Active listening and expressive communication for children with hearing loss using getatable environments for creativity

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Abstract

This paper describes a system for accommodating active listening for children with hearing aids or cochlear implants, with a special focus on children at an early stage of cognitive development and with additional physical disabilities. A system called the Soundscraper is proposed and consists of a software part in Pure data and a hardware part using an Arduino microcontroller with a combination of sensors. For both the software and hardware development it was important to always ensure that the system was flexible enough to cater for the very different conditions that are characteristic of the intended user group.

The Soundscraper has been tested with 25 children with good results. An increased attention span was reported, as well as surprising and positive reactions from children where the caregivers were unsure whether they could hear at all. The sound generating models, the sensors and the parameter mapping were simple, but they provided a controllable and sufficiently complex sound environment even with limited interaction. A possible future application is the adoption of long-time analysis of sound preferences as opposed to traditional audiological investigations.

1 Introduction

In this paper, we address a dire problem that applies to a small population of children with known hearing loss and several additional disabilities. Because of technical advances, hearing aids such as cochlear implants are provided and through objective audiology individually fitted, but the pedagogical support for hearing development is limited. Children with combined disabilities in sensor, motor and cognitive domains often face defeating challenges in participating in everyday-life activities that most people take for granted. While society provides necessary support, attention and care, there is probably more that can be done to improve the children’s quality of life. In this work we focus on the capacity to hear and listen. We argue that there are unexplored
possibilities in enabling expressive, and thus meaningful, communication, which in turn will have significant benefits for participation.

Our idea is to employ technology developed within the framework of modern electronic music as a means for therapeutic intervention. Using music technology in health care is considered to be a promising direction within the Sound and Music Computing community (Bernardini and de Poli, 2007).

The work presented here is technologically informed with an open-minded approach to user interaction. It derives from development of a sound toy that gives great liberty in producing and exploring sounds, designed for children with a cochlear implant combined with physical and cognitive disabilities. Furthermore, the resulting sounds are unconventional compared to traditional use of music in therapy. Discussions with involved clinicians reveal that much can be learnt about the children’s hearing abilities and preferences by providing means for gestural control of sound, and by analyzing this interaction.

1.1 The Soundscraper project

We propose an interactive sound toy system—called “Ljudskrapan” in Swedish and “The Soundscraper” in English—with two initial aims: First, to reduce limitations of activity due to functional disability, thus engaging in guided control movements, and second to encourage the child to train their listening skills, both from a sound perception and a sound interpretation perspective (Hansen et al., 2011a).

The system consists of a software synthesizer part for generating sound, and a hardware part for interaction where sensors connected to a microcontroller board track the child’s gestures. The sensors can be concealed in toys, or attached to the body or clothes, or placed within reach for the child. Gestures control sound parameters such as amplitude, tone quality, delay, looping and audio effects through movements, all in a playful manner.

An illustrative case of the Soundscraper in use involved a boy with very poor hearing above the lower frequency region, who had fun when “driving a motorcycle” (see Figure 1). Using a sound recording of a big motorbike, an inertia sensor placed in a plastic toy controlled the parameters of a vocoder effect: a forward motion changed the pitch from low to high frequency and tilting changed the playback position in the sound file. Additionally, delay effects were controlled by the measured amount of movement. These three simple gesture-to-sound mappings created a noisy and unrealistically rich motor sound, and it kept him attentive for longer than half an hour.

In the envisaged scenario, the Soundscraper is used in a school or a clinic, supervised by a caregiver and with the software operated by a trained technician. The underlying framework has been inspired by work on alternative and augmentative communication, where a variety of sensory stimuli is commonly employed to support or in some instances replace verbal communication, providing support for comprehension as well as reinforcing expressive functions (Calculator, 2009; Light and McNaughton, 2012).

In the text, caregiver and technician represent two different roles that can be performed by e.g. special needs teachers, speech therapists, audiologists, or parents.
1.2 Getatable environments

Ultimately, our ambition is to create a responsive sound toy that offers rewarding means for play and operates within the hearing ranges of the user, providing a get-at-able environment for expressive nonverbal communication: flexible, adaptable, accessible and attractive. We believe that the presented method may offer many possibilities to support the development of listening capabilities for these children. The main advantages are that these children can influence what they hear, and thereby also actively make choices that positively affect their listening experiences.

We address both parties in the mutual communication process: One goal is to empower children through the use of creative sound manipulation and easily adaptable gesture control devices so they can influence what they hear. The second goal is to provide caregivers with tools to investigate the hearing capabilities of the child, and thereby improve the possibilities to interpret the feedback from the child with greater certainty. In a wider sense, we try to expand the children’s real-world orientation by audition, with sound as a means for communication. This promotes participation in their environment and can be an important step towards a higher degree of independence.

In the initial studies presented here, the analysis is based on reactions and insights from experts present at a number of test sessions with 25 children. However, the situation for many of the children we target is such that measuring the success of our intervention is not possible in a short term perspective. The Soundscraper makes long-time recording and collection of objective data possible, including information on sound preference and spectral characteristic, time spent playing with different sounds, and more. This method could potentially be an alternative method for audiological examination, and also for planning intervention and training.

2 Background

The children associated with this study are defined by a multitude of prerequisites that form specific individual learning profiles, where each obstacle threatens that com-
munication can take place. Underlying causes may be early acquired brain damage, congenital syndromes, intrauterine or postnatal infections, while in some cases there are no explanation for the condition (Picard, 2004).

2.1 Hearing and hearing aids

Young children with impaired hearing are ideally provided with hearing aids at an early age. The most common form of impairment, sensorineural hearing loss, is caused by lack of sensory cells in the inner ear. If there is sufficient function preserved, an acoustic (traditional) hearing aid (HA) can be fitted so the remaining sensory cells are stimulated. With profound hearing loss a cochlear implant (CI) can be the only possible alternative.

A CI consists of an electrode array that is surgically inserted into the inner ear, the cochlea (Loizou, 1998). The electrode array is fed with an electrical stimulus pattern generated by an externally worn sound processor. The device is programmed to convert the acoustic signals, and continuously forward these by the electrode array to the hearing nerve, and then further on into the central auditory system where the synthetically produced signal pattern is processed.

The sound processor may have several programs to accommodate specific listening conditions, but the strategy towards children is to optimize for acoustic information important for speech intelligibility. Furthermore, CI technology is still considered too premature for realistic perception of music (Veekmans et al., 2009; Di Nardo et al., 2011). Tonal information is less well conveyed as compared to rhythmical patterns, and the perception of intensity variations may be affected by the compression of intensity range. This may be a shortcoming for children functioning at a prelinguistic level, as non-verbal information (on for instance voice quality, speaker identity and emotional tone) may be less salient.

2.2 Hearing development

Hearing is a gradually emerging skill underlying the development of spoken language, and is a time-consuming process in all children, but especially so in our target group (Edwards, 2007). By the age of 9–12 months, the majority of children understands several spoken words and expressions. A child with impaired hearing awaiting CI surgery experiences a delay of many months compared to typical auditory development. In many cases, implantees develop hearing and spoken language with little or only minor difficulty. Unfortunately, this does not always happen: in a study of 398 prelingually deaf children, Daneshi and Hassanzadeh (2007) found that 15% were diagnosed with additional disabilities. Children with such impairments are especially vulnerable both in terms of risk of under-development of language skills and of the consequences.

The intervention required following the implantation may be different from that of typically developing children (Wiley et al., 2005). It has been suggested that the benefits of CI use in such situations should be seen in a broader perspective than speech outcome (Nikolopoulos et al., 2008).

Audition constantly provides us with important information, for instance on activities surrounding us but are hidden from sight. A child who lacks this ability may
often encounter unpleasant surprises—an example is when someone approaches from out-of-sight and accidentally makes physical contact. Enabling the children to perceive auditory signals will thus reduce stress also increase their capacity to connect to the surroundings. Studies also show that children unable to communicate with their environment in a meaningful way may have a disrupted emotional and cognitive development and experience their surroundings as being chaotic (Wass, 2009).

2.3 Assessing hearing capability

Objective audiological diagnostic methods are applied for evaluating hearing as well as for adjusting the HA/CI, but the procedures are problematic in assessing the performance for young children. For instance, it is possible to get the ear’s response to sound through acoustical and electrophysiological measurements close to the inner ear (Müller-Wehlau, 2010), but this does not disclose how the sound is perceived qualitatively by the individual. Subjective methods target both qualitative and quantitative aspects of hearing. Primarily these are speech recognition and pitch perception (Preto- rius and Hanekom, 2008; Di Nardo et al., 2007), but also melody perception (Carlyon et al., 2007) and music enjoyment (McDermott, 2004).

The ability to hear is established through auditory stimulation thereby enabling physiological maturation as well as higher level learning. A prerequisite for this is however a constant acoustic stimulation. In the case of a child with multiple disabilities may the lack of reactions discourage the caregivers, who may in turn give up the endeavor to ensure that the HA/CI is used continuously. This results in suboptimal stimulation and in further suppressing of auditory processes.

2.4 Active listening

CI was initially designed for persons who had become deaf after acquiring spoken language, but the technology has been successfully introduced to deaf-born children as well. Generally, the surgical procedure is performed as early as medically possible following the diagnosis. The challenges are, however, quite different in the pediatric population as hearing development depends on physiological maturation as well as exposure to stimulation (Vlastarakos et al., 2010).

Studies by Kraus et al. (2009) have shown that active listening has a positive and lasting effect on perception following surgery. Wiley et al. (2004) concluded that caregivers reported a variety of benefits for children using CI, such as more awareness to environmental sounds, higher degree of attention and clearer communication of needs.

Typically, improvement in music perception is also subject to training. Gfeller et al. (2002) showed significant effects of long-term training for instrument timbre, and Donnelly and Limb (2008) even for several other aspects, such as pitch and rhythm. Looi and She (2010) argued that a structured training program with a focus on improving the ability to recognize tunes also will improve music appreciation.
2.5 Creativity and expressivity

Creativity is a concept with many definitions (Runco and Jaeger, 2012). Adult creativity is often described as being a part of intelligence and refers to an ability to generate genuinely new ideas. Children's creativity may be interpreted differently (Mindham, 2005). In learning new skills the young child employs acquired knowledge in unexpected, non-standard manners. Creativity plays an important role in the contact with adults and the child's effort is an important driving force in the development (Kudryavtsev, 2011). It can be assumed that reduced expressive behavior may hamper this process significantly.

2.6 Sound interaction in medical and therapeutic contexts

Magee and Burland (2008) give a review of different technologies for music-based therapy and their use in the UK. Sensory impairments are briefly mentioned, and the authors especially advise to be careful with non-haptic interfaces where the cause–effect relationship can be hard to establish. Tam et al. (2007) describe a camera-based gesture tracking system for playful interaction with music adhering to the International Classification of Functioning, Disability and Health model (WHO, 2005). Little research has been found on new interfaces which aim at assessing hearing and stimulating active listening (Dravins et al., 2010), or on studies focusing on the acoustic quality of sounds used in therapy situations (Rapoport et al., 2008).

3 Method

The target user group of Soundscrapper have individual functional profiles with few common characteristics. It is therefore necessary that the system has a high degree of flexibility in software behavior and hardware configuration. Furthermore, a promising set-up for one child in a session might be inadequate in the next. Design decisions were mainly based on solid prior background knowledge about the children, gathered from caregivers and clinical experience.

3.1 Requirements

As the system is exposed to states ranging from unresponsiveness to hyperactivity, adaptations to the situation must be done within seconds to ensure a working system and safety. Field testing has shown that the hardware will often be vigorously handled and put under a lot of strain. Safety must be ensured with regards to for instance sharp edges, loose parts, and wires. For the tests reported here, wireless technology was not used, and extra care was therefore taken with respect to cabling.

Sudden changes in amplitude or sound characteristics must happen without risking discomfort. The amplitude should not exceed the levels planned on beforehand with the caregivers. Attention should also be given when creating exercises where the interaction controls gradual or sudden amplitude changes, so they happen in a foreseeable way.
3.2 Prototyping and design

The programming was done in Pure data\textsuperscript{2}, and the hardware has for the most part consisted of sensors connected to an Arduino\textsuperscript{3} digital–analog board. Sensors were bundled in detachable units such as small casings fitted with velcro, which made them easy to place on clothing or objects (see Figure 2).

This low-cost solution promotes both easy distribution to schools and individuals, easy extensions of the system, and accommodates foreseen needs for set-up adjustments. Other costs, however, which are seldom reported in studies like the one presented here, relate to the continued development and most likely to future training of technicians. Magee (2006) found in a survey towards use of technology in music therapy that the three by far most common statements of negative attitude were lack of equipment (80%), lack of skill for using it (65%), and expenses (40%).

New modules for sound generation, as described below, can easily be added and is expected to be a continuous process. In future revisions, we expect that the main modifications will concern continued improvements of the software interface, and of the calibration routines for the sensor hardware. New and replacement sensors are also expected to be added when needed.

3.3 Audio and sound generation

The name *sound scraper* alludes to both noise and friction. The sound and interaction was initially inspired by the way scratching disc jockeys drag and push the vinyl on the turntable and isolate small fragments of a recorded sound (Hansen et al., 2011b). Scratch music typically has a lot of broadband energy that swiftly sweeps the audible frequency range.

\textsuperscript{2}http://puredata.info
\textsuperscript{3}http://www.arduino.cc
Since CI users have known limitations in sound perception, we decided not to use music in a traditional sense (i.e. tones with well defined pitch height) but sounds with a rich spectrum regardless of their “musical quality”; examples are given in the next section. This could seem effective for listening with CI even when programmed for speech signals. Another rationale for using a more unconventional approach to musical sounds, is that research results mainly come from experiments with CI users that have well-established communicative abilities, and can thus not be trusted to be true for our target group (Vongpaisal et al., 2004).

In the tests reported here, all audio was transmitted via loudspeakers at a comfortable level, judged for each individual session by the caregivers and technician. This was done in accordance with the aim of training everyday listening in the normal surroundings.

4 The Soundscraper: A system for active listening

The Soundscraper is described below as composed by two parts: the software sound generation and the hardware control input. The system presented here corresponds to the last version as used during the tests. Since the testing took place over a long period, the system did develop during this time, although very few changes concerned the child’s interaction. Routines for calibrating sensors, managing the graphical user interface and saving set-ups were however made simpler.

4.1 Software sound modules

For sound generation, the system uses modules that can be divided into three main categories: synthesized sounds, audio files, and sounds captured live with a microphone. Recorded sounds are placed in a structured library which can also be extended and tailored for each child.

4.1.1 Looping recorded sounds

In the so-called Looper module a segment of a recorded sound is selected and played back with continuous repetition, inspired by a DJ-application called Skipproof (Hansen and Bresin, 2010). Loop segments can be varied from the whole sound file down to a few milliseconds, but the typical loop lengths are at least 200-300 ms. Other parameters are starting point and length. The loop playback works best with music recordings and spoken phrases, and is particularly interesting for isolating a part of the sound.

The Vocoder module enables to ‘freeze’ a prerecorded sound and move around in it. Available parameters are playback speed, pitch change, and playback position. This module works well with any recording and is interesting for exploring the start and ending points of sounds and characteristics of speech (such as one’s name spoken out) in a playful way.
4.1.2 Expressive and Immediate Sound Generation

An implementation of a Theremin plays sweeping tones across a broad frequency range to assess pitch perception. The module generates both sine wave tones and tones with richer overtones. To introduce variations in tones when they are kept at a stable pitch level, frequency-modulated vibrato was added. The main parameters are pitch, harmonics, and frequency modulation speed and range. A variation of the Theremin uses discrete tones, assignable to scales, instead of continuous pitch.

**Pulse trains** of bandpass-filtered white noise bursts offer possibilities to manipulate parameters in a rhythmic sequence of tones. The module was added to explore the temporal resolution which reportedly can be problematic with CI. Adjustable parameters include tone attack steepness, tempo, tone duration, filter bandwidth, filter central frequency, and rhythmical patterns.

4.1.3 Playing Tunes

A basic Music player plays compressed audio files. A common compressed format was chosen to use existing music collections and to save storage space. Only two parameters can be changed: track selection and track position. The music player represents a mode with less interaction as a supplement to the more participation intensive modules.

An application for changing the expressive rendition of MIDI files, Director Musices, was included in its real-time adaption for Pd, called pDM (Friberg, 2005). In this module, the control parameters are tempo, instrument, key, and other score-based parameters, and low-level parameters for changing the performance such as articulation, velocity and tempo changes, but the most interesting parameters are the high-level control of all the performance rules. These are often mapped out two-dimensionally as in the activity–valence space, or with expressive dichotomies such as hard–soft and happy–sad.

4.1.4 Global Parameters

In addition to the parameters mentioned above, it is possible in all modules to control the amplitude, to add echo for making sounds more complex, and to add filtering for modifying the frequency range. To some extent, loudness perception effects are compensated for in the frequency modulations (filters and pitch shifts).

4.2 Hardware and Sensors

All interaction with the software from the child comes through capturing body movement and gestures with sensors.4 Such sensor data include inertia measurements, proximity, bending and pressure. Naturally, even analyzing audio or video input would work well (for recognizing speech, facial expressions and body movements, see e.g. Castellano et al., 2008), but this has not been tested in respect of personal integrity.

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4In addition to these we have made tests with game controllers, a full motion capture system, smartphone sensors, the Kinect camera and other devices, but not for the sessions reported here.
Figure 3: Three sensor-equipped “toys” produced for the test sessions. All were made to be gripped or handled easily.

and also since the included sensors already present a sufficiently rich environment for interaction.

In the latest tested versions, the hardware consisted of up to four sensor “bundles” that could be placed on or near the child. Each bundle was connected to the Arduino board with a 2–3m flat-cable or twinned wire to provide the child with room for movement in a surrounding, defined space (many would have wheelchairs). The bundles were enclosed in protective material and could easily be fastened with tape, rubber bands or velcro. In no circumstance were safety compromised, and caregivers inspected all material before the session.

The sensor bundles were integrated in toys or familiar objects provided by the caregivers or found in the session rooms. Among the toys used, we had a rubber duck, sand-box items made of plastic, dolls, balls, toy vehicles, and many more. Some we produced ourselves, such as a small rubber mat, a ring wrapped in fabric, and a foam-rubber handle, all equipped with buttons and additional sensors (see Figure 3). Alternatively, the sensor bundles were placed on or around the body. To place sensors on body parts, we used armbands, headbands and similar. For placement on toys or objects, the combination of expected movement, sensor type and fastening possibility had to be explored.

Choosing sensors is a continuous process, but bundles typically have a mix of inertia sensors with up to six degrees-of-freedom (accelerometer, gyroscope), analog sensors (pressure, light intensity, bending), and one or more momentary buttons. Substantial effort was also put into design of the toys containing the sensors, to make them interesting and inviting to play.

4.2.1 Sensor data

As a consequence of having to settle with tracking movements that are very limited, we aim at always defining and using a full-range signal where the range of values from the sensor readings in normal activity is scaled into a [0..1] interval. Typically, it can be necessary to recalibrate or rescale the sensor output even during use. To avoid sudden spikes in the input sensor data, which may cause unwanted or even harmful sound output, a limiter clips the data stream outside the [0..1] interval.

While most sensors, like inertia sensors, are used conventionally, several parame-
ters are extracted that correspond to energy or movement activity. Momentary buttons, for instance, were used with some sophistication and not as simple triggers: First, one parameter value represents the push duration. Energy rises while the button remains pressed, with a programmed tendency to return to the resting state (zero energy) when either the button is released or after a short time of reaching maximum level, depending on the situation. Second, one parameter value is calculated from the push frequency, either from an individual button or from the accumulated pushes on more buttons. Also here the tendency to return to a resting state was implemented. Third, one parameter value represents the number of simultaneously pushed buttons when there are more than one. Used together, these button parameters constitute a surprisingly (to the fellow experts who have tried it) rich and responsive control interface.

4.2.2 Parameter mapping

One aspect of adjusting the system to a given situation is to change the mapping between input and output parameters (on mapping see for instance Miranda and Wanderley, 2006). As an example, imagine that a repeated horizontal movement of an accelerometer-equipped toy is set to control amplitude, whereas the child only moves it vertically. In this case, a simple re-mapping would solve the problem. Each input and output parameter are made available for mapping, and new parameters can be easily added.

The actual mapping will be a balance between creating realistic couplings between gesture and sound, and creating a rewarding sound result. Depending on the individual, the purpose of the session can lean more heavily on either realism or expressivity. We can also have a conflict where an action generates good sensor readings, but there is an incentive to suppress that activity, for instance for involuntary movements. Likewise, a limited output from a sensor may have to be tolerated, as a more pressing concern is to encourage a certain action.

5 Field testing

We have so far let a small population of children test the system as an activity in their everyday environment. All children in our study have a hearing loss and intellectual disabilities, and a personal combination of other characteristics such as visual impairment, autism, cerebral palsy, over- or under-sensitivity to touch, and several of the participants have medical conditions such as susceptibility to infections, heart malformation and epilepsy.\(^5\)

The experiment sessions took place in three locations in Sweden and one in Latvia over a two year period. The set-up remained constant throughout the tests, except for the development of the technician’s user interface and the assembly of sensors, as explained above. In total, 25 children have participated, but with such varying profiles that comparisons across type of impairment were not feasible. The age range was 4–19 years with almost even gender distribution.

\(^5\)Parts of the data from the tests, especially information on medical background—or conclusions drawn therefrom—are not available for dissemination due to the sensitive nature.
Before each test session, background information on the children was collected including general level of functioning, motor skills, personal interest and special fears (if any), and auditory functions. A plan was made for each child that outlined the selection of auditory stimulation and adaption of sensor equipment. During the sessions, we minimized the involvement from the caregivers to adjusting sensors or comforting if needed. The child was presented with the toy/sensor and the sound it produced and left free to play with it.

Often the anticipated interaction was in at least some respects compromised by unforeseen behavior. Explanations could be several, including it being an unfamiliar activity for the child, sensed expectations from the people in the room, unusual exposure to sound, excitement or anxiety, insecurity towards new persons, or even factors unrevealed to the experimenters.

5.1 Data collection

We have collected and analyzed both qualitative and quantitative data. Qualitative data include session logs, background information and informal interviews with caregivers. The quantitative data come directly or indirectly from the sensors. Sensor data recordings can also potentially be used to recreate the sounds from the session. Also the acoustic signal or the parameters set for the generation of the sounds are available for analysis, but this approach is not reported here.

While the analysis of short-term interventions will rely heavily on qualitative data and interpretations, objectively measured responses are relevant for evaluating long-term effects. One quantitative measure to consider is the time spent on a specific task. For example, we can find if there seem to be a preference of a frequency region over others, a preference for a sound, for a motor activity, for a sound level, and so forth. It is necessary to reflect on the mapping so that data from a sensor do not coincide with a comfortable resting position. In the experiments the children generally show a considerably higher amount of attention to the task than they normally would do, and more data is needed before making conclusions from a time-measure method.

A second quantitative measure requires a more developed motor control and intellectual capacity from the child: By restricting the range where a sensor produces the aspired result (for instance, making an appreciated sound louder) we can evaluate the determination to achieve the wanted effect. This can be measured both from assessing the difficulty of controlling the sensor over a restricted range as well as the time spent.

5.2 Evaluation

In the tests, the children were seen together with a caregiver and the sessions were videotaped. The testing included reactions to and handling of sensors, answer to sound and sound manipulation, attention span, and mood following the session. Caregivers were asked to evaluate the child’s reactions after the sessions, and also during when possible.
5.2.1 Reactions to and handling of sensors

The children reacted differently to the sensors, both those attached to the body and to the objects holding sensors. Generally, the impression was that they could be described as having a toy-like function. All children were able to either handle or move the sensor sufficiently for the purpose, generating sounds that could be heard in the session room. One child rejected all types of sensors due to hypersensitivity in all extremities.

Sensors attached to arms or hands were generally less well tolerated than sensors manipulated purposely by the child (i.e. attached to an object or placed within reach). This was also true for children with very limited range of movement. Sensors attached to the head were well tolerated and used for especially demanding situations. When the movements were voluntary, such as for one child who could control turning and tilting of the head, the child immediately used the link between movement and sound. However, when the movements were mainly involuntary, it became a challenge to make relevant parameter mappings. Two children with autism and autism-like symptoms devoted all attention to the cords attached to the sensors. One child moved arms and hands freely but stopped moving the extremity when a sensor was placed in the hand or attached to the arm.

Generally, compromises between individual preferences and capabilities requires adaption of inviting toys to facilitate the interaction. For a teenager with poor head control, and specific opinions on clothing style, we designed a hat with sewn-in sensors. A blind boy with cerebral palsy and hypersensitive hands needed a small touchpad, highly sensitive to contact. A young girl with autism and visual problems engaged in interaction with a doll equipped with light-emitting diodes and bright clothing.

5.2.2 Answer to sound and sound manipulation

All but five children showed clear reactions, and according to caregivers, appreciation to sound and sound manipulation. This group included the four children mentioned above and a child with profound hearing loss who had HA but not yet received a CI. In the last case, a boy who was not scheduled for the test but visited the room of curiosity, played extendedly with a toy that should be unappealing to him, considering his only mild cognitive disability. Three children were seemingly intrigued by the sound feedback but did not seem to explore the connection between movement and sound.

5.2.3 Attention span

For 20 children, an increased attention span was registered, where focus could be held up to and exceeding 15-20 minutes, compared to typically a few minutes. It should be noted that these observations were based on the children’s first encounters both with us and The Soundscraaper, and long-term effects on attention span have not been investigated.

Five children did not show particular interest in the sessions. Characteristic of this group was that they all quickly made the coupling between their actions and the
They also more quickly became bored and would likely need a more complex mapping between gestures and the sound output, or clear frameworks for the interaction.

5.2.4 Behavioral feedback

Two children showed mild negative reactions during the session. This was the child with hypersensitivity in all extremities and one child who did not make the connection between movement and sound. The negative mood did not persist for any extended period. A few children fell asleep directly following the session, but this was reportedly normal and due to reasons outside the test situation. A majority caregivers were positively surprised by the interest in sound and the persistence showed by the child. One mother, on the contrary, said that she did not believe that her son reacted to sound but rather to the sensor as such. However, this impression was not shared by the audiologist and the other caregivers present.

One unexpected observation was that a girl with spastic tetraplegia and involuntary reflex movements was able to relax when listening to a particular sound—a loud, noisy looped hip-hop beat with multi-tap echo. During this relaxed state she was able to move one hand voluntarily. With other sounds, such as more melodic loops, she returned to her typical non-relaxed state. This suggests that active manipulation and listening to preferred sounds may strongly influence the overall motor pattern, which will be explored further in forthcoming tests.

During a session with a boy having a hearing loss combined with blindness, it was noted that he was eager to explore objects with his hands. This behavior was seldom observed for this boy, who for most of the time was reluctant to use his hands. This suggests that the Soundscraper could even be useful for normal-hearing children with other impairments.

Several of the children in our study displayed behaviors that were, reportedly, new or seldom observed. We regard these actions as creative in some sense, as they were novel and carried out voluntarily, and gave rise to new sets of dyadic interaction. The actions and reaction patterns of children are important driving forces for the communication with caregivers.

6 Conclusions

The Soundscraper was applied as projected in field tests involving 25 children with hearing aids or cochlear implants, in addition to other physical and cognitive impairments. Both the software and hardware parts could be adjusted to the conditions of each individual session. The results are encouraging, and the caregivers have indicated that the concept is promising and could be included in the children’s school activities.

The reactions of the children were surprisingly emotional and gave rise to mood changes that appeared immediate and linked to the subjective experience of sound. It seems that the sound-play as such was enjoyable and rewarding. It is reasonable to

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6There can be many explanations to why this was so, however these children did not have a common differentiation from the rest of the group.
suggest that there are other applications of the Soundscraper than the use for alternative and augmentative communication, such as for mood regulation and personal expressive behavior.

Sensors that require active handling by pushing, pulling or moving an object were more often accepted than sensors that were directly attached to the body of the child. Children with autism-spectrum diagnosis presumably need specially designed sensors to overcome problems not directly related to movement constraints.

The sound modules were simple but provided a complex sound environment through limited interaction. When the sensor readings were poor, alternative mappings successfully compensated for poor in-data. Having a small but versatile arrangement of sensors that could be placed freely was a great advantage for making quick adaptations during sessions.

7 Discussion

Initially, the Soundscraper was driven by the idea to support the development of hearing and listening skills and to later develop the system for alternative and augmentative communication. However, the reaction of many of the children revealed that the possibility to gain control over the sound was rewarding in itself. This observation inspired a shift of focus from practical-only to creative play.

In addition to engaging the children in free play, there is also a potential for more structured use of the system, where professionals plan and design learning or training sessions for the individual child. Then, the interaction can take place both at home and at school, which is necessary for having as much listening experience as possible.

Both HA and CI technologies offer other possibilities for sound transmission. The experimental set-up consisted of consumer grade loudspeakers to resemble the normal situation in the schools and practices. However, we would strongly recommend to always use a high quality sound system, and we plan to investigate the benefits.

7.1 Future work

Data collection will continue with a group of children included in the present study, where the Soundscraper will be included in the daily activities at school. Three different functions will be explored: listening for joy and amusement; active listening and training; and using sound for communication and as a means for raising context awareness. Here, a more analytical experimental design can be realized.

Future analyses of the logged data will hopefully reveal characteristics of sound perception and listening preferences. Such efforts need to be carried out in collaboration with audiologists and other caregivers who know the child well. An important application is the adoption of long-time analysis of sound preferences as opposed to traditional audiological investigations. We cannot expect to be able to get reliable results from methods based on short-term experiments; likely, we need the children to use the system continuously over long periods of time.

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7 One example of this would be the sound of water signaling “bath time”.

15
A further field of investigation concerns if and how the children’s sound-play facilitates spontaneous interaction, and possibly could initiate and reinforce creative actions. Also, variations on the session setup, like group play and more classical dialogue techniques, are promising directions.

Finally, the software and hardware components need to be developed further to provide an effective and stable environment for the involved caregivers. This involves considering if wireless sensors is a better alternative than the current technical design.

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References


19