Designing a Platform for Child Rehabilitation Exergames Based on Interactive Sonification of Motor Behavior

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ABSTRACT

Designing multimodal systems for interactive computer play, as tools for supporting rehabilitation of children with motor and/or cognitive impairment is a complex process, requiring interaction of many stakeholders, including clinicians, therapists, engineers, human factors experts, parents, and children themselves. This paper discusses the participatory design process, leading us to conceive, develop, and iteratively refine a flexible and modular open platform for nonverbal interactive child rehabilitation exergames, with a specific focus on interactive sonification of motor behavior. The process was implemented through a collection of case studies carried out using an early prototype of the platform.

CCS CONCEPTS

• **Applied computing → Life and medical sciences**; **Consumer health**;

KEYWORDS

Multimodal systems; interactive computer play; exergames; rehabilitation; participatory design.

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1 INTRODUCTION

Multimodal systems for interactive computer play (ICP) [5] [13] are recently receiving an increasing attention as tools for supporting rehabilitation with a special focus on child rehabilitation, see for example [12] [15]. ICP systems motivate children with several mechanisms: control over game and task selection [2] [3], competition against another player or presence of a virtual opponent [3] [18], the challenging variety of game options and environments [9] [10] [18]. Auditory and/or visual feedback provides information about task performances or results [3] [7]. User problem-solving is promoted through task-driven training [3], game unpredictability, and provision of obstacles [4]. Moreover, ICP systems allow tailoring parameters to the user's needs [2] [3] [7] [10], enable remote monitoring by a therapist [7], and equalize opportunities for

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impaired children by providing social interaction, acceptance, and barrier-free inclusion in play situations [11].

Designing an IPC system is a complex participatory design process, requiring interaction of stakeholders with different background, such as clinicians, therapists, engineers, human factors professionals, parents, and the children themselves.

This paper discusses the participatory design process that led us to conceive, develop, and iteratively refine a flexible and modular open platform for interactive exergames, grounded on nonverbal multimodal interaction, and on interactive sonification. Recent research in neuroscience demonstrated how human brain use sensory feedback, including sound, to keep track of the changing structure and position of the body in space, to adjust actions. Interactive sonification was already used for improving motor tasks (e.g., see [17]). Moreover, a rehabilitation approach grounded on interactive sonification of motor behavior recently proved effective with adult chronic pain patients [14]. A major objective here is to extend it also to pediatric rehabilitation. The platform is conceived as a complement to conventional rehabilitation interventions both by improving monitoring and collection of information, and by supporting the recovery process of children with motor and/or cognitive and/or sensory impairment. The iterative design process was implemented through a collection of real-world case studies in the framework of hospital rehabilitation programs, performed with an early prototype of the platform and involving the stakeholders.

The paper is organized as follows: the addressed problem is stated; then the initial platform used for carrying out the case studies is introduced; finally, the case studies are discussed with reference to objectives, activities, collected feedback, and input provided to the design process. This work was carried out at a newly created joint laboratory between pediatric hospital and university.

2 PROBLEM STATEMENT AND REQUIREMENTS

The design process started with a series of meetings with therapists in order to (i) identify pathologies that can possibly benefit from a rehabilitation approach based on interactive sonification of motor behavior and (ii) define an initial set of requirements for the platform. From discussion, it emerged that rehabilitation of severe disability in children is often a tough problem. Indeed, the frequent association of motor, cognitive, and sensory impairment is challenging and frustrating for therapists. The child, in many cases, has a huge difficulty to understand and interpret the signals she or he receives from the environment and is not able to produce a sufficient understandable and meaningful response (low selectivity, amplitude, and consistency). Therapists have to modulate and interpret environment signals and to capture and interpret (multimodal, nonverbal) child 's behaviors in order to support a meaningful and therapeutic rehabilitative session (relation). Multimedia and multimodal technologies can have a great positive impact in these cases. In order to apply interactive sonification of motor behavior as a rehabilitation approach, the envisaged platform should:

- Capture non-verbal multimodal child's behavior.
- Provide real-time feedback mainly in terms of interactive sonification, of active experience of music content, possibly integrated with interactive visual content.
- Introduce meaning and motivating elements in interactive narrative structures: sonic content, music, vocalizations and speech, images, and stories.
- Support authoring of interactive narrative structures, and the possibility to keep track of parameters and history of repeated sequences of sessions along a period of time.
- Collect, measure, and analyze signals and responses. This includes supporting automated analysis of nonverbal, multimodal motor behavior, not only limited to low-level physical features (e.g., trajectories, speed, and so on), but also extended to (i) movement qualities (e.g., symmetry, energy, changes in head directions, contraction, rigidity, fluidity, impulsiveness, and so on), and to (ii) social movement qualities of the child toward the caregiver, such as forward and backward leaning, eye contact, synchronization, entrainment, and so on.

The platform has to be flexible, scalable, and modular, so that it can be used by the different types of stakeholders and for different categories of impairment. Scalability should enable the instantiation of the platform in different environments, e.g., in the hospital and at home and in different treatments of several impairments. The platform should support different exergames and a broad range of input and output devices ranging from low-cost configurations at home (e.g., exploiting IMU sensors in smartphones or tablets, game interfaces, webcams, and personal computer) to more sophisticated configurations supporting multimodal interfaces for analysis of behavior, integrating motion capture, professional video cameras, multichannel audio, and physiology sensors. The platform should therefore support a wide number of adaptive, flexible, and customizable rehabilitation programs, to respond to the varying needs and impairments, often significantly different for each child. It should also support inclusion of novel exergames as far as they become available.

3 PROTOTYPE PLATFORM AND SAMPLE EXERGAMES

Following the requirements stated above, an early prototype of the platform was developed [6] for carrying out an initial set of case studies. The prototype platform was endowed with a small number of exergames. Each of them addressed recovering of specific cognitive and motor skills.

Figure 1 illustrates the platform architecture. Input modules encompass a broad range of devices, including:

- *Motion Capture systems*, extracting with high accuracy 3D coordinates of markers in environments endowed with fairly controlled setup. They perform measurements having accuracy close to 1mm. Motion Capture systems are expensive and are included for use at the hospital.
- *Kinect for X-Box One* (also known as Kinect V2), extracting 2D and 3D coordinates of relevant body joints, and capturing RGB image, grayscale depth image, and infrared image of the scene. Kinect is cheaper than motion capture systems and portable, but its precision is much lower. It is included for use at home.
- *Leap Motion*, a sensor device capturing hand and finger movement. It does not require hand contact or touching.

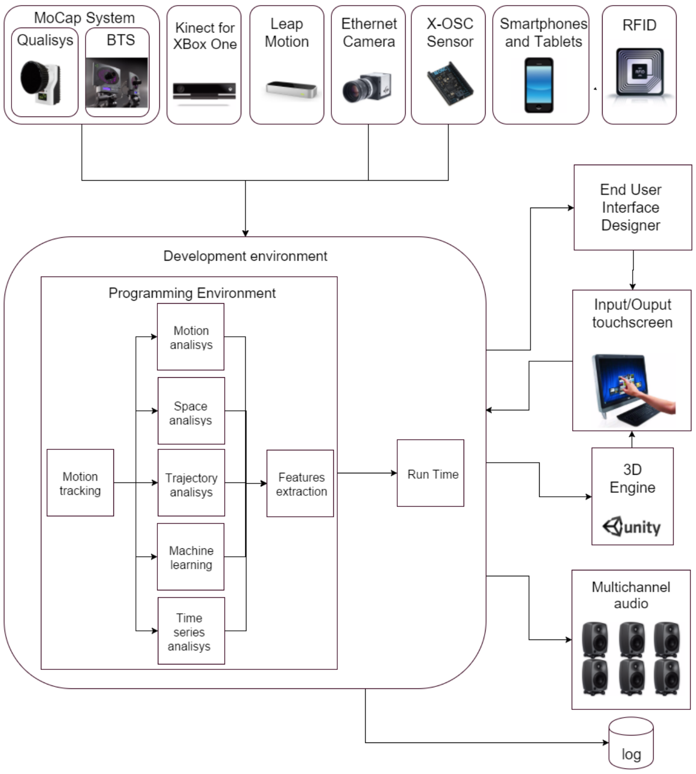

Figure 1: The overall architecture of the platform. Data from input devices is processed by the EyesWeb XMI Platform to capture child's non-verbal multimodal behavior and to provide real-time feedback in terms of interactive sonification and visual content. EyesWeb also serves as development and programming environment. Moreover, tools for designing interactive storyboards, for designing the user interface for exergames, and for recording and managing session data are also available.

- *Ethernet camera*: integrated with devices having a higher latency, such as for example Kinect, this device enables obtaining a sensor with a fast response and relatively high accuracy.
- *X-Osc sensors*, i.e., accelerometers children can easily wear to extract features such as acceleration and jerk.
- *RFID (Radio-Frequency IDentification) devices*, used to detect the presence of a child in a specific area, in order to enable a given interaction in that area.

Since the focus on interactive sonification, multichannel audio is the main output of the platform. Loudspeakers positioned around the space allow designing exergames and interactive stories including 3D spatialization. Devices for visual output are also available for specific tasks and needs and encompass projectors and computer displays, including touchscreens. Visual output is obtained by integrating in the platform the Unity cross-platform game engine [1], a game engine widely employed for developing games for personal computers, consoles, mobile devices, and websites. Basic functionalities Unity provides include a rendering engine for 2D and 3D graphics, a physics engine, and support for e.g., collision detection, sound, scripting, animation, and networking. Smartphones and tablets are used as both input and output devices to control exergames remotely.

The core of the platform, including the development and programming environment, grounds on EyesWeb XMI [8]. EyesWeb includes a collection of software modules, which are assembled in a visual language to build applications. In particular, the platform exploits the EyesWeb modules for analysis of nonverbal motor behaviour, including motion trackers, modules for real-time extraction and analysis of motion qualities (e.g., energy, contraction, fluidity, and so on), modules for measuring how a user moves in the space (e.g., which areas are most frequently occupied), modules for trajectory analysis (e.g., kinematic features of 2D and 3D trajectories). Moreover, modules for time-series analysis and for machine learning (e.g., SVMs, clustering, neural networks, Kohonen maps, and so on) are also available. The EyesWeb Social Signal Processing Library [16] was used for analysis of synchronization (e.g., to assess coordination of motor behaviour).

The platform comes with (i) a tool for designing the end-user interfaces for each exergame, (ii) a tool for designing interactive storyboards, and (iii) a tool for recording and managing session data. The End User Interface Designer, developed using the EyesWeb Mobile software, aims at building end-user interfaces for caregivers. This tool hides the implementation details of the patches and allows an easier use of the platform. It consists of a designer and a runtime application. The *Interactive Storyboard Designer* is used to design exergames having an articulated narrative structure, composed of a sequence of single interactive stages, or by repetitions of the same stage with different parameters and tuning. Consider, for example, an exergame enabling the progressive reconstruction of a song while performing circuit training. At the beginning of the training, the song seems scarified and does not include any melodic components, but just a rhythmic pattern. The user performs an initial exercise trying to synchronize with the proposed rhythmic pattern. As long as synchronization is achieved, instruments are added step by step and the user moves to other exercises in the circuit. At the end of the training the singer's voice is finally added to the song. *The Data Manager* manages a repository of session data.

At the moment three different exergames [6] were used for the case studies:

- CULT *(Cognitive Upper Limb Trainer)* was designed to support the recovery of upper limb functions such as strength, control of movement, bilateral integration and coordination, with the possibility to add cognitive tasks for attention, memory, and executive functions. The child is expected to choose the object, which better suits a proposed background. A song is played. To keep music alive and advance in the game, the child needs to reach and grab the object properly moving his/her hands or with his/her elbows or his/her head (in case this kind of movements is compromised because of a severe disability).
- HTCT *(Head Trunk Control Trainer)* aims to improve control and balance of head and trunk while sitting. When control

and balance meets therapists, requirements, a full and high-quality reproduction of the child's preferred song is played, otherwise audio quality deteriorates. To enhance the perception of the variation of intensity of the sonic stimulus, we control both the loudness and the bandwith of the signal (continuous reduction of the low and high frequencies associated to a reduction of loudness, and viceversa).

- CERT *(Coordination Endurance Rehab Trainer)* focuses on developing and recovering general cardio-respiratory endurance and global coordination. Children have to keep rhythm and coordination (both intra and inter-personal synchronization or alternate movement between limbs, or, in a group, between members).

4 CASE STUDIES

We enrolled 6 children, 4 to 14 years old (M=9.3, SD=4.1) in as much case studies at hospital Giannina Gaslini. For each of them, diagnosis and child's functional conditions, specific objective of rehabilitation activity, performed tasks and system settings, and feedback (in terms of reported problems, operator's and possibly child's comments, and suggestions) are here reported for each child.

Case Study 1 (4 years old)
Diagnosis: bilateral spastic cerebral palsy with epilepsy and cognitive and visual impairment;
Functional conditions: low interaction with the surrounding environment; 4 limbs hypertonia and trunk hypotonia; no head and trunk control; no independent sitting and standing. The child is able to turn his head towards sounds. He needs help of a caregiver for postural changes and transfers and is not able to move with a wheelchair without assistance.
Objective: stimulating and fostering interaction with the surrounding environment and behavioral activation (amount of motion in the time unit, amplitude and frequency of motion, and movement awareness).
Activity and settings: the child seats in a wheelchair with wheelchair table. One operator assists him. The platform enables the child to control an acoustic feedback by analyzing in real-time his head's movement. The volume of the sound is low when flexing the head and it gradually increases with head extension.
Feedback: the real-time response of the system emerged as a critical aspect. Given the temporal response to auditory stimuli, it is important to keep the system response below 100ms: if the system needs too much time to adapt the auditory output to the micro-movement of the child, the patient is not able to understand the causality relation between his movement and the acoustic feedback. Moreover, according to the operator, the acoustic feedback needs to be more sensitive to small posture changes. The child should be made aware of the relation between movements and sound, even if the range of motion is very small. As a guideline for refining the system, therapists suggest that music is chosen according to the cognitive and sensory impairments of the patients, e.g., volume (in terms of joint loudness and timbral) variations demonstrated to be easier to understand than variations of harmony, melody, or rhythm. Moreover, the system should be capable to adapt its sensitiveness to movements (from very little movements to larger movements), and to patients in different settings, e.g., on wheelchair, big cushions, and gym balls.

Case Study 2 (5 years old)
Diagnosis: genetic syndrome with intellectual disability, speech dyspraxia, coordination and gait impairment.
Functional conditions: the child has a psychomotor delay; he shows difficulty in self-regulation (hyperexcitability and impulsivity) and in sustained attention. He can produce vocalizations, a few words, and performs context gestures. He displays fair comprehension, and walk independently.
Objective: supporting cognitive and motor rehabilitation with focus on training for attention, executive functions, and upper limbs bilateral integration and coordination.
Activity and settings: the child is asked to reach a moving target before it disappears from the screen. A sound is associated with the position of the target and is deteriorated (volume decreases and some distortion is introduced) if the target is not reached. The acoustic feedback is associated with the free movement of the child. This task stimulates the movement of the upper limbs in order to improve their functions and also has a cognitive valence. Therapists assist the child.
Feedback: in this case the child had difficulties in understanding the task and displayed impulsiveness in the touching gesture. Moreover, he had difficulties to reach precisely the target because of attentional lability, poor coordination, and poor quality of motor gesture. Some graphical features of the system (the background of the moving objects) revealed to be distracting. The room where the child moved with a walker was too big to allow him understand that the acoustic feedback was associated with his movements. Therapists suggest customizing system features (such as target appearance, background graphic images, and audio feedback) according to the cognitive and motor profile of the user. Different levels of difficulty (e.g., distractors, double tasks) should be offered to modulate the activity, and to compose the design of a sequence of sessions. Moreover, it would be interesting to build auditory paths with different sound sources, which are activated when the child passes nearby and drive him through the room.

Case Study 3 (9 years old)
Diagnosis: spastic bilateral cerebral palsy with visual, cognitive and behavioral impairment.
Functional conditions: the patient is quite collaborative, he communicates with speech, but he displays lot of language stereotypies (repetition of sentences and words). He needs help for postural changes, but he can move on a wheelchair in safe places.
Objective: stimulating and fostering postural alignment and improving autonomy in postural changes.
Activity and settings: the child is in kneeling position, with an anterior support (a bench), and is assisted by two or three operators. He tries to align head and trunk by listening to an acoustic feedback. While moving from kneeling to standing, the volume of the acoustic feedback increases. The acoustic feedback is associated with the free movement of the child who after standing can further move around with a wheelchair or a walker.
Feedback: the child understood the relation between music volume and his changes of posture. His movement became easier and more

coordinated even in presence of interfering factors. Therapists noticed an improved participation and attention when the child was performing postural changes. The child tended, however, to move towards sounds rather than trying to adapt his movements to the sound. As in case study 2, when the child moved with the wheelchair or the walker, the room was too big to allow him to understand that the acoustic feedback was associated with his movements. Again, this is something that can be addressed by creating auditory paths with sound sources being activated when the child passes nearby.

Case Study 4 (11 years old)
Diagnosis: dystonic bilateral cerebral palsy with epilepsy and cognitive and visual impairment.
Functional conditions: the child suffers of visual disorders, and hyperexcitability. His lack of postural control limits interaction with the surrounding environment. The patient adopts a generally flexed posture, the head tending to bend forward (hypo-posture). Sometimes he can shift his gaze towards a visual stimulus (high-contrast images). He uses vocalizations to communicate. If administered with the right stimulus, he can control his head. He needs the help of a caregiver to transfer and to move with the wheelchair.
Objective: stimulating and fostering interaction with the surrounding environment and behavioral activation (amount of motion in the time unit, amplitude and frequency of motion, and movement awareness); suggesting new ways of interaction between child and caregiver.
Activity and settings: the child is sitting in a wheelchair with wheelchair table. Two operators assist him. His mother also participates in a training session. The child is enabled to control an acoustic feedback by his head 's movement. The volume/quality of the sound gradually decreases when flexing the head and it gradually increases with head extension. Moreover, the distance between caregiver and child also modifies the volume of the acoustic feedback. Such changes in the volume motivated the child to look up and extend his head.
Feedback: therapists noticed that the child could keep head- trunk alignment and fixation for a few seconds. Postural control and vocalizations improved, especially when he kept his upper limbs on the wheelchair table. In tight interaction with the caregiver, due to occlusions, the system could not distinguish between the silhouette of the patient and the silhouette of the caregiver. This suggests that the system may implement different kinds of training sessions involving one or more persons interacting with each other, and that it can rely on the global features of the overall silhouette, when occlusions prevent identifying each single participant. Alternatively, on-body inertial sensors might be used to measure child's head movement.

Case Study 5 (13 years old)
Diagnosis: spastic bilateral cerebral palsy with cognitive and visual impairment.
Functional conditions: interaction is poor both in terms of social interaction and with the surrounding environment. The child suffers of cognitive impairment. He can produce vocalizations, and head and upper limbs stereotypies. Transfers and postural changes need the help of a caregiver.
Objective: stimulating and fostering interaction with the surrounding environment and behavioral activation (amount of motion in the time unit, amplitude and frequency of motion, and movement awareness).
Activity and settings: the child is sitting on a wheelchair with wheelchair table. One operator assists him. The platform enables the child to control an acoustic feedback by analyzing in real-time his head's movement. The volume of the sound is low when flexing the head and it gradually increases with head extension.
Feedback: therapists noticed that the boy could keep head- trunk alignment and fixation for a few seconds. Sometimes the system could not correctly capture the movement of the child due to typical computer vision issues. The use of markers (e.g., colored markers) may help movement tracking and analysis.

Case Study 6 (14 years old)
Diagnosis: dystonic bilateral cerebral palsy with epilepsy, anarthria, involuntary movements and attention deficit.
Functional conditions: the child can interact with the surrounding environment, he smiles, and he can understand spoken language. The child displays tongue protrusion with dystonia, and perseveration. He is able to use a walker with help of a caregiver and to stand up without help.
Objective: improving upper limbs motor control (dystonia with involuntary movements) and supporting cognitive rehabilitation (training for general and visual attention).
Activity and settings: the task requires the movement of the upper limbs to improve their functions and/or to implement a cognitive task. The child is asked to reach a moving target before it disappears from the screen. A sound is associated with the position of the target and is deteriorated (volume decreases and some distortion is introduced) if the target is not reached.
Feedback: the child had difficulties to reach precisely the target because of poor coordination and of his difficulty to modulate motor control. Therapists noticed an increasing difficulty in motor control due to emotional activation. They suggested to let the acoustic feedback occur also when the boy stand still. Moreover, a better tuned adaptation of the system may help in controlling emotional activation.

5 CONCLUSION

We presented the participatory design process that led us to develop an initial prototype of modular open platform for interactive exergames, grounded on nonverbal multimodal interaction, and on interactive sonification. The platform was used in a series of real-world case studies producing refined requirements and guidelines to the design process. Results are promising and the developed platform showed good adaptability to the needs of rehabilitation in children with severe disability. The platform design has to be improved with respect to sensitiveness, real time response, ability to detect the child's silhouette even in complex conditions (e.g., in case of occlusions, tight contact with other persons, the child holding objects or keeping unusual postures, and so on), amount and quality of available content. The space where the platform operates also need careful design. These results will be the input for the next iteration of the participatory design process, which will start from the valuable feedback of operators and children.

REFERENCES

[1] 2016. The Unity game engine. Retrieved January 20, 2016 from https://unity3d.com/

[2] Yu-Ping Chen, Lin-Ju Kang, Tien-Yow Chuang, Ji-Liang Doong, Shwn-Jan Lee, Mei-Wun Tsai, Suh-Fang Jeng, and Wen-Hsu Sung. 2007. Use of Virtual Reality to Improve Upper-Extremity Control in Children With Cerebral Palsy: A Single-Subject Design. *Physical Therapy* 87, 11 (2007), 1441–1457. https://doi.org/10.2522/ptj.20060062

[3] Judith E Deutsch, Megan Borbely, Jenny Filler, Karen Huhn, and Phyllis Guarrera-Bowlby. 2008. Use of a Low-Cost, Commercially Available Gaming Console (Wii) for Rehabilitation of an Adolescent With Cerebral Palsy. *Physical Therapy* 88, 10 (2008), 1196–1207. https://doi.org/10.2522/ptj.20080062

[4] Ann-Christin Eliasson, Birgit Rosblad, and Charlotte Hager-Ross. 2003. Control of Reaching Movements in 6-year-old Prematurely Born Children with Motor Problems - An Intervention Study. *Advances in Physiotherapy* 5, 1 (2003), 33–48. https://doi.org/10.1080/14038190310005780 arXiv:https://doi.org/10.1080/14038190310005780

[5] Darcy Fehlings, Lauren Switzer, Briar Findlay, and Shannon Knights. 2013. Interactive Computer Play as “Motor Therapy” for Individuals With Cerebral Palsy. *Seminars in Pediatric Neurology* 20, 2 (jun 2013), 127–138. https://doi.org/10.1016/j.spen.2013.06.003

[6] Simone Ghisio, Paolo Coletta, Stefano Piana, Paolo Alborno, Gualtiero Volpe, Antonio Camurri, Ludovica Primavera, Carla Ferrari, Carla Maria Guenza, Paolo Moretti, Valeria Bergamaschi, and Andrea Ravaschio. 2015. An open platform for full body interactive sonification exergames. In *2015 7th International Conference on Intelligent Technologies for Interactive Entertainment (INTETAIN)*. 168–175.

[7] Meghan Huber, Bryan Rabin, Ciprian Docan, Grigore C Burdea, Moustafa Abdel-Baky, and Meredith R Golomb. 2010. Feasibility of Modified Remotely Monitored In-Home Gaming Technology for Improving Hand Function in Adolescents With Cerebral Palsy. *IEEE Transactions on Information Technology in Biomedicine* 14, 2 (March 2010), 526–534. https://doi.org/10.1109/TITB.2009.2038995

[8] Stefano Piana, Maurizio Mancini, Antonio Camurri, Giovanna Varni, and Gualtiero Volpe. 2013. Automated analysis of non-verbal expressive gesture. In *Human Aspects in Ambient Intelligence*. Springer, 41–54.

[9] Pawel Pyk, David Wille, Edith Chevrier, Yves Hauser, Lisa Holper, Ismael Fatton, Roger Greipl, Sonja Schlegel, Luzia Ottiger, Bärbel Rückriem, et al. 2008. A paediatric interactive therapy system for arm and hand rehabilitation. *Virtual Rehabilitation* (2008), 127–132.

[10] Qinyin Qiu, Diego A Ramirez, Soha Saleh, Gerard G Fluet, Heta D Parikh, Donna Kelly, and Sergei V Adamovich. 2009. The New Jersey Institute of Technology Robot-Assisted Virtual Rehabilitation (NJIT-RAVR) system for children with cerebral palsy: a feasibility study. *Journal of neuroengineering and rehabilitation* 6, 1 (2009), 40.

[11] Denise Reid and Kent Campbell. 2006. Randomized Trial. *Therapeutic Recreation Journal* 40, 4 (2006), 255–268.

[12] Yasser Salem and Ahmed Elokda. 2014. Use of virtual reality gaming systems for children who are critically ill. *Journal of pediatric rehabilitation medicine* 7, 3 (2014), 273–276.

[13] Marlene Sandlund, Suzanne McDonough, and CHARLOTTE Häger-Ross. 2009. Interactive computer play in rehabilitation of children with sensorimotor disorders: a systematic review. *Developmental Medicine & Child Neurology* 51, 3 (2009), 173–179.

[14] Aneesha Singh, Stefano Piana, Davide Pollarolo, Gualtiero Volpe, Giovanna Varni, Ana Tajadura-Jiménez, Amanda CdeC Williams, Antonio Camurri, and Nadia Bianchi-Berthouze. 2016. Go-with-the-flow: tracking, analysis and sonification of movement and breathing to build confidence in activity despite chronic pain. *Human–Computer Interaction* 31, 3-4 (2016), 335–383.

[15] Matthew JD Taylor, Darren McCormick, Teshk Shawis, Rebecca Impson, and Murray Griffin. 2011. Activity-promoting gaming systems in exercise and rehabilitation. *Journal of rehabilitation research and development* 48, 10 (2011), 1171–1186.

[16] Giovanna Varni, Antonio Camurri, Paolo Coletta, and Gualtiero Volpe. 2009. Toward a real-time automated measure of empathy and dominance. In *Computational Science and Engineering, 2009. CSE’09. International Conference on*, Vol. 4. IEEE, 843–848.

[17] Giovanna Varni, Gaël Dubus, Sami Oksanen, Gualtiero Volpe, Marco Fabiani, Roberto Bresin, Jari Kleimola, Vesa Välimäki, and Antonio Camurri. 2012. Interactive sonification of synchronisation of motoric behaviour in social active listening to music with mobile devices. *Journal on Multimodal User Interfaces* 5, 3-4 (2012), 157–173.

[18] David Wille, Kynan Eng, Lisa Holper, Edith Chevrier, Yves Hauser, Daniel Kiper, Pawel Pyk, Sonja Schlegel, and Andreas Meyer-Heim. 2009. Virtual reality-based paediatric interactive therapy system (PITS) for improvement of arm and hand function in children with motor impairmentâĂŤa pilot study. *Developmental neurorehabilitation* 12, 1 (2009), 44–52.