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Turning movement into music

**– issues and applications of the MotionComposer,
a therapeutic device for persons with different abilities**

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Abstract

The article discusses the ways in which the MotionComposer (MC), a newly developed device that turns movement into music, engages users with different abilities,[1] so as to provide positive psychological and somatic effects. It begins with a case study – the story of one application of the device involving a young man with cerebral palsy. His experiences are typical of many others and provide some useful generalisations. The article then discusses a number of goals and related design principles that have been important in the development of the device, including a discussion of two conflicting strategies which must be reconciled: On the one hand, there is a need for clear causality. On the other hand, for such a device to remain interesting over time, there is a need for variation. A technical description of the hardware and software is given, followed by a discussion of general mapping issues pertaining to the different sound environments or interaction modes of the MC.

Introduction

12-year-old Adam has just arrived with his mother. His assistant is accompanying them and has been helpful in getting Adam and his wheelchair out of the car. He is placed in a section of the room where the floor has been cleared – elsewhere there are chairs, equipment and persons with and without disabilities. He is facing a table with a shoe-box sized device on it a few metres away. 'It's on!' the woman controlling the system says. Adam, who due to his cerebral palsy has difficulty holding still, immediately begins to generate sounds. Hectic piano music is pouring out of the loudspeakers – the arpeggios flow up and down without pause, and although they harmonically make sense, the music seems to be in overdrive. 'Is this him?' the assistant asks, clearly not fully convinced. Adam waves his hands incessantly, while his torso sways back and forth in the wheelchair, which due to the excessive energy of its user threatens to loosen its breaks. 'Try to be still for a moment', the woman suggests, but because of the intense music, she has to repeat her suggestion several times before Adam responds: his torso reclining to the back of his chair, with arms directed forwards above his lap. He is still moving, but a lot less than before. The music is much sparser now. Single notes here and there, forming occasional notes and short melodic motifs.

Adam's right arm suddenly makes an upward jerk, followed by a sway to the side before it falls back into his lap. All the people watching him understand what is happening when they hear the short surging phrase accompanying Adam's movement – the music, like his arm, ascends and then moves sideways. They all see the boy's face break into a big smile. The woman controlling the system says what everybody must be thinking: 'He's got it! He's totally got it!' After a session of about 20 minutes Adam folds his torso down onto his lap and remains still for several seconds. Spontaneously the audience responds to what he seems to be signalling: the dramatic end of the performance. A few moments later we talk to him as he is getting

ready to leave. It is hard to understand a lot of what he is saying because of his condition, but one word comes out perfectly clear: 'More!' [2]

This account describes a session with the MotionComposer (MC), a device that turns movement into music, developed especially for persons with different abilities. It uses video tracking techniques to track the movements of the users and feeds the movement-derived data to sound-generating software so that the users' movements in front of the camera are converted into sound and music in real time. Beginning in 2010 with support from the Bauhaus University, the MC team has been seeking support for the claim that interactive digital movement-to-music technologies can play a role in affording dance and music engagement among highly diverse users, including those with severe physical or mental conditions. At the time of writing it is being developed by an independent group of artists and engineers from different European countries.

With a focus on therapeutic, healthcare and pedagogic contexts, the MC falls among a small but growing number of devices and applications developed over the last few decades, which 1) use novel sensor and music technology, 2) let all kinds of users play music, and 3) do all this as part of a therapeutic or other health-related agenda. Other examples of this kind of technology include MIDIGRID (Kirk et al., 1994), Soundbeam (Swingler, 1998), WaveRider (Paul & Ramsey, 2000), the Movement-to-music (MTM) system (Tam et al., 2007), L'orge sensoriel (Picotin, 2010), MusicGlove (Friedman et al., 2014), ORFI (Stensæth & Ruud, 2014) and the Shakers system (Baalman et al., 2016).[3]

General purpose video-based motion tracking systems like EyeCon (Weiss, 2008) and EyesWeb XMI (Camurri et al., 2007) have also been used with success for therapeutic purposes (Acitores & Wechsler, 2010; Camurri et al., 2003a), and indeed the MC team has used both systems extensively.

Goals and design principles

During this five-year project certain goals and design principles have emerged:

Goals	Design principles
1. Inclusion Providing persons with different abilities the tools they need to participate in creative activities together with their 'normal ability' peers.	a) Allow many different body parts and kinds of movements to be used. b) Allow multiple modes of use. c) Easy to operate, both for the user and the therapist (if present). d) Sound pretty good no matter how it is played. e) Provide intuitive mapping and clear causality.

2. Multimodality of expression We are interested in encouraging dance expression as well as music expression.	a) Mapping torso movements as well as extremities. b) Using music with a strong pulse.
3. Artistically satisfying and/or entertaining	a) Offering varied experiences. b) Offering aesthetic experiences. c) Inviting the user to develop skills.
4. Promoting health and well-being	a) Rewarding movement involving great effort. b) Rewarding outstretched movements. c) Rewarding long-term activity.

In the following section we will consider each of these in more detail:

1. Inclusion

Inclusion is our main goal. We want users with all sorts of abilities to be able to make music, alone or with others, and on an equal or almost equal footing. In other words, the project is aligned with concepts such as 'universal design' and 'design for all', which ultimately rest on philosophical/ethical ideas of equality and democracy (Iwarsson & Ståhl, 2003, p. 61).

New artistic practices and research activities show how digital technology such as motion sensors, gestural and choreographic analysis, and musical synthesis and composition can extend the possibilities inherent in traditional modes of dancing and practising music (cf. e.g. Miranda & Wanderley, 2006; Siegel, 2009; Mandanici & Sapir, 2012). If applied with care, not only does this technology allow a greater range of body parts and gestures to be used in playing music; it can also contribute with 'open affordances' – features that afford a more open form of exploration, where searching, discovering and playing are basic afforded actions (Bergsland, 2015).

To facilitate inclusion, we consider the following design principles to be important:

a) *The MC must allow many different body parts and kinds of movements to be used.* Our philosophy is that all human movement has musical potential. Movements as different as blinking one's eyes, shaking one's head, moving one's hips, waving an arm, finger movements and falling to the floor can render interesting musical results with appropriate tracking and mapping (Bergsland & Wechsler, 2016). This can open possibilities of expression for people with a restricted movement repertoire, for example due to paralysis, hypertonic or hypotonic cerebral palsy or limited motor control.

This design principle is to a large degree a result of the way Quantity of Motion (QoM), a common and easily calculated parameter in video tracking involving image subtraction, can represent the dynamic qualities of all kinds of movements

(Camurri et al., 2003b; Camurri & Moeslund, 2010, p. 247). As the term indicates, the parameter measures the *amount* of movement in the image, rendering small movements into small values and large movements into large values, corresponding roughly to the experience of *energy* or the *size* of the movements. (We will go into more detail on this below). Thus, regardless of the individual user's movement abilities, our system can track them as one central quality.

b) *The MC must allow multiple modes of use.* The MC has three different interaction modes: Room, Chair and Bed. They allow for vastly differing movement abilities to play the same music. The three different modes are explained in more detail below.

c) *The MC must be easy to operate, both for the user and the therapist (if present).* To make the MC easy and intuitive to use, we have limited the number of choices available to the user: three interaction modes (cf. point b above) and six sound environments, each of which offers a particular sonic world and type of interaction (cf. Figure 1 and the section below).

Figure 1. MC, graphical user interface (GUI)

In addition, the user or therapist can adjust the volume and sensitivity – the latter to compensate for the fact that users with different abilities can have vastly different quantities of movement under their conscious control.

d) *The MC should sound pretty good no matter how it is played.* For many traditional instruments, like the trombone or violin, players usually need to practice to acquire relatively basic skills such as playing notes with stable dynamics and proper intonation. New musical instruments based on sensor technology and digital audio, by

contrast, often require what is referred to as a 'low entry fee'; that is, they can be played with no or little practice (Wessel & Wright, 2002).

By basing the sound production of the device on high-quality digital sampling and synthesis, the perceived audio quality is independent of the user's direct physical input. By parsing salient musical parameters so that some are clearly under the user's control and others are not, the device will ensure that the sonic output projects musicality combined with high-quality sounds, thereby making all movements sounding 'pretty good'.

e) *The MC must provide highly intuitive mapping and clear causality.* The user should get a clear sense that his/her movements affect or cause the music – with no explanation required – despite the fact that there is no physical contact between the user and instrument. As mentioned above, most (though not all) of the six environments use QoM as a primary controller in order to make the mapping intuitive and the causality clear. Each also employs a small number of secondary tracking features (cf. Mapping issues below), but the salient point here is that transparency (clear causality) is paramount in our design decisions.

A relevant technical issue in this regard is the reduction of latency, so that the sound follows the movement with no noticeable lag (cf. Technical description below).[4] On a general level, research suggests that temporal contiguity affects the perception of causality between two events (Gruber et al., 1957; Mäki-Patola & Hämäläinen, 2004a) in such a way that an event occurring a short while after a preceding action is less likely to be perceived as caused by it. More specifically, latency in the form of delayed auditory feedback can affect a number of musical tasks negatively, for example the ability to synchronise with an external beat (Aschersleben & Prinz, 1997) or another player (Chafe & Gurevich, 2004), the ability to maintain a steady pulse (Pfordresher & Palmer, 2002; Dahl & Bresin, 2001) or the ability to match a target pitch (Mäki-Patola & Hämäläinen, 2004b). Furthermore, high latency in new electroacoustic instruments can point to the functionality of the instrument itself, being 'late' or not responding 'promptly' (Tarabella & Bertini, 2004), thus taking attention away from the music or the act of 'playing'. All in all, keeping the latency as low as possible seems to be an important component of retaining a sense of causality and supporting temporal organisation of musical actions.

2. Multimodality of expression

We want the MC to be a device that allows users to express themselves through dance as well as music. Using a traditional musical instrument, the player usually has to move one or more of his/her extremities to make sound. The playing gesture itself normally has fewer expressive qualities than the sound it produces.[5] Dancers, on the other hand, move *in response to* the music. They express themselves through movements that are sound accompanying rather than sound producing. In com-

bining these modes of expression, a feedback loop is implied: Movement generates music, and music generates still more movement.

We identify two important design principles for achieving this multimodality of expression:

a) *Mapping torso movements as well as extremities.* This is similar to 1a above, but here we wish to stress how this principle relates to dance and music making. Movements involving the centre of the body, the so-called 'core muscles', are of great importance in dancing and indeed are commonly seen as the source of its puissance.[6] Thus, the MC uses torso movements as well as the more 'instrumental' movements of the extremities. On the one hand, such movements are less accurate, rendering them less effective as controllers. On the other hand, though, their importance to dance is undeniable and their inclusion becomes essential to our aim – allowing and encouraging all kinds of movements to be expressive.

b) *Using music with a strong pulse.* A good groove tends to make people want to dance. Therefore, we have chosen to base three of our six environments on rhythmic music, and two of the remaining three have rhythmic variants that can be chosen by the user. However, producing rhythmical movements to a beat is not the only way to dance or interact meaningfully with sound through movement, and so the remaining environments and variants do not have a pulse.

3. Aesthetically satisfying and/or entertaining

One of the continuing challenges we face is to create experiences that are aesthetically satisfying and/or entertaining for the user, *and which remain so over time.* This may be difficult to measure empirically, but observations of our users' display of positive emotions and indications of 'flow' experiences (cf. case studies below) can still give us valuable information in this regard. This design principle must be delicately balanced with the equally important imperative of having a 'low entry fee' (cf. point 1b above). On these grounds, the following design principles are considered important:

a) *Offering varied experiences.* The three interaction modes (cf. point 1b and the section below) and six environments of the MC, each playing different types of sounds, together allow a variety of interaction metaphors and ensure wide variation for the user. But even without switching environments, identical movements do not necessarily produce identical sounds. The exact repetition of a sound sample enabled by digital audio technology can quickly become tiring and even irritating to the user, and we thus introduce minor variants that are similar enough to maintain causality and different enough to maintain interest.

b) *Offering aesthetic experiences.* In accordance with Luhtala et al. (2012), we regard aesthetic experience in the context of interactive technologies as 'a phenomenon in which an interactive environment, including the arrangement of audio, visual and

physical materials, users and spectators form a whole and meet each other at sub-jective, sensory, emotional and sensual levels' (Luhtala et al., 2012, p. 272). Although it is not always easy to pinpoint what triggers aesthetic experiences in an individual user, we are constantly trying to do so, thus setting goals that are not just therapeu-tic in nature.

c) *Inviting the user to develop skills.* With practice the user should be able to develop skills and be better able to shape his/her movements to achieve a desired effect.

4. Promoting health and well-being

By encouraging people to move expressively, to dance and to make music at the same time, our goal is to promote better health and well-being among users of the MC, independent of their physical and mental abilities. It is well established that dance and music can play a role in human health as motivators for movement, crea-tive expression and social interaction (Stuckey & Nobel, 2010; Four, 2002). Murcia & Kreutz (2012) review a number of studies showing the positive health benefits of dance and music: They reduce the risk of physical illnesses as well as mental disor-ders; they develop and enhance fitness indicators such as aerobic capacity, balance, elasticity and coordination; and they reduce stress levels and positively affect brain health and cognition. The point that increased movement leads to increased health can hardly be overstressed. According to the World Health Organization, physical inactivity is 'the fourth leading risk factor for global mortality causing an estimated 3.2 million deaths globally' (n.d.).

Furthermore, we can point to the benefits of dancing in social relations, creat-ing a sense of group cohesion and togetherness (Murcia & Kreutz, 2012, pp. 128-129). This issue may be particularly important for people with different abilities. For instance, Kontogeorgakopoulos et al. (2013) note how people with different abilities more often face social isolation and reduced physical activity compared to non-disabled.

In addition to the general way the MC encourages movement, we have imple-mented a few design principles providing specific sonic rewards for specific ges-tures that involve heightened effort or extension:

a) rewarding movements involving effort, that is, large and fast movements

b) rewarding expansion through reaching out of the limbs

c) rewarding sustained activity (through accumulated activity-based musical variations or by allowing users to 'pump up' the musical intensity)

Technical description

The current version of the MC is the MC 2.0, which was sold for a short time in 2014 and 2015 by the German company IMM-Gruppe. The MC 3.0 is currently under

development by a consortium including the German Fraunhofer Institute and is anticipated to be ready in 2017.[7]

Hardware

The MC 2.0 contains a small (ATX format) computer and two video sensors: an ASUS time-of-flight (TOF) depth sensor and a CCD Ethernet bus video camera (cf. Figure 2).[8]

Figure 2. MC hardware

The data from the two sensors is combined by custom software. The TOF is used to isolate the human form from the background. Meanwhile, the CCD has a much higher resolution and lower latency than the TOF alone can achieve. The low latency is necessary for the system to calculate the QoM parameter rapidly enough to achieve the clear sense of causality discussed above. Meanwhile, the high resolution is critical in detecting very small movements, such as the movement of an eyelid, finger or mouth (cf. design principle 1a above).

Software

The software in the MC consists of three parts: a) motion tracking, b) music generation and c) a graphical user interface (GUI).

   a) *Motion tracking.* The high-resolution video images from the CCD along with the 3D data from the TOF sensor are interpolated in the tracking software developed by Simone Ghisio and Paolo Coletta[9] in the EyesWeb XMI programming environment. The tracking software employs a number of algorithms to calculate the various movement parameters, which are fed to the music software via the Open Sound Control (OSC) protocol (cf. Figure 3). They include:

- QoM (also called 'activity') – continuous
- First movement following stillness
  (also called 'sensitive', derived from QoM) – boolean
- Activity level, which groups the activity into
  one of four categories (derived from QoM) – discrete[10]
- User position perpendicular to the camera
  direction (also called 'centre X') – continuous
- Height – continuous
- Height level – in which of four height zones
  is the user's highest point located – discrete
- Width – continuous
- Arm height for each of the arms (Chair mode only) – continuous
- Rapid arm movement upwards – boolean
- Rapid movement to the side – boolean

b) *Music generation.* The sound software is programmed in Pure Data, Csound and Supercollider. The sound software generates the sound output, consisting of synthesised sound and processed playback of sampled sounds, and this is directed to the loudspeakers and thus made audible to the user.

c) *GUI.* The GUI is designed for ease-of-use with a minimum of user controllers (cf. Figure 1). This was consistently requested by our test users. At the same time, though, another group of users, including universities and independent artists, requested a more 'open' system, for example providing access to the data streams. Thus, the MC 3.0 will have two versions: a 'light' version for maximum ease-of-use and a 'pro' version with an open platform.
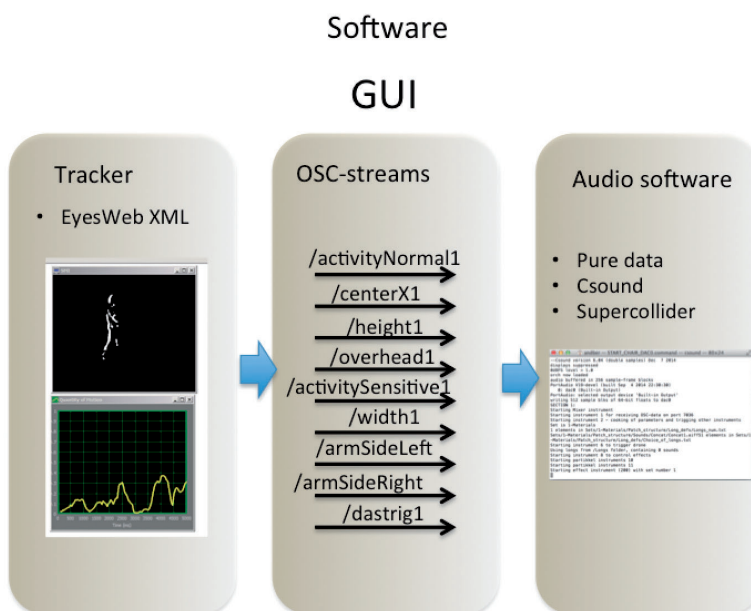

Figure 3.
MC software layout

Mapping issues

Mapping deals with how body movement parameters are linked to sound parameters as part of an interactive design. Over the last decades a number of researchers have explored mapping for different kinds of digital musical instruments (DMIs), both theoretically, experimentally and in relation to specific applications (Rovan et al., 1997; Hunt & Kirk, 2000; Wanderley, 2001; Tanaka, 2010; Murray-Browne et al., 2011). A main issue has been the overall mapping strategy, that is, whether one or several performance/control parameters are mapped to one or several synthesis parameters: 1) one-to-one, 2) one-to-many, 3) many-to-one, or 4) many-to-many (Rovan et al., 1997; Hunt & Wanderley, 2002). Even while parts of the research literature have implied that many-to-one and many-to-many mappings will facilitate more interesting and expressive interaction (e.g. Rovan et al., 1997; Hunt et al., 2003; Dobrian & Koppelman, 2006), we have argued that all of these strategies, including simple one-to-one mappings, can provide expressive possibilities (Bergsland & Wechsler, 2015).

Our strategy emphasises:

1. *Stillness = silence, movement = sound.* This is, in our view, perhaps the most basic mapping of all. Holding still is not a passive experience; it requires concentration and effort.[11] When you are walking in the woods and you hear something, you hold perfectly still. Holding still causes you to listen more carefully. Just as silence is important in music, so stillness is important in dance, and thus the MC rewards stillness as a method of increasing bodily and aural awareness.

2. *Amount/size of movement corresponds to amount/size of sound.* For acoustic sound production there will, in most cases, be a correspondence between the effort/energy applied and the experienced loudness (Gaver, 1993; Halmrast et al., 2010). Following this logic, the sound level in our environments generally increases with larger movements (QoM).[12]

3. *Small, discrete movements make small discrete sounds.* In several of our environments the user can play what we call 'sensitives', discrete sounds triggered by discrete movements like moving a finger or blinking one's eyes. We have very different expectations in the sound world, depending on whether we use finger movements to control sound or the entire body. They are based on metaphors such as 'the musician', who very carefully controls small movements, and 'the dancer', who uses his/her body to physicalise an artistic intent. Both are valid, and in combining them we seek a rich and varied experience for the user.

The three modes of interaction: Room, Chair and Bed

Throughout the development process of the MC we have faced fundamentally con-flicting design criteria. We have prioritised simplicity of operation, but at the same time, in order to ensure the inclusion of truly *all* users, different modes of interaction had to be available. For example, the differences in abilities between persons with blindness and persons suffering from quadriplegia or dementia are considerable. At the time of writing, we have found that a one-size-fits-all solution, a machine that 'intelligently' adapts to users' abilities, seems out of reach. Instead, we have adopted three modes of use, which we have labelled Room, Chair and Bed. Each mode implies a distinct mapping paradigm adapted to users who 1) can move around the room, 2) can raise their arms above their head or 3) can do neither of these.

The Room mode uses the position of the user perpendicular to the camera (centre X)[13] as the central parameter for *choosing* the sounds, and the user's activity and various gestures to *play* the sounds.

With special consideration for users with restricted mobility we have developed a mode of interaction where the instrument can be played from a stationary posi-tion – that is, a Chair mode. In this mode the musical parameters that were mapped to centre X in Room mode are instead mapped to arm height. Each of the arms then controls the music on the respective channel.

After doing a workshop at a children's hospital it became clear to us that many people can neither move around the room nor raise their arms. Thus, we developed the Bed mode in which QoM is tracked in two areas of the body and is the sole movement parameter. Admittedly, this mode leaves quite a lot of the musical deci-sions to the system (that is, the composer), but we have put a great deal of effort into maintaining variation and interest even for this interaction mode. And indeed, QoM, unlike shape- or position-based parameters, still retains the powerful compo-nent of timing.

The musical environments

Each of the six environments offers different mappings and different styles of music. In addition, several of the environments have variants with several sound banks or other settings. They include elements from classical, jazz, techno, Latin, soundscape and electroacoustic music. The variations in style and mapping reflect aesthetic choices of the composers who have developed them.[14]

Tonality

The metaphor used in this environment is that of playing an instrument and, for most users, one that they are familiar with. The choice of instrument – in the cur-

rent version there is a choice between piano, vibraphone and harpsichord[15] – can be set by the user or the therapist in the GUI. The choice of notes is made through a combination of user input and features built into the system. The user chooses the *approximate* note value, while the *exact* selection is controlled by the system, using algorithms to ensure that the notes are in accordance with an underlying musical logic, thus rendering a strong sense of tonality.

For example, in Room mode the user goes from low notes to high notes by moving around the room (varying centre X), but the system will only play notes in the particular scale chosen from the GUI. In addition, when the user places his/her hand above his/her head, it triggers a chord appropriate to the scale and pitch range based on the location in the room (centre X). A Markov model is used within a rhythmic matrix to achieve this.

In addition to controlling the pitch range, users can play chords with various gestures, affect the dynamics and add various kinds of articulation (e.g. arpeggio). The result is an environment that is 'musical' in a relatively traditional manner, often displaying similarities with music in the classical and jazz idioms, but where the user can also feel that he/she is 'playing' the music.

Particles

The Particles environment is perhaps the most sonically complex of the six environments. Currently, it lets the user choose between four sound worlds, each consisting of a large number of short samples, or particles, where each position on the axis perpendicular to the camera (centre X) is linked to one particle.[16] Thus, by crossing the room (and thereby changing centre X) the user will go through all of the particles in a given sound world. And at each position the user's activity (QoA) will determine the rate at which these particles will be played back. Thus, small movements can be used to play single particles, and larger movements to play chained sequences or even dense clouds of sound particles.

Within each sound world the samples are organised so that particles sharing a similar characteristic or which belong to the same source category are contiguous. Moreover, the transitions between different groups of sounds are continuous, so that even if there is a pronounced change in quality, this change will still come about as a smooth and sonically continuous transition.

The sound worlds have different qualities and suggest different metaphors. In one the user can play the sounds of materials like glass, metal, water, wood and skin by navigating to different areas of the interaction space. In another vocal sounds from a Chinese opera singer, including song notes in all registers, gliding syllables, spoken words with different emotions, isolated consonants etc. are heard. The large number of sounds gives the environment a sonic richness that is intended to evoke interest and curiosity.[17]

Fields

This environment invites interaction metaphors of narrativity/impersonation as well as playing a musical instrument. Sounds include animal sounds and activity sounds (such as riding a motorcycle), thus inviting a game of impersonation where the user 'becomes' the maker of the sound. Other fields offer objects like drums and glass or weather phenomena like 'wind' and 'rain'. Musically, this environment is based on soundscape composition and an expanded notion of what sounds can be musical.[18] Fields allows a division of the interaction space into two distinct areas, which can be played simultaneously by two users.[19] This makes this environment ideal for duets, enabling, for example, an imagined 'conversation' between a chicken and a frog.

Accents

Dance music with a steady pulse is a challenge to interactive system design. Given that it is the beat that motivates movement, it is difficult to find a convincing interactive role for the user to begin the feedback loop in the first place. On the other hand, once the beat is playing, it can be difficult to find a meaningful role for the user within the musical paradigm, since the beat is already in place. We struggled with this for many years, before finally arriving at three workable solutions. They are implemented in the environments Accents, Techno and Drums.

When you turn on Accents, a metre-less pulsing drum sound is immediately heard. The effect of movement, then, is not to play the drum, but to intensify (accent) the beat being played the moment you move. The user can thus 'pump up' the musical intensity, but also build metres into the music by alternating between moving and not moving. The user's height or the height of his/her arms, meanwhile, determines the pitch of the drum.

Techno

One of the most basic aspects of the techno genre is the groove. This environment is based on a popular contemporary dance metaphor, where the user is given an underlying beat to which he/she can dance. The system reacts to the user's movement by making the music more active and engaging (cf. the feedback loop mentioned for goal 2). Thus, as with a DJ, elements can be added and taken away, but the underlying groove is immutable. As with Accents, we designed the Techno environment to depart from our general mapping idea, that is, that bodily stillness equals silence. Thus, in this environment music is always present. The user 'pumps up' the music, first by his/her presence and then by moving to the beat (cf. design principle 2b above). Other mappings used in this environment include bending low (low pass filtering), extending the arms over the head (high pass filtering) and extending the arms to the side (melodic layering).

Drums

The Drums environment 'surrounds' the user with five virtual drums, represented by five directions away from the body – low left, high left, over the head, high right and low right. A hitting gesture in one of those directions activates one of the percussion instruments. If the user plays many notes, a quantising function is activated. This aids users in being rhythmic, even when they are not. Finally, with even more playing an underlying (non-interactive) rhythmical accompaniment is added.

Social issues

The two-person interaction mode of Fields invites a reflection on interaction issues involving more than one user. Allowing multiple users facilitates creative social and musical interaction, either involving a friend or therapist. The positive experience of listening to music and dancing is multiplied when shared with others – either by showing them something we are proud of or by sharing an activity. As Eide (2014, p. 122) points out, the dialogical perspective in music has become important to music therapists in recent decades, emphasising co-experience and co-creation. In our work we have experienced that games of imitation, mirroring and dialogue can heighten the engagement. However, multiple-person interaction introduces challenges, making it difficult to hear who does what (cf. design principle 1e concerning causality). Certain technical and musical mappings can help here, such as panning and variations in frequency range. Finally, if the number of players is kept at a minimum – two or three – then these issues can usually be solved through guidance and indeed offer the pedagogical benefits of conscious interaction and listening to others.

User interaction case studies

The development of the MC has been guided by sessions with users from different user groups. The aim of these sessions has been two-fold. First, we wanted to test, observe and collect feedback on issues concerning both the motion tracking and musical environment aspects of the device. Thus, these sessions constituted a 'user testing' component in an iterative design process. Second, a main goal is to allow persons with different abilities to engage in expressive movements through dance and music, since for many people with different abilities opportunities for these kinds of activities are often limited.

Since 2010 the MC team has held 28 workshops in seven countries with participation of a total of 242 persons with different abilities and 119 therapists, teachers and caretakers.[20] The age and demographics of the users in these workshops varied greatly, as did their abilities. The conditions we worked with included Rett syn-

drome, blindness, autism (autism spectral disorder), cerebral palsy, quadriplegia, Parkinson's and Alzheimer's disease.[21] Most workshops also included 'non-disabled' participants, including, in some cases, professional dancers and musicians.

The workshops were organised together with hospitals, schools and institutions for persons with different abilities, and participation was free. Sessions alternated between individual and group exercises, beginning with a group warm-up lasting approximately 30 minutes. This was followed by a demonstration of the interactive system, which gave the participants a sense of the experience. Next, we divided the participants into groups of three to six persons, where the participants were given more time to experiment. In this part of the workshop the needs of individual participants guided the workshop, which included storytelling scenarios and short performances. At the end, we would bring everyone together for a finale, followed by a debriefing focussing on the experiences of participants with different abilities and evaluations by the therapists.

The following three accounts refer to sessions held between May 2014 and March 2016. They are based on notes from the workshops, communication with those involved and studies of video recordings of the events.[22] They are anecdotal in nature and lack systematic methodology. Still, as more or less typical examples, they can give insight into the usage of the MC. The names of the users have been anonymised.

Frederick

Frederick is an adult male in his early 20s suffering from cerebral palsy. He uses a wheelchair and has limited speech capability. He made a particularly strong impression during one workshop, playing the Tonality environment in Chair mode. The music he generated projected a sense of dynamics and phrasing that was surprising, even for the members of the project team who knew the potential of the Tonality environment well. It seemed to transcend the usual 'pathological view' of Frederick's movements. Due to spastic cerebral palsy his movements are characterised by a high degree of muscle tension, mobility impairment and stiff muscle movements. This also affects his motor control and movement patterns. Half lying, half sitting in his wheelchair, he experienced several moments of high energy movements where all extremities were in constant motion. This included arm movements in big circles to the sides and lifting both legs/knees alternately in an almost rhythmical manner (cf. Figure 4). At other times an arm would move up and down in a bouncing manner, while the rest of his body remained relatively still. Frederick's lowest levels of activity, as they were tracked by the system, however, were far from what most people would perceive as bodily stillness. Nevertheless, the differences he achieved between high and low activity, combined with the arm height he could control, generated highly dynamic piano music with arpeggios running up and down, melodic

trills and variations from soft and sparse sections to dense sections characterised by much energy and a quick pace.[23] This illustrated to us the importance of the QoM parameter, and how a user with limited motor control can still express himself/herself musically.

Figure 4. Video stills of Frederick's performance (identity anonymised)

Additionally, it has to be mentioned that Frederick seemed to have a great time during his performance session. His face and vocal utterances clearly expressed positive emotions: immense joy, well-being, concentration and pride.

Daniel

Daniel is a male in his mid-20s. He moves well, but has limited cognitive abilities. He participated in a full-day workshop together with a few other persons from his institution. Daniel loves music and dance, especially Latin and classical, which he enjoys on a regular basis. People who know him characterise him as active and full of humour, although he can be timid and needs time to adjust to new sensory impressions and social settings. Daniel may react in a pertinent manner in various situations, but has problems with comprehension and communication, especially at the verbal level, and his abilities in that area can be compared to those of a three- or four-year-old.

What was most striking about Daniel was how quickly he became absorbed in the music and in exploring the role of his body here. In his first session he played the Fields environment together with a close friend. At first he acted a bit insecure, seeking the safety of eye contact with his friend, but after this initial hesitation he seemed to gain confidence and started to engage more actively and exploratively in the interaction. When he moved and made a sound he seemed at first quite sur-

prised that he had produced the sound with his body. After having established the causal relationship, he seemed to engage in an exploration of how different parts of his body corresponded to the sounds he made (cf. Figure 5). Daniel's movements evolved from quite stiff and limited movements to rotations of his wrists and arms, foot movements and even small jumps. Perhaps most striking, however, were the pauses he employed, freezing in place to delineate the effect he had on the music. Precisely freezing and moving again is a strong way of establishing the causal relationship between movement and sound, at least when the system responds without noticeable latency. While many users, 'normal' as well as 'disabled', need overt instruction and a bit of training to do this, Daniel did it spontaneously. Subsequently, he would smile broadly, something we as observers interpreted as joy and satisfaction.

Figure 5. Video stills of Daniel

During his session Daniel seemed to listen intensely and respond immediately to the sounds he made. We learned from his friends that this behaviour was in contrasted to how Daniel responds verbally in everyday settings – it can sometimes take him 30-40 seconds to answer a question or make a request. The psychological absorption, acuity and presence we observed in Daniel suggest a state of mind described by Csikszentmihalyi called 'flow' (cf. e.g. Csikszentmihalyi, 2014). This state is characterised by a 'merging of action and awareness; a concentration that temporarily excludes irrelevant thoughts, feelings from consciousness', and there is clear feedback in the interaction (Csikszentmihalyi, 2014, pp. 215-216).

Anna

Anna is a young female teenager with Rett syndrome. She depends on her wheelchair and cannot speak at all. She participated in a relatively long session at one

of our workshops with predominantly non-disabled participants. Her parents and her therapist were present during the session, where she played the Tonality environment in Chair mode using the vibraphone sound bank. In the beginning of the session she made few movements other than the typical hand-wringing gesture characteristic of Rett syndrome girls (the condition only affects females). When one of the MC team members positioned himself behind her and began moving her hands, she seemed to respond positively to the gentle vibraphone notes generated by this movement. After some minutes she began to make slow rocking movements and to raise her hand. In the debriefing following Anna's session we learned from her parents and her therapist that this type of self-initiated physical response was very unusual for her. We have found this method – first assisted and then alone – useful in cases where verbal instructions are not possible.

Conclusions and further development

In designing music-movement tools for persons with different abilities, we face large, but also very interesting challenges. This user group is not only incredibly diverse, but also incredibly open to trying new things. We have made many surprising discoveries in our workshops. Users would play the MC 'incorrectly' and in so doing reveal creativity, inventiveness and musicality. For example, Frederick (described above) played the Tonality Chair environment where arm height is tracked along the vertical axis. But Frederick was almost horizontal in his special wheelchair, and thus his arm movements did not follow the intended trajectories. This led to unintentional, yet interesting results.

Other wheelchair users extended both arms to one side of their body (not an illogical movement, since this is also done when playing a 'real' piano) or forwards towards the audience. These movements are expressive and completely justified from a choreographic standpoint, even though the system was not intended to be played this way.[24]

The question, then, is how we can design dance-music systems that offer 'rules' for their control and yet, for those who either cannot or choose not to follow those rules, allow for alternative mappings and modes of playing. This dichotomy – rules and freedom – requires a careful balance and strategies for choosing modes of playing, for example:
- Letting the therapist (or other outside person) choose via the GUI
- Letting the user choose (e.g. through a particular gesture)
- Randomly
- Via an intelligent system, which analyses the style, range of movement etc. of the user

While the evaluation of the MC device has been largely exploratory and non-systematic, it has indicated a possible role for such technologies in therapeutic settings.[25] Future systematic studies are necessary to confirm and expand this claim, but coupled with increased awareness of the needs and creative potential of persons with different abilities, this could lead not only to a healthier, richer life for those affected, but also to startling new artistic creations from which the world at large could benefit.

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Notes

1   We have adopted the term 'different abilities', because it is 'a sign of respect, emphasizes the strength of all individuals, and allows any special treatment to be given according to the needs of each individual, and not according assumed limitations'. (Web page of the Centro Ann Sullivan del Perú, http://en.annsullivanperu.org/people-with-different-abilities/, accessed 7 April 2016). The term has been used to some extent in academic literature as a substitute for 'disabled' or 'persons with disabilities'. Cf. e.g. Mayo & Leblanc (2010).

2   This anecdote describes a user session from March 2016 involving a 12-year-old boy with cerebral palsy. His name has been changed for the context of this article.

3   Cf. also Crowe & Rio (2004) for an extensive review of instruments, application, medical technology and technology-based health music/sound health practices up to that year.

4   Mäki-Patola & Hämäläinen (2004b) have found that the just noticeable difference (JND) for the detection of action-sound latency for an electronic instrument without tactile feedback (the Theremin) is 30 milliseconds.

5   As Jensenius (2007, pp. 43-54) points out, musicians show movements that are not directly related to sound production, but are instead *ancillary* (e.g. to support the sound-producing movement, to play a part in the formation of phrases or to synchronise body parts with the music) or *communicative* (e.g. to use non-verbal affect display while playing).

6   In *Dance Words* this aspect of the torso is expressed in three citations by Martha Graham: '[...] it is the torso which expresses [...]', 'the torso is the source of life [...]', '[...] the motor [...]'. (Graham cited in Preston-Dunlop, 1995, p. 260).

7   The MC 3.0 will be produced by MotionComposer (GbR). Updated information is available at the website www.motioncomposer.com.

8   The MC 3.0 will have a different motion tracking technology involving stereo vision (using two identical CMOS sensors). Preliminary tests indicate that this will create more robust tracking.

9   InfoMus, University of Genoa, Italy (www.infomus.org).

10   These levels can roughly speaking be divided as follows: 1) very small, discrete movement, such as of fingers or eyes; 2) medium-sized gestures of the hands, head, shoulders, feet etc.; 3) bursts of large, high-energy movement; and 4) jumps, where both feet leave the floor.

11   As the research of Jensenius and colleagues shows, what we regard as 'still' is really a state in which we engage in micro movements that can only be measured with high resolution motion capture systems (see e.g. Jensenius et al., 2014). Thus, being 'still' in our context is about moving in a way that the threshold of the system, what is often referred to as the 'pixel threshold', fails to register.

12   The fact that amount/size can be interpreted in several ways opens up for some complexity, however. For example, in one of the settings of the Fields environments, movements trigger the sound of birds. Different metaphors can be used to interpret the mapping between size of movement and size/amount of sound: While a larger movement may cause an increase in sound level, the expected increase in size/amount could be interpreted both as a more agitated bird (higher arousal), a bird of a larger physical size or a larger number of birds.

13   A note about centre X: It is a common myth that tracking human movement in three dimensions requires either multiple cameras or a so-called 3D camera. Normal video cameras acquire motion in all three dimensions! In any normal situation, when we move around a room our centre X value will change. True, movement directly towards or away from the camera is not detected, but in practice such movement is impossible. Human beings do not move like machines.

14   See http://www.motioncomposer.com/en/who-we-are/ for a presentation of the composers (accessed on 21 April 2016). The first author of this article is one of the six composers.

15   Sitar, guitar and a moog-like synthesizer will be added in the MC 3.0.

16   See Bergsland & Wechsler (2013, 2015) for a more in-depth description of mapping and sound design in the Particles environment.

17   The Particles environment has also been used to create interactive dance performances. See Bergsland & Wechsler (2015).

18   See Drever (2002) for a discussion of soundscape composition and acousmatic music.

19   In the MC 3.0 all of the environments can be used by one or two persons.

20   See http://www.palindrome.de/sites_MC.PDF for an overview of workshops and other activities. See http://www.motioncomposer.com/en/welcome/ for videos from some of these workshops (accessed on 24 May 2016).

21   Although we have not yet worked with persons with deafness, we know others who have (Higgs & Furlong, 2016).

22   These use cases are also described in Wechsler et al. (2016). In the present article we have expanded and adapted our discussion to match the themes presented here.

23   To hear a recorded sample of Frederick's playing, go to http://www.palindrome.de/frederick (accessed on 24 April 2016).

24   This kind of 'incorrect' playing has a history in music technology as a driving influence on both technical and aesthetic development. One notable example is the way hip-hop DJs from the 1970s and onwards turned the record player into a musical instrument requiring skill and practice, instead of merely being a system for playback (Katz, 2010, pp. 124-145). This new praxis in turn led to the design of record players specially adapted to 'scratching' and other techniques associated with hip-hop DJs. Other examples are the so-called 'glitch' genre, based on digital clicks and other sounds stemming from error or malfunction (Cascone, 2000), and 'hardware hacking', where taking apart, modifying or even destroying electronic toys or devices is a means to making music (Collins, 2006).

25   See Peñalba et al. (2015) for preliminary results of a study of the use of the MC.