# Human Bodily Micromotion in Music Perception and Interaction

Application to FRIPRO/IKTPLUSS
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## 1 Relevance relative to the call for proposals

This project seeks to investigate the close couplings between musical sound and human bodily *micromotion*. Micromotion is here used to describe the smallest displacements of human body parts, either voluntary or involuntary, typically at a speed smaller than 10 mm/s. The last decades have seen an increased focus on the role of the human body in both the performance and the perception of music (Gritten and King, 2006), and today it is difficult to imagine talking about the experience of music without also focusing on how music is experienced through the body (Godoy and Leman, 2010). Up to now, however, the micro-level of these experiences has received little attention. This project will investigate such music-related micromotion, with an aim of contributing to:

- knowledge about how musical sound influences human motion at the micro-level. This will be based on literature studies, theoretical modelling, and a longitudinal observational study as well as three large-scale experiments of sound-motion relationships.
- a large, annotated and metadata-rich database of the micromotion recordings mentioned above. The database will be central to the current project, and will also be made available for future research in the field.
- conceptual models and software tools for using micromotion to control musical sound in computer-based systems. Such musical microinteraction can be used for music performance or production, or for "active listening".

The project is:

- at the *research frontier* of basic issues in cognitive musicology, embodied music cognition, music technology, and human-computer interaction.
- truly *interdisciplinary*, bridging over between so-called "hard" and "soft" research approaches, as well as between science and the arts.
- *innovative*, with research outputs in the form of scientific publications, an open database, and open source software tools.

I am already established as a leading, young researcher within the international music technology and music cognition communities, and this project will give me the possibility to set up my own research group and carry out a bold and novel project. Results from the project will feed directly into current trends in musicology and in music psychology/cognition, where more knowledge about the human body is of great importance for the further understanding of how humans produce, perform and perceive music. The conceptual models and software tools developed in the project may also have a wider impact. For example, my previous research on (more large-scale) music-related body motion has resulted in the development of software-tools for detecting cerebral palsy (CP) in young infants (Adde et al., 2010). If succesful, this project's ambition of using micromotion to control interactive systems may have a transformational impact on how we use tomorrow's technologies.

# 2 Aspects relating to the research project

## 2.1 Background and status of knowledge

Try to sit still for a couple of minutes... What did you observe? Did you notice the small motion happening in various parts of your body? Did you notice the rhythmic patterns of your breathing, pulse and postural adjustments? Most such microactions are produced unintentionally and are so small that they are not easily observed by others. But the "invisibility" of such microactions does not mean that they do not affect us and those around us. I believe that nuance and expressivity in music to a great extent are conveyed and experienced through micromotion.

The underlying premise for this project is built on the idea that bodily motion is integral to both the performance and the perception of music. While this may seem obvious, it is only in the last decades that music researchers have started to study music from an *embodied* perspective (Leman, 2008), and there are still many unanswered research questions. My own contributions to the field include a series of observational studies of people's spontaneous motion to music, including that of "air piano" performance, "sound tracing" and "free dance" to music (Jensenius, 2008). Based on these studies I have been able to present a more thorough classification scheme of music-related motion, including the four main types: sound-producing, sound-facilitating, sound-accompanying, and communicative (Jensenius et al., 2010). Alongside this theoretical development, I have also contributed with a set of video-based analysis methods and tools for studying music-related body motion systematically (Jensenius, 2013).

**Towards micromotion** Having studied music-related motion for ten years, it has become clear to me that most research projects in the field are generally limited to actions that are large and intentional. Music performance is rife with examples of intentional, micro-level interaction, such as the minute actions found in the mouth of wind performers, or in the fingering of string players. But such micromotion has mainly been studied from a sound-producing and acoustic perspective rather than a perceptual one. Even studies of performer's unintentional motion, such as the "ancillary" motion of clarinetists (Wanderley et al., 2005), have primarily focused on medium to large-scale motion, rather than the micro-level. This is puzzling, given that it is well documented that the "invisibility" of micromotion is at the core of how we perceive others (Ekman and Friesen, 1969). So what if we dispense with all motion larger than, say, 10 mm/s? What are we dealing with then?

**Exploring standstill** In 2012 I carried out a pilot study on music-related micromotion together with dancer-choreographer Kari Anne Vadstensvik Bjerkestrand, in which we explored the act of standing still in silence for ten minutes at a time, what is sometimes referred to as a "human pendulum" (Collins and De Luca, 1994). The experience of standing consciously still for such a long time is overwhelming. Not only does one's own micromotion become apparent, such as swaying, shifting of weight, breathing and heart beats, but it is also easy to see and relate to other people's spontaneous micromotion (Jensenius and Bjerkestrand, 2012).

Based on the findings in the pilot study, I continued the exploration of micromotion in the scientific-artistic research project *Sverm*,[1] where two musicians, two dancer-choreographers and one scenographer were recruited. Here we employed the same observation strategy as tested earlier, standing still together on the floor for 10 minutes at a time (Figure 1). Using a state-of-the-art motion capture system to quantify our motion, we found an average quantity of motion (QoM) of around 6.5 mm/s for a head marker of a person standing still (Jensenius et al., 2014). We also found that the QoM values remained remarkably linear over time for

[1] http://www.fourms.uio.no/projects/sverm/

each person for each recording, and that they were also very consistent for each person across recording sessions.

More careful analysis of the data revealed clear person-specific patterns in the data sets, such as seen in Figure 2. Here we could identify (at least) three levels of periodic motion: (a) quasi-random motion happening on a millisecond scale, probably caused by the ankles working to keep the body in balance (Loram and Lakie, 2002), (b) periodic motion at intervals of approximately five to ten seconds corresponding to our respiratory patterns, (c) "spikes" every two to three minutes that were presumably explained by postural adjustments. All in all, the patterns that emerged from the recordings were not as random as we expected, but rather were individually systematic to such an extent that we could identify a person through the plots.

Figure 1: Picture from a standstill session in the Sverm project. Reflective motion capture markers can be seen on the heads of each person.

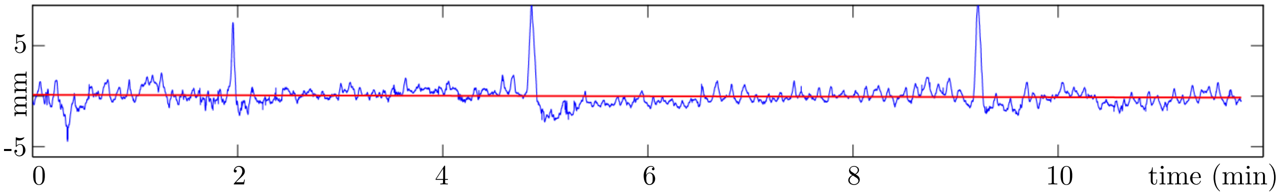


Figure 2: Normalised vertical position of the head marker of a person standing still.

**Towards music-related micromotion** It is well known that musical sound can induce both motion and emotion in humans (Leman, 2008). One example is that of rhythmic *entrainment*, meaning that two or more independent rhythmic processes may synchronise with each other (Pikovsky et al., 2003). Such entrainment has been shown to exist at multiple levels in music performance (Clayton, 2005), most likely based on the experience of both the individual pulses and the metrical structure in the rhythm (Large, 2000). Similarly, studies of human walking have shown a preference for a frequency of two steps per second (2 Hz), independent of gender, age, height, weight, or body mass index (MacDougall, 2005). These findings coincide well with studies on the perception of musical rhythm, indicating a clear preference for musical tempi of two beats per second (120–125 bpm) (Moelants, 2002), and that the preferred tempo of dance music is a little faster (125–130 bpm) (Moelants, 2008). These studies, however, are based on voluntary and large-scale motion. Would we be able to find evidence of similar types of periodicities or entrainment in micromotion recordings of people standing still?

To test this, I have conducted two informal experiments, each camouflaged under the heading "Norwegian Championship of Standstill," so as to recruit a large amount of people. For each of the experiments around 100 people stood still for six minutes, three minutes in silence and three minutes with music. Since these were only informal experiments we have not published the results, but the preliminary analysis does support, to some extent, the hypothesis that our involuntary micromotion will synchronise with musical features. However, controlled, full-scale experiments are needed to properly validate these findings, and to find out which musical features influence different types of micromotion. This is what this project is about.

**Microinteraction** In addition to understanding how musical sound influences micromotion, I am also interested in the opposite: exploring how micromotion can be used to control sound in interactive music systems. The last years we have seen a gradual shift in human-computer interaction from keyboard-based devices to touch-screens, and further to so-called "gestural" controllers. However, current gestural controllers mainly focus on large-scale body motion, such as waving the hand in the air. If we manage to understand micromotion better, both voluntary and involuntary, we might finally get closer to *affective systems* that adapt to a person's emotional state (Picard, 1997).

One could envisage such *microinteraction* as limited by technological constraints. But technologies for capturing micromotion are available, implying the problem is more of a conceptual one. In the above-mentioned Sverm project we explored musical microinteraction briefly. During a set of music/dance performances, the dancers' and musicians' microactions were sonified by mapping realtime motion tracking data to different types of computer-based sound synthesis techniques (Jensenius, 2015). In the current project I am interested in building on this proof-of-concept when developing a set of motion–sound models and related software tools for interactive musical applications. Since this project is primarily focused on exploring and explaining fundamental questions about human cognition and behaviour, the developed models and software tools will be of a prototype nature. But the further development of microinteraction could open for more engaging and interactive entertainment systems, as well as tools for use in clinical music therapy (Thaut, 2005), and for various types of audio-biofeedback to correct postural sway (Chiari et al., 2005) or balancing (Varni et al., 2007).

## 2.2 Approaches, hypotheses and choice of method

### Research questions

The fundamental research question of this project is:

- What are the relationships between musical sound and the human bodily micromotion of music perceivers[2]?

A number of sub-questions arise from this:

- What types of sub-categories of music-related micromotion exist?
- How does musical sound influence the micromotion of perceivers? How do different musical features (such as melody, harmony, rhythm, timbre, loudness, spatialisation) come into play?
- How can micromotion be exploited in musical microinteraction, that is, in interactive, computer-based systems intended for producing/performing/experiencing music?

The project is organised in four work packages (WPs), which will be described more thoroughly in the following sections. Figure 3 shows a sketch of how the WPs and their outcomes are interrelated.

**WP1: Theoretical development and modelling** As a basis for the other empirically and practically oriented WPs, WP1 will focus on the development of a theoretical understanding of music-related micromotion in perceivers, and how such micromotion can be influenced by (musical) sound. This work will draw on a broad range of literature from the humanities, social and natural sciences, and will also continuously incorporate findings from the empirical work

[2] *Perceiver* is here used to emphasize that music perception/cognition is inherently multimodal within an embodied cognitive perspective. Hence, it does not make sense to talk about a *listener* in such a context, since the act of listening to music is only one part of the larger, multimodal experience.

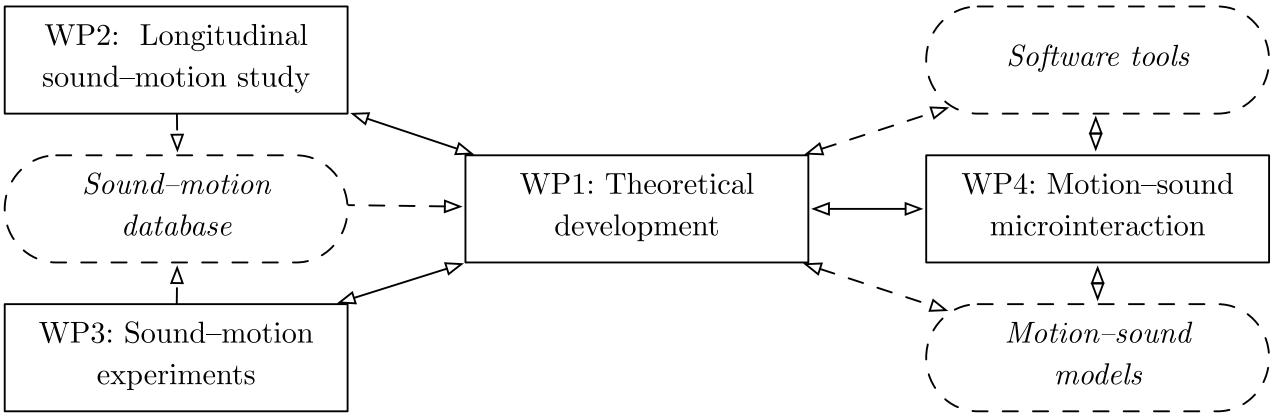


Figure 3: Sketch of how the work packages and outcomes interact.

packages in the project. We will create a classification of different types of micromotion starting from the functional categories of music-related motion I have already proposed (Jensenius et al., 2010). We will also create a theoretical framework of relationships between sound features and micromotion features building on the proof-of-concepts developed in the Sverm project (Jensenius, 2015).

- Responsible: As project leader, I will be responsible for the development of the theoretical foundations in the project, in close collaboration with the other members of the group.
- Methods: Literature studies and theoretical modelling.
- Results: Publications, including one monograph. Conceptual models of sound–motion and motion–sound relationships to be used in the other WPs.

**WP2: Longitudinal study of sound–motion relationships** This work package will run throughout the whole project, and will be carried out by all the project members and guests. The idea is to use these sessions as a test-bed for studying how different types of sonic stimuli influence micromotion, focusing on testing different types of sound material: (a) silence, (b) non-musical sound (environmental, noise and periodic sounds), and (c) musical sound. The latter will include music of all genres, with a focus on testing out how various features (such as melody, harmony, rhythm, timbre, loudness, spatialisation) influence our micromotion. Gathering such a large collection of micromotion recordings will also be of importance for the development of adequate visualisation and analysis methods.

- Responsible: The PhD student in music psychology will be responsible for the data collection and analysis. All members will participate in the study.
- Methods: A multi-method approach will be taken, based on statistical analysis of motion capture recordings and sound features (Burger and Toiviainen, 2013). We also plan to use *functional data analysis* to allow for more large-scale comparisons of motion and sound curves (Ramsay and Silverman, 2005). The quantiative analyses will be seen in comparison to qualitative analyses of the subjective notes taken after sessions, and discussions between the participants.
- Results: Publications. Database of micromotion recordings. Input to the conceptual models developed in WP1.

**WP3: Experiments on sound–motion relationships** Based on the results from WP2, we will carry out one large-scale experiment each year. Here the idea is to systematically test out the sound–motion models developed in WP1 and WP2 on groups of at least one hundred subjects, ensuring a wide gender and age distribution, as well as subjects with different levels of music/dance training.

- Responsible: The PhD fellow in music psychology will be responsible for the data collection and analysis. All members will assist in running the experiments and carry out the analyses.
- Methods: The same methods will be used as for WP2, but with more focus on machine-learning techniques to allow for large-scale comparisons (Nymoen et al., 2013).
- Results: Publications. Database of micromotion recordings. Input to the conceptual models developed in WP1.

**WP4: Experiments on musical microinteraction** Based on the knowledge gained from the other WPs, we will develop a set of prototypes and carry out validation experiments on how micromotion might be used to control musical sound in realtime applications. Here the aim is to systematically explore the level of control that it is possible to achieve through microinteraction, both spatially (how small?) and temporally (how short?). An important aim is to test out interaction on the boundary between intentional and unintentional (voluntary and involuntary) micromotion. We will also define a set of mappings between micromotion and (musical) sound that are so reliable and repeatable that they can be used in interactive systems for both artistic and clinical applications.

- Responsible: The postdoctoral fellow in music technology will be responsible for the development and validation. All members will take part in testing and discussion of the prototypes.
- Methods: Prototyping will be based on both state-of-the-art motion capture systems (Qualisys, Xsens) and more affordable systems (Wii, Kinect, Myo) that are available in the fourMs lab at University of Oslo. Motion–sound mappings will be developed in relevant realtime environments (Max, PureData, Python), with the aim to develop open, flexible and portable code.
- Results: Publications. Software toolboxes/packages. Prototypes of musical microinteraction to be used for artistic and clinical usage.

# 3 The project plan, project management, organisation and cooperation

**Project plan** — is outlined in the application form.

**Organisation** The project will consist of the following members:

- **Alexander Refsum Jensenius**. Project leader and principal investigator. I will manage the project, supervise the fellows/students, and be involved in all research tasks.

- **PhD fellow in music psychology**. The aim is to recruit a musically interested psychology student or a music student with knowledge of music cognition and statistical analysis. This researcher will be responsible for WP2 and WP3, so a thorough knowledge of experimental methods will be emphasised in the recruitment process.

- **Postdoctoral fellow in music technology**. The aim is to recruit a musically interested informatics or computer science researcher, or a music(ology) researcher with specialisation in music technology. The recruitment will be based on finding an experienced and independent researcher with broad development skills.

- **Research assistants**. Two part-time research assistants will be recruited, each for two-year periods, to help with all parts of the project. This includes search for literature, assistance with running experiments, keeping track of recordings for the database, and organising seminars.

- **Master's students**. A group of master's students will be recruited from the departments of musicology, psychology and informatics in the University of Oslo, for whom I will be either the main supervisor or co-supervise together with relevant colleagues. The students will be included in the research group and participate with sub-projects connected to the different work packages. My experience is that it is beneficial for students to become involved in a real research group, and it is positive for the project to get more people to work on the different sub-projects.

The PhD fellow will follow relevant courses at the University of Oslo (music, informatics, psychology) and will also participate in international PhD training schools (International Summer School in Systematic Musicology, Sound and Music Computing Summer School, etc.). The master's students will follow their local programmes, and will be encouraged to participate in international activities.

**Project management** The project will be managed by myself as the principal investigator. I have extensive management and leadership experience, not least as being Head of Department since 2013 (ending 2016). The small number of people in the project will make it straightforward to manage, and makes it possible to have weekly meetings and establish a close working relationship within the group.

**Feasibility** I have extensive experience in all parts of the project, including the theoretical foundations, music-related motion capture/analysis, and technology development. The recruited researchers will each have complementary knowledge. All necessary equipment, infrastructure, and laboratory spaces are readily available and well-functioning, which should further ensure that the project can be carried out as planned.

**Local cooperation** The project will draw on the excellent local human resources within the fourMs group (Music, Mind, Motion, Machines) at the University of Oslo, including Professor Rolf Inge Godøy (music cognition and theory), Professor Anne Danielsen (rhythm and popular music), Assoc. Professor II Sofia Dahl (musicians' motion), Professor Bruno Laeng (cognitive neuroscience), Researcher Kathrine Frey Frøslie (functional data analysis), and Professor Jim Tørresen (artificial intelligence). The local experts will also assist in recruiting master's students to the project, and help co-supervise them.

**National cooperation** I will continue to build on the two formal networks I have initiated over the years, one for *music technology research* and one for *interdisciplinary motion studies*. These two networks together cover more or less all relevant expertise in the field in Norway. Additionally, I will continue my close connections to the *CIMA* (Computer-based Infant Movement Assessment) group at St. Olav University Hospital, Trondheim, with whom I have developed motion analysis tools for children and infants with cerebral palsy (Adde et al., 2009). On the musical/artistic side, I will also continue my close connections to various professional musicians, including Kjell Tore Innervik (percussion performance), Lisa Dillan (voice performance), and Victoria Johnson (violin performance), as well as dancer-choreographers Kari Anne Bjerkestrand and Maja Roel.

**International cooperation** I have large, international networks within systematic/cognitive musicology and music technology, and these will be used when needed. For this project, it will be most relevant to draw on the expertise of Professor Petri Toiviainen (University of Jyväskylä) and Assoc. professor Marcelo Wanderley (McGill University), and the aim is to secure both shorter and longer research visits for the fellows/students to these two institutions.

**Facilities and Equipment** The project will use existing laboratories and equipment available at the University of Oslo (at the Depts. of Musicology, Informatics and Psychology). All of the necessary equipment is available, including state-of-the art motion capture facilities (Qualisys, Xsens), high-resolution/speed video cameras (PointGrey, Unibrain), physiological sensors (MEGA EMG), eye tracking (IView), sound facilities (36.2, 24.6, 12.2 channel Genelec sound systems), and a database/server solution.

### 3.1 Budget — is outlined in the application form.

## 4 Key perspectives and compliance with strategies

### 4.1 Compliance with strategic documents

The proposal fits well with European, national and local strategic plans:

- The European Commission has identified sound and music computing as an emergent field (Serra et al., 2007), and has supported several projects that build up to this proposal — for example, COST Actions 287–ConGAS and IC0601–SID.
- The Research Council of Norway has supported two projects leading up to this proposal (Musical Gestures 2004–2007, and Sensing Music-related Actions 2008–2012), and has provided considerable funding for motion capture equipment in the fourMs laboratories.
- The University of Oslo has placed interdisciplinarity on the top in its strategic plan, has provided funding for the fourMs laboratories, and secured "runner-up" funding after the fourMs group reached the final round of becoming a Norwegian Centre of Excellence.
- The Department of Musicology has invested substantially in the fourMs laboratories and will continue to support research in this area in the coming years.

### 4.2 Relevance and benefit to society

This project is focused on exploring and contributing knowledge on a so far poorly understood phenomenon, and one that most people relate to in one or more ways. My pilot studies leading up to this project has received a great deal of media attention and coverage in national newspapers, radio and TV, which should attest to a general interest in knowing more about the topic. In addition to the knowledge gained from the project, the database of micromotion recordings will be open to new scientific (and possibly artistic) exploration, and will hence be able to lead to new research results in future projects. The software tools and microinteraction models and prototypes may be more directly exploited in education, the arts, in industry and in the society at large. The social implications of improvements in sound and music technologies are potentially very large, and the possibilities of general microinteraction may be even larger.

### 4.3 Environmental impact

There are no known environmental consequences of this research.

### 4.4 Ethical perspectives

Observational studies and experiments will be carried out following the guidelines of the Norwegian Social Science Data Services (NSD). This includes anonymisation of all recordings, and secure storage and handling of recorded data.

### 4.5 Gender Issues

Although gender is not a topic in itself in the project, the research project is relevant for both males and females, and all experiments will be carried out with attention to securing an equal gender balance in the subject groups. I will also strive for obtaining gender balance within the group of recruited fellows/students for the project.

## 5 Dissemination and communication of results

### 5.1 Dissemination plan — is outlined in the application.

### 5.2 Communication with users

**International seminars** We intend to host annual seminars with international researchers, and these will be open to the public.

**Artistic dissemination** This project is growing out of the scientific-artistic project Sverm, in which we used artistic working methods and dissemination techniques. Although this is primarily a scientific project, I still plan to include some artistic outcomes, such as lab concerts, installations in relevant locations (for example during the Ultima contemporary music festival) and at international music technology conferences.

**Teaching** I will continue to use relevant courses at the Department (*Musikk og bevegelse* and *Musikkognisjon*) to teach students about the latest research results, and to recruit students to write term papers and bachelor's/master's theses on topics related to the project.

**Publicity** I have a good track record of being visible in national mass media, and will continue this in the coming project. The plan is to turn the "Norwegian Championship of Standstill" into an annual event, which is an excellent way of collecting valuable research data at the same time as getting broad media coverage.

**Software** The software developed will be open source and freely available on the web.[3]

[3] http://www.fourms.uio.no/software/

**Knowledge transfer** If relevant, knowledge and models from the project may be channelled into further commercial projects in collaboration with the University of Oslo's Inven2 office.

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