Demands on a mobile auditory feedback system for gait rehabilitation

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ABSTRACT:

The treatment of gait disorders is of high importance in clinical rehabilitation. Clinical gait analysis is usually applied in laboratories using videobased systems as well as force or pressure measuring mats. Due to the need for systems applicable for therapy and everyday situations an increasing number of mobile gait analysis systems has been developed in recent years, which include sensors and electronics that are integrated in the shoe or insole.

These systems can also be applied in clinical rehabilitation and therapy of gait disorders. Used as feedback instrument it is possible to represent gait parameters visually or auditorily. The auditive representation of motion is called sonification. The increasing number of prototypes developed in recent years for the use of sonification in sports, as well as first applications in rehabilitation, show high potential for the use of sonification in gait rehabilitation.

Therefore, this work comprises a review of current literature in order to provide recommendations for the development of a mobile system for the sonification of gait. This system may serve as a feedback instrument to support both, therapists and patients in clinical gait rehabilitation. Furthermore, possible application scenarios are discussed.

1 INTRODUCTION

Instrumented diagnosis and treatment of gait disorders using video-based systems, and force or pressure measuring devices, require expensive equipment and time resources for data collection. Therefore, in the clinical setting gait analysis and rehabilitation are mainly performed through visual inspection by the treating therapist, ideally supported by the use of video recording (Götz-Neumann, 2011).

Highlighting critical aspects of walking through an external source of feedback is called "augmented" feedback. It enables the perception of relevant gait characteristics and intensifies motor learning processes. This kind of feedback is important for people with injuries or impaired sensory capabilities.

In general, augmentation is performed with verbal or visual feedback presented e.g. via video recordings or the representation of kinematics and kinetics. Alternative approaches represent the use of vibro-tactile or auditory feedback (Magill & Anderson, 2013). A specific method is the auditory representation of movement, also called sonification (Rosati et al., 2013).

Several approaches in sports and rehabilitation have shown the effectiveness of sonification to improve motor learning and motor control. Existing approaches of sonfication in gait rehabilitation range from a simple system that delivers a ticking sound on every heel strike (Baram &

Miller, 2007), to more complex applications, such as sonification of the swing phase of walking using an optical system (Rodgers et al., 2013).

For daily training sessions, integrated into usual activities of daily living (home-based or in therapeutic practice) there is a need for mobile, inexpensive feedback scenarios. Due to the rapid development of wireless communication and disintegrated sensor technologies mobile gait analysis systems have already emerged (Grenez et al., 2013; Noshadi et al., 2013; De Rossi et al., 2011). First attempts of sonification in gait rehabilitation show its potential for application as a feedback tool.

Therefore, the objective of this work is to review current literature in order to provide recommendations for the development of a mobile system for the sonification of gait. Possible application scenarios for the system's use in clinical gait rehabilitation are discussed.

2 METHODS

The current literature was reviewed searching PubMed and Google Scholar. Two independent reviewers systematically combined keywords classified to gait disorders, clinical syndromes and diseases, sonification and feedback mechanisms including synonyms. Full texts were examined and tested for relevance of content. Furthermore, reference lists of all those identified as relevant were checked manually.

Literature sources were included if they were not older than 10 years, were published either in a peer-reviewed journal or in conference proceedings. Further, included literature had to approach either auditory feedback techniques in gait rehabilitation of different clinical syndromes or sonification of movement in sport or therapy.

Based on the results of this research existing approaches for auditory feedback in gait rehabilitation, as well as existing scenarios for movement sonification were analyzed, and recommendations for the construction and use of a mobile, cost-affordable system of sonification for gait rehabilitation were summarized.

3 RESULTS

From 54 tested full-text references 19 literature sources were included in the following analysis. Based on the included literature, the requirements for an auditory feedback system for gait rehabilitation are presented.

The analysis of these requirements will be summarized assigned to three units, which are required for the collection, transmission or reproduction of gait data with the aim of a mobile, auditive feedback application for use in gait rehabilitation:

- **Sensor unit:** by measuring different pressure levels, acceleration and angular velocity parameters such as step number and width, foot and posture can be derived within the gait cycle phases (Liu, Inoue & Shibata, 2010; Muro-de-la-Herran, García-Zapirain & Méndez-Zorrilla, 2014; Shu et al., 2010; Tao et al., 2012; Wagner & Ganz, 2012).

(1) So far, accelerometers, gyroscopes, pressure sensors, magneto-resistive sensors, and goniometers have been applied in mobile gait analysis systems.

(2) The selection of appropriate sensor size, mass, and placement is crucial to avoid alterations of the user's normal movement behavior. These could either result from physical influence via changes of the sole surface if sensors are not miniaturized, or from given auditive feedback, which will depend on the placement and sensitivity of the sensors and should enable the highlighting of characteristic gait parameters.

(3) Therefore, in normal gait placement of sensor units has to enable normal auditive feedback, but in gait disorders will also have to highlight asymmetries or unhealthy behaviour.

(4) To avoid physical influence through sensor units, they could be embedded in a shoe or insole. Because of its adaptability to different shoe sizes, the shoe insole approach seems to be superior and should be thin and flexible.

- **Control unit**: this is to be constructed in the smallest possible design, with low energy demands, including a radio module for data transmission to the feedback unit (Grosshauser et al., 2011; Redd & Bamberg, 2012; Noshadi et al., 2013).

(1) If aiming to ensure natural exercise and normal movement behavior, especially the size, weight and stability of the required electronic elements will have a great impact on the design of such a mobile feedback application. Again controlling units could be embedded in a shoe or insole, but they could also be constructed as additional devices connected to shoe and/or insole. In the first case the device itself, in the second case cables and fixation of the device must not result in physical constraints of the patients gait characteristics.

(2) Wireless data transmission will be crucial to enable normal gait behaviour by constructing the auditive feedback system free from cables or additional weight of a feedback unit, which would have to be placed near the controller unit and lead to further limitations.

(3) Sufficient power supply: For use in therapeutic settings, as well as in self-directed training at home, the power supply should be sufficient for at least 30 minutes. This requires batteries of small size and a minimum of weight. Ideally, they could be integrated into the insoles and be charged wireless. Alternatively, if the controller unit is constructed as additional device, a second pair of batteries could be used to replace and recharge unloaded ones and therfore enable the use of auditive feedback in more than one therapy session or changing the controller unit (including its battery) to different shoe or insole sizes.

(4) Auditory information in real-time: Data should be transmitted with minimum latency to provide optimal learning results. This leads to increased requirements on the hardware. In motor rehabilitation, real-time auditory feedback can be defined as the perceivable synchrony of a specific movement and its auditory representation. The threshold for intermodal detection of asynchrony is set at 180 ms (± 104 ms) for non-musicians, when coupling a simple key press with an auditive signal (van Vugt & Tillmann, 2014).

- **Feedback unit**: for data processing and generation of auditory feedback, ideally a standard mobile device is used, as for example a smartphone or tablet (Baram & Miller, 2007; Effenberg, 2005; Effenberg, Fehse & Weber, 2011; Maulucci & Eckhouse, 2011; Riskowski et al., 2009; Rodger, William & Cathy, 2013; Vinken et al., 2013). For optimal sound quality audio-enhancing systems may be used.

(1) Range of wireless data transmission will be limited, therefore the feedback unit should be small and light enough to be carried by the patient, ideally in a trousers or jackets pocket, enabling thereby natural arm movements.

(2) Application installed on the feedback unit: The application used to start, stop and direct different modes of auditive feedback should be of easy and self-explanary use. Therapists

might need to add or remove feedback elements, change the audio design or record the patients sonification for repetitive replay. Patients might want to use the auditive feedback system at home in self-guided exercises, which will add further demands as a simplified display and function of the application and exercise programmes pre-designed or created from their therapist according to the latest therapy session.

(3) The selection of exemplary parameters of gait may vary depending on the patient population. In general, two main classifications of gait disorders may be applicable: those of gait asymmetries between right and left foot, and those of impaired rolling performance of one or both feet.

(4) An appropriate audio design should be able to represent changes in the measured gait parameters and highlight critical aspects with auditive stimuli easy to interprete.

4 DISCUSSION

In order to develop a first prototype based on these recommendations, concrete application scenarios are needed in terms of target populations, which show typical deviations of normal gait. As a possible application scenario patients with osteoarthritis of the knee were identified (Ornetti et al., 2010). These patients typically exhibit the following changes: reduced speed, proportional shift of each limb towards longer double leg stance, reduced swing times, reduced stride length and increased step width. For this target group, it is possible to match the requirements of patients and their supervising therapists with the presented recommendations in this paper. In future, further patient populations may benefit from a mobile, auditory feedback system, as for example gait disorders resulting from other orthopedic disorders, but also from neurological disorders (e.g. stroke, Parkinson’s disease or multiple sclerosis).

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