The Beathealth Project: Synchronising Movement and Music

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Abstract. *This paper will describe the new EU Beathealth project[1]: an initiative to create an intelligent technical architecture capable of delivering embodied, flexible, and efficient rhythmical stimulation adapted to individuals' motor performance and skills for the purpose of enhancing/recovering movement activity. Additionally, it will explain how it can exemplify the principles of Ubiquitious Music and how knowledge from this field can suggest creativity-driven social enhancements.*

1. Introduction

In recent times scientists have begun to seriously investigate how using rhythm and music can be harnessed as a drug-free way of simulating health (Pollack, 2014). Music works on our autonomic nervous system, thus stimulating our sensations of wellbeing at a subconscious level (Ellis and Thayer, 2010). This has naturally led behavioural scientists to posit that this could be a source of inspiration for a whole new set of therapeutic tools. Innovations in mobile technology in the last 10 years offer a very promising means by which such therapies can be delivered whenever the user or patient is free to practice them.

The collaborative research project 'BeatHealth' aims to be at the forefront of these technological developments (Beathealth Consortium, 2014). The objective of the project is to create a new method for improving health and wellness based on rhythmic stimulation. To achieve this requires an age-friendly, portable system that has the capability to invigorate the user through musical playlists and then simultaneously record their movements (i.e., during walking or running) and physiological activity via advanced sensors. These sensors must be tailored to the individual's motor performance and physiological response. Additionally, as the kinematic data and stimulation parameters are collected on the fly they are to be recorded via a dedicated e-Health service network-based application for storage on a cloud service. This will facilitate the visualization of information on movement performance for the individual themselves and for sharing among family members, doctors and coaches. Such access to this information will empower the user to become aware of her/his motor condition, whether healthy or deficient, and encourage them to adopt a more active lifestyle to either enhance their performance or compensate for a motor disorder they might have.

[1] http://www.euromov.eu/beathealth/homepage

An essential component to this application is the delivery of the music used to stimulation the kinematic activity. However, it is not simply a playback mechanism, but instead takes a significant role in the process. The belief is that by encouraging an entrainment, or synchronization, between the music and the movement then the maximum benefits should be obtained. This can be realized at both a coarse and fine degree, by choosing music whose tempo is simply close to the rhythm of movement, or even further by using audio processing techniques to dynamically adapt the beat pattern of the music to exactly match it.

While not specifically being a music making application, the integration between music and computing in the 'BeatHealth' project means that it is related to a branch of the research field of Ubiquitous Music Systems. According to (Pimenta et al, 2009) these systems should support mobility, social interaction, device independence, and context awareness. Certainly, from a first glance, it would seem that 'BeatHealth' would satisfy these criteria. Additionally, in establishing such a connection ideas from Ubiquitous Music systems may inspire tangential developments. The remainder of the paper aims to investigate this more fully. Firstly, some detail on the conceptual framework behind 'BeatHealth' will be given, followed an outline of the technological architecture. These will be covered in Sections 2 and 3 respectively. Section 4 will set out the characteristics of Ubiquitous Music System, while Section 5 will discuss the relationship between 'BeatHealth' and these systems. Section 6 will provide some conclusions and future work.

2. The Theory and Science of BeatHealth

Appreciation of musical rhythms is an important feature of human culture. A key feature of rhythm is an underlying regular beat: a perceived pulse that marks equally spaced points in time (Cooper and Mayer, 1960), (Lerdahl and Jackendoff, 1983).

Humans are unique in their ability to couple movement to external rhythms. Beat perception can feel automatic and the majority of the adult population can easily achieve this (Drake, Penel, and Bigand, 2000); the ability to engage in dancing being an obvious example. It occurs without musical training and can even be seen in young children. Neuroimaging has confirmed activity in "motor areas" of the brain during the production and perception of rhythm (Schubotz, Friederici, and von Cramon, 2000), (Danielsen et al, 2014). Thus, moving to the beat of an external auditory stimulus is sustained by a dedicated neuronal circuitry including subcortical areas, such as the basal ganglia and the cerebellum, and cortical regions (e.g., temporal cortex, prefrontal areas, and the Supplementary Motor Area) (Repp and Keller, 2008), (Zatorre, Chen, and Penhune, 2007). The basal ganglia particularly show a specific response to the beat during rhythm perception, regardless of musical training or how the beat is indicated. A natural extension of these findings to applied research is to exploit rhythm as a way to enhance movement performance. Rhythm, by its tendency to recruit regions of the brain involved in motor control and timing (Zatorre, Chen, and Penhune, 2007), (Grahn and Brett, 2007), and by fostering synchronized movement, is ideally suited for modifying and improving movement performance (e.g., increasing movement speed or frequency or reducing variability). It is worth noting that the basal ganglia mentioned above are compromised in people suffering from motor disorders, for example Parkinson's disease, and patient studies have shown that they exhibit deficits in timing tasks (O'Boyle, Freeman, and Cody, 1996). However, rhythmic signals with a strong external beat have been observed to ameliorate gait problems in persons with Parkinson's disease (Nombela et al., 2014).

2.1 Entrainment and Self-Entrainment

This link between an external rhythm and the human body's movement response is a phenomenon known as *entrainment* (Clayton, Sager, and Will, 2004). This theory describes the synchronicity of two or more independent rhythmic processes. Among its many applications entrainment also appears as a topic in music research and is best illustrated in its use in the study of musical meter. An element of Meter is the 'beat': this is a perceived emphasis of certain events or pulses within it that are equally spaced in time. (Trost et al., 2014). A current model under study by music psychologists is the Dynamic Attending Theory (DAT) that focuses on the role of metrical structure as an active listening strategy (Bolger, Trost, and Schön, 2013). Essentially, rather than assuming that the perception of time and meter are solely determined to be within the musical cues transmitted from performer to listener, this model proposes that rhythmic processes endogenous to the listener entrain to cues in the musical sound. This entrainment model appears to better reflect the cognitive processes than others (Bolger, Trost, and Schön, 2013). It has also been suggested that the entrainment concept can be used to study of proto-musical behavior in infants (Bolger, Trost, and Schön, 2013).

Not all entrainment involves an external stimulus, either environmental or inter-personal. 'Self-entrainment' describes the case where two or more of the body's oscillatory systems, such as respiration and heart rhythm patterns, become synchronized (Phillips-Silver, Aktipis, and Bryant, 2010). It is the rhythmic responsiveness to self-generated rhythmic signals. A simple block diagram of the process involved is shown in Figure 1 (Phillips-Silver, Aktipis, and Bryant, 2010). In the figure the feedback from the output to the rhythmic input of the entrainment system is the source of the self-entrainment.

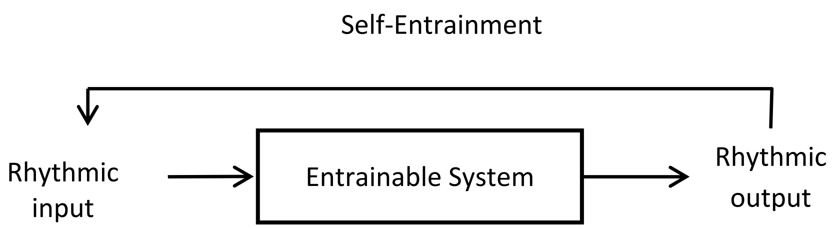

Figure 1 Block Diagram illustrating the process of Self-Entrainment (Phillips-Silver, Aktipis, and Bryant, 2010)

It has been considered that complex-bodied humans and animals typically exhibit self-entrainment in their physical activity, that is, a gesture by one part of the body tends to entrain gestures by other parts of the body (Clayton, Sager, and Will, 2004). For example, arm movements in walking could, in principle, be totally independent from leg movements, but in fact they are not. It 'feels' much easier, is more harmonious, and less strenuous if the arms lock into the leg movements. A similar effect is reported for the locking of step and inhalation cycles in jogging (Clayton, Sager, and Will, 2004). The degree and kind of self-entrainment exhibited depends on the individual and the task being carried out.

2.2 Entrainment and Health

As mentioned above, the concept of Entrainment is readily applicable to the human body and its response to external stimuli. Relevant medical research has considered the behavior of endogenous physiological rhythms in humans (such as the variation of body temperature over the 24-hour cycle), and how the study of those rhythms might be further developed as a tool in the diagnosis of pathological states. The hope is that this could lead to the development of new treatments. Other research investigations are considering the field of music therapy and determining a link between entrainment and socialization.

However, the relationship between entrainment, the stability of biological rhythms and health is still not well understood. There are examples of where relatively stable and entrained biological rhythms are associated with good health. A good example is the enhanced stability of the heart rate afforded by a pacemaker. Conversely asynchrony and instability of rhythmic processes can be associated with pathologies (Clayton, Sager, and Will, 2004). However, entrainment does not necessarily imply stability of biological rhythms, and stability on its own is not necessarily associated with good health. The behavior of Brain waves is a case in point: stable brain waves may indicate a condition such as epilepsy, while unstable waves can indicate a healthy state (Clayton, Sager, and Will, 2004). A certain amount of flexibility and dynamic equilibrium is more likely to be associated with health in many systems, as is a degree of "noise", or random variation in normal physiological rhythms (Clayton, Sager, and Will, 2004).

According to (Phillips-Silver, Aktipis, and Bryant, 2010) the capacity to exhibit the simplest form of entrainment emerges when three critical building blocks are in place: (1) the ability to detect rhythmic signals in the environment; (2) the ability to produce rhythmic signals (including rhythmic signals that are byproducts of other functions, such as locomotion or feeding behavior); and (3) the ability to integrate sensory information and motor production that enables adjustment of motor output based on rhythmic input. Observing these three criteria can indicate whether entrainment is being manifested in a healthy or less healthy, or pathological, manner. If the healthy functioning of a system requires a certain degree of entrainment, then either a lack of entrainment, a weakening or even an excessive strengthening of entrainment can be associated with a change to a pathological state (Phillips-Silver, Aktipis, and Bryant, 2010).

2.3 Stimulating health through entrainment

The fundamental idea is that by stimulating an entrainment between auditory rhythmical cues and spontaneous or deliberate movement, it boosts individual performance and leads to enhancements in health and wellness. For healthy people, this means that they should synchronize their movement with the beat of an external music source when dancing or when performing physical and sport activities such as running or cycling. This should lead to measurable improvements in their gait kinematics, for example increased velocity and cadence (Wittwer, Webster, and Hill, 2013), and produce (i) better coupling between breathing and running, (ii) a reduction of energy expenditure, and (iii) a general increase in endurance and (iv) a desire to run (Hoffmann, Torregrosa, and Bardy, 2012). Additionally, entrainment has a role in a therapeutic context where movement is constrained by a motor disease. One study reported how it been integrated into a rehabilitation therapy in patients with motor disorders (Wittwer, Webster, and Hill, 2013). The idea is to use external rhythmical cues to help patients' regularize their gait. The patient is asked to match her/his walking speed to a regular stimulation in the form of a repeated isochronous sound (metronome) (Nombela et al., 2013).

2.3 Related Consumer Technologies

To date only a few consumer applications and technologies that exploit rhythm for enhancing movement have been introduced. These have been designed for healthy people that are trying to improve their exercise regime. Yamaha released BODiBeat in 2007 (Yamaha, 2007) followed by Philips Activa (Philips, 2010) in 2010. Applications are now appearing for mobile devices. No similar commercial products are available for people with movement disorders.

This technology is in its infancy however. There is a lack of sophistication in means of achieving and maintaining synchronization between the music and movement. Furthermore, there is a need for more scientific insight into how best to capture and analyze the relevant physiological signals and to relate them to the auditory cues. This is the motivation for BeatHealth. Its objective is to realize an intelligent technological architecture that can deliver flexible and efficient rhythmical stimulation that can be adapted to any individual's skills, whether the individual is healthy or not, which will enhance and monitor features of their movement performance. The next section will explain the organization of the 'Beathealth' project.

3. Beathealth Organisation

The fact that there are gaps in both the current science and technology meant that the Beathealth project needed to be a highly multidisciplinary endeavor, requiring input from physiology scientists, medical consultants, music technology researchers, and software engineers. The BeatHealth project was designed for healthy citizens of various ages that engage in physical activity and for patients with the movement disorder of Parkinson's disease.

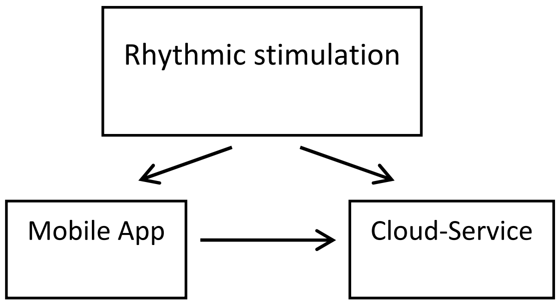

Figure 2 Three areas of Beathealth and their interconnections

Three primary challenges were identified for the project: (i) fundamental research aimed at improving information parameters for maximizing the beneficial effects of rhythmic stimulation on movement kinematics and physiology, (ii) technological development to a achieve state-of-the-art implementation platform to deliver the rhythmical stimulation that has attributes of portability, flexibility and reliability, (iii) the creation of a new IT service in the form of a network-based application for collecting on the fly kinematic data and sharing them with online with others such as medical doctors, family, and trainers. The process of facing these challenges can be illustrated in the three interconnected areas as shown in figure 2 above.

Rhythmic stimulation is about the boosting of motor performance. It is a fundamental scientific research component of the project. This aims to improve our knowledge of the auditory stimulation parameters that are best suited for entraining movement. This will be investigated for both healthy individuals and patients with motor disorders. For patients with motor disorders it will investigate how to produce more effective novel therapies using such stimulation parameters. It is of particular interest to find rehabilitation strategies that can create long term benefits that will extend beyond the clinic.

For the audio stimuli, attention will be devoted to understanding which type of stimulus (i.e. existing music or artificially generated signals) best fits the particular individual preferences and functionalities in relation to the motivational effort. Possibly, the use of automated composition tools may also help for certain tasks.

The **Mobile Application** for the Beathealth system is a redevelopment of and builds on the ideas of D-Jogger (Moens, Van Norden, and Leman, 2010), which was previously developed by one group in the project consortium. The structure is that a sensor or sensors detect bodily movement and complimentary physiological responses, and these sensor responses are transmitted to a mobile device that is carried by the user. Processing of the sensor signals is required to smooth out noisy fluctuations if the user is engaged in vigorous activity. Special algorithms are required in the case of multiple sensors to fuse the signals together into a single waveform that is used to synchronize the auditory stimulation with the rhythm of the activity in an optimal manner.

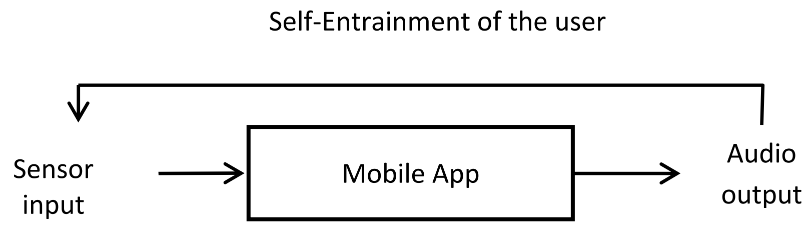

Figure 3 The user process of Self-Entrainment using the mobile app

The mobile application will contain the playlist of audio stimuli. It will either reside on the device itself or be streamed over the network. A music synchronization (Moens, Van Norden, and Leman, 2010), algorithm will be responsible for the alignment of the tempo of the audio stimuli with the movement. Thus, the user will exhibit self-entrain their movements with the audio, which will in turn effect the periodicities of the sensor input. Figure 3 shows a block diagram of the process and it is obvious that it matches the feedback system of Figure 1. Lastly, the mobile application will be available to run on a cost-effective smartphone platform.

The **Cloud Service** is a network-based application for the visualizing and sharing of information on the movement performance collected via the application. This will be sent on-the-fly over the internet and made available on a dedicated e-Health platform. The user will be able to create and maintain a profile facilitating ongoing regular assessment and monitoring of physical fitness and wellbeing. The user's health consultants can also access this information for assessment. Examples of current commercial services are Apple's HealthKit (Apple Corp., 2014) and Microsoft's HealthVault (Microsoft Corp., 2014).

3.1 Beathealth Evaluation

The BeatHealth application will be validated continuously throughout the project with healthy users and in patients with motor disorders. Close to the end of the project a full evaluation procedure will be carried out. Indicators of change in performance along with changes in health status and the motivation to perform physical activity will be recorded. Alongside this, measurement of the quality of the actual software product using metrics to assess attributes such as usability and efficiency will be done and subject to analysis.

4. Ubiquitous Computing and Music

Following mainframe and personal computing, ubiquitous computing is considered to be the third wave of computing technology (Moloney, 2011). It is also known as 'Pervasive computing'. The underlying idea is that as technology improves devices become smaller but with increasing power such that they can be imperceptibly embedded in the general environment, thus delivering ubiquitous access to a computing environment (Moloney, 2011). Its benefit is that it simplifies people's lives with technology that facilitates that uses sensors to understand what they are doing in the world and then self-adapts to respond to their users' needs. The five key components of ubiquitous computing systems have been determined as being (Kurkovsky, 2007): (1) Embedded and Mobile Devices (2) Wireless Communications (3) Mobility (4) Distributed Systems and (5) Context Awareness and Invisibility. Ubiquitous computing integrates a broad range of research topics, which includes, but is not limited to, distributed computing, mobile computing, location computing, mobile networking, context-aware computing, sensor networks, human-computer interaction, and artificial intelligence. The initial incarnation of ubiquitous computing was in the form of "tabs", "pads", and "boards" (Weiser, 1991) built at Xerox PARC from 1988-1994. However, it has come through a revolution with the advent of the mobile smartphone. It facilitates a Ubiquitous computing that is "invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere" (Weiser, 1991). The mobile phone has now become a true manifestation of the pervasive service and is much easier for the majority of users to conceptualize and interact with (Roussos, Marsh, and Maglavera, 2005).

Ubiquitous music is a research area that is a subset of ubiquitous computing and features mobile and networked music, eco-composition and cooperative composition. A ubiquitous computing music system can be defined as a musical computing environment that supports multiple users, devices, sound sources and activities in an integrated way. The technology allows for mobility, social interaction, device independence, and context awareness (Pimenta et al., 2009). However, a Ubiquitous music systems places strong demands on the computing interface. A good example is the use of mobile devices. Depending on the desired activity, there may be needs beyond the screen interface requiring context awareness mechanisms and location-specific configuration of parameters that necessitate sensor or actuator capabilities to the system. However, the benefit of the Ubiquitous computing platform for music is that it may empower both non-musicians as well as musicians to express themselves though the medium of music in a collective, open-ended manner.

5. Relationship of Beathealth to Ubiquitous Music and Computing

In its architecture the Beathealth application certainly references all the components of Ubiquitous computing given in Section 4. It facilitates external sensors for gathering physiological and kinematic information. It runs on a smartphone. Data gathered is stored on a cloud service. Ideally, the audio tracks will come from a streaming service. Lastly, it reacts to the user movement by adapting the audio in terms of its beat pattern to fit with the rhythm of the movement.

With respect to the definition of ubiquitous computing and music the Beathealth application, with some adjustment, can align itself with the concepts promulgated by the practitioners in this field. It facilitates an alignment between movement and music so strictly speaking it is not an instrument of musical expression or composition. However, the alignment it does facilitate embodies a profound interaction between the human user and the computing system playing the audio: the rhythmic time-scale of the audio adapts to the movement of the user. Thus, the user is engaging physically and mentally with the music in a dynamic feedback system, as in the self-entrainment system of Figure 1. Additionally, the Beathealth application is not necessarily constrained to use standard commercial audio tracks as mentioned in Section 3. Actually, it has the flexibility of allowing the use of artificially generated test signals that can be applied in the scientific study of movement. An example could be Amplitude Modulated sounds (Joris, Schreiner, and Rees, 2004). Moreover, if desired, the commercial audio can be extended or replaced to incorporate other compositionally inspired sounds that a user may desire or even require. This means that the Beathealth application can be brought beyond its original intention as an ‘exercise app’ or a novel therapeutic tool for patients with motor disorders. This can lead to more creative approaches to auralizing all the potential kinematic features derived within the complete Beathealth framework where specific apps are just particular manifestations of what it can be configured to achieve.

If it is configured to support multiple users, dealing with user-selectable audio streams that can be modified by the users’ activities, it can therefore become a compositional tool within a suitable environment that stimulates kinematic activity. The activity and setting then define what the Beathealth application can be. Thus, with real-time modification of multiple-user defined audio performed as a collective activity it can transform the activity into a social and artistic experience. This interacts on many levels, harnessing the intellectual and the emotional along with their physical selves. The impact this may have on the sense of wellness could be more profound than just a kinematic motivator alone.

6. Conclusion

This paper has discussed the scientific background to the Beathealth project, explaining its origins from the theories of entrainment, and particularly self-entrainment. It then explained the organization and components of the Beathealth application itself. The features of Ubiquitous computing systems were discussed that were followed by the specifics of such systems when designed for music. Finally, it described how the Beathealth application fits within these definitions but also suggested how it can be brought beyond its original health and therapeutic contexts to a vision where it can embody social interaction among multiple users where it could stimulates a musical creativity fused with kinematics that could enhance the sense of wellness it can deliver to collectives of users.

7. Acknowledgement

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