to track the position of the user. The use of WiFi emitters for position tracking is not easy, as the signal strengths decay differently, depending on the room size and objects therein. To increase the positioning accuracy a pre-sampled radio map with carefully selected WiFi emitter locations was used. Additionally, a digital compass was employed as simple head-tracking device to determine the player’s orientation. A third challenge was the combination of the real sound environment with the artificial game world and the latency effects introduced by the tracking system. The application explored several game related possibilities along their potential for augmented audio edutainment, such as an augmented audio version of our audiogame “The hidden Secret” or an acoustic guiding and navigation system for the University’s campus [15] (see example videos S21.7, S21.8 and S21.9).

21.3.5 Rethinking Audiogames

Although the programming of simple audiogames is relatively easy, several guidelines should be observed to make the interface more intuitive and the audiogame more enjoyable. The most important goal is to immerse the player in a virtual auditory world and to use sonification and interaction methods to support and enhance this perception. The display must not be cluttered with too much information and should be designed in a way to balance function with auditory design. The quality of the sound and music used is of the utmost importance, as a poor sound design will otherwise ruin the game.

Because of the large design space for sonification and interaction techniques, a careful selection that concentrates on a clear presentation and an intuitive interaction will deliver a better performance. One of the most interesting genres for audiogames is adventure games, as they strongly focus on narration and storytelling. A rethinking of audiogames and their design will move them to the next level. Audiogames are not just acoustic adaptations of visual computer games; instead they present a new genre with different advantages and new possibilities.
21.4 Sonification-based Sport games and Performance Tests in Adapted Physical Activity

Oliver Höner and Thomas Hermann

21.4.1 Core assumptions and objectives of the research approach

According to the framework presented in Fig. 21.1, this section deals with the sonification-based aiding of movements which are fun-related (movement as a part of play) and leads to the aiding of performance-related movements (in traditional and competitive sports). The core objective is to aim at joining principles and methods of the research program on interactive sonification (see chapter 11) with special requirements of the research field “Adapted Physical Activity” (APA). APA is a professional branch of kinesiology and physical education as well as sport and human movement sciences. It is directed toward persons with physical disabilities or special needs who require adaptation for participation in the context of physical activity.

The use of sonification allows the investigation of two long-term topics relevant for APA:

1. Can motivating sport games be developed using non-visual, audio-only information for action control (which are specially suited for players with visual impairment)?

2. Can such games be used for testing and training abilities such as auditory-perception-based orientation in space?

The following section briefly discusses sport games and their suitability for people with visual impairments (section 21.4.2) then introduces a technical system called “AcouMotion” which is used to investigate the two topics mentioned above (section 21.4.3). Next are described some initial applications of the system: a new kind of audiomotor sport game adapted for people with visual impairment and an audiomotor performance test for paralympic goalball players (section 21.4.4). Finally, the future directions of the research are outlined (section 21.4.5).

21.4.2 Sport games for people with visual impairments

One of the main research objectives is to provide new opportunities for movement intensive games for people with visual impairments. This is a difficult task, as the leading (afferent) information in sports is obviously visual. This is especially true in ball games where players generally depend on their visual perception system to perceive information on the location and movement velocities of several objects, such as the ball, team mates or opponents. As a consequence, cognitive research on action control processes (such as anticipation and decision making) in sports is generally focused on visual perception. This is also true for the development of diagnostics for sensory-motor performance factors which usually investigate

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10 This project was conducted as an interdisciplinary research project between computer and sport scientists. It was funded by the Federal Institute of Sport Science ("Sonifikationsbasierter Leistungstest", VF 07 04 SP 00 69 05).

11 See the definition by the International Federation of Adapted Physical Activity (IFAPA) on http://www.ifapa.biz/?q=node/7.
the visuomotoric competence of players, e.g., in using film-based stimuli for anticipation tests in games such as soccer, tennis, badminton and so forth [16].

We can draw at least two conclusions from the dominance of visual information for action control in sport games against the background of the APA perspective. One of the major tasks in the field of APA is to push the boundary of ordinary sport games in search of new opportunities or enabling techniques to facilitate the participation of people with visual impairment. Secondly, sensory-motor performance tests for blind-specific games cannot be adapted from ordinary sensory-motor performance tests which are in most cases visual-based (e.g., anticipation tests for goalkeepers). Therefore, there is a need to search for new ideas and new types of performance diagnostics in order to develop adequate, and in most cases blind-specific, performance tests. For both directions just outlined, the search begins with interactive sonification, i.e., the acoustic presentation of information in the presence of rapid feedback to users [17].

**Sonification-based PC games**

Interactive sonification presents information through non-speech sound and focuses on the development of systems integrating human actions into a tightly closed human-computer interaction loop. This interaction is enabled by providing immediate feedback on the user’s actions with sound. Suitable interfaces for interacting with sonification systems can be conventional computer-based physical controllers, e.g., a computer mouse, but for sports applications these can also be tangible objects such as rackets.

To set the context there are promising examples in the field of game entertainment. One impressive example is described by Röber (see section 21.3). Further examples are given by Targett and Fernström [18], who present audio PC Games such as Mastermind or Tic Tac Toe. Using interactive sonification these games of strategy and dexterity can be played at a PC without using the visual display, but interacting solely with the auditory display. Further examples of audio PC games can be found with an internet search on “games for the blind” or “audiogames”\(^\text{12}\). These audiogames represent many of the genres found in traditional computer gaming (e.g., adventure games, but also sports such as SuperTennis). In all these examples the player receives no visual information and interacts with the computer by perceiving only auditory feedback following mouse or keyboard actions.

However, from the APA perspective there is one important disadvantage of the games mentioned above, i.e., their lack of movement experience. In contrast, “real” sports provide players with extensive movement experience and are expected to promote psychomotor development particularly for people with visual impairment [19].

**Existing non-visual sport games**

Several attempts to create new games for people with visual impairments are to be found in the field of (adapted) physical education, where new kinds of games result from modifications to traditional sports [20]. Further non-visual games are found in the competitive Paralympics. The game with the greatest tradition for people with visual impairment is the blind-specific

game goalball, played at the Paralympics ever since Toronto 1976. Goalball is played within the rectangular court of a gymnasium (9 × 18 m) by two opposing teams of three players. The aim of the game is to roll the sounding bell ball across the opponents’ 9 meter wide goal line while the other team attempts to prevent this from happening. Since Athens 2004, there has been another non-visual sport at the Paralympics. The modified soccer game “Football 5-aside” is played with a sighted goalkeeper and with a guide behind the opponents’ goal to direct the four non-seeing field players when they shoot. In both games players wear eyeshades so that it is impossible to perceive visual information during the games.

These and other blind-specific games are often based on certain methodological principles. These include the use of a rolling ball to generate a continuous sound and the use of tactile markers supporting players’ spatial orientation in the playing area [21]. Another methodological principle is that these games use sound as the leading information. In particular for defensive movements the auditory information on the ball position and direction can be seen as the leading afferent information for motor control. As a consequence, audiomotor abilities are very relevant performance factors in competitive games of APA such as goalball.

A field inquiry was conducted at the Goalball European Championships in Belgium 2005 to investigate this proposition. Nearly all of the 22 questioned coaches of the international teams rated audiomotor abilities as “very important” for the performance of goalball. This inquiry also discovered that goalball-specific performance diagnostics to test audiomotor abilities do not exist [22]. Whereas goalball coaches can adapt performance diagnostics from ordinary competitive sports to test the players’ physical condition (i.e., strength, movement velocity, general endurance, etc.), blind-specific tests for sensorimotor abilities have to be developed.

Conclusion and challenges

The examples mentioned above show impressively the adapted perceptual skills of players using non-visual information and prove the possibility of playing computer, sports and even ball games without any visual information. Is it possible to go beyond the existing audiogames by providing more intensive movement experiences, and beyond the existing games by using the sound in a more systematic way? The key question is whether it is possible to combine sport games, as practiced in APA, and sonification-based audio PC games to create motivating audiomotor games and blind-specific audiomotor performance tests. If so, it would be possible to initiate motivating sport games under educational and pedagogical perspectives as well as to conduct audiomotor performance tests for competitive sports. The next section describes the development of an Interactive Sonification System for Acoustic Motion Control (“AcouMotion”).

21.4.3 The Interactive Sonification System for Acoustic Motion Control (“AcouMotion”)

AcouMotion provides a link between body movements and auditory feedback through interactive sonification. The core idea behind AcouMotion is to employ sonification in order to create a new channel of proprioception aiding body movements in a virtual space whose
properties and objects can be designed to support a wide range of different applications. The user's physical interactions with objects in the real world are mapped to manipulations of corresponding objects (e.g., a virtual racket) in a virtual model world. Reactions in the model world are displayed using sonification as the only feedback modality. From a technical perspective, AcouMotion connects three system components to implement this idea [23]: (i) a tangible sensor device providing movement-related information, (ii) a computer simulation model formalizing the coupling between body movements (reflected in the sensory data provided by the tangible device) and the object dynamics in the virtual space, and (iii) a sonification engine for the perceptual rendering of the joint dynamics of body and modeled object states.

Firstly, the sensor device in AcouMotion is provided by the Lukotronic motion analysis system. The invention of AcouMotion pre-dated later controller developments such as the Nintendo Wii and Microsoft Kinect. Importantly, AcouMotion needs a proper localization of the sensor device in space, which many sensor-only devices rarely deliver. The Lukotronic system consists of a measuring beam and an active infrared marker set. Four infrared markers are fixed to a small handheld tangible device such as a table tennis racket or a self-made hemispherical wooden device (see Fig. 21.7). These markers can be used to assess the position and orientation of the racket in convenient accuracy (1-2mm) and frame rates (using here 100 Hz, which is sufficiently high to create the illusion of latency-free control in real-time interactions). Velocities and accelerations can be computed at high accuracy from successive frames. Secondly, a dynamic computer simulation model serves as the basis for representing processes and interactions in AcouMotion. The model represents the internal state of the AcouMotion system, and evolves according to its own “physical laws”. For this, physical objects are modeled; for instance the tangible device (e.g., a racket), a ball and the walls limiting the virtual space. Physical parameters are also modeled, such as gravitation, damping of the ball or the general speed of the game. While real-world settings have to

Figure 21.7: The hemispherical wooden device with fixed IR-Markers, used as a tangible device in the sports-related applications of AcouMotion.

http://www.lukotronic.com
operate within existing physical laws, the computer simulation enables the control of any circumstance, for instance the viscosity of the air. This might cause a retardation of the ball due to increasing aerodynamic resistance, etc. The simulation needs to check at every point in time whether there are interactions with objects (e.g., ball and virtual racket), and respond accordingly with an update of the situation (e.g., an elastic impact).

Such event-based information is highly relevant for the auditory display created by the third component of AcouMotion, the sonification engine. The sonification serves as an interface between the computer simulation and the sensor device. It presents all information about the position of relevant virtual objects to the user via sound. Interactions such as the hit of a virtual ball update the ball’s motion state in the simulation environment and thus the sonification. The user receives instantaneous auditory information to control and regulate his action. This real-time control and auditory feedback creates a closed interaction loop engaging the player in the game activities.

The basic elements of the auditory display are:

1. continuous sound streams which convey information by the change of acoustic attribute (an example is a pulsed sound whose pulse rate represents distance to the player),
2. discrete sound events, which are used to communicate discrete events (e.g., physical contact interactions in the model), and
3. ambient elements such as sound effects that influence the overall display.

The AcouMotion system connects the three components via OSC\(^\text{14}\) (Open Sound Control) interfaces, allowing an easy exchange of sensors (e.g., webcam based sensor devices instead of the Lukotronic system), and distribution on different computers. Thus, AcouMotion integrates interactive sonification, movement experience and virtual game simulations and provides a technical basis offering new kinds of auditory sports that can be played with real motor activity by using non-visual sonification-based information alone. The following section presents the first applications of AcouMotion in the field of APA and illustrates the development of the sport game “Blindminton”. Following that, it introduces a sonification-based performance test for the paralympic sport game goalball.

### 21.4.4 Applications of AcouMotion in the field of APA

**“One-Player-Blindminton”**

AcouMotion enables the creation of sport games operating within customizable “physical laws” (see 21.4.3). This means that the complexity and difficulty of the task can be controlled in detail to create a challenging game, even for novices. This is an advantage for APA in particular, because one of the most important barriers to participation in APA is that real sport games are too hard to learn for novices with impairments. Actually, this is often also true for “ordinary” sports, which tend to provide optimum excitement if the opponents reach a similar performance level when playing against each other. For example, badminton matches between two players at different performance levels are often boring for the more skilled player and overstrain the weaker player. From a motivational perspective, the matching of a game’s challenges and players’ skills and abilities is missing. But according to the concept

\(^{14}\)http://www.cnmat.berkeley.edu/OpenSoundControl/OSC-spec.html
of flow-experience [24], this a necessary condition for high intrinsic motivation and therefore the aim is to provide this matching through computer simulation. Thus, the game concepts are built upon three ideas:

1. Game-relevant information needs to be transferred to an auditory display for people with visual impairment.
2. Audio sport games provide intensive movement experiences, and thus go beyond existing audio PC games.
3. A computer simulation enables the control and adaption of difficulty for each player in order to create exciting sport games independent of the performance level of each player.

Building on the above analysis, the first game concept created was “one-player-Blindminton”. It is named Blindminton to denote that it is similar to the racket game badminton, but adapted to blind-specific needs. The name ‘Blindminton’ is used as a general term for one- or two-player ball games. The simulation engine can easily be modified to render the trajectory of a shuttlecock (as in Badminton) or a ball\textsuperscript{15}. Although currently sound is considered as the main carrier of game-relevant information, certainly other modalities accessible to visually impaired players, such as haptic cues, can be added by integrating vibration motors into the racket.

In the pilot application shown in the Figure 21.8 the second player is replaced by a wall so that currently only one player is involved (in contrast to badminton). The player is expected to hit the ball against a wall (using a virtual racket) without bouncing it on the floor. The goal is to keep the (virtual) ball in the game as long as possible. The score increases with every contact and is also dependent on the speed of the ball when hitting the wall. This introduces an element which motivates the player to increase the amount of effort expended in order to obtain better scores.

All components of AcouMotion are required for implementing this game. In particular the AcouMotion \emph{sensor device} is able to deliver position and orientation of the racket. Orientation is crucial since the ball reflects from the racket and this is an essential control for conducting the game. The \emph{simulation model} creates a 3D model space with a limited number of objects represented by their coordinates, velocities and orientations. For instance, the objects in “one-player-Blindminton” are the racket, the ball, and a set of planes and walls to model the game field. The ball flies through the 3D space influenced by gravitational force and aerodynamic resistance.

The \emph{sonification} is designed with a multilayered auditory display for the game concept. It consists of one multidimensional sound stream for the relative position of the player’s racket, discrete sound events and verbal markers for game control. In detail, a 3-parameter stereo sound stream represents the three dimensional distance in space between the positions of the ball and the racket (see Fig. 21.8, sound and video example S21.10). The horizontal displacement of the racket, i.e., the $x$-distance between racket and ball, is presented by spatial sound cues such as stereo-panning: the sound for the ball is presented on the left speaker if the player has to direct his racket more to the left side and vice versa. The vertical displacement is presented using three levels of pitch: a high (or low) pitch directs the player to move the racket upwards (or downwards). The middle pitch indicates that the vertical

\textsuperscript{15}In this case the game may perhaps better be called blind squash.
Figure 21.8: Illustration of the Blindminton game setting and the directions of racket’s displacement (see also [23]).
position of the racket currently matches the ball’s altitude. The third acoustic dimension is represented via a pulsing of the sound to represent the $z$-distance. A high the pulse rate indicates a large $z$-distance between racket and ball. Thus, the pulsing slows down as the ball approaches the player.

In games like Blindminton there are different types of information-carrying variables. In this system the 3D soundstream is continuous and thus accomplishes the “rolling ball” principle as known from goalball (see 21.4.2). It is extended by discrete sound events in the sonification design. To provide the player with a representation of the playing area, zone markers strike with sound as the player crosses them. Further discrete sound events represent certain ball collisions with the racket or the walls. Finally, the sonification design is completed by verbal markers to provide game control information about events such as the start of the game, ball out and so forth. The first application is illustrated in Figure 21.8 and can be seen on videos on the project homepage [25].

**Goalball-specific performance test**

AcouMotion’s second application in APA aims at creating new kinds of performance tests, which are blind-specific and therefore very suitable supplements for the current inventory of diagnostic instruments in competitive sport games (such as goalball) for athletes with visual impairments. For a goalball-specific performance test AcouMotion is used as a virtual “ball-throwing machine”. In the first pilot study with a female international goalball player, this machine throws (or rolls respectively) a virtual ball from a 4 meter distance to a 3 meter wide goal line. A test set consists of 15 trials with 15 different ball throws standardized by the computer simulation (see Fig. 21.9). The set was conducted seven times varying the ball velocities from 1 to 4 meters per second.

The sonification engine provides auditory information on the rolling of the ball by using an audio-setup with five speakers fixed on a segment of circle (see Fig. 21.9, and sound and video examples at S21.11 and S21.12). Intensity panning and distance dependent level mapping was used to provide information about the ball’s position. Further on, the player received verbal information on the start of the next trial as well as verbal feedback on the success of her movement behavior in defending her goal line (e.g. “0.3 meters left!” for 30 cm distance between the racket and the ball). Based on this auditory information it was the task of the goalball player to anticipate the ball as exactly as possible in order to defend her goal by moving her racket to the anticipated ball position on her goal line. The accuracy of her goal defending movements was measured by the sensor device held by the player.

In order to get a feedback from goalball experts, the international player and her coach were interviewed about the appropriateness of the performance test. Both gave positive feedback. The player stressed that - after a short adaptation phase which took about 15 minutes - she was able to perceive the start and final position as well as the course of the ball.

A quantitative analysis of the recorded data was in unison with the player’s estimation. She was able to locate the position of the ball crossing the goal line with an absolute average error of 36 cm (median observed on all 105 throws). Additionally, the accuracy was clearly dependent on the ball velocity. The player reached her peak performance at ball velocities between 2 and 3 m/s (each median < 0.25 m). Balls with higher velocities and also lower – from a first glance surprisingly – led to reduced accuracy. On further inquiry, the player was
Figure 21.9: Laboratory setting for the goalball-specific performance test with the five-speaker audio-setup and the (not exactly to scale) illustration of the 15 standardized ball throws to the 3 meter wide goal line (here a test with Conny Dietz, the national flag bearer of the German paralympic team in Peking 2008 who played six paralympic goalball tournaments).

able to relate these results to her experience as she was unfamiliar with the slower balls from her goalball practice. She stated that she became insecure when waiting a long time for these balls. For a more demonstrative impression of this first goalball-specific performance test, videos are available showing parts of the test session [25].

21.4.5 Future directions

In addition to the first empirical case studies presented in this section, the two applications of AcouMotion in the field of APA shall receive further evaluation through empirical research. Current work includes the evaluation of performance diagnostics with the German national goalball teams (male and female) and collection of quantitative data on the performance level of each player as well as qualitative data from interviews with the goalball experts on the validity of this test [26, 27]. Concerning the audiomotor sport games it is an aim to develop experimental designs which scale up the speed of Blindminton and test the influence of matching a game’s difficulty to a player’s personal skills on the flow-experience. Further on, there are promising perspectives for the research on audiomotor control and learning. It is now possible to vary the parameters of the game in the computer simulation. This can be used to check whether standardized simplifications such as the enlargement of the racket size in games such as Blindminton lead to more effective learning processes. Thus, methodological learning principles like the simplification of an audiomotor task may be investigated in experimental settings designed with AcouMotion.
21.5 Enhancing Motor Control and Learning by Additional Movement Sonification

Alfred O. Effenberg

21.5.1 Motor control and learning, vision and audition

When learning new closed skills in sports or relearning basic skills in motor rehabilitation, the observation of the skill and the reproduction of it are key elements. These processes are dominated by visual perception; a well known theory in the field of motor learning is the theory of 'observational motor learning'. But vision is not the only sense providing information about movement patterns realized by trainers or therapists. Audition is another perceptual channel suitable for gathering information about movement patterns. You can hear the rhythm of a runner, even of a swimmer, and you can hear it more precisely than you can see it. Additional auditory information is achieved, because in some domains the ear is more precise than the eye, e.g., in temporal discrimination or in integrating sequenced sounds into a rhythm. Utilizing the ear in movement related perception can result in a broader spectrum and enhanced precision of perceived information supporting motor learning. Beside modality specific auditory benefits there are further perceptual effects achieved by multisensory integration [29, 30] and intersensory redundancy [31], if convergent visual information is available.

The main restriction for supporting auditory and multisensory information in motor control and learning seems to be the weak acoustical effectiveness of human movement, which is limited to short movement phases of ‘getting in contact’ - when the shoe hits the ground or the racket hits the ball. The movement itself is low-frequency and impossible to hear because it is below the human hearing range of about 20 - 20,000 Hz. Audification or Sonification of naturally silent movements can be helpful to motor learning and can result in a better performance, as shown in freestyle-performance (see, for example [32]). But the idea of creating additional movement sound is not completely new. There are different traditional forms of additional movement acoustics:

- Clapping the hands with the observed or aspired movement rhythm
- Simple forms of articulation or singing to emphasize duration and dynamic characteristics of selected movement phases
- Using simple musical instruments such as whistles or tambourines
- Using music as guiding rhythm and enhancing expression of movement (e.g., ice dancing, gymnastics)
- Using simple forms of body-instruments such as wrist- or ankle-bands with little bells etc.
- Using some technical sensors to detect discrete features of the movement and create an error-signal via electronic sound devices.

The research was realized at the Institute of Sportscience and Sport at the University of Bonn, Prof. Dr. Heinz Mechling. It was funded by the ‘German Research Foundation’, grant no. ME 1526.

Closed skills are skills “performed in a stable or predictable environment where the performer determines when to begin the action” [28]
21.5.2 Movement Sonification

Movement sonification, the sonification of human movement patterns is a new approach for creating ‘authentic’ acoustic movement sounds. This is achieved by transforming computed - kinematic as well as dynamic - movement parameters into sound. The ‘MotionLab Sonify System’ is a motion capture and sonification system, which is capable of real time sonification and computing force data by inverse dynamic algorithms [33].

![Image 1](image1.png)

Figure 21.10: Breast stroke: Horizontal components of relative wrist and ankle motion - strokes only - are computed and used to modulate sound frequency and amplitude. 8 cycles in about 9 sec are shown, indicating a high stroke frequency.

![Image 2](image2.png)

Figure 21.11: Horizontal components of relative wrist and ankle motion - complete cycles - modulating sound frequency and amplitude.

The system allows a direct acoustic transformation of movement parameters via MIDI\(^\text{18}\). MotionLab Sonify’s architecture consists of a set of plug-ins for the MotionLab framework. The internal representation uses streams of motion data, which can be visualized as a skeletal

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\(^{18}\text{MIDI (“Musical Instrument Digital Interface”) is a serial control protocol customized for musical note event and control information.}\)
Aiding Movement with Sonification

Figure 21.12: Horizontal components of relative wrist and ankle motion and vertical component of relative neck point motion.

representation. A parser for the AMC/ASF\textsuperscript{19} file-format is implemented, which is available widely and is supported by a number of motion capture systems, such as the VICON\textsuperscript{20} system. The MotionLab Sonify system can easily be adapted to handle motion data existing in different formats. Also the system can process streams of real-time motion capture data. Figures 21.10 - 21.12 represent a sonification of breast stroke based on kinematic parameters. Sonification was realized in three steps, and the example can be downloaded\textsuperscript{21} or found in example videos S21.13, S21.14 and S21.15.

Emerging sound patterns are typical for a sophisticated technique in breast stroke and contain concise temporal information about phase relations of arm cycle vs. leg cycle. Such kinds of movement sonification can be used to support the processes of motor learning.

21.5.3 Empirical data on effectiveness of movement sonification

Movement sonification of swimming breast stroke has not been used so far in an empirical study. But there is some information about the effectiveness of sonification on motor assessment and motor control related to another kind of movement, which is very common in sports; the counter-movement-jump (CMJ)\textsuperscript{22}. Since the data has been reported elsewhere [34], here is just a brief summary. Investigations were realized in two distinct areas:

1. The precision of perception and judgment of sport movements was addressed. \textit{Method:} Subjects sat in front of a video-/audio-projection watching videos of CMJs of different unknown heights. They were asked to judge the height-difference of two consecutive CMJs. Subjects were treated with visual, auditory and audiovisual stimuli comparatively. Audio consisted of a movement sonification based on the vertical component of the ground reaction force of a jump. The force parameter was measured with

\textsuperscript{19}AMC/ASF: The ASF file holds the skeleton data while the AMC file holds the motion information.

\textsuperscript{20}Vicon Peak is the new name for the combined businesses of Vicon Motion Systems and Peak Performance Inc..

\textsuperscript{21}see http://www.sportwiss.uni-hannover.de/alfred_effenberg.html at “Mediadownload”

\textsuperscript{22}A CMJ is a common athletic test of leg condition, and involves the subject standing straight, squatting, then leaping vertically off the ground and back into the standing position.
a KISTLER force plate 9287BA and acoustically transformed as a first order sonification: The force parameter modulates sound frequency and amplitude as shown with the breaststroke example above. **Results:** Judgment of jump-height differences was significantly more precise audio-visually compared to both unimodal conditions. Precision was enhanced by about 20% without any learning experience.

2. Secondly the accuracy of perception and reproduction of sports movements was studied (motor control). **Method:** The method was nearly the same as reported above: Subjects observed a single CMJ as video- or audio/video-projection and were asked to reproduce or jump the same height as accurately as possible. Presented CMJ-heights ranged between 60% to 90% of subjects individual maximum jump height. **Results:** The precision of movement reproduction was significantly different between visual and audiovisual treatment. The absolute error under the audiovisual condition was reduced by about 20% compared to the visual condition.

Further research on the effectiveness of sonification on motor control had been realized by Chiari et al [35]. Also there are some references on the effectiveness of sonification on motor learning, in competitive sports [36] as well as in rehabilitation [37].

### 21.5.4 Discussion and Conclusion

This was the first investigation demonstrating that even a non-cyclic, non-rhythmic movement pattern (CMJ) can be perceived and reproduced more accurately with additional acoustic information created via movement sonification of dynamic parameters. The effectiveness of the movement sonification without convergent visual information was tested only for perception and judgment of movement patterns. Thereby no significant difference between accuracy achieved under auditory and visual treatment became evident, but absolute values had been more precise under the visual condition. Even though perceptual and motor control functions are also fundamental functions for motor learning, the effectiveness of additional movement sonification on motor learning has not been tested directly so far. That will be the next step of the empirical work described here. If effects on motor learning are detectable, there will be a broad application of movement sonification in the fields of competitive sports as well as in motor rehabilitation. Motor learning of closed skills in competitive sports could be shaped more effectively, supported by additional movement sonification, because audiovisual movement information is more precise and easier to keep in memory than visual or auditory information alone. Movement sonification could be used to enhance instruction by using audiovisual models as well as supporting feedback particularly when sonification is available in real time (see also section 21.4). Also mental training can be facilitated with simultaneous sonification. In motor rehabilitation, therapy could be started earlier for instance by addressing subliminal sensorimotor – audiovisuomotor – interconnections within the Central Nervous System (CNS) additionally by using movement sonification.
21.6 Concluding Remarks

Oliver Höner

The framework of this chapter integrated movements that are executed under distinguishable purposes and meanings. To help solve the problem of defining the common and distinctive elements of the terms “sport activities” and “movement activities”, Figure 21.1 presents the applications to the field “Exercise, Play and Sport” in its widest meaning.

This figure could be divided into yet more sub-sections due to the distinction between more close and more open skills used to reach the specific action goal (e.g., promoting health for quality-of-life improvements, having fun and flow-experience in playing games, or enhancing performance due to yet unused resources and augmented information). A further dimension could be inserted with respect to a specific user group such as people with special needs (e.g., orthopedic patients, people with visual impairment).

Therefore, the applications of sonification described in this chapter could provide an important contribution for the cross-disciplinary research field of Adapted Physical Activity (APA). But in some sections, the target groups go beyond people with special needs. In particular, the contributions on the use of gestural audio systems for designing auditory computer games and for the enhancement of motor control and learning (sections 21.3 and 21.5) offer new perspectives for entertaining or performance enhancing activities that able-bodied people as well as top sport athletes may benefit from.

Owing to the multidisciplinary nature of these topics, this chapter has attempted to portray some examples of the manifold aspects of aiding physical activities. But such variety also implies difficulties in arranging and integrating these multidisciplinary applications into research programs such as gestural audio systems or interactive sonification, and this provides a challenge for the future. The common ground of the presented use of sonification systems in motor rehabilitation, game entertainment and competitive sports can be interpreted as a promising start for interdisciplinary approaches which provide useful systems for the future.

Bibliography


