# MIB 2017

The Danish National Research Foundation's

Center for Music in the Brain

MIB Annual Report 2017

Danmarks Grundforskningsfond
Danish National Research Foundation

THE DANISH NATIONAL RESEARCH FOUNDATION'S MIB CENTER FOR MUSIC IN THE BRAIN

Annual Report 2017

Center for Music in the Brain
Department of Clinical Medicine, Health, Aarhus University &
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# WORDS FROM THE DIRECTOR

2017 – the third year of The Danish National Research Foundation's Center for Music in the Brain (MIB) – has been a year of consolidation, cooperation and growth. Due to hard work of the center's now more than 30 researchers we had a number of significant findings resulting in a growing number of publications in high ranking peer-reviewed journals and growing international recognition as testified by the forthcoming conference The Neurosciences and Music VII in Aarhus in 2020. Mentionable are the papers by Alluri, Toiviainen, Burunat, Kliuchko, Brattico and Vuust published in Human Brain Mapping showing the involvement of more action-based neural networks during naturalistic listening in musicians than in non-musicians and the paper by Atasoy, Roseman, Kaelen, Kringelbach, Deco and Carhart-Harris published in Scientific Reports comparing brain states in participants experiencing LSD and music using a connectome-harmony decomposition (see Emotion on page 24).

A particular highlight in 2017 was the participation of 15 MIB researchers at the Neurosciences and Music VI conference in Boston, sponsored by the Mariani Foundation. MIB presented 14 posters, and Peter Vuust and Stefan Koelsch's symposium on predictive coding of music, including speakers Marcus Pearce and Uta Noppeney moderated by Robert Zatorre, was chosen among a highly competitive field of proposals for this conference, which is considered the most prestigious within the field of neuroscience and music. At the final day of the conference, during the closing ceremony, it was announced that Center for Music in the Brain will be hosting the next Neurosciences and Music conference in 2020 in Aarhus. This is a great international acknowledgement of our centre and we look very much forward to hosting scientists from all over the world.

On the agenda this year has also been a number of outreach activities. We consider the task of communicating our results to both fellow scientists and laypersons an important and natural task for our centre. This is evident in the number of invited talks at international conferences and the media attention that our research generates. Already at the beginning of the year, when the results of the Mass Experiment were published, MIB found itself in the middle of the limelight receiving an enormous amount of media attention in both local and national news. The results from more than 20,000 children from schools all over Denmark, demonstrated a correlation

*Director Peter Vuust.*
*Photo: Stephen Freiheit*

## MISSION STATEMENT

The Danish National Research Foundation's Center for Music in the Brain (MIB) is an interdisciplinary research centre aiming at addressing the dual questions of how music is processed in the brain and how this can inform our understanding of fundamental principles behind brain processing in general.

With a strong foundation in music practice and theory at the highest level, and a focus on clinical application of music, MIB combines neuroscientific, musicological and psychological research in music perception, action, emotion and learning, with the potential to test the most prominent theories of brain function, and to influence the way we play, teach, use, and listen to music.

between music practice and working memory in children. Later in the spring this was followed by the center leader's book "Musik på Hjernen", in which he in layman terms tries to answer the million dollar question: Why do we have music? The critics liked it and the book received 5 stars in Gaffa, making its way into the evening news on national TV.

Combining outreach and science, MIB ran a live-experiment during a concert with the power-trio *Randolph Cricket* at the annual SPOT festival in Aarhus in May. Equiped with a simple motion capture device, the movements of each person in the audience were followed while they listened to music of various rhythmic complexity. The results extend Witek et al.s laboratory findings showing an inverted U-shaped relationship between rhythmic complexity and wanting to move, into a real world setting.

MIB received acknowledgement throughout the year: PhD student Patricia Alves da Mota won the prize for Best Poster at the Annual PhD day at Aarhus University, PhD student Signe Derdau Sørensen won the clinical research Flash Presentation prize for her 3 minutes' talk about the Mass Experiment at the annual Neuroscience Day 2017 at Aarhus University and finally Prof Peter Vuust was awarded Dansk Lydpris 2017 in Struer.

In 2017, we hired postdocs Massimo Lumaca, Marina Kliuchko and Angus Stevner and started up no less than seven PhD students: Mette Kaasgaard (financed by Trygfonden, Danmarks Lungeforenings Fond, Region Sjællland, Region Midtjylland, Aase og Ejnar Danielsens Fond and Fonden til Lægevidenskabens Fremme) Rasmine Mogensen (fully financed by the Graduate School of Health), Signe Hagner (1/3 financed by the Graduate School of Arts), Nadia Høgholt, Leonardo Bonetti, Pauline Cantou and Marie Dahlstrøm (fully financed mobility stipend from the Graduate School of Health). In June, Manon Grube agreed to join MIB in 2018 as assistant professor, and in December, Christine Ahrends arrived to start preparing her PhD studies that will commence in early 2018.



This year was also a sad goodbye to two highly treasured long-time members of MIB. Assistant professor Maria Witek accepted a Senior Birmingham Fellow Position, but fortunately, Maria remains a close collaborator to MIB. Associate professor Line Gebauer left us to finish her approval as a clinical psychologist, but thankfully, she will still maintain supervising tasks at MIB. We thank both of them for a number of years of excellent research and strong commitment to the center and wish them the best of luck.

International collaborations are highly prioritized at MIB. Funded by Aarhus University Research Foundation (AUFF) Senior Lecturer Marcus Pearce from Queen Mary, University of London spent five months at MIB, and Prof Maria Dolores Roldan Tapia from University of Almeria, Spain visited for six months. Furthermore, during the year we hosted many prominent guest speakers, such as Brain Prize winner Prof Wolfram Schultz, Prof Isabelle Peretz, Prof Luisa Lopez, Prof Sonja A. Kotz and Prof Maria Chait. Furthemore, ten international pre- and postgraduate students stayed at MIB for shorter and longer periods of time. Finally, we signed cooperation agreements with among others Prof Virginia Penhune at Concordia University, Canada.

With this annual report we wish to highlight the scientific progress and key events in 2017 and to thank MIB and CFIN scientists and collaborators, the Danish National Research Foundation, Central Denmark Region, the Department of Clinical Medicine at Aarhus University, The Royal Academy of Music Aarhus/Aalborg, Aarhus University and our other generous funding sources for their continued support.

On behalf of MIB
Peter Vuust

*Center for Music in the Brain at the Make Time to Think retreat in Grenå where MIB researchers develop novel innovative research projects in groups that transgress the boundaries between the different MIB strands.*

*Photo: Ole Heggli*

# PREDICTIVE CODING

*Peter Vuust*

Prediction is increasingly viewed as a fundamental principle of brain processing that determines perception, action, and learning. Emerging predictive coding theories[1] have offered novel explanations for how specialized brain networks can identify and categorize causes of its sensory inputs, integrate information with other networks, and adapt to new stimuli. Briefly, predictive coding as recently formulated by Friston and colleagues[2] proposes that perception, action and learning is a recursive Bayesian process by which the brain attempts to minimize the prediction error between lower-level sensory input and the brain's top-down predictions.

The PCRI model for how the brain processes rhythmic incongruity is a special case of the general predictive coding theory. Under a Bayesian formulation of predictive coding in the brain, perception corresponds to inverting a generative model of the things in the world that cause our sensations.

Computationally, this model inversion could be achieved in continuous time by minimizing a free-energy bound on the surprise $\mathcal{F} > -\ln p(\tilde{s}|m)$ about sensory input $\tilde{S}$ given the brain's model $m$ of the world. In predictive coding, top-down connections provide lower levels with predictions in the form of prior expectations about states of the world, whereas bottom-up connections carry prediction errors that update posterior expectations in higher levels to provide better predictions. This leads to the following hierarchical equations for how top-down predictions $g(\mu^{(i)})$ given by posterior expectations $\mu^{(i)}$ at higher levels and bottom-up prediction errors $\epsilon^{(i)} = \mu^{(i-1)} - g(\mu^{(i)})$ from lower levels evolve when exposed to changes in stimuli $\tilde{s}$.

Predictions

$$\dot{\mu}^{(i)} = \frac{\partial g(\mu^{(i)})}{\partial \mu^{(i)}} \cdot \xi^{(i)} - \xi^{(i+1)}$$

Precision-weighted prediction errors

$$\xi^{(i)} = \pi^{(i)}(\mu^{(i-1)} - g(\mu^{(i)}))$$

where the dot notation $(\cdot)$ denotes the time derivative and $\pi$ is the precision assigned to the prediction errors. The i index is used to refer to a relative hierarchical level. Both higher-level predictions and lower-level prediction errors are weighted by their precision. The precision is the inverse of the variance and encodes the confidence about sensory inputs in lower areas, relative to the confidence with which states in the world that cause sensory inputs can be predicted in higher areas.

The PCRI model proposes that the precision weighted prediction error caused by a given rhythm's syncopation (the occasional appearance of a surprising beat followed by a surprising rest) is at the heart of how the brain models rhythm and meter based on priors, the metrical uncertainty (precision) and the stimulus deviation (Figure 1).

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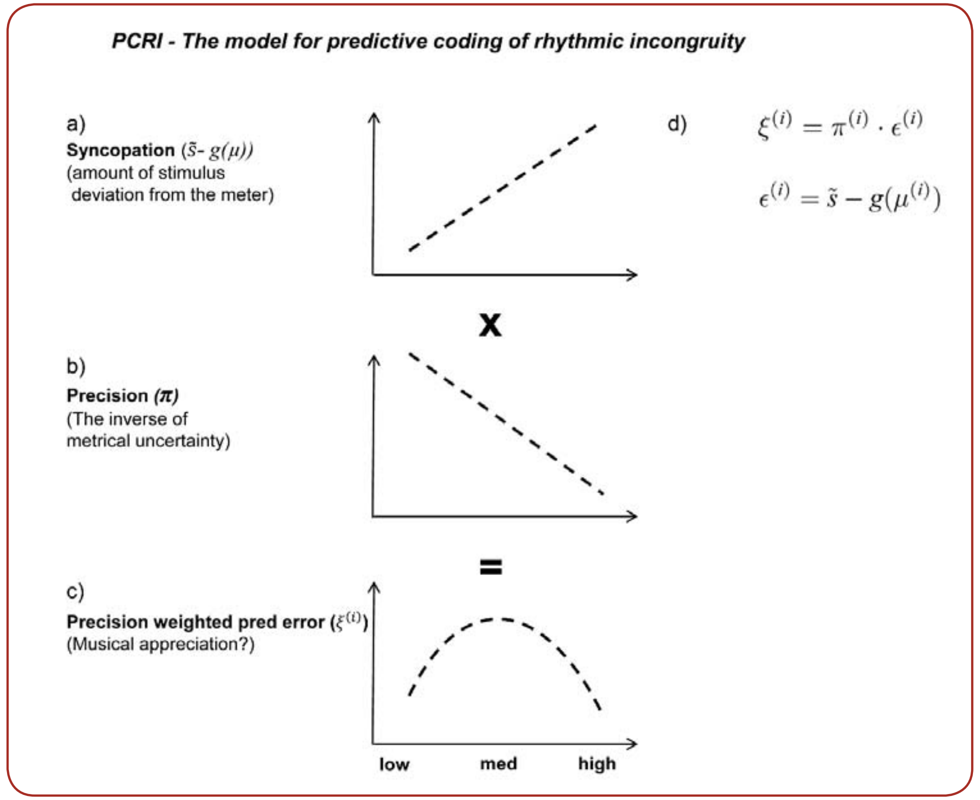



***Figure 1**: Proposed model of the predictive coding of rhythmic incongruity (PCRI). The figure provides a schematic illustration of the variables related to increasing syncopation of musical grooves (dotted lines). A) Under predictive coding, the precision-weighted prediction error is given by the difference between the sensory stream $\tilde{S}$ and the brain's predictions g(μ) timed with the precision π. The i index is used to refer to a relative hierarchical level in the brain. For grooves the syncopations result in a prediction error $\epsilon = \tilde{s} - g(\mu)$, which can be calculated directly from the score by using e.g. Witek et al's modification[3] of Longuet-Higgens & Lee's formulation. B) By assigning more or less precision or confidence to the ensuing prediction errors, the brain perceives the grooves as more or less groovy. C) We propose that the observed U-shaped relationship between syncopation and grooviness[4] can be explained by the PCRI model as a function of the level of syncopation and precision or confidence assigned to the ensuing prediction errors. D) The formulas for describing the relationship.*

# PERCEPTION

*Lauren Stewart*

The perception of music concerns the process by which low-level 'building' blocks of sound are encoded, integrated and represented as higher order features such as melodic contours and rhythms. While listening to music may seem effortless, it is only because of the brain's capacity to a) integrate incoming sound with the memory of the upcoming phrase and b) anticipate what will come next, that we are able to discern structure and (in most cases) aesthetic appeal from the pattern of vibrations arriving at the eardrum.

The Perception strand has been led by Prof Lauren Stewart. In its current form, its members comprise Rebeka Bodak, Suzanne Ross, Marie Dahlstrøm and Christine Ahrend, all PhD students at the centre, and Assistant prof Boris Kleber.

**Music as a Model of Perception/Action Coupling**

Suzanne Ross' PhD work investigates the effect of auditory feedback on sequence learning in musical novices. Understanding how beginners learn to play a musical instrument is essential for developing research that has real-world applications in music education.

One interesting question that has importance for all learners, regardless of instrument, is whether learning to play a musical instrument is a purely motoric process in the initial stages, or whether the auditory feedback contributes to learning and memory of motor sequences.

Prior research in expert musicians shows that presence or absence of auditory feedback has no effect on recall of well-learned music. It does, however, affect learning of new music, with musicians making fewer errors after learning new musical sequences with auditory feedback compared to learning without feedback[1]. This suggests that auditory feedback facilitates initial motor learning, but has no effect once the motor sequence becomes automatised. While expert musicians have formed coupling between sounds and actions over many years of musical training that likely explains this facilitation effect, beginners have no such prior auditory-motor associations. To therefore understand how auditory feedback affects beginners, Ross is currently investigating the effect of auditory feedback on learning and recall in musical novices with little-to-no prior experience of playing a musical instrument.

Fifty musical novices learned a short musical sequence on the piano either with or without auditory feedback. Participants were then tested on their sequence recall by performing from memory immediately after learning and following a 24-hour consolidation period, performing again with or without auditory feedback.

*Demonstration of a participant taking part in the experiment.*

*Photo: Suzi Ross*

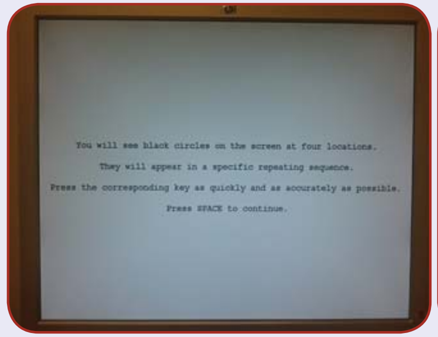
Congruent with research in expert musicians, preliminary results show a significant effect of the presence of auditory feedback at sequence learning and no effect of presence or absence of auditory feedback after the initial learning has occurred. In contrast to findings in expert musicians, however, novices who learned the sequence with auditory feedback made significantly more errors (21% errors) at recall than those who learned without feedback (8% errors). Specifically, the auditory feedback group recalled the latter half of the sequence less successfully than the no-feedback group, suggesting that auditory feedback actually impaired sequence learning. This result suggests that beginners process the auditory and motor information as two separate, potentially competing streams, while learning a new musical sequence, resulting in an impairment at the initial stage of learning; in contrast, previous research on expert musicians shows that the integration of auditory and motor information facilitates learning.

A replication study is planned to corroborate and better understand these novel findings which have implications for musical pedagogy.

**The Role of Auditory Feedback in Musical Learning**

Building on previous work that demonstrates obligatory mappings between sound and action in skilled musicians (e.g. [2-3]), Rebeka Bodak's PhD work assesses whether exposure to a sound sequence can facilitate motor sequence learning, once individual sounds have become linked with individual actions.

Stephan and colleagues[4] recently explored whether this principle would also be seen in novice musicians (with up to 4 years training). After establishing consistent mappings from tones to fingers, participants listened to a simple piece that comprised the tones to which their individual fingers had been mapped. Following 20 minutes of listening (and a test to confirm successful encoding), participants were required to execute a motor sequence (no auditory feedback) based on visuo-spatial cues. The motor sequence was either congruent or incongruent with respect to the auditory sequence they had heard. Facilitation was seen in the congruent condition, suggesting that motor learning could occur simply by listening,




*Demonstration of a participant taking part in the final silent visuo-spatial task. Participants were asked to press the coresopnding key - press the far left key with index finger following presentation of black circle on the far left of the screen - as quickly and as accurately as possible. The presenation of the black circles followed a sequence, either congruent or incongruent withvwhat they had previouslyu memorised.*

Photos: Rebeka Bodak and Hella Kastbjerg

once tone to finger mappings had been established. This is potentially highly impactful, having implications, for instance, for the design of protocols for clinical populations such as stroke.

Bodak's current project therefore aims to refine our understanding of this effect, by replicating the previous work and addressing two limitations in the previous design. First, by testing motor learning at different points in time (in a way that does not confound time of testing with repeated testing) and second, by establishing whether the demonstrated effect generalizes beyond the single motor sequence tested.

So far, the effect previously reported by Stephan and colleagues does not appear to replicate. This may relate to a difference in the participant characteristics. While the original sample had several years of musical training, Bodak's study was careful to restrict musical training to no more than one year (to ensure that the effect can be generalized to the non-musician population).

While further work needs to be done to fully understand the limits of the cross-modal learning findings, Bodak's work has been useful in highlighting the importance of accounting for musical training background.

PhD students Christine Ahrends and Marie Dahlstrom are in the planning stages of their PhD work.

*As of March 2018 Lauren Stewart is no longer affiliated with Center for Music in the Brain*

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## MIB AT THE SPOT FESTIVAL

Photos: Allan Høgholm/SPOT

As part of the Spot Festival 2017 in Aarhus, MIB was invited to do a public mass experiment. Previous work by MIB researchers has shown the existence of a sweet spot of groove, wherein the rhythm is neither too complex nor too simple. The festival offered a great opportunity to explore how this affects behaviour in a real-world setting.

In collaboration with the trio Randolph Cricket a special concert was composed, with music spanning different degrees of rhythmical complexity. Attendees at the festival were invited to the concert and given special caps that enabled us to do motion tracking. After the concert, the participants were given a short lecture and debriefing.

Our hypothesis is that motion, be it head nodding or dancing, correlates with the sweet spot of groove. Analysis is currently ongoing.

This type of experiment provides a great way to combine public outreach with data acquisition in an ecologically valid setting.

*MIB researchers:*
*Ole Adrian Heggli, Maria Witek, Bjørn Petersen, Cecilie Møller, Stine Derdau Sørensen*
*Assistants:*
*Patrick Valiquet, Anders Eskildsen, Anne Sofie Friis Andersen, Johanne Hollands Steffensen.*
*Band (Randolph Cricket):*
*Steen Lavigna (drums), Emil Sommer (synth-bas), Sune Pors (guitar).*

Photos: Bjørn Petersen

# PERCEPTION

## Predictive coding of visceromotor information in musicians

**By Boris Kleber**

When we create our perception of the world, we are driven by the sensory events we encounter as we learn through experience and development. This implies that what we hear, feel, or see during our interactions with the environment evokes activity in sensory neurons that otherwise lie dormant. However, scientific evidence suggests otherwise, indicating that sensory regions in our brain are not only active during sensory processing but also contribute to the generation of probabilistic estimates about the cause of a sensation[1]. Generative models anticipate incoming sensory signals based on experience (i.e., active inference), thereby modulating the firing of sensory neurons prior to feedback processing with the goal of minimizing the error between the predicted and the actual sensation. If an error is encountered, it can be reduced either by propagating it back along cortical connections to modify the prediction, by changing the attention to or the integration of sensory inputs, or by moving the body to generate the predicted sensations, as perception and action are closely coupled[2,3].

Empirical evidence for such models is mostly based on externally generated stimuli, which require visual and auditory interfaces (among others). However, our perception of the world also involves a multisensory representation of our body within it – based on interoceptive signals. Interoception refers to the perception and integration of autonomic, hormonal, visceral and immunological homeostatic signals that collectively describe the physiological state of the body. The idea is that interoceptive sensations operate by the same principles of active inference, thus following the flow of prediction and prediction-error signals through the cortical lamination gradients[4].

This idea has been incorporated in the Embodied Predictive Interoception Coding (EPIC) model[3], which assumes that agranular cortical areas with less laminar differentiation issue predictions to granular cortical areas with greater laminar differentiation, where they modulate perception and action by changing neural firing rates in anticipation of the thalamic input that arrives in sensory cortex (Fig. 1). In motor control, proprioceptive and kinematic representations of the body are updated with prediction errors from motor commands in primary somatosensory cortex (S1), thereby improving performance with practice. Consistent with this model, our previous study with singers demonstrated increased neural activation in larynx S1 as a function of singing experience during the performance of an Italian aria in an fMRI scanner[5], as well as increased gray matter volume in S1[6]. With respect to limbic visceromotor control, the EPIC model posits that the agranular ventral anterior insula (vAI) adjusts



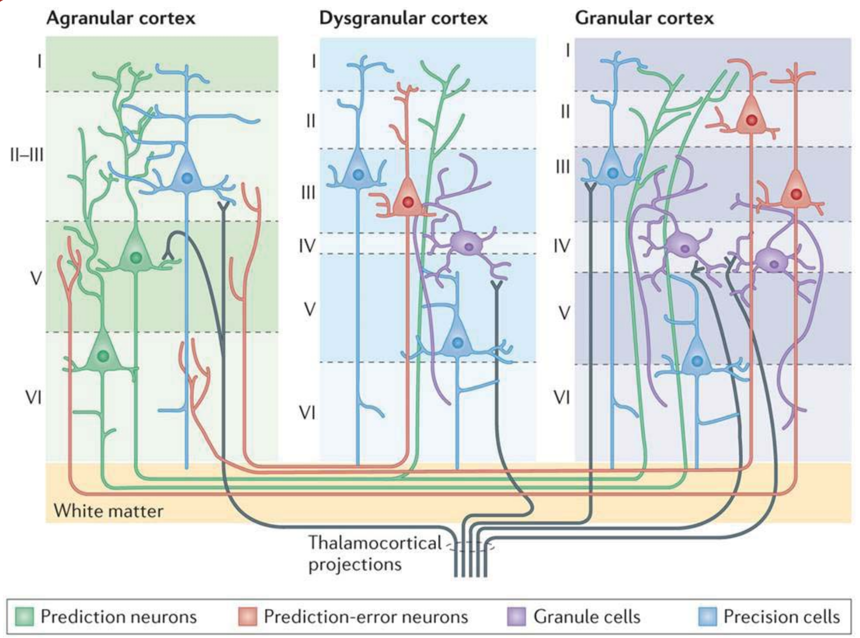


***Figure 1.*** *Prediction neurons (depicted as green pyramidal neurons) in deep layers of agranular cortex drive active inference by sending sensory predictions via projections (green lines) to supragranular layers of dysgranular and granular sensory cortices. Prediction-error neurons (depicted as red pyramidal neurons) in the supragranular layers of granular cortex compute the difference between the predicted and received sensory signal, and send prediction-error signals via projections (red lines) back to the deep layers of agranular cortical regions. Precision cells (depicted as blue pyramidal neurons) tune the gain on predictions and prediction error dynamically, thereby giving these signals reduced (or, in some cases, greater) weight depending on the relative confidence in the descending predictions or the reliability of incoming sensory signals (from Barrett and Simmons, 2015).*

the physiological state of the body by issuing interoceptive predictions to the granular posterior insula (PI), where prediction errors are computed based on interoceptive input and propagated back to visceromotor regions to modulate the response. The AI is also a multisensory integration hub within the salience network and may reduce prediction error by changing the attention to or the integration of sensory inputs. This is compatible with our observation that distinct insular activation patterns in response to singing with perturbed sensory feedback support motor performance as a function of singing experience[7,8].

Interoception is considered a relatively stable trait and is often measured using heartbeat detection paradigms, which engage the AI. Heartbeat tracking procedures require an individual to count the number of times they perceive their heart beating during various time periods, whereas heartbeat discrimination procedures assess the perceived synchrony of the own heartbeats with external stimuli[9]. Discrepancies between subjects' ratings and the actual number of heartbeats/synchronously presented tones determine the level of interoceptive accuracy. We used the latter test in a previous study and found first evidence for enhanced interoception in trained musicians (singers and string players) relative to non-musicians[10]. This led to the development of the "arts hypothesis", suggesting that musical training can shape the precision of interoceptive predictions.

We performed a subsequent study at MIB using a heartbeat tracking task[11]. Professional musicians (n=19), semi-professional triathletes (n=15), and untrained controls (n=14) were chosen in order to test if the nature of sensorimotor training could alter interoceptive accuracy differently. In addition to interoception, participants also performed tactile (i.e., non-nociceptive electrical) and nociceptive (i.e., pressure and heat pain) perceptual tasks. Our results confirmed the previous outcome, indicating increased interoceptive accuracy in musicians but also in athletes relative to controls (Fig. 2A). Both trained groups furthermore showed higher pain sensitivity (Fig. 3A/B), although athletes were less sensitive to tactile stimulation. As expected, musicians demonstrated enhanced tactile temporal discrimination accuracy compared to both athletes and controls. Most importantly, however, accumulated training in musicians was the only predictor (r=.56) of interoceptive accuracy (Fig 2B/C). In athletes and controls, in contrast, positive correlations between pain thresholds and interoceptive accuracy suggested an association with better self-regulation capacities.

We conclude from these data that musical and athletic training contribute differently to interoception. Physical fitness may affect interoception through the self-regulation of health-related behaviors, whereas concurrent multimodal integration training may be the cause of enhanced cardiac prediction in musicians.

This hypothesis is now being tested at MIB in a large study with trained singers (classical/

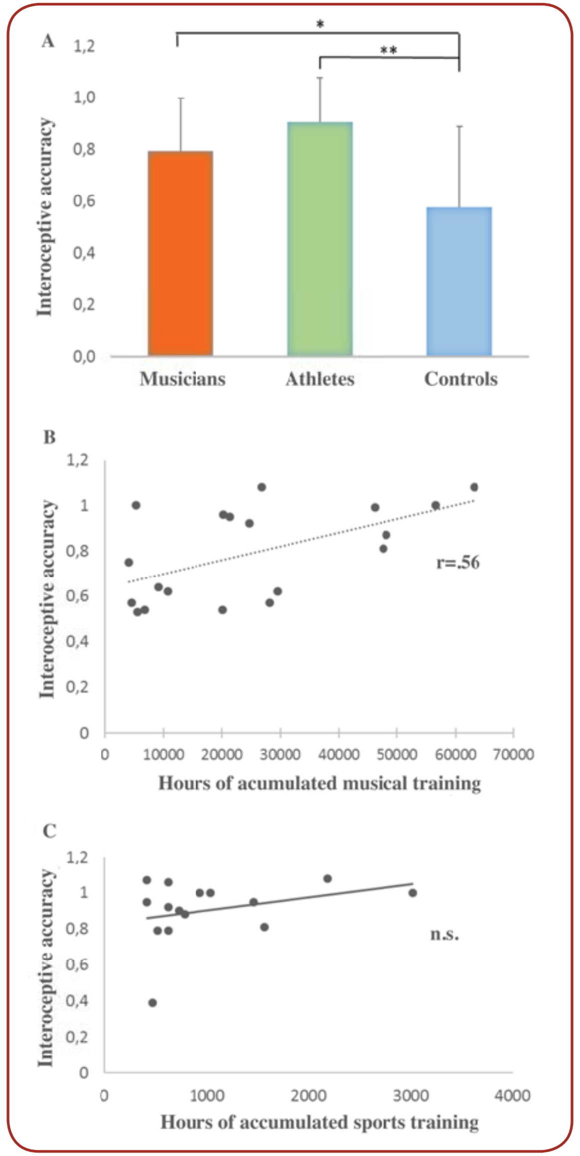


***Figure 2**:. Interoceptive accuracy based on heartbeat tracking performance. A. Musicians and Athletes show enhanced interoceptive accuracy relative to untrained controls (significance indicated by *). Hours of accumulated practice predicted interoceptive accuracy B. in musicians but not C. in athletes.*





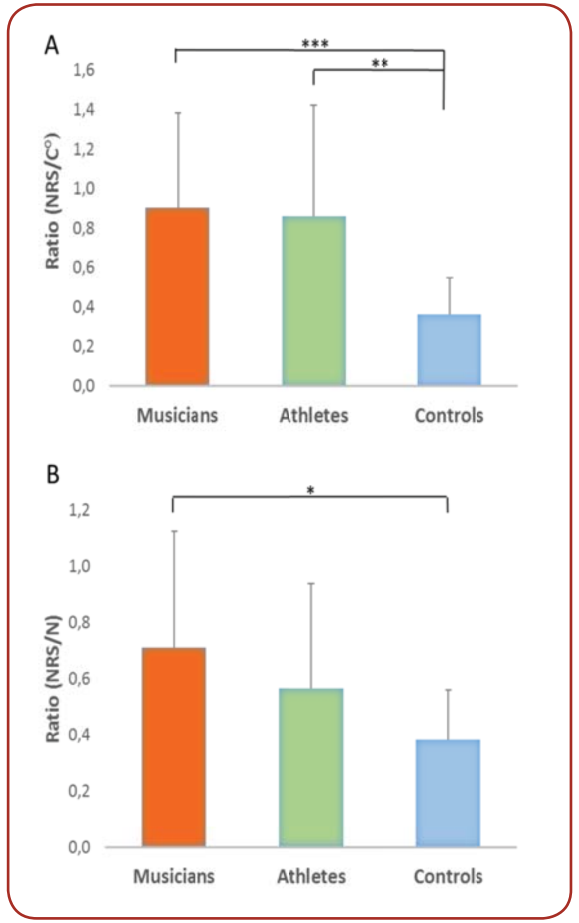


***Figure 3.** Group differences in pain sensitivity. A. = heat pain. B. = pressure pain (significance indicated by *).*

rhythmic) and non-musical controls. Participants (n=61) first performed a comprehensive behavioral test-battery consisting of musical listening tasks, heartbeat discrimination accuracy, and tactile perceptual thresholds. Subsequently, pitch-matching singing tasks were performed in an fMRI scanner, during which acoustic pitch feedback from the own voice was unexpectedly shifted up- or downwards in order to trigger auditory prediction errors. We hypothesized that singers with enhanced interoceptive accuracy would show reduced compensatory motor responses to auditory prediction errors while simultaneously enhancing somatosensory based motor control. Data from this study are currently being analyzed.


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# ACTION

*Peter Vuust*

In 2017, the Action strand - centered around music production, performance and interaction with a special focus on rhythm – had a theoretical breakthrough with the presentation of the PCRI model (the model for predictive coding of rhythmic incongruity) at The Neurosciences and Music – VI conference held at Harvard Medical School in Boston, June 2017 and in subsequent publications[1]. This model (see Predictive Coding, pages 6-7) allows for operationalization of the predictive coding of music theory into concrete experiments with clearly defined hypotheses for behavioural data as well as for neuroscientific measurements. It has been conceived in the realm of rhythm research but can be extended to both melody and harmony, and informs our understanding of musical expertise and the use of music for clinical purposes.

Our model explains prominent features of brain processing of syncopation, which can be captured with behavioral as well as neuroimaging methods. Using the syncopation paradigm, developed in collaboration with the Emotion strand, we have previously found an inverted U-shaped relationship between syncopation/rhythmic prediction on musical pleasure and wanting to move[2,3]. This shows that individual pleasure and urge to move increases the more unpredictable a rhythm becomes until a certain point from which is decreases. The hypothesis derived from the PCRI is that this can only be true if the precision of the underlying predictive brain model (the meter) correlates negatively with increasing syncopation (deviation from regularity) in the stimulus. In 2017, in a motion capture study, we proved this indeed to be the case[4].

In collaboration with Prof Virginia Penhune, and PhD student Tomas Matthews, Concordia University, we further developed this paradigm incorporating three levels of rhythmic and harmonic complexity. Using this paradigm we have been the first to show that the medium levels of rhythmic and harmonic complexity, which provides the greatest pleasurable sensation of wanting to move[5], is linked to brain regions specialized for motor activity and reward processing. Furthermore, we found an interaction between musicianship and rhythmic complexity showing that musicians have a stronger urge to move to medium levels of complexity than non-musicians. Using fMRI we have shown that this sensation of groove is coupled with more pre-motor activity as measured with fMRI[6], which is consistent with brain connectivity studies showing more action-based network activity in musicians[7].

The PCRI model may also explain observed differences between musicians and non-musicians, where results typically show stronger brain activity in relation to prediction error, marked by larger amplitude of the mismatch negativity (MMN), recorded by MEG or EEG, e.g. to rhythmic syncopation[8]. The musicians simply predict the timing of rhythmic event more precisely than non-musicians, leading to stronger precision-weighted prediction error, consistent with PCRI. PCRI is furthermore consistent with the recent finding by Davies and colleagues[9], that the contribution of systematic increase in microtiming (small deviation from isochronous rhythms in music) leads to decreased groove ratings in normal subjects, which is contrary to common belief among musicians and musicologists. Accordingly, the development of PCRI has informed the studies of musical expertise by newly appointed postdoc Marina Kliuchko in collaboration with the Learning strand, as well as PhD student Cecilie Møller's studies of how visual cues may enhance auditory perception testing the Principle of Inverse Effectiveness behaviourally[10] and using MEG[11]. PCRI has led us to form novel hypotheses, which are now being tested by PhD student Ole Adrian Heggli, who studies the influence of predictive model on interpersonal tapping using EEG[12], and the studies of David Quiroga on the influence of predictive context on the MMN in a paradigm, being the first to show MMNs when participants are listening to real music material[13].

PCRI is furthermore highly relevant for understanding musical reward[14], aesthetic appreciation[15,16], music pedagogy[17] and in particular for clinical studies where different patient groups may show either low or high precision in relation to musical predictions[18-25].

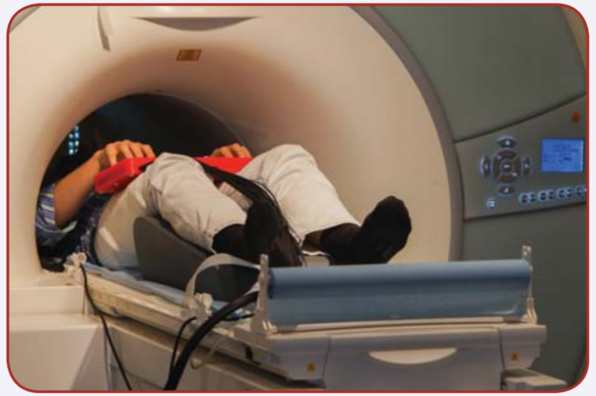
In 2017, the Action strand developed novel and strengthened already existing collaborations within the center, at AU, with other DG centers of excellence, with external companies as well as research institutions abroad. As a clinical example of this medical student Anne Sofie Andersen successfully completed her research project using the "MuMufe" and the "free listening" paradigms to test music listening abilities in cochlear implantees[26]. This project was a collaboration between the Learning and the Action strand in MIB, funded by Oticon Medical performed in collaboration with researchers in Helsinki.

On a similar note of particular relevance to music pedagogy we released the press report from the mass experiment including data from more than

20,000 school children (age 6-18y)[17,27], showing that music abilities correlate with auditory working memory regardless of grade level. The data, which was collected in collaboration with MIB's Learning strand, Astra and Dansk Naturvidenskabsfestival is now being further analysed together with among others, Daniel Müllensiefen, reader in psychology (formerly Computing) at Goldsmiths College, London.

As a curiosity, PhD student Ole Adrian Heggli developed a fMRI-compatible keyboard[28] in collaboration with CFIN-employe Martin Snejbjerg, which has already been used successfully by PhD student Patricia Mota who in collaboration with the Emotion strand studies musical improvisation.

As an off set for future studies the Action strand published theoretical papers on rhythm[3], book chapters on music improvisation[29] and the future of neuroscience and music[30], and a monograph on music in the brain targeting the general public[31].



*The MRI compatible keyboard* *Photo: Ole Adrian Heggli*

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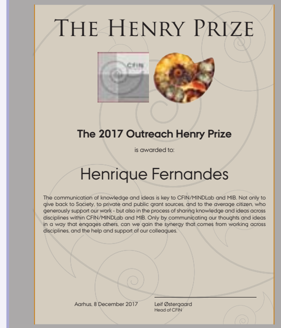
## PRIZES

Patricia Alves da Mota won the prize for Best Poster at the Annual PhD day at Aarhus University.

Stine Derdau Sørensen won the clinical research Flash Presentation prize for her 3 minutes' talk about the Mass Experiment at the annual Neuroscience Day at Aarhus University.


Peter Vuust was awarded Dansk Lydpris 2017 at Danish Sound Day.




Henrique Fernandes was awarded The Outreach Henry Prize at a ceremony during the annual joint CFIN & MIB Christmas Dinner.

# ACTION

## Neural prediction error in complex temporal patterns: an information theoretical characterisation

**By Massimo Lumaca**

The human's brain ability to form predictions is critical in rhythm perception and, more in general, in temporal perceptual analysis. Within the framework of predictive coding (PC)[1,2], the auditory system evaluates temporal patterns with respect to their statistical properties, from which it forms predictions about future events. The brain's task is to minimize the discrepancy between the expected and the actual event, i.e. the error (or 'surprise'), to progressively attain a more accurate model of the sensory input[3,4]. But how does the information content of rhythmic stimuli affect this process?

The predictability of rhythmic patterns decreases as a function of their information content: for example, by increasing the amount of distinct inter-tone time intervals. An entropy metric derived from information theory[5] summarizes this information by a single value, measured in bits. When tone patterns have only a single time interval - they are 'isochronous'- their entropy is 0, and they are fully regular and predictable. Conversely, when patterns have several different duration values, their entropy is large and their events are more difficult to predict in time. According to PC, the brain not only forms predictions about future events but also generates estimates about their reliability (or precision). When precision is high - i.e., when the brain's estimate of the internal model is deemed as accurate - deviations from expectations are up-weighted and the signal is prioritized for further processing[6]. Instead, when precision is low, the stimulus may be deemed as uninformative and down-regulated.

In a recent work, Vuust and colleagues[7] extended this idea to the processing of musical rhythms with the predictive coding of rhythmic incongruity (PCRI) model.  In line with PC assumptions, the PCRI model predicts that an error signal is elicited by meter-rhythm incongruities, whose magnitude reflects the precision of prediction - there, the brain's estimate of the uncertainty about the meter. Regular (low-entropic) rhythms tend generally to be in accordance with the meter, and, as a result, their prediction errors are given more salience (viceversa for more entropic, irregular stimuli). More generally, the authors hypothesized an increased prediction error (or surprise) for violations of regular stimuli and  opposite effects for violations of more uncertain patterns.

Here, we addressed this hypothesis with electroencephalography (EEG) by relating the entropy of rhythmic patterns to the magnitude of a neural marker of prediction error: the mismatch negativity (MMN) evoked potential[8]. The MMN is a fronto-central negative evoked response that is observed when a regularity established via





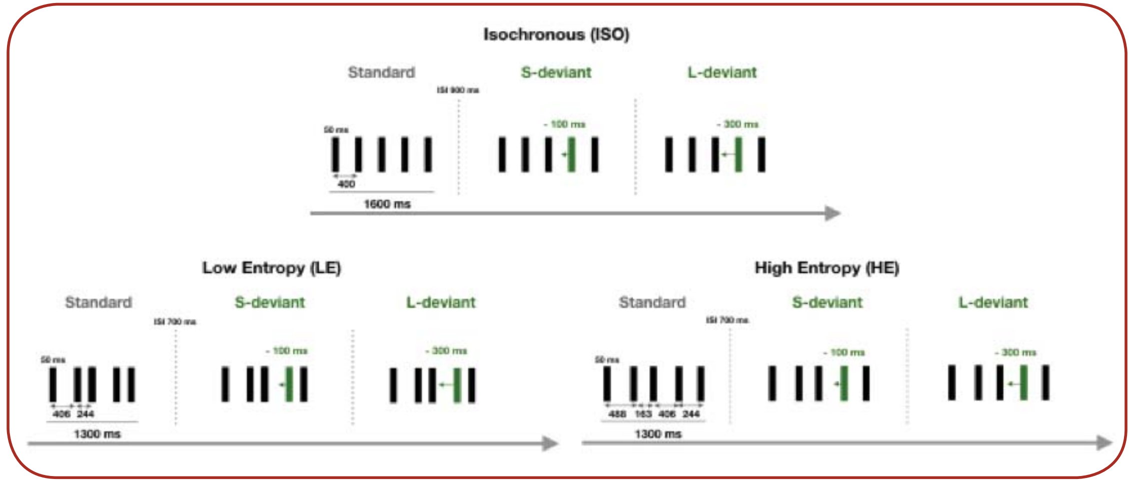



***Figure 1.** Schematic illustration of the paradigm. The upper panel displays the isochronous condition, in which standard sequences are five isochronous tones of one pitch (randomly varying on three pitch levels). The lower panel displays the low-entropy (LE) and high-entropy conditions (HE), in which similar five tone sequences vary in their time intervals: two time intervals in the LE and four time intervals in the HE. In all conditions, the deviant is an anticipation of the fourth tone by 100-ms (small deviant; S-deviant) or 300-ms (large deviant; L-deviant).*

repetitions of a 'standard' stimulus is violated by rare 'deviant' stimuli. It is automatic (i.e., it does not require attention) and typically peaks at 100-220 ms from the deviant onset. Under PC, its magnitude directly reflects the cortical prediction error signal. To understand how information content of temporal patterns affects precision-weighting in temporal predictive coding, we parametrically modulated the entropy of stimuli across three recording oddball runs: isochronous (E=0 bit), low-entropy (E=1 bit), and high-entropy (E=2 bits). The order of runs was counterbalanced across participants. EEG data was in the meanwhile recorded from the participants (non-musicians). In each run, 5-tone standard stimuli (80%) of one given entropy were infrequently interrupted by identical stimuli with the fourth beat shifted backward by 100-ms (small deviants; 10%) or 300-ms (large deviants; 10%) (Fig. 1). Our aim was to examine changes in the neural prediction error signal (i.e., MMN amplitude) as a function of the rhythms' information content, and how this was affected by the magnitude of violation.

Figure 2 shows our results. An MMN evoked potential was generated from both time-deviant stimuli, peaking at 160-200 ms from the deviant onset over the fronto-central electrodes. Critically, we observed a gradual decrease in the magnitude of the error signal as a function of entropy, but only for small deviant sounds.

Our findings extend past work on the effects of regularity on neural change detection mechanisms. Behavioural data reveals an enhancement of temporal perceptual analysis in the presence of regular statistical structure, as assessed by the listener's ability to detect timing-deviant events[9]. However, the underlying mechanisms - neuronal adaptation versus prediction (more in[10] - are as

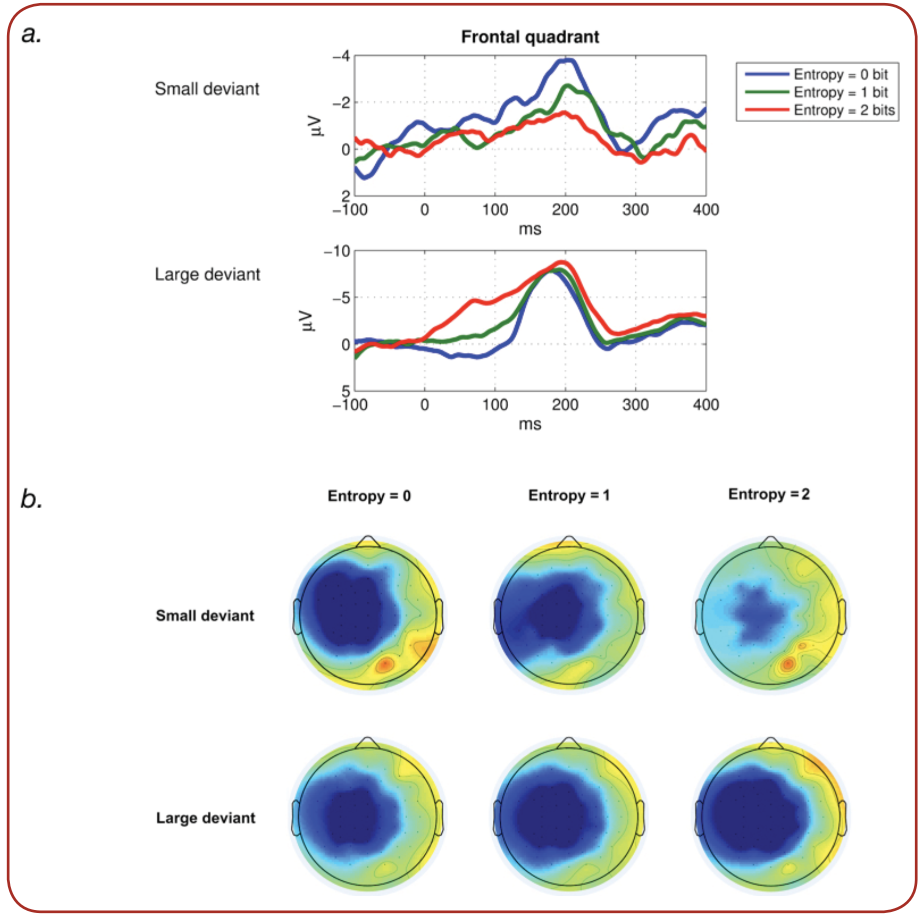



***Figure 2.*** *(a) MMN difference waves and (b) scalp topographies for small and large deviant sounds.*

yet debated. A number of studies reported an enhanced MMN to violations of regular versus irregular stimuli[11–13], which however was mainly attributed to neural adaptation - a diminished N1 response to repeating “standard” tones in regular compared to irregular stimuli. Conversely, no effect of temporal statistical structure was observed in deviant-evoked activity. To date, this pattern of findings has designed neuronal adaptation as the only mechanism subserving timing-change detection behaviours[14,15]. Our results cast doubts on this conclusion. We showed that deviant responses, but not standard responses, were affected by temporal regularity. This finding suggests that at least part of the MMN enhancement in regular contexts may arise from a (failed) prediction. Overall, it indicates the existence of predictive mechanisms sensitive to the uncertainty of the sensory context.

Also, our results are consistent with mechanisms that compute the information content of temporal patterns and uses this information to up- or down-regulate neural prediction errors. One key assumption of precision accounts is that error signals can be larger or smaller depending on the confidence of prediction. In past work, the investigation of this issue was limited to a simple contrast between isochronous and randomly generated sequences[11–13,16]. These conditions represent only the two ends of a continuous spectrum of predictable configurations. Here, we showed a modulation of the prediction error signal as a function of multiple levels of uncertainty. Specifically, we showed that the MMN amplitude decrease as the stimulus entropy increases. One interpretation is that the brain’s metrical precision estimates for high-content stimuli are deemed as unreliable, with a consequent down-regulation of the prediction error signal[7]. This mechanism appears to be fast (within 200 ms from the deviant onset) and automatic (irrespective of directed attention). The specificity of the effect, limited to small deviant responses, also suggests a fine-grained dependence of precision-weight mechanisms to the accuracy of the internal model. This idea needs to be further examined in future studies using deviants of multiple magnitudes (>2).

Finally, our results support the view of Shannon entropy as a reliable perceptual measure of rhythmic uncertainty. In most previous works, the attempt to relate rhythmic complexity and prediction error has taken a music-theoretical approach: complexity was operationalised as the degree of perceived tension created by going against metrically salient pulses[4,17]. Here, we showed the sensitivity of predictive coding to a more general index of rhythmic complexity: the amount of information content.

Our findings provide evidence in support of precision accounts and contribute to the understanding of how the brain acquires an internal model of regularities under different states of temporal uncertainty.

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# EMOTION

*Morten L. Kringelbach*

Emotion is most powerfully evoked by music and we continue to explore how this can give rise not only to hedonia (hedone, the ancient Greek word for pleasure derived from the sweet taste of honey, hedus) but also to eudaimonia (a life well-lived)[1,2]. This distinction was already proposed by Aristotle, but music has proven a powerful empirical tool for investigating the underlying brain states constituting and underlying emotion[3-6].

The research is supported by the strong collaborative links between MIB, Oxford and Barcelona, where we are developing new groundbreaking whole-brain computational models with Prof Gustavo Deco[7-12]. As such this enables us to study music with methods from many disciplines including psychology, neuroscience, physics, engineering and computer science to create groundbreaking science.

An excellent example is the feature ”Music, sleep and state transitions in the brain” on page 28 by postdocs Kira Vibe Jespersen and Angus Stevner. Another example is the project conducted by doctoral student Patricia Alves da Mota using neuroimaging to explore the underlying neural mechanisms of spontaneous musical composition in jazz musicians. Yet another example comes from the research of doctoral student Ole Heggli on describing the intricacies of interpersonal tapping through coupled Kuramoto oscillators.

**Music and psychedelics expands the brain's repertoire**

Here we highlight one example of recent published findings of how the effects of music can be powerfully synergised with psychedelics to expand the repertoire and criticality of the human brain[13,14]. Working with Dr Selen Atasoy, Prof Gustavo Deco and Dr Robin Carhart-Harris, we investigated the effects of music and LSD (lysergic acid diethylamide) which was initially synthetized by Albert Hofmann in 1938 to stimulate the respiratory and circulatory systems. Yet, it was 5 years later that he accidentally discovered the profound effects of LSD on perception and consciousness, which led to its extensive use as a research and therapeutic tool in psychiatry in the 1950s. Today, LSD and related psychedelics are considered by some to be ‘microscopes’ or ‘telescopes’ for the psyche, because they reveal more of the mind than is normally accessible. However, the brain mechanisms underlying LSD's profound effects have remained largely elusive.

To decode the effects of music and LSD in the brain, we used a novel harmonic language of brain activity (Figures 1 and 2), which was firstly introduced in a Nature Communications publication in January 2016[15]. This harmonic decoding of fMRI data showed that LSD increases the total energy and enriches the repertoire of connectome harmonics - the basic elements of this harmonic language (Figure 3). The research



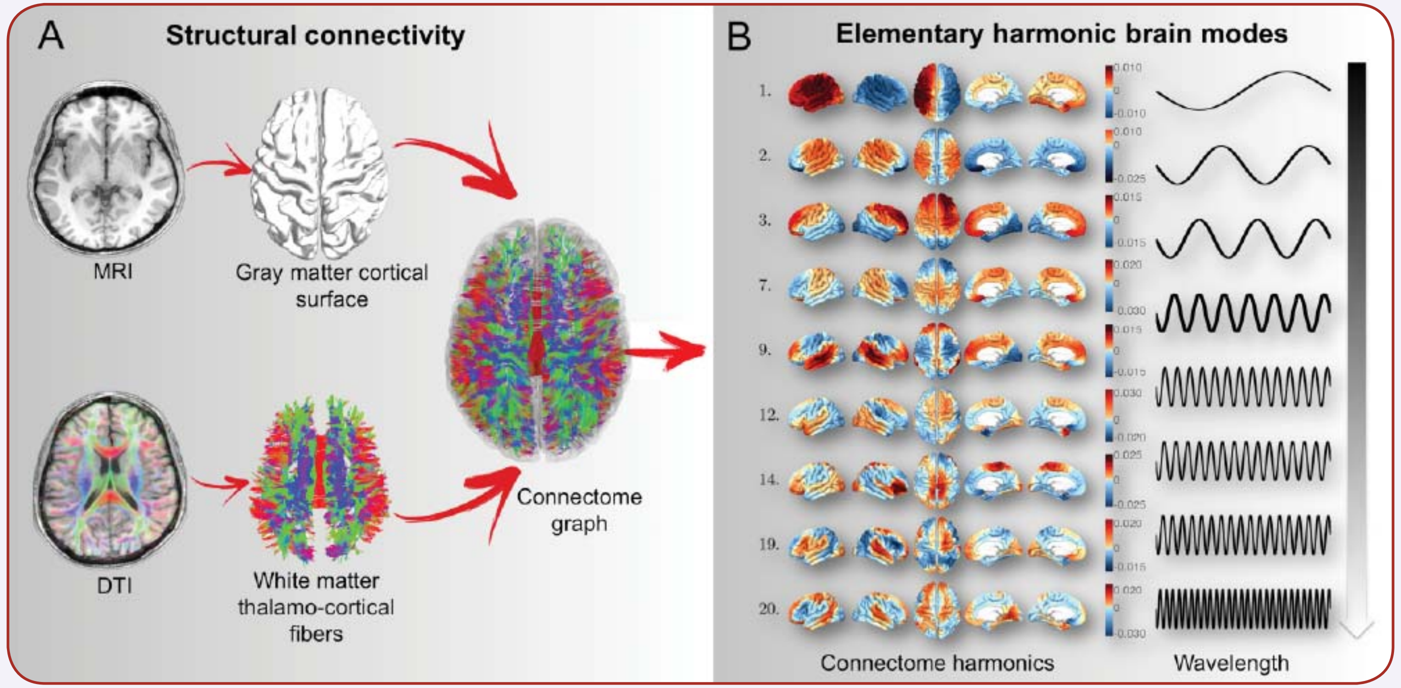


***Figure 1**. Connectome Harmonics Framework. (A) Structural connectivity of the human brain defined as the combination of local cortical, gray matter connections. (B) Elementary harmonic brain modes defined as fully synchronous patterns of neural activity are estimated as the harmonic modes of structural connectivity; that is, connectome harmonics.*

also revealed that LSD selectively activated high-frequency connectome harmonics, which remarkably caused the brain activity to self-organize right at the edge of chaos. This effect was enhanced when listening to music.

The connectome harmonics used for decoding brain activity are universal harmonic waves, such as sound waves emerging within a musical instrument, but adapted to the anatomy of the brain. Translating fMRI data into this harmonic language is actually not different than

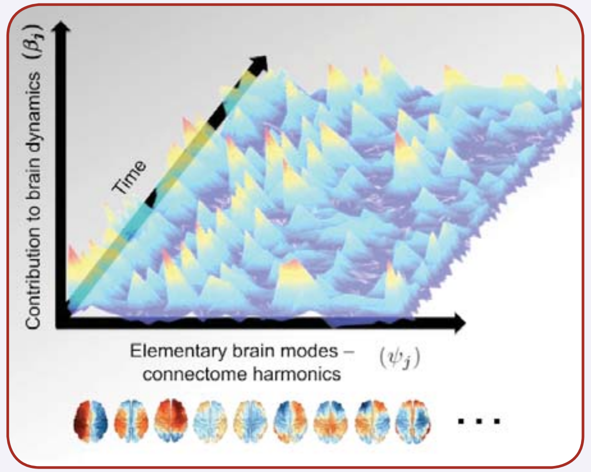


***Figure 2.** Connectome Harmonics. Projection of spatiotemporal patterns of neural activity reveals the contribution ($\beta_j$) of each connectome harmonic ($\psi_j$)—elementary harmonic brain mode—to brain dynamics.*

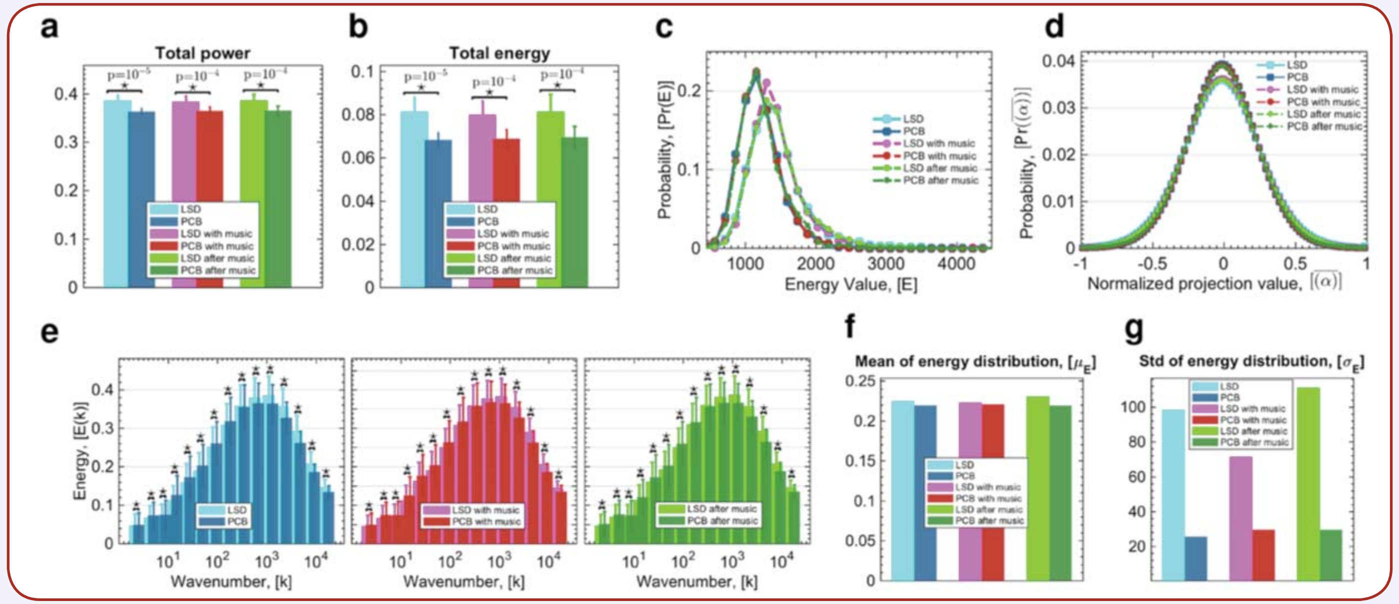


***Figure 3.*** *Changes in power and energy of brain states under LSD and music. Total power (**a**) and total energy (**b**) of all harmonic brain states for all 6 conditions, where stars indicate significant differences ($p < 10^{-4}$, two-sample t-test) between each pair of LSD vs. PCB conditions with indicated p-values. (**c**) Probability distribution of total energy values (sum over all harmonics) for all 6 conditions. (**d**) Probability distribution of the occurrence of projection values (the amount of contribution) of connectome harmonics after normalization of each harmonic's contribution by the maximum value of the baseline (PCB) condition, shown for all 6 conditions; LSD, PCB, LSD with-music, PCB with-music, LSD after-music, PCB after-music. (**e**) Energy of connectome harmonics quantized into 15 levels of wavenumbers k (in the log-scale) for conditions (le ) LSD vs. PCB, (middle) LSD with-music vs. PCB with-music, (right) LSD after-music vs. PCB after-music. Stars indicate significant differences ($p < 0.01$, Monte-Carlo simulations after Bonferroni correction). (**f**) and (**g**) show the mean (μ) and standard deviation (σ) of the fit of the energy distribution of frequencies shown in (**e**) to normal distribution for all conditions, respectively.*

decomposing a complex musical piece into its musical notes. In many ways what LSD is doing to the brain seems to be similar to jazz improvisation, where the brain combines many more of these harmonic waves (connectome harmonics) spontaneously yet in a structured way, just like improvising jazz musicians play musical notes in a spontaneous, non-random fashion. The method introduces a new paradigm to study brain function that links space and time in brain activity via the universal principle of harmonic waves. It also shows that this spatio-temporal relation in brain dynamics resides at the transition between order and chaos.

Our findings reveal the first experimental evidence that LSD tunes brain dynamics closer to criticality, a state that is maximally diverse and flexible while retaining properties of order. This may explain the unusual richness of consciousness experienced under psychedelic drugs and the notion that they 'expand consciousness'.



By revealing the characteristic differences between LSD and normal awake state, the applied harmonic wave decomposition opens-up the possibility of extracting the signatures of various mental states, including sleep, anesthesia, and disorders of consciousness as well as psychiatric and neurological disorders.

## Continued development of novel methods

As shown, we are continuing to develop new methods to study the dynamic effects of music on emotion. In particular we have developed whole-brain computational modelling for revealing the underlying causal brain mechanisms[16]. These developments will help us identify how music evokes emotion and how music can best help emotion regulation. As shown elsewhere, one pertinent finding is the role of music in controlling sleep which can contribute to regulate overall mood in neuropsychiatric disorders.

Overall, careful experimental methods combined with novel analysis methods including connectome-harmonics and causal whole-brain modelling are helping to reveal the brain mechanisms of music and emotion, potentially opening up for new treatments; perhaps even eudaimonia and better lives - especially if coupled with early interventions.

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# EMOTION

Music, sleep and state transitions in the brain

**By Kira Vibe Jespersen and Angus Stevner**

When Count Keyserling had one of his many sleepless nights, he would call upon his harpsichordist Johann Gottlieb Goldberg and have him play for him. Johan Sebastian Bach was the young Goldberg's music teacher, and during a visit to Leipzig, Count Keyserling mentioned that he would like some clavier pieces that Goldberg could play to soothe his insomnia. Bach granted him this request and thus gave us the famous Goldberg variations – or at least so the story goes…

As illustrated by this tale, the idea of music as a tool to improve sleep is not a new one. As early as 500 BC Pythagoras claimed that specific music could purify the mind and bring sound sleep, and all over the world parents sing their children to sleep. Studies show that listening to music is a common strategy when people have sleep difficulties, but there is very little scientific research in this field, and it remains unclear if music can actually improve sleep.

At Center for Music in the Brain, a number of studies have contributed to a growing knowledge in the field of music and sleep. In a recent study, we evaluated the effect of bedtime music on sleep in adults with insomnia disorder. Insomnia disorder is a diagnosis characterized by frequent and persistent difficulties initiating and maintaining sleep associated to substantial daytime impairment in important areas of life[1]. To assess the effects of bedtime music on sleep in this population with persistent sleep problems, we conducted a randomized controlled trial with three parallel groups: one intervention group listening to music daily at bedtime, one active control group listening to audiobooks daily at bedtime, and one passive control group with no intervention. The results showed that significantly more participants in the music group experienced sleep improvement compared to the control groups (see Figure 1). In addition, the quality of life of the music group improved, but there were no changes in objective measures of sleep[2]. These results suggest a positive effect of the music intervention on sleep quality, but these effects were not captured by the polysomnography (PSG) used to objectively register sleep architecture.

The discrepancy between the subjective rating of sleep quality and objective measures of sleep is well documented[3,4]. Individuals, insomniacs in particular, will regularly report wakefulness, when objective signs indicate sleep[5]. In general it is not possible to identify individuals with insomnia based on current definitions of their sleep architecture. As a consequence, the diagnostic criteria of insomnia disorder do not include objective assessments of sleep[1,6]. Insomnia is primarily a disorder of perceived rather than of





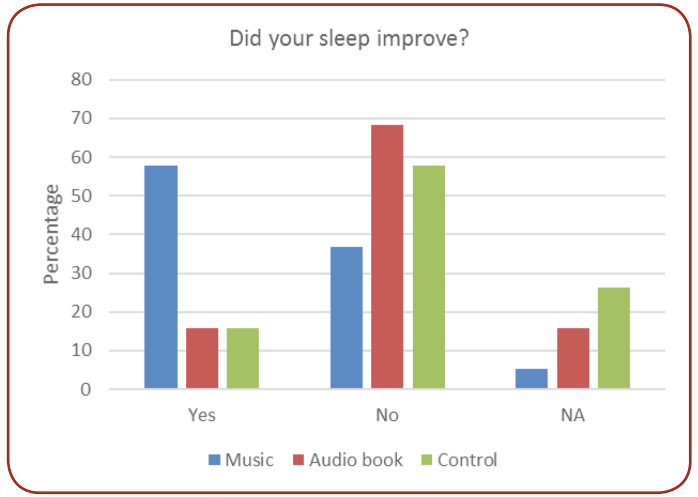


***Figure 1.*** *Ratings of sleep improvement after the intervention period: Significantly more individuals in the music group reported improvement in sleep than those in the other two groups, in spite of no differences in objective measures of sleep. From Jespersen and colleagues[2].*

measured sleep. While the paucity in objective insight impedes the understanding and treatment of insomnia, it also suggests that our description of sleep may be incomplete. PSG, the current gold standard of sleep categorisation, distinguishes between wakefulness, rapid eye movement (REM), and three stages of non-REM (NREM) sleep. This staging is based on visibly different patterns of amplitude and frequency in EEG recordings, typically measured with no more than six electrodes[7]. Spatially and temporally PSG represents a very coarse summary of brain activity and is unlikely to capture the complexity of human sleep. Sleep misperception and the limited usefulness of PSG in the understanding and diagnosis of insomnia could stem from PSG being a too simplified account of on-going brain activity.

To address the finer spatiotemporal detail of normal sleep brain activity, we recently took advantage of a rare dataset from a cohort of healthy individuals falling asleep while being measured with simultaneous fMRI and EEG[8]. The EEG was used to score sleep according to standard PSG guidelines, while the fMRI signals were submitted to a completely data-driven analysis of dynamic functional connectivity (FC) in a network comprised of cortical and subcortical areas. Independent of the EEG-based sleep staging, the employed Hidden Markov Model (HMM)[9] was able to track over time the emergence and dissolution of large-scale FC networks, including well-known resting-state networks, such as the default mode (DMN) and fronto-parietal attention networks. Aligning in time the transitions between these dynamic FC networks and the independently scored PSG stages of sleep, yield the transition map shown in Figure 2A. Generally, traditional PSG stages of wakefulness and NREM sleep mapped on to different compartments of the transition map. However, the superior resolution of the FC network states in time (multiple states of shorter life times per sleep stage) and space (whole-brain region specificity) provide several new insights regarding the complexity of normal sleep. In particular, the improved resolution of the large-scale network transitions occurring around the onset and termination of traditionally defined sleep stages could help generate network-based hypothesis regarding the mechanisms underlying insomnia and sleep misperception (see figure text of Figure 2B).

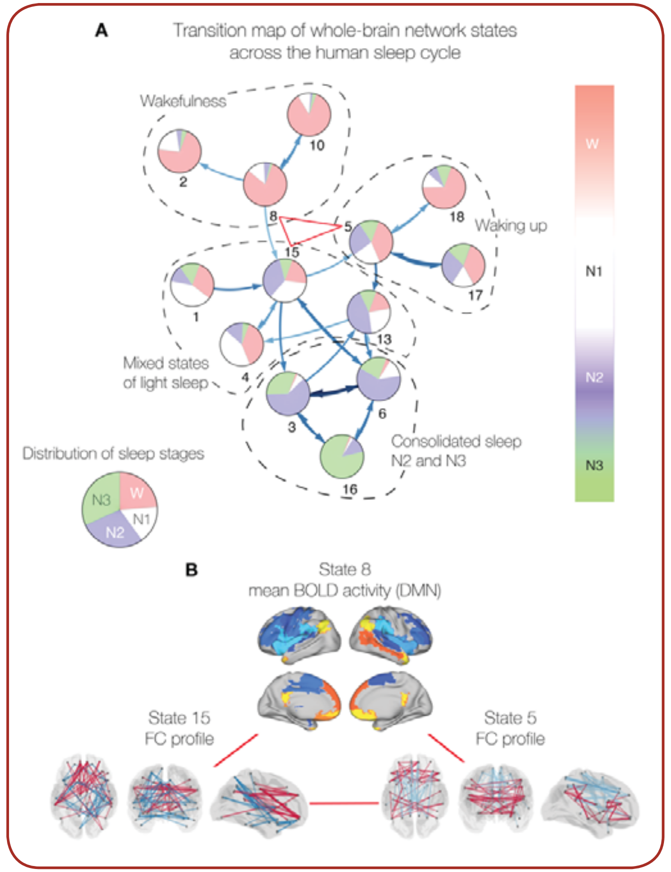


***Figure 2.*** *Whole-brain network transition of the normal sleep cycle: A) When applied to continuous fMRI recordings of 56 individuals, the data-driven Hidden Markov Model derived a transition map between a set of whole-brain networks states. Using traditional sleep staging from simultaneous EEG, it is clear that the whole-brain network states generally describes the cycle between wakefulness (W) and individual stages of NREM sleep (N1, N2, and N3). B) The whole-brain network configurations surrounding the transition between wakefulness and sleep (see red triangle in A) are highlighted. The most likely descent to sleep goes through an increased BOLD activity in the DMN (state 8), and one hypothesis could be that insomniacs either cannot enter the DMN or leave it in a way appropriate for the initiation of sleep. It is also possible that brain networks of insomniacs are affected in ways related to the whole-brain network states of light sleep (state 15) or waking up (state 5). From Stevner and colleagues[8].*

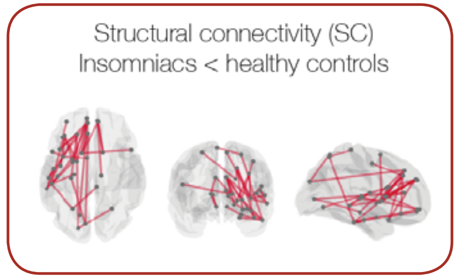


***Figure 3****. Differences in structural connectivity between people suffering from insomnia and healthy controls: Persons with insomnia had reduced structural connectivity in a largely left-lateralized network involving brain regions related to interoception, emotional processing and stress-responses. It remains unknown how these structural alterations relate to functional connectivity as measured with fMRI or MEG. From Jespersen and colleagues[12].*

The dynamic functional brain networks explored above may be seen as realisations of the underlying structural connectome[10,11]. Using diffusion tensor imaging (DTI) it is possible to construct whole-brain networks quantifying the strength of white-matter fibre connections between grey-matter brain areas. We recently compared the structural connectivity (SC) networks from a group of participants suffering from insomnia to that of a group of age-matched controls (see Figure 3). Interestingly, we found a network of decreased connectivity in insomniacs relative to controls localised primarily to the left hemisphere, with connections overlapping the FC profiles of dynamic whole-brain states identified as important for transitions between wakefulness and sleep in healthy sleep (see Figure 2, states 5 and 15). These include connections between medial frontal areas, the left temporal cortex and left insula[12].



A refined understanding of the neural sleep processes is essential for unravelling the dynamics of insomnia and assessing the effect of music as a tool for sleep improvement. Based on the presented work, we hypothesize that music may facilitate the transitions from wake to sleep, and future studies will investigate the effect of music on whole-brain state transitions.

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## NEW FACE AT MIB

**Angus Stevner, DPhil**

Angus Stevner obtained his bachelor's degree in Medicine in 2013 from University of Copenhagen. For his bachelor's thesis he worked on developing tools for source reconstruction of MEG data under the supervision of Prof Morten Kringelbach in Oxford as well as at the Center of Functionally Integrative Neuroscience (CFIN), AU. He went on to study for a DPhil (PhD) at Department of Psychiatry, University of Oxford, which he completed in 2017, again under the supervision of Prof Kringelbach. During his doctoral work he investigated the role of large-scale brain networks in transitions between wakefulness and sleep, using neuroimaging data including magnetoencephalography, functional MRI, and diffusion tensor imaging (DTI).

Angus continues to pursue his interests in how the brain's large-scale network activity and rhythms support the wide range of behavioural and cognitive states we as humans experience. Sleep remains a primary topic, which is reflected in his close collaboration with MIB's Kira Vibe Jespersen on developing a better understanding of the sleep disorder insomnia.

Angus has been affiliated to MIB throughout his DPhil, and after a brief stay as postdoctoral researcher at Department of Psychiatry in Oxford, he has now joined MIB for a 1-year postdoc.

# LEARNING

*Elvira Brattico*

Music represents a multifarious tool for studying learning. Compared to other school disciplines mainly based on conceptual skills and knowledge (e.g., history or geography), learning music, intended both as theory, culture and instrumental practise, involves the acquisition of different abilities[1]: precise associations between motor sequences and auditory events that lead to multimodal predictions, accuracy in feature encoding and discrimination, kinaesthetic control, visual perception of the score and hand movements, pattern recognition and memorisation, bimanual coordination, and translation of visual symbols into audio-motor sequences (see Figure 1). Both in healthy and clinical conditions, these musical abilities transfer to the improvement of other non-musical skills that are either related to the trained skills (e.g., auditory acuity), use the same brain substrates (e.g., speech) or are domain-general and implicitly fostered by music training (e.g., attention, empathy, self-esteem).

Different learning mechanisms are at play: enculturation, habituation, sensitization, non-instrumental learning, episodic memory, pleasure cycle and so on. Among them, predictive coding theory hypothesizes that our brain continuously forms models for predicting future sounds which are updated based on experience and their repetition generates the probabilistic acquisition of new models.

Different methods for learning to play an instrument (didactics) exist, some of them being so formalized that neuroscience studies are feasible. To name a few, the Suzuki method teaches young children how to play the violin by imitation rather than starting from the score, and El Sistema emphasizes collective teaching. Finally, both the learning process and outcomes are strongly determined by individual dispositions.

The Learning strand at MIB addresses all these aspects of music learning across the lifespan: acquired skills, underlying mechanisms, didactics and individual styles. We also care about the impact of our research on the Danish school system and society at large: collaborations with several educational institutions in eastern Jutland have been launched, and MIB's participation in the Danish Science Festival in 2016 resulted in the development of new tools for developmental music research. MIB also supports Orkestermester, a music programme with many Danish primary schools funded by Nordea Fonden.

**Looking at the final product to understand the changes**

One approach for studying music learning consists in looking at the final product, the professional musician, who has already acquired the palette of skills, as opposed to the nonmusician. This allows us to understand the main differences that characterize the behaviour, psychology and brain of a trained individual, isolating the neurocognitive signature of music expertise. In 2017, we found that musicians can be discerned from nonmusicians by looking at their fMRI responses to musical pieces with 77% accuracy[2] (see Figure 2). In a related fMRI study[3] we discovered that the neural connectivity patterns of musicians involved greater integration of motor and somatosensory homunculi representing the upper limbs and torso. In contrast, the neural networks activated during music listening in nonmusicians were only related to perceptual processes. We also noticed strengthened functional integration of action-perception fMRI networks associated with pulse clarity perception in musicians than in nonmusicians[4].

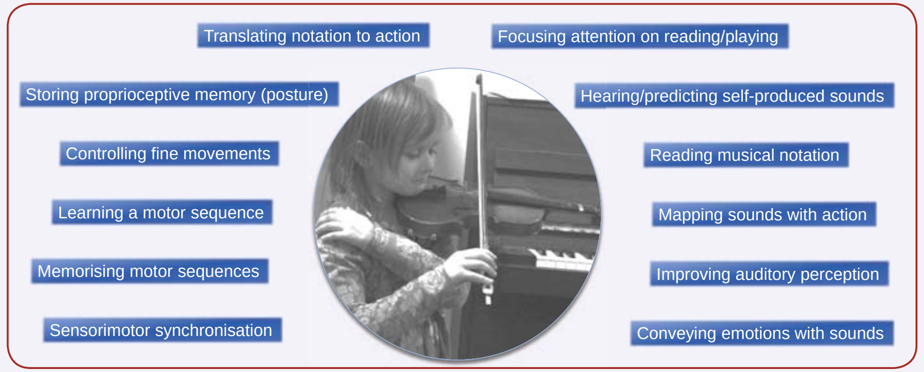
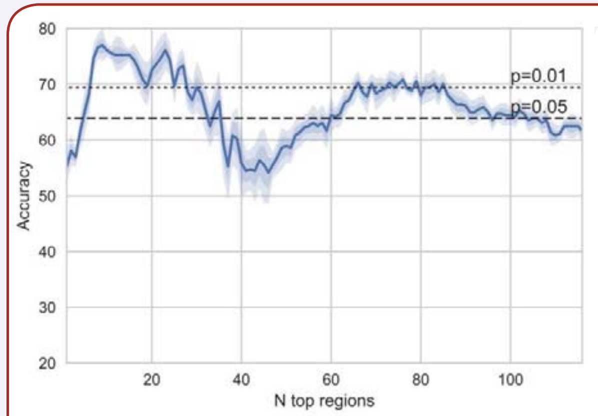



***Figure 1**. The different abilities acquired when learning to play a musical instrument, e.g.,the violin.*

Besides motor skills, the study of musicians can shed light on how musical structure shapes the predictive processes. This is particularly exemplified by experts of contemporary classical music (CCM), a genre characterized by a sensorily unpleasant and unique sound content[5] (see feature by Haumann & Mencke on page 36). Furthermore, the measurement of brain responses to style-specific sound patterns of Sub-Saharian African music in both African and Danish participants showed the superior discrimination of polyrhythmic changes in experts of African music as compared to non-experts[6].

**Studying the process to reveal the factors**

Several of our studies are aimed at discovering the different factors that affect the learning process and lead to a successful outcome. One study focused on adult pianists who learned to play by heart a piano sonata by D. Scarlatti[7]. They were measured with fMRI before and after the 4-weeks learning period while they listened to the sonata, and at the end of the study audio-visual recordings of each subject's piano performance were obtained. Previous studies had either merely looked at the outcome or examined the process by requiring untrained participants to memorize simple motor sequences in laboratory setting. Our study is innovative in the sense that it reproduced learning as it happens in the music school. Moreover, it took into account the individual factors that impact the learning process and outcome, such as engagement with the task. Results evidence the importance of the ventral striatal and action observation regions of the brain for reaching an optimal performance outcome.




| Region | Z-value | p-value |
|---|---|---|
| Caudate nucleus L | −0.122 | 0.549 |
| Caudate nucleus R | 0.428 | 0.334 |
| Middle frontal gyrus R | 0.008 | 0.497 |
| Middle frontal gyrus, orbital part R | 1.000 | 0.159 |
| Anterior cingulate and paracingul. gyrus L | 1.901 | **0.029** |
| Anterior cingulate and paracingul. gyrus R | 2.229 | **0.013** |
| Inferior frontal gyrus, opercular part R | 2.225 | **0.013** |
| Inferior frontal gyrus, triangular part R | 0.299 | 0.382 |
| Superior temporal gyrus R | 1.654 | **0.049** |


***Figure 2.*** *Top, left: Accuracy and confidence interval of decoding musicians from fMRI responses to music using different numbers of regions. The average decoding accuracy for the top regions reached 77%. Top right, Z-values and p-values for the log-likelihood ratios averaged across the cross-validation runs for nine regions (p < 0.05 in boldface). Bottom, Z-value maps depicted over 3D brain of musicianship discrimination in discriminative regions.*

In a series of ongoing studies by PhD students Fasano and Cantou[8,9], we are transferring this paradigm for studying the learning process to pre-adolescent children (9-12 years). In these studies, we combine fMRI measurements during listening to musical pieces before and after the children learn to play them with the violin, with psychological tests, questionnaires and audio-visual recordings. A particular attention is given to specific pedagogic methods, such as Suzuki and El Sistema[10].

Another set of ongoing studies by PhD student Sørensen, involving over 20,000 Danish participants and conducted during the Danish Science Festival, investigates the association between musical skills, working memory abilities and sensitivity to musical reward in school-age children by using listening tests, psychological tests and questionnaires[11–13].

A study by postdoc Kliuchko examines the impact of formal active training of a musical instrument and style versus the informal knowledge of a musical style derived from daily listening[14]. The study, including MEG recordings and questionnaires of 80 adult participants, evidenced that brain responses to style-specific changes (e.g., slide for jazz music) in the auditory sequence were increased in participants who were active in playing that musical style but were attenuated in those style-fans with no practical musical experience.

**Unveil the person to facilitate the learning**

To understand learning and music, it is pivotal not to neglect the role of individual dispositions towards sounds (see also feature by Kliuchko on page 48). For instance, the daily mood of a person can impact even on the way she perceives sound features, for instance, by enhancing the discrimination of pitch-related features crucial for decoding negative affect in speech or music[15]. Moreover, the impact of a relaxing or irritating sound environment on mood and visual emotions is determined by the genetic repertoire of dopamine receptors and related striatal brain function[16]. Indeed, according to new studies by PhD student Tiihonen[17], cross-modal contaminations of affect from visual to auditory channels do exist.

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# LEARNING

Bringing real music into the laboratory

**By Niels Trusbak Haumann and Iris Mencke**

The ability to hear music is for the majority related to aesthetic experiences leading to emotional wellbeing and social engagement in concerts, singing, music playing, or dance. To investigate how specific regions and networks in healthy and disabled auditory brain systems respond to musical sounds, various sound stimulation protocols have been developed. It has been found that the brain responses to music are dependent on principles of perception, cognition, memory, attention, emotional evaluations, and expectations, and also on the particular music style[1-4]. Until recently, the majority of research has focused mainly on artificially designed music stimuli, in order to control the involved musical sounds and neuropsychological mechanisms. However, brain responses to real music are shaped by more complex musical patterns, acoustical nuances, and neural mechanisms[5-6].

Recently, together with Finnish colleagues, the Learning strands's PI Prof Brattico introduced a novel non-invasive paradigm that can be baptized "FreeListening EEG/MEG" for measuring evoked cortical responses in study participants while they are listening to whole pieces of music as they would do in everyday life[7]. This method was inspired by a paradigm previously introduced by Alluri et al[5] for fMRI and combines recordings of electric brain potentials with electroencephalography (EEG), or their magnetic field counterpart with magnetoencephalography (MEG), with the computational extraction of acoustic features by means of the MIR Toolbox in Matlab environment[8]. Due to the high time resolution of the EEG/MEG measurements, and the relevance of investigating brain responses to rapid acoustical changes unfolding in real music, the

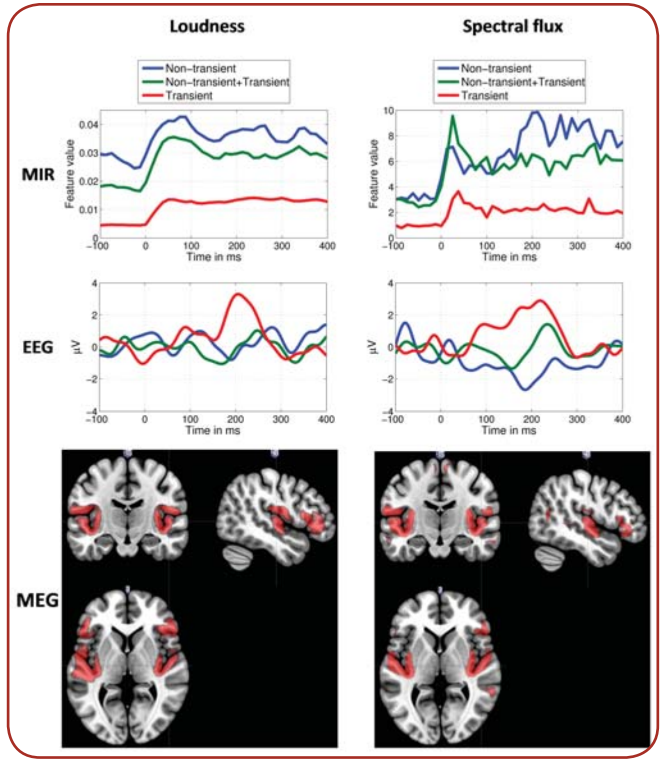


***Figure 1**. Automatically captured brain responses to changes in loudness and timbre in Astor Piazzolla's tango piece Adiós Nonino.*



FreeListening EEG/MEG paradigm is promising for both basic and clinical research.

**Collaboration with Oticon Medical: Neural prostheses**

An example of clinical applications of the FreeListening EEG/MEG paradigm is for testing auditory perception in patients with hearing loss. Recent advances in the medical sciences has led to neural prostheses, such as microelectrode arrays that stimulate the auditory nerve. The main goal is to make these technologies restore the patients' auditory functionality in everyday environments. In a collaboration with Oticon Medical and Aarhus University Hospital, Dr Haumann and others from MIB's Learning strand aim at obtaining objective measures of cochlear implant (CI) users' auditory neurorehabilitation, by measuring the brain responses of CI users while they listen to real instrumental music and Danish songs. These studies are described in the feature by Andersen and Petersen on page 42.

**Solving challenges in measuring brain responses to real music**

The largest challenge in EEG/MEG analysis is to isolate the brain response of interest from a cacophony of interfering signals, and the related methods are still under development[9]. This becomes even more challenging with FreeListening EEG/MEG, since the measurements are constrained to relatively few qualitatively similar responses. One other major challenge is to capture the brain response to a sound accurately in time. The brain responses are ephemeral, and if they are captured a few tens of milliseconds too early or late, they are completely lost in the averaged measurements. Another complication is that only few acoustical changes lead to measurable brain responses, since the auditory nerve fibers interact with auditory processing systems within subcortical and cortical layers of the brain. It is therefore crucial also to take into consideration the underlying neuropsychological mechanisms of the cortical responses.

We have currently succeeded in automatically isolating the precise time points when acoustical changes lead to measureable cortical brain responses by developing an acoustical signal analysis procedure[11]. With the novel FreeListening EEG/MEG methods we have replicated findings in classical controlled auditory neuroscience studies[10] by showing that evoked cortical responses are higher in amplitude when musical sounds are preceded by a silent break when compared to frequent acoustical stimulation (Figure 1)[11]. Moreover, we are currently extending our research into state-of-the-art topics on predictive coding, with preliminary findings of prediction error-related cortical responses to progressive metal/rock music and modern classical music and contemporary classical music (Figure 2).

**Collaboration with Max Planck Society: Disruption of quantum leaps**

Another study conducted by PhD fellow Iris Mencke at the Max Planck Institute for Empirical Aesthetics, Frankfurt am Main, Germany, aims at investigating brain plasticity and musical predictions in musicians of classical (tonal) music and contemporary (atonal) classical music. This research utilizes MEG measurements of the locations in auditory brain regions, where the magnetic fields around the electric potentials from the brain responses propagates, causing disruptions of quantum leaps in superconducting circuits of the MEG system.

Contemporary classical music (CCM) is a highly specified musical genre that lacks strong tonal relationships, is therefore missing the tonic as an auditory reference point, is lacking a hierarchical structure and is finally additionally due to its irregular metre very hard to predict[12-13], particularly for unexperienced listeners. Because of the high degree of dissonance, it furthermore can lead to a sensorily unpleasant experience. These are some of the reasons for CCM being a niche, nevertheless a very lively, creative and experimental one. Our specific interest is how such a complexity and the lack of predictability is neurally represented in the brain, and more specifically how long-term experience with such auditory unpredictability affects brain plasticity. By adopting the FreeListening MEG paradigm, we will therefore compare brain activity of CCM expert musicians with classical music (CM) expert musicians and non-musicians using MEG. Musical stimuli will be in the style of CCM as well as CM. They differ significantly in their key and pulse clarity values (Figure 2[14]), which is affecting the predictability of the musical stimuli. Based on previous literature showing that predictability might affect early cortical responses[15], we test the hypothesis that CCM experts - due to their

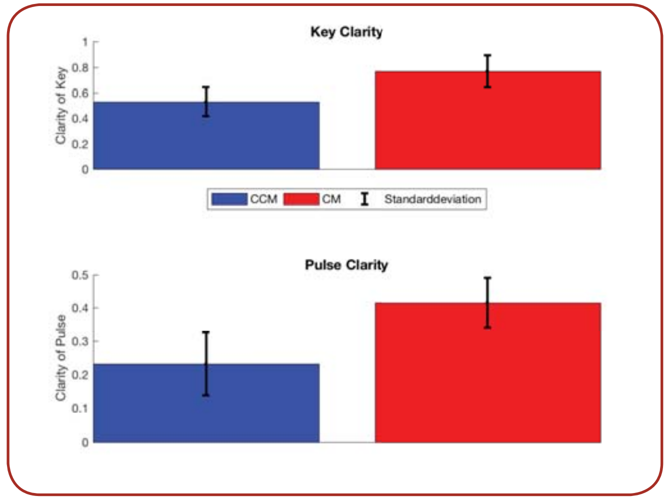


***Figure 2**. Corpus analysis of key clarity and pulse clarity in 50 contemporary classical music (CCM) and 50 classical music (CM) piano piece segments, computed using the MIR Toolbox in Matlab environment[14]*

longlasting experience - have adapted to the unpredictable auditory environment and therefore show different neural signatures in response to feature peaks in CCM music as compared with musicians not familiar with CCM.

**Future studies**

The FreeListening paradigm applied to EEG/MEG has a great potential for objectively determining the neural processing of auditory features in ecological sound environments, and to monitor the plastic adaptations of neural processing as a consequence of learning or rehabilitation from sensory deprived conditions such as hearing loss. Our ongoing studies aim at investigating the neural plastic changes in perception of realistic complex stimuli in people with normal and reduced hearing, and to continue optimizing the analysis methods for this novel paradigm.

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## NEW FACE AT MIB

**Marina Kliuchko, PhD**

Marina graduated with Bachelor's and Master's degrees in Biology at the Saint Petersburg University in Russia. As a student there, she majored her studies in psychophysiology and worked as a lab assistant at the Laboratory of Sensorimotor Systems. Then she started an internship at the Cognitive Brain Research Unit (CBRU), University of Helsinki, and continued there as a research assistant and later on as a PhD student. She conducted research on auditory processing and brain plasticity. Marina's doctoral thesis work focused on an investigation of the structural and functional changes in the brain of people sensitive to background noise.
Marina is now a postdoc at MIB and continues her work on auditory neuroplasticity studying the brain of subjects with different musical profiles. Her newest study is on how enculturation shapes pitch prediction in the melodies from own or a foreign musical culture.

# CLINICAL APPLICATIONS OF MUSIC

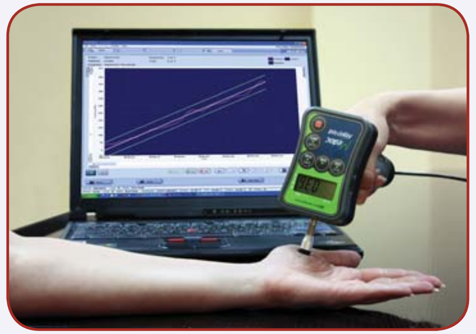
*Kira Vibe Jespersen*

Music engages brain processes at many levels from the perception of basic acoustic features to higher-order musical patterns, associations, movement, pleasure and reward. At Center for Music in the Brain, we are curious to investigate how these basic mechanisms of music perception and engagement may be applied in a clinical context.

This research is important because music is a non-invasive, inexpensive supplement to standard treatment, and due to its obvious usefulness for society, it attracts considerable support from external funding agencies.

A number of MIB researchers are involved in studies aiming at identifying evidence-based music interventions and unravelling the mechanisms behind the putative effects of music in clinical populations.

One line of research focuses on music and pain. The impact of music on chronic pain is investigated by Dr Eduardo Garza-Villareal together with PhD candidate Victor Pando-Naude. In collaboration with Prof Peter Vuust and Prof Elvira Brattico, they recently discovered that the analgesic effects of music on fibromyalgia are related with neural connections in limbic and default-mode areas of the brain[1]. Furthermore, in a MIB collaboration with Prof Lene Vase at the Department of Psychology (AU) PhD student Sigrid Juhl Lunde is working on a project testing analgesic effects of music and how they are mediated by dopaminergic and opioid systems. A different approach to pain is taken by Assistant prof Boris Kleber and Dr Anna Zamorano (Center for Neuroplasticity and Pain, AAU) who are studying musculoskeletal pain in musicians (see photo).



*Pressure pain threshold measured with an algometer.*

*Photo: www.cephalon.dk*

Another line of research aims at evaluating the effect of music interventions on clinical conditions such as cancer, Chronic Obstructive Pulmonary Disease (COPD) and insomnia. PhD student Margrethe Langer Bro is investigating the effect of live and recorded music in reducing cancer-related anxiety, pain and depression, and she recently published a systematic review on this topic[2]. PhD student Mette Kaasgaard is conducting a clinical trial to assess the effects of singing on respiratory measures in people with COPD (see PhD feature on page 48). PhD student Kira Vibe Jespersen has conducted a study on the effect of bedtime music on sleep in adults with insomnia disorder, and additional work on sleep is done by PhD student Nadia Flensted Høgholt and Postdoc Angus Stevner (see feature by Jespersen and Stevner on page 28). Nadia began her PhD project in 2017 focusing on pregnancy-related sleep problems and music interventions. In 2017, Kira and colleagues also initiated an innovation project on music for sleep problems in elderly persons with dementia in collaboration with DTU.

Music and hearing loss may not be an obvious match, but in a series of studies Assistant prof Bjørn Petersen, in collaboration with Prof Elvira Brattico and other MIB researchers, are using novel paradigms, termed ‘multi-feature’ and ‘free-listening’ paradigms, aimed at monitoring the auditory neurorehabilitation of CI patients after implant. Details of these studies are found in the two features by Andersen and Petersen on page 42 and by Haumann and Mencke on page 36. Other uses of music for neurorehabilitation are examined in the PhD project of Rebeka Bodak. In this project, Rebeka aims to identify the audio-motor coupling mechanisms underlying potential effects of music in physical neurorehabilitation after stroke.

Music is not always beneficial, and in some situations, it may be considered noise. Noise sensitivity is considered a risk factor for cardiovascular diseases, and it has been the focus of Postdoc Marina Kliuchko’s work. In recent publications she investigates the neurobiological substrate of noise sensitivity[3-4] (see feature on page 56). MIB researchers also identified altered processing of emotion-related auditory cues in adults with increased risk of depression[5]. Furthermore, perceptual alteration in persons with autism spectrum disorder (ASD) is evaluated by Associate prof Line Gebauer and PhD student Rasmine Holm Mogensen. Rasmine began her PhD project in 2017 focusing on how altered sensory-motor integration in children with ASD may affect their social interaction skills.

As reflected in these MIB studies involving clinical perspectives, we emphasize the close link between basic and applied sciences and contribute also with theoretical perspectives[6-7] to enhance the evidence base for music interventions.

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# CLINICAL APPLICATIONS OF MUSIC

*Anne Sofie Friis Andersen & Bjørn Petersen*

## The Times They Are A Changin'

*Two Novel EEG Paradigms for Studying Music Discrimination in Electric Hearing*

### The Past

Since the advent of cochlear implants (CIs) in the early 1990s, an increasing amount of research has reported on the perception and appreciation of music in CI users. Since 2007, researchers from MIB have contributed to the field with several studies which investigated the potential of targeted musical ear training to improve CI users' music discrimination abilities[1,2]. Typically, musical skills are measured by behavioural methods. However, to provide objective measurements and an understanding of the cortical changes which underlie the auditory progress, neuroimaging methods are in demand.

Due to metal parts in the CI's speech processor, neither functional MRI or MEG are feasible and may even be hazardous. PET measurements have been used but are limited with respect to the spatial and temporal resolution and the invasiveness of the procedure. By contrast, EEG is a non-invasive, silent and objective method which enables recording of event-related brain potentials (ERPs) and offers the opportunity to investigate the neural basis of perception with a high temporal resolution.

Although the recording of EEG in CI users represents many challenges, it has shown to be a viable and reliable method for the measurement of auditory functioning. Particularly, the mismatch negativity (MMN) response has been proven a strong tool for measuring auditory functioning in CI users (for a review see[3]). At MIB, we successfully applied a modified version of the 'Musical Multifeature' paradigm[4] in two previous studies to investigate music discrimination skills in adult and adolescent CI users[2,5].

### The Present

The current study was initiated in cooperation with the Danish CI manufacturer Oticon Medical (OM) with two goals. In the first step, the goal is to develop and validate two new musical EEG paradigms to be used in future CI research. In a parallel step, we aim to examine the effect of a novel sound compression strategy (xDP). Compared to the typical automatic gain control, xDP leaves room for a wider dynamic range, which could prove beneficial for the music perception of CI users.

As data collection from CI users has not been concluded at the time of writing, only results from normal-hearing (NH) participants are reported. The aim is to include twelve experienced and twelve recently implanted CI users, of whom six are expected to use an OM implant.



### The Paradigms

We created an MMN 'Musical Multifeature' paradigm including four deviants (intensity, pitch, timbre and rhythm) at four levels of magnitude (S, M, L and XL), using the Alberti bass configuration introduced by Vuust et al.[4] and a no-standards approach introduced by Kliuchko and colleagues[6]. To account for the limited musical abilities of the CI users, deviation magnitude was adjusted such that the changes would be detectable through a CI. The novelty of the paradigm is a significantly reduced duration and potentially more precise estimations of the participants' discrimination thresholds as compared to previous MMN paradigms used in CI research.

As a secondary measure, we adapted a version of The 'Free-Listening' EEG paradigm, introduced by Poikonen and colleagues[7] and inspired by the approach first presented in[8] (for more details see the feature by Haumann and Menchke on page 36.) The adapted version presents three musical pieces: a short version of the tango composition Adios Noniño and two versions of Danish composer Anne Linnet's song "Forårsdag": the original and an instrumental version (here, only tango results are reported). The paradigm represents a completely novel and ecologically valid approach for investigating music perception in CI users.

### The Procedures

Seventeen young adults (mean age 25y, range 21-31; females 9) and fourteen older adults (mean age 63y, range 55-77; females 7) with normal hearing were recruited for the study with the purpose of validating the efficacy of the paradigms. The older adult group was chosen as age matched controls for the CI participants.

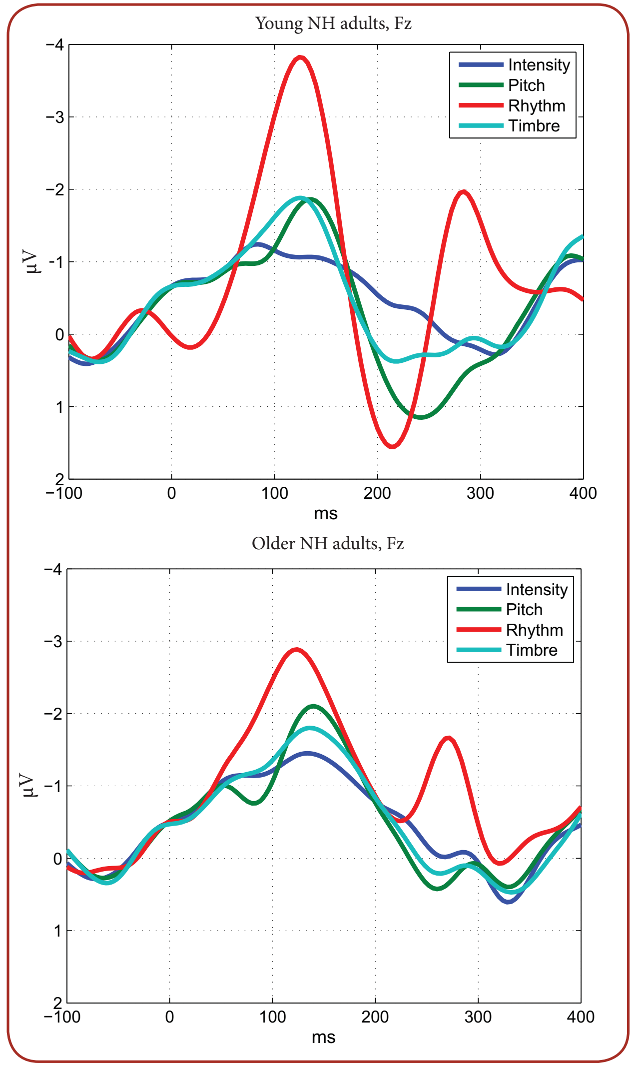



***Figure 1:*** *Average MMN difference waves for all four deviants across levels in the Young adult and Older adult groups, respectively.*

EEG was recorded with 32 electrodes and the participants received audio through in-ear Shure headphones at approximately 70 dB SPL. EEG data from the MMN paradigm were pre-processed with SPM12 and analysed in SPSS 20. Data from the Free-Listening paradigm were analysed using MIR toolbox for the musical features and Fieldtrip for the EEG data.

For provision of supplementary behavioural data, participants completed a three-alternative forced choice task, testing discrimination of the same musical parameters and levels of magnitude as presented in the MMN-paradigm.

### The Products

The study's main finding was that the new MMN paradigm elicited significant responses to all four deviants at all levels of magnitude (Figure 1). In addition, there was a consistent relationship between MMN amplitudes and deviation magnitude; the larger the deviation, the larger the MMN response (Figure 2). In addition, we found that MMN amplitudes were largest to the rhythm deviant, whereas gradually lower to timbre, pitch, and intensity deviants. Finally, group comparisons showed that MMN amplitude for the rhythm deviant was significantly higher in young adult as compared to older adult NH listeners (Figure 1).

As a preliminary finding, we were able to show significant MMN responses for all deviants except intensity in single subject analyses. With clinical application in mind, this is important since it suggests potential use of the MMN paradigm for

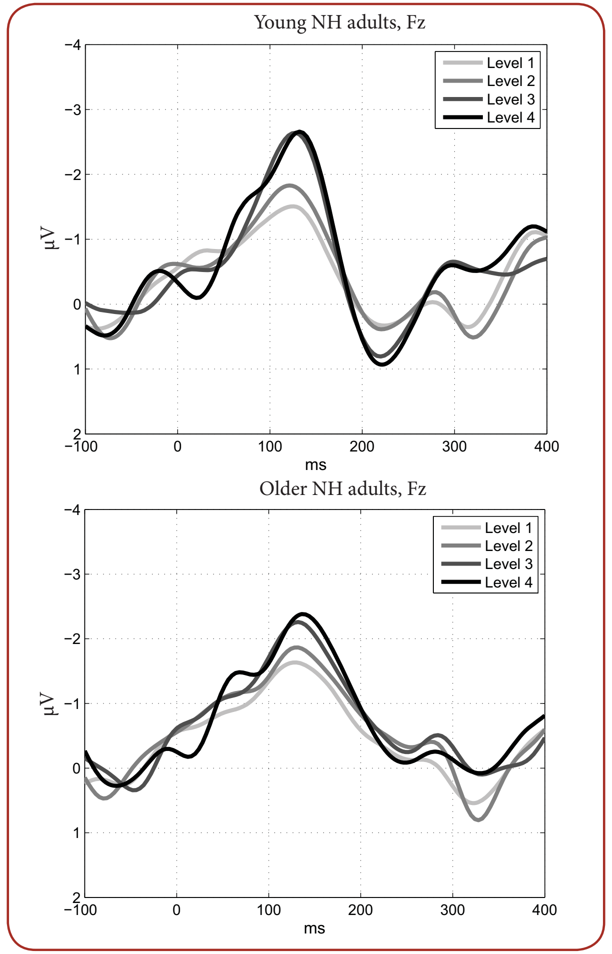



***Figure 2***: *Average MMN difference waves across deviants as a function of deviation magnitude levels.*

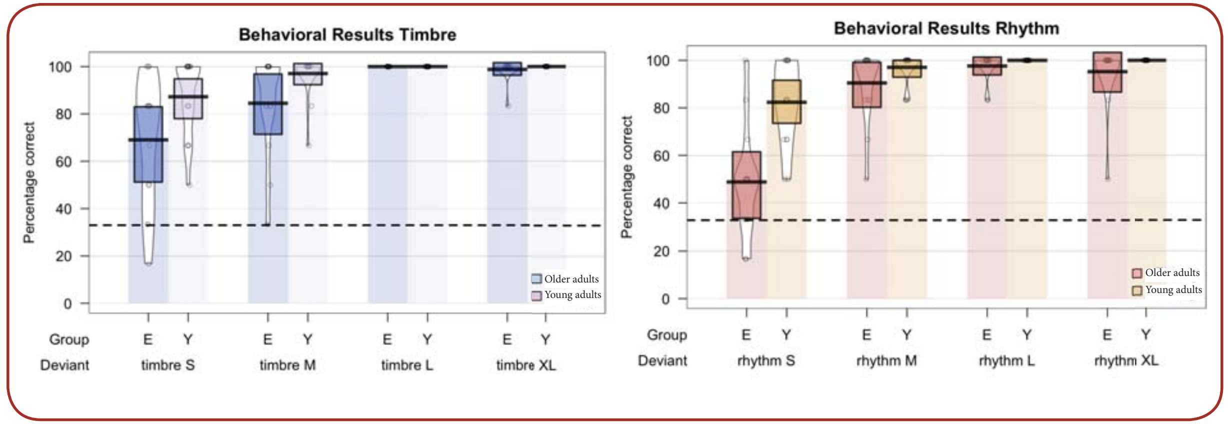
objective prognostication and assessment of CI functioning in individual CI patients.

Unsurprisingly, behavioural test results showed an overall trend towards ceiling effects for larger deviants. For smaller levels, young adult NH listeners showed a higher discrimination accuracy





***Figure 3:*** *Violin plots showing behavioural hit rates for the timbre and rhythm deviants. The dotted lines indicate chance level.*




than the older adult group, particularly for timbre and rhythm (Figure 3). Moreover, across deviant levels and experimental groups, higher MMN amplitudes tended to predict higher behavioural test scores. Finally, for the rhythm deviant, we found a statistically significant relationship between MMN amplitudes and behavioural test scores.

The free-listening paradigm elicited significant P2 responses for the features brightness, spectral flux, RMS and roughness (Figure 4). By contrast, P2 response to the zero-crossing rate feature was nonsignificant.

### The Parallels

In line with previous studies, we found significantly larger amplitudes in the young adult group than in the older adult group, for the three largest rhythm deviants. Moreover, correlation analyses showed a positive correlation between age and MMN amplitude for the rhythm deviants, further indicating an advantage of young age in detection of subtle details in rhythm[8,9]. This, confirming findings by Näätänen et al.[3], was also reflected in behavioral performance.

In comparison with previous MMN studies[4,6,10], we found MMN amplitudes that were smaller, especially for the pitch and intensity deviants. However, as Vuust et al. propose[10], the complexity of a multi-feature paradigm might influence pitch and intensity deviants the most. Thus, the high complexity of the new paradigm, incorporating levels as well as a no-standards design, might explain the observed diminished amplitudes.

In contrast to pitch and intensity, the timbre and especially the rhythm deviants seem to elicit quite robust and large responses, even compared with other studies[4,5,7]. The reason could be that these deviants are more noticeable in nature than the other deviants, even in a fast an ever-changing paradigm like this.

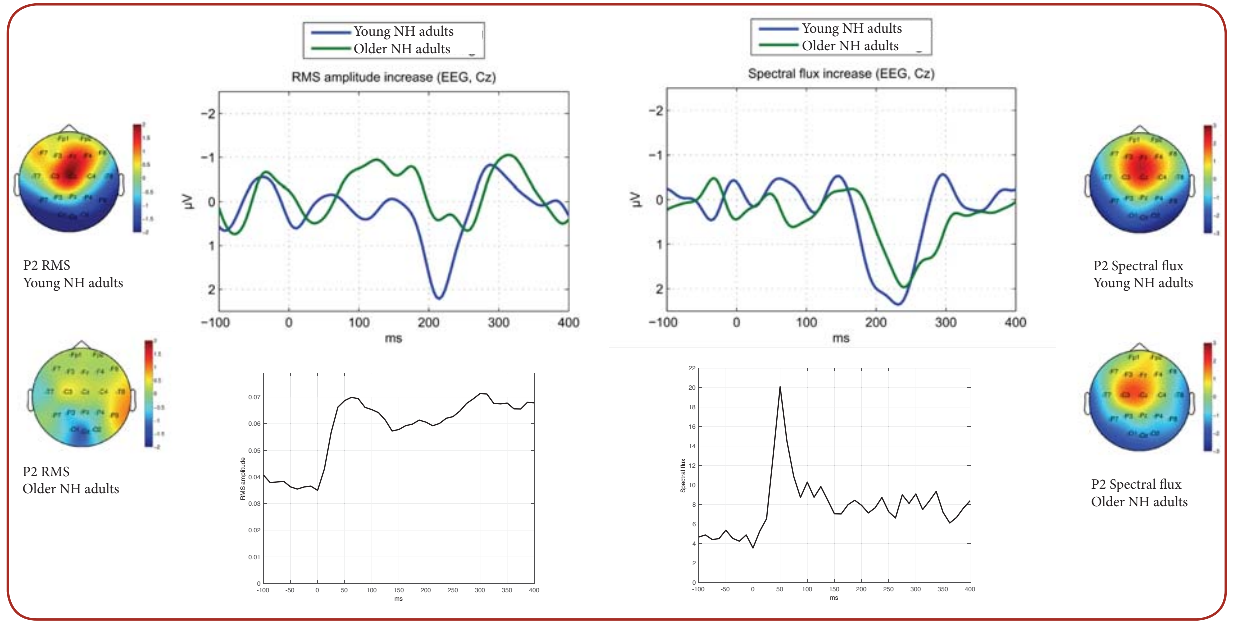



***Figure 4:*** *ERP responses to the two musical features RMS and Spectral flux are shown in the top of the figures. The averaged representations of the musical features are shown below. Topoplots centred around the time of the P2 response for the young adult and older adult group are presented in the side.*

In the Free-Listening EEG paradigm, we found significant P2 responses for all features except zero-crossing rate. This indicates that our paradigm is capable of eliciting significant brain responses even by a tango piece that is half the duration of the one used by Poikonen et al[7]. In line with previous studies, components were largest on the central region of the scalp, suggesting that the activity primarily originates from the auditory cortices[7].

**The Prospects**

In the present study, normal hearing listeners were subjected to two novel musical EEG paradigms to validate the usefulness of these paradigms in future CI studies. We found significant MMN responses to all deviants at all levels of magnitude in both groups and a synchrony between MMN amplitude and deviation magnitude. The result is encouraging and indicates that the new Musical Multifeature paradigm is both accurate and feasible despite a high complexity. Furthermore, significant P2 responses were elicited by all but one musical feature of the Adios Noniño piece, suggesting promising potential for using the Free-Listening paradigm forward on. Based on previous experience, we are confident that future analyses of data from CI users will further support these findings with the perspective of bringing important new knowledge about music perception and CI.



*This study, including preliminary CI data, was presented at the CIAP and CI2017 conferences, July 2017 and is under preparation for submission[12].*

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## MIB AT THE DHL RELAY RACE

On a rainy evening in August 2017, MIB and CFIN participated with more than 30 runners and walkers at the annual DHL Relay Race. The DHL Relay Race is the world's largest running event taking place in 5 Danish cities.

Participants can either participate in a 5 x 5 km relay race or a 5 km walk.

In Aarhus, 47,000 people participated over 3 days - nearly 2,000 of those were from Aarhus University.

*Photos: Suzi Ross*

# CLINICAL APPLICATIONS OF MUSIC

*Mette Kaasgaard*

## Is singing training relevant in rehabilitation for patients with Chronic Obstructive Pulmonary Disease?

Chronic Obstructive Pulmonary Disease (COPD) is expected to be the third leading cause of death worldwide in 2020. At the present time 430,000 people in Denmark suffer from COPD, though only half of them are diagnosed and hence treated appropriately. Expenses related to COPD amounts to 10% of the national health care budget, and the number of patients is rapidly increasing.

COPD is a syndrome with progressive pulmonary obstruction leading to increasingly impaired lung function due to chronic inflammation in the respiratory airways and pulmonary tissue. Living with COPD, everyday life is a struggle and often marked by continuous dyspnoea, cough and sputum. Comorbidities such as muscle wasting, anxiety, depression, hypertension and infections are common, which again leads to further complications. Patients are hence severely affected by the disease on both physiological and psychosocial aspects, and these two aspects seem to influence each other significantly, leading to a vicious circle of physical inactivity, lack of social contact, and impaired Quality of Life.

Patients are encouraged to join a multidisciplinary rehabilitation programme in order to improve physical condition, improve Quality of Life, and prevent exacerbations, hospitalisations and early mortality. However, there is a high dropout rate, often due to lack of motivation. Therefore, it is important to investigate alternative rehabilitation activities that are motivating and are perceived relevant, and that include both physical training and support empowerment and Quality of Life.

Singing training may be one such new relevant interventional therapy. The core of singing is to learn how to control the respiratory function, posture, and general body awareness. Singing is also a social activity with an ability to create emotions and cohesion, and is described as having a positive impact on well-being, anxiety and depression. Initially, a number of small international studies have investigated the effects of singing in relation to COPD patients. Although there are no conclusive clinical results yet, previous studies show positive indications on both physical and psychosocial aspects.

In our study, we aim to investigate the effects of singing training compared with physical training – the current ”golden standard” in pulmonary rehabilitation - through a 2-armed cluster-randomised controlled trial (RCT). Effects will be investigated on both physiological and psychological/psychosocial aspects. Also, musical competence will be tested. Patients in both arms will participate in a 10 weeks’ programme, twice a week for 1 ½ hour. Intervention arm will participate in singing training, led by professional singing teachers, who have been trained and educated specifically in singing for COPD patients. Physical training (control arm) is led by local physiotherapists in each municipality. Data are collected pre- and post-intervention by external assessor, an experienced nurse from the Pulmonary Department at Aarhus University Hospital.

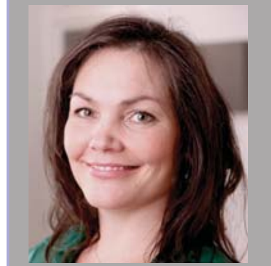
*COPD patients from Vordingborg are singing an African song including dance, clapping and drums.* Photo: Mette Kaasgaard

The project will be the first in Denmark to investigate the effects of singing training in COPD and the far largest worldwide. In all, 11 Danish municipalities participate in the project: Lolland, Vordingborg, Faxe, Slagelse, Rudersdal, Helsingør, Hedensted, Ikast-Brande, Silkeborg, Vesthimmerland, Lemvig. We expect a number of 26 clusters and in all 260 patients. The intervention period started August 2017 and is expected to run until November 2018.

Besides MIB, the study is closely affiliated with Respiratory Research Unit Region Zealand at Næstved Hospital. The research group consists of Mette Kaasgaard (PhD student), Prof Peter Vuust (MIB), and three leading pulmonologists: Uffe Bødtger (MD, PhD, Head of Research, Næstved Sygehus), Ole Hilberg (MD, DMSc, Associate prof, Sygehus Lillebælt, Vejle), and Anders Løkke (MD, Associate prof, Aarhus University Hospital).

The PhD project is financially supported by TrygFonden, Aase og Ejnar Danielsens Fond, Region Midt (Folkesundhed i Midten), Fonden til Lægevidenskabens Fremme, Danmarks Lungeforenings Fond, Næstved-Slagelse-Ringsted Sygehuse - Lokal Forskningsfond 2017, Næstved-Slagelse-Ringsted Sygehuse - Lokal Forskningsfond 2018, Region Sjællands Sundhedsvidenskabelige Forskningsfond, Region Sjælland (PFI) and Aarhus Universitet.

## NEW FACE AT MIB



**Mette Kaasgaard, PhD stud.**
Mette graduated from the Royal Danish Academy of Music as a classical singer and singing pedagogigue in 2003 and has several years of experience as a self employed professional opera singer, music teacher and art-based consultant. Furthermore, she holds a MSc in Information Technology (Digital Design and Communication - Experiences and Art) from the IT University of Copenhagen in 2014 with emphasis on user centered design, qualitative methods and concept development.

# EDUCATIONAL ACTIVITIES

*Elvira Brattico and Bjørn Petersen*

In 2017, MIB has consolidated its reputation as a lively and central place to visit among international scholars. All these visits have contributed to teaching, knowledge sharing, internationalization, visibility of MIB and have strengthened existing collaboration as well as opening new ones. In this context, long-term and fresh collaborators from e.g., Finland, Germany, Spain and UK provided twelve talks on topics related to neurophysiology, (auditory and brain) signal processing and music psychology (see list on page 54).

**MIB/CFIN cooperation**

Besides these selected MIB visitors, MIB's cooperation with CFIN in organizing shared seminars was successfully implemented to its full extent with a total of seven talks. The framework is built upon high profiled international guest researchers who give talks every first Monday of the month. Topics are broad touching upon issues of scientific relevance to MIB as well as CFIN researchers. Typically, visiting speakers stay for two days or more giving students an opportunity to meet and discuss methodological or other aspects of their studies with an experienced expert within the field. MIB/CFIN seminars in 2017 included seminars by Prof Sonja Kotz from Maastricht University and Max Planck Institute for Human Cognitive and Brain Sciences sharing her findings on timing and rhythm in motor behaviour.

**Visiting researchers**

Thanks to a grant from Aarhus University Research Foundation (AUFF) obtained by MIB Prof Brattico, Dr Marcus Pearce from Queen Mary University of London, could stay at MIB for a period of five months. During his stay, Dr Pearce delivered two presentations in the CFIN/MIB seminar series: the first synthesised his research developing and using the IDyOM model of statistical learning and probabilistic prediction in simulations of auditory perception; the second addressed the question of ecological validity in music cognition research using a combination of computational modelling and minimalist music (Steve Reich's Clapping Music) that allows high degrees of both ecological validity and experimental control, in line with MIB research on naturalistic paradigms (see previous annual reports and feature by Haumann & Mencke on page 36). In addition to numerous informal discussions with PhD fellows and research staff about their work, Dr Pearce has also embarked on extensive collaborations with several junior researchers at MIB (Leonardo Bonetti, Marina Kliuchko, Iris Mencke and David Quiroga), giving them practical and theoretical instruction in IDyOM and helping them to incorporate IDyOM modelling into new and existing research projects.

Moreover, Prof Brattico and Prof Vuust have been active in supervising international visiting students at all levels. Nader Segdhi, psychology MSc from Italy, has done his professional internship required by the Italian psychology trade union during 10 months, funded by Erasmus Plus, collaborating on ongoing data collection/analysis and working on two manuscripts, one of them already accepted for publication[1,2]. Moreover, Antonio Criscuolo has prepared his bachelor's thesis in Psychology at University of Bologna during his 3-months Erasmus stay at MIB and contributed to two manuscripts, one of them submitted to a peer-reviewed journal[3,4]. Claudia Amendola completed a 1-month internship for her master's studies in Musicology at the University of Pavia, Italy. Jose Santacruz, PhD student in Engineering from University of Malaga, also visited MIB for 3 months and prepared an article that is now under submission[5]. Alessandra Brusa prepared her master's thesis in Psychology (University of Milano Bicocca, Italy) during her Erasmus stay at MIB and is now submitting a manuscript resulting from that work[6]. MIB also hosted two visitors from University of Jyväskylä, Finland, Dr Imre Lahdelma and Marianne Tiihonen. The latter, after her stay decided to apply for PhD studies at Aarhus University. Frank Schulze, medical student from Germany, also visited MIB with Erasmus funds and participated in studies by PhD student Ole Heggli.

**Young visitors**

In August and September, for a period of 4 weeks, we hosted a team of 14 talented students aged 17-18 selected from the Italian high schools IISS Simone and Morea, Conversano, Bari. From MIB, tutors and coordinators of daily activities were Prof Brattico and research technician Dr Haumann. Additionally, several PhD students (Leonardo Bonetti, David Quiroga, Suzi Ross, Pauline Cantou, Stine Derdau Sørensen) gave lectures in cognitive neuroscience, experimental psychology, neurophysiology and neuroaesthetics. The students were exposed to our vibrant research environment and had the possibility to visit the laboratories of DNC, including MRI, MEG and EEG. Some of the students also eagerly volunteered to participate in our ongoing studies with listening tests and neuro- and psychophysiological recordings. The outcome of this stay was extremely positive with enthusiastic feedback on how much they learned about Scandinavian work culture, laboratory life and the specific neuroscientific contents taught. Two of them were selected by Prof Brattico to write invited review papers for the Italian journal Musica Domani on the application of neuroscientific finding to instrumental education and practice. Moreover, internet blogs and articles

*The group of Italian students visiting MIB in August-September 2017, here portrayed together with Professor Brattico (at the left).*

in widely-distributed newspapers have been written by the students and their teachers on the experience.

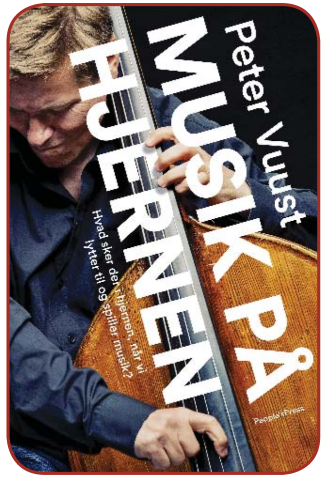
**The Neurosciences and Music 2020 site visit: Isabelle Peretz and Luisa Lopez**
In April, MIB was fortunate to host two internationally acclaimed music researchers: Prof Isabelle Peretz from the University of Montréal, Canada and Dr Luisa Lopez, MD, from Eugenio Litta Clinic, Rome, Italy. Drs. Peretz and Lopez each gave lectures on topics of their expertise on the first day. On the second day they took part in a session with four project presentations in which they gave invaluable reviews, comments and suggestions to ongoing PhD projects. The visit by Drs Peretz and Lopez were part of MIB's efforts to host The Neurosciences and Music conference in 2020. Thus, their stay also included the site visit of suggested venues and The Royal Academy of Music Aarhus/Aalborg which is intended to play a key role in the execution of the conference

*Cake to celebrate that MIB is going to host The Neurosciences and Music conference in 2020.*

**MIB staff teaching activities and materials**
In 2017, medical student Anne Sofie Friis Andersen, under the supervision of Dr Petersen, completed her research year by both publicly defending her report and having it successfully assessed as her master thesis. Andersen has been an essential part of a project on CI and music perception, which has developed and tested two new EEG paradigms for objective measurements of discrimination of music in new and experienced CI users (see feature on page 42). This case is another fine illustration of the potential prosperity of the MIB educational environment, involving both qualified and regular supervision and specialized training by researchers within the MIB and CFIN staff.

Moreover, Prof Brattico continued her professional collaboration with the University of Helsinki, where she is Adjunct Professor in Biological Psychology. There, in August 2017, she taught a full intensive course on Imaging Genetics, providing 5 ECTS credits to graduate students of Psychology and Medicine. Furthermore, still in August 2017, Prof Brattico was invited teacher at the Helsinki Summer School in Cognitive Neuroscience. Finally, in a new book called "Det Biokulturelle Menneske" published by Aarhus University[1], Prof Brattico provided a chapter, summing up knowledge previously shared in the course "What Makes us Human". The book will serve as educational material for future courses planned at Aarhus University.

MIB researchers also put consistent efforts in disseminating knowledge outside academia. Prof Vuust published the book "Musik på Hjernen" divulgating the foundational concepts of MIB




research to professional audience and the interested readers. New collaborations with schools and cultural institutions have been formed during 2017. For instance, Prof Brattico and PhD student Cantou gave a lecture to the general public on the beneficial effects of music in Pakhuset, Odder, organized by Odder Musikskole. Several interviews by MIB personnel and particularly by Prof Vuust in occasion of his book release have been periodically released for Danish and international media channels.

**RAMA cooperation**
In 2017, Dr Petersen and Prof Vuust organized a whole-day seminar for RAMA's annual conference on "Music and Learning" (taking place on January 3-4 , 2018). The seminar is aimed at music teachers and presents four different views on the implication of recent neuroscientific research on the teaching of music. The programme includes talks by Profs Peter Vuust, Eckart Altenmüller from Hannover (Germany), Glenn Schellenberg from University of Toronto (Canada), and Dr Mari Tervaniemi from Helsinki (Finland) . As an additional source of outcome, the programme also includes workshops at which the audience are given the chance to ask further questions directly to the presenters and discuss the raised issues.

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3. Criscuolo, A., Bonetti, L. & Brattico, E. Music training effects on brain structures – A metaanalysis. (in prep.)
4. Criscuolo, A. et al. Musical training is associated with cognitive abilities in adulthood. Psychol. Music (submitted)
5. Haumann, N. T. et al. Automatic capture of acoustic changes in real pieces of music: Transient and non-transient brain responses. (in prep.)
6. Brattico, E. et al. The beauty and the brain: Investigating the neural substrates of musical beauty during a realistic listening experience. (in prep.)

## NEW FACE AT MIB

**Massimo Lumaca, PhD**
Massimo obtained a Bachelor's degree in Biology, followed by a Master's degree in Neurobiology, both at La Sapienza - Università di Roma. Later, he obtained a PhD in Cognitive Neuroscience at SISSA - International School of Advanced Studies (IT). Concurrently he carried forward musical studies at the conservatory Santa Cecilia and Alfredo Casella.
He is now a postdoctoral researcher at MIB investigating the neural underpinnings of the cultural evolution of music and language.

## Guest speakers 2017

Dr Roel Willems
Radboud University Nijmegen
The narrative mind: Neurocognitive insights into literary reading (MIB/CFIN)

Dr Antoni Rodriguez-Fornells
University of Barcelona
The Intrinsic Reward of Language and Music Learning

Prof Sonja A. Kotz
Maastricht University
Timing and rhythm in motor and non-motor behavior (MIB/CFIN)

*Professor Isabelle Peretz from Université de Montréal*

*Dr Antoni Rodriguez-Fornells from University of Barcelona*

Jan Stupacher
Department of Psychology, University of Graz
Neural correlates and prosocial effects of entrainment to music

Prof Isabelle Peretz
Université de Montréal
Born to be musical: what we can learn from congenital anomalies

Dr Luisa Lopez
Villaggio Eugenio Litta, Grottaferrata and University of Rome "Tor Vergata", Rome
Dyslexia and Music

Antonio Criscuolo
University of Bologna
Cognitive benefits and neuroplasticity induced by musical training



Dr Pasi Saari
Jyväskylä University
Experiences and findings from fMRI and MEG studies on the neural processing of musical features

Prof Mark Woolrich
Oxford University
Transient Brain States and Metastates (MIB/CFIN)

Dr Marcus Pearce
Queen Mary University of London
Learning and Probabilistic Prediction in Musical Style Acquisition (MIB/CFIN)

Dr Diana Omigie
Max Planck Institute for Empirical Aesthetics
Zygomaticus activations and Amygdala oscillations: The structure of musical pleasure

Iris Mencke
Max Planck Institute for Empirical Aesthetics
Comparing brain correlates of classical and modern music with MEG

*Brain Prize Winner Professor Wolfram Schultz from University of Cambridge*

Dr Marcus Pearce
Queen Mary University of London
Steve Reich's Clapping Music: Balancing Ecological Validity and Experimental Control in the Study of Music Production and Perception (MIB/CFIN)

Dr Molly Henry
Western University, Ontario
Neural dynamics of auditory rhythm perception

Prof Wolfram Schultz
University of Cambridge
Getting the best reward: neuronal mechanisms for utility maximisation

Prof Maria Chait
Ear Institute, UCL
How the brain discovers patterns in sound sequences (MIB/CFIN)

Prof Isabel Barbancho
University of Malaga
Music Information Retrieval & some of its applications

Prof Lorenzo J. Tardón
University of Malaga
Audio Signal: Characterization and Classification

Prof Ruth de Diego Balaguer
Universitat de Barcelona
Attention through Prediction: a Two-Stage Language Learning Mechanism (MIB/CFIN)

# PHD FEATURE

*Marina Kliuchko*

## Noise sensitivity in the function and structure of the brain.

Some people experience a strong discomfort of sounds around them and complain that they suffer from noise. The reasons why some are sensitive to noises are not yet known. Nevertheless, noise sensitivity – a term describing an individual attitude towards noise - plays a concerning role in public health because individuals who are highly sensitive to noise have a higher risk of developing noise-induced health problems. Noise sensitivity is often viewed as purely attitudinal or psychological phenomena, and only a handful of studies has addressed the biological underpinnings of it.

In my thesis work, completed under the supervision of Profs Brattico and Vuust, and co-supervised by Dr Tervaniemi (University of Helsinki), we took into account physiological correlates of noise sensitivity, rather than considering it as an entirely psychological trait in its origin and were able to shed a new light on fundamental questions in understanding noise sensitivity. Namely, we explored the psychophysiology and neuroanatomy of noise sensitivity by using structural magnetic resonance imaging (MRI), electro- and magneto-encephalography (EEG/MEG) as well as questionnaires.

First, we showed that a fine-tuned auditory system, as developed in professional musicians after years of musical training, does not make one more sensitive to noise[1]. Moreover, noise-sensitive people are involved with music listening and playing as much as people who are not as sensitive, but they prefer not to have music in the background.

Second, we used musical multifeature mismatch negativity (MMN) paradigm, developed by Prof Vuust and Prof Brattico (Fig. 1, top), to access functioning of the central auditory system in noise sensitivity[2]. We observed attenuation in different components of an evoked auditory response, which may be interpreted within predictive coding framework. The magnitude of P1 component to the sound onset was smaller in subjects with higher noise sensitivity (Fig. 1, bottom left), indicating that they may have impairments in the encoding of sound features in the central auditory system. Accordingly, building a prediction about auditory sensory information becomes more challenging, and that is reflected in a low MMN response in noise-sensitive participants (Fig. 1, bottom right), especially to deviant sounds with increased noisiness.

Furthermore, the third study showed that these changes in the function of the central auditory system in noise sensitivity are accompanied by increased grey matter volume in several auditory-related cortical areas, the hippocampus, and the right anterior insula[3]. Taken together, studies of my thesis conclude that individual differences in



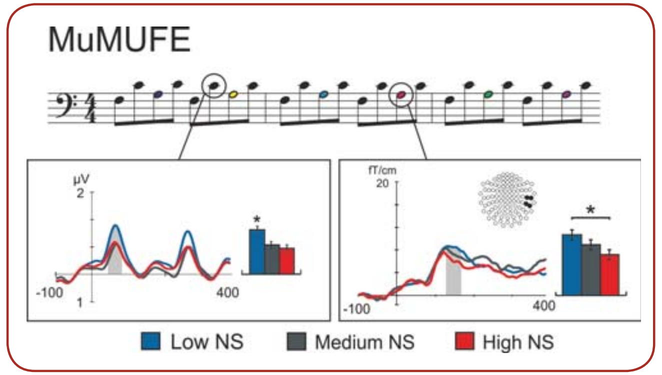


***Figure 1**. Top row: Musical multifeature MMN paradigm (MuMUFE). Bottom left: Attenuated P1 component (grey area) in Medium and High NS (= noise sensitivity) groups as compared to Low NS group in evoked response to a standard note (EEG data, Fz). Bottom right: Diminished MMN response (grey area) to a noisy deviant note in High NS group (MEG data). The findings demonstrate NS is related to compromised sound feature encoding and automatic discrimination skills.*

noise sensitivity are associated with functional and morphological variations in brain areas involved in auditory perceptual, emotional and interoceptive processing. These findings are important for the understanding of how subjective experience of sound links to neurophysiology and brain morphology. Moreover, this work could inform medical research on the nature of noise sensitivity, which is an important topic in health science and policy making on noise environment, especially when considering the prevalence of noise sensitivity in the general population, and even more so in a number of clinical populations.

Our findings attracted attention from media and were featured in major science news portals worldwide. Also, I had a pleasure to give interviews to the Danish newspaper Weekendavisen and the radio channel DR P3 who both were interested to hear about how noise sensitivity affects people.

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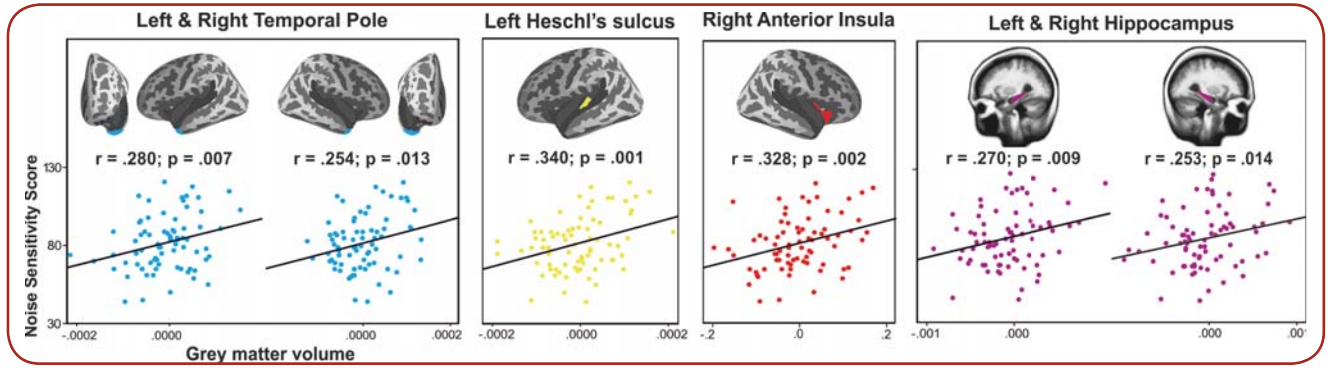



***Figure 2.** Brain regions where grey matter volume positively correlated with noise sensitivity score. The findings suggest morphological variations in brain areas involved in auditory perceptual, emotional and interoceptive processing.*

# VISITING PERSPECTIVE

*Maria Dolores Tapia - visiting professor at MIB*

Aarhus, Denmark, January 2017. We have landed in Aarhus coming from Almeria, a small city just in the south of Spain ("Where the sun crosses the winter" it's the motto of my city). It's 5.00 in the afternoon and it's already dark. "We" are 4 people, my husband and two children and a large amount of luggage (considering Denmark's cold climate, we had bought all our winter's clothes). We are just in the hall of the train station, in a place that is strange to us, but over the next months will become our home. Just as DOKK1, Risskov forest, Moesgaard Museum, the Aros rainbow, the Deer Park, the Rådhuset, Tir Na Nog and the MIB!

Aarhus (in the end we learned to pronounce it) is a small city with plenty of interesting places and full of life. The student atmosphere is present in the life of the city, by the canals when it is sunny, on bicycles on the way to the university (despite the inclement weather), at conferences, at the bars… Arhus is a vibrant city (It reminds me of the Spanish city Grenada where I was a student) that surprises us since our first step into the city.

But, it all started several months before. My government launched a call for Senior researchers to visit an Research Excellence Center. I had always thought to lead my expertise to the implication of music to the brain function. I searched the network for a centre of excellence in music and brain research and, voilà! I found MIB.

Since that point both people at MIB and people at the International Centre at Aarhus University made things easy. I come from a country where bureaucratic procedures can be eternal, so, I was surprised by the effectiveness and the friendly staff: in a few months my children had a school, my husband a research contact in astronomy, my family an apartment and everything was ready for our arrival.

11th January 2017. Center for Music in the Brain. I was met by my new colleagues. I like the cordial atmosphere that the place breaths. We bounced work ideas for the following months, and I joined the Learning strand. My area of expertise is the role of music in relation to the cognitive reserve. How music training in different stages of life can contribute to improve the reserve, and how it can influence in managing aging or neurodegenerative diseases. I wanted to test several ideas about musicians' brain function but, really, 6 months is not enough time to carry out new research. It is not easy to start up the machinery so that new ideas are carried out since ethic approval takes time. Maybe in that case, I find differences with my university, where, if the resources exist one can start working experimentally whenever you want. Maybe in that sense, we improvise more and then we solve (if necessary we ask for help, approvals, etc.) which is sometimes an advantage in research.



*The familiy visiting AROS*

For me MIB has three characteristics that makes it unique and special: First, the willingness to receive students, PhDs, teachers and staff from all sites, from different universities and countries and with different academic status. It breathes an integrating atmosphere and an incredible professional wealth and collaborative work.

Second, and very similar to the previous, the possibility of enriching all the visitors and permanent researchers with talks and conferences. For those who, like me, dedicate a large part of our time to teaching, it is a real pleasure to attend talks by pioneering researchers in musical research.

Thirdly, the passion for music. I have visited other research centers where I have learned about neuroscience or neuropsychology, but never before have I visited a place where music is paired with so many scientific disciplines. And it is the core which everything revolves around. This is the key to why MIB is such a special place. I think that this integrative and multidisciplinary model will reaffirm you as an excellent research European nucleus, researching in consonance with European guideline of investigation and dissemination of results.

One of the reason I choose to do my research visit in Denmark was because of education. It is said that education in the Nordic countries is at the top of Europe. And, the reality has not disappointed us. The culture, society and values of the Danes are really revealed in the school. I was surprised that there were no fences in the playgrounds, that the doors were open, that the children played in the afternoons at the schools or that they were available for community activities. This is really the best of the Danish people, education in respect to both individual and community. Maybe this is not surprising for Danish people, but for me, I come from a country of"every man for himself". On the other hand, education is also different. There is less content and concepts to memorize and it is more focused on procedures, the reinforcement of skills and abilities, the emotional intelligence, more centered on the student, who participates in the aims of their education. My youngest son, Dany, still asks about his school in Aarhus, the school where "although it was raining you could go out to the playground!" It was an unique experience.

It was also a unique experience to go to the supermarket for the first time! 15 types of rye bread, 10 types of milk in that strange letters! What pack do I buy? The Danish language, that multi sensorial experience that I could write a whole other article about …

Our time in Aarhus was a great experience, as a family and as a researcher. I take good friends in my backpack, good projects and ideas of shared future, feeling like coming back, and the memory of some beers in the Studenternes Hus on Fridays.

# VISITING PERSPECTIVE

*Marcus Pearce - visiting professor at MIB*

I came to MIB in May 2017 on a five-month sabbatical from my home institution, Queen Mary University of London, where I run the Music Cognition Lab. I had already worked with several members of the centre and the visit was intended to develop new collaborative research projects with Elvira and Peter that combined my background in computational modelling with the Centre's expertise in MEG research on predictive processing of music. This was supported by a generous award from the Aarhus University Research Foundation (AUFF) that provided funding for accommodation, travel and expenses.

It's a daunting prospect moving one's entire family to a new country, especially when one doesn't speak the language. However, the staff at the international centre of Aarhus University really helped enormously with housing, childcare, official documentation and other useful information about living in Denmark. Very quickly we were struck by contrasts between life in Aarhus compared to at home in London. In particular, one never has to commute very far and I soon became used to short walks or bicycle rides into work and around town. The network of segregated bicycle lanes is truly amazing and you feel completely safe cycling all over town and beyond, even with children in tow, though contrary to its reputation as a flat country, there are one or two hills to negotiate in Aarhus (at least compared to London). It's common to see people cycling along with children in the front of a cargo bike or pulled behind in a trailer, to and from nursery or kindergarten, even in the depths of winter.

In 2017 Aarhus was the European Capital of Culture but with young children, we perhaps didn't take as much advantage of Aarhus' cultural and artistic side as we might have done though we did spend some happy hours appreciating the Scandinavian art in the permanent collection of Aros and made several visits to the Moesgaard museum about 20 minutes outside Aarhus which has fantastic interactive exhibitions of the history of mankind, including the Vikings of course, which entertained us and the children. We regularly walked through the botanic gardens to the biodome for lunch and visited the neighbouring Den Gamle By ('The Old Town') on several occasions, enjoying the genuine historical architecture and exhibitions of daily life (including traditional and very delicious food). Further afield, we enjoyed excursions to Silkeborg, set on a series of lakes in a hilly region west of Aarhus, to the tropical zoo in Randers (with biodomes for Africa, Asia and South America) and to the Manor House museum at Gammel Estrup. We made a trip to a family open day on a farm organised by Arla (a huge Danish dairy farming cooperative) where our son was excited by all the tractors and animals. Of course, we also made the obligatory trip to Legoland, which was entertaining and enjoyable for young and old alike.

*Our home in Nobel Parken*

Turning to academic matters, I found MIB a highly engaging and rewarding place to be embedded during my sabbatical, with an open and enquiring research culture. Shortly after I arrived in May, there was a visit from the organisers of the triennial Neurosciences and Music conference, who were assessing Aarhus as a venue for the conference in 2020. I joined the tour which was a very nice way to be introduced to some of the sights of the town, including the very impressive cathedral, concert hall and royal deer park. I was very pleased when it was announced that Aarhus had been successful in its bid and will host the next conference. Congratulations MIB!

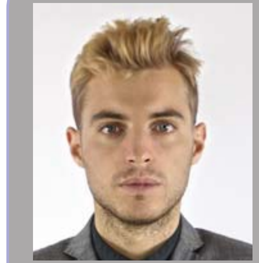
Throughout my visit, I had many stimulating discussions with various members of the centre at different stages of their research careers ranging from corridor conversations through to detailed design and planning of experimental studies.

*The Cathedral of Aarhus*

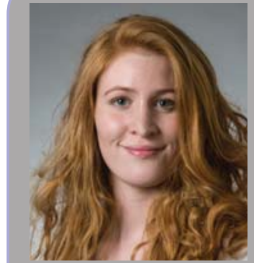
The latter collaborations have spawned three ongoing research projects, one of which has already produced results while another is at the stage of piloting. However, even through these many interactions, I still didn't manage to meet everyone in the centre. But every year MIB has a retreat called Time to Think, which is a good opportunity to get everyone together all in one place. Although this took place several months into my visit, I was truly astonished by the size of the centre when I saw all its forty or so members in the same room.

The time has passed very quickly which reflects how productive and enjoyable it has been and I look forward to continuing the collaborations formed during 2017 and hopefully returning to visit in future.

## NEW FACES AT MIB: PHD STUDENTS

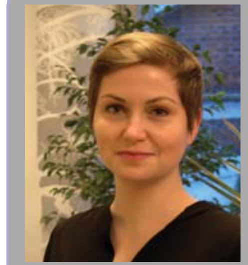


**Leonardo Bonetti** completed his Master's (honor) in Cognitive Applied Psychology (2016) at the University of Bologna and in Classical Guitar (2013) at the Conservatory of Bologna.
During his PhD he is going to use the whole-brain computational modelling to model differences in brain activation and functional connectivity between musicians and non-musicians, highlighting the causality aspect in brain processing, both in resting state network and when listening to music, taking into consideration also psychological differences between individuals in the cognitive domain.
He has performed as a guitarist and speaker in several Italian cities and in few European countries. Furthermore, he has been the artistic director of international music festivals in Bologna and, in 2014, he was Professor at Conservatory "G.B. Martini" of Bologna.



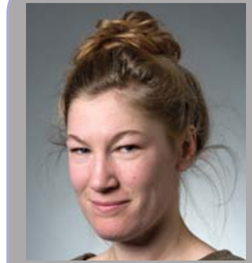
**Nadia Høgholt** is a medical student at Aarhus University and has started a MD/PhD at MIB.
Since March 2016 she has been working as a student researcher with Professor Kringelbach and Postdoc Fernandes on the ERC CAREGIVING project, the first longitudinal study to examine the development of the parental brain. Working with this project led Nadia to the idea of her PhD project about sleep deprivation during pregnancy, which now will be a supplement to the ERC project.
During her PhD project Nadia will be using fMRI and MEG techniques to examine the effects of insomnia on resting state networks and perception of baby communicative cues. Furthermore, she will be conducting a clinical trial testing the effects of music listening and light therapy on insomnia symptoms and brain function.

**Marie Dahlstrøm** studied music performance and production (BA honors) at the London Centre of Contemporaory Music as well as psychology at Birkbeck before being awarded a Master´s Degree in Music, Mind and Brain from Goldsmiths University of London in 2016.
As PhD fellow at MIB, she will be looking at the effects of parental singing in early infancy.
In parallel with her post-graduate studies, Marie is also an active professional musician.



**Christine Ahrends** studied music and musicology at the University of Music Carl Maria von Weber Dresden, the Conservatoire Santa Cecilia Rome, and the University of Music and Dance Cologne, as well as neuroscience at the Universities Maastricht and Florence.
She was research assistant at the Dresden Music Cognition Lab and visiting scholar at the Centre for Music and Science at the University of Cambridge. Parallel to her studies, she has worked as ensemble singer and participated in many concerts around Europe, as well as in a number of TV- and radio-productions.
In her PhD project, she will use behavioural and fMRI methods to investigate cross-modal integration in decision-making under uncertainty.

**Rasmine Holm Mogensen** recently attained a master's degree in psychology at Aarhus University, and she is now working as a PhD student at MIB.
Last fall she did a research internship at MIB where she conducted a project, which examined children with Autism Spectrum Disorders (ASD) and their ability to store and integrate different kinds of sensory and contextual information in memory.
During her time as a research intern, the neural dynamics of sensorimotor integration in children with ASD caught her interest. Therefore, this area of interest will be the focus of her PhD project where she will apply a finger-tapping paradigm to examine sensorimotor integration during synchronisation of behaviour in children with ASD. The project will include both MEG and MRI scans.



**Signe Hagner** graduated from Aarhus University as Master of Arts in Musicology and Psychology in December 2016, where she also completed her Bachelor's degree in 2014.
Her Master's thesis was on rhythm and meter and its anchorage in the body and received top grade.
The thesis included a behavioural study on rhythm and coordination that revealed a hierarchical relationship between different limbs (hands, feet and mouth), which will be the foundation of her PhD project. Using fMRI and MEG she plans to study how this relationship relates to the brain's processing of rhythm and meter, and how it can be affected with musical training.
Signe has been around MIB for a while as personal assistant to Peter Vuust and research assistant to Cecilie Møller. Her project is co-funded by MIB and the Faculty of Arts at AU.

# MIB ANNUAL RETREAT 2017 - GRENÅ
*Make Time to Think*


Peter Vuust introducing the ”Make Time to Think” concept and guest speaker Andreas Roepstorff

Making time to think

More thinking.....

Birthday girl Rebeka

The Incredible MIB Campfire String Band

Petersen, Vuust & Toiviainen

*Photos: Ole Heggli, Suzi Ross & Hella Kastbjerg*




Social activities:
Salsa, yoga, filming the video for the MIB song, beach volley


The winners of our Make Time to Think Competition: Manon Grube, Anne Sofie Andersen, Maria Celeste Fasaso and David Quiroga with the project ”Predicting with the Body”

# PEOPLE

Peter Vuust
Professor
Director
Principal investigator

Elvira Brattico
Professor
Principal investigator

Lauren Stewart
Professor
Principal investigator
*(Maternity leave Jan-June)*

Morten Kringelbach
Professor
Principal investigator

Line Gebauer
Associate professor

Bjørn Petersen
Assistant professor

Boris Kleber
Assistant professor

Maria Witek
Assistant professor

Angus Stevner
Postdoc

Henrique Fernandes
Postdoc

Joana Cabral
Postdoc

Marina Kliuchko
Postdoc

Massimo Lumaca
Postdoc

Tim van Hartevelt
Postdoc

Cecilie Møller
PhD student

Christine Ahrends
PhD student

David Quiroga
PhD student

Leonardo Bonetti
PhD student

Marie Dahlstrøm
PhD student

Nadia Høgholt
PhD student

Kira Vibe Jespersen
PhD student

Maria Celeste Fasano
PhD student

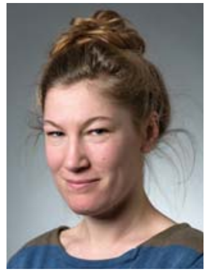
Mette Kaasgaard
PhD student

Ole Adrian Heggli
PhD student



Patricia Alves da Mota
PhD student
*(Maternity leave April-Dec)*

Rebeka Bodak
PhD student



Signe Nyboe Hagner
PhD student
*(Maternity leave Nov-Dec)*

Suzi Ross
PhD student

Pauline Cantou
PhD student

Rasmine Mogensen
PhD student

Stine Derdau Sørensen
PhD student

Niels Trusbak Haumann
Technician

Pauli Brattico
Technician

Hella Kastbjerg
Centre secretary

Tina Bach Aaen
Centre administrator

Laura Vestergaard
Student worker

Anne Sofie Andersen
Research Year Student

## GUEST RESEARCHERS AT MIB

**Professor**
- Maria Dolores Roldan Tapia

**Senior Lecturer**
- Marcus Pearce

**PhD students**
- Imre Lahdelma
- Jose Santacruz
- Marianne Tiihonen

**Master's and Bachelor's students, interns:**
- Alessandra Brusa
- Antonio Criscuolio
- Claudia Iorio
- Frank Schultze
- Giulia Gaggero
- Inez Fernandes
- Kendra Oudyk
- Magdalena Flexa
- Marcin Zarzycki
- Nader Sedghi
- Rui Rodrigues
- Victor Pando



Center for Music in the Brain
at The Neurosciences and
Music - VI,
Music, Sound and Health
at Harvard Medical School,
Boston

Photos: Suzi Ross

# PUBLICATIONS 2017

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## Conference abstracts in proceedings

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Brattico, Elvira; Liu, Chao; Abu Jamous, Basal ; Nando, Asoke. Exploration of distance metrics in consensus clustering analysis of FMRI data. 22nd International Conference on Digital Signal Processing (DSP) 2017-

## PhD thesis

Kliuchko, Marina Noise sensitivity in the function and structure of the brain.

## Books and reports

Vuust, Peter. Musik på hjernen. People's Press, 2017.

Vuust, Peter; Petersen, Bjørn; Sørensen, Stine Derdau; Ross, Suzi. Musik i hjernen: Resultatrapport for Masseeksperiment 2016. Astra, 2017.

## Book chapters (selected)

Abu-Jamous, Basel; Liu, Chao; Roberts, David, J.; Brattico, Elvira; Nandi, Asoke. Data-driven analysis of collections of big datasets by the Bi-CoPaM method yields field-specific novel insights. In: Frontiers in Electronic Technologies. Ed./ Prabaharan, Thalmann, Magnenat, Bhaaskaran. Singapore: Springer, 2017.

Brattico, Elvira; Vuust, Peter. Brain-to-brain coupling and culture as prerequisites for musical interaction. In: The Routledge Companion to Embodied Music Interaction. ed. / Micheline LeSaffre; Marc Leman; Pieter-Jan Maes. UK Routledge, 2017. p. 249-257.

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Petersen, Bjørn. Arosian Stew: Tværgående rytmik og metriske modulationer. In: Antologi over Kunstnerisk Udviklingsvirksomhed på Det Jyske Musikkonservatorium. ed. / Bjørn Petersen. Det Jyske Musikkonservatorium. 2017. p. 76-86.

van Hartevelt, Tim Johannes; Fernandes, Henrique; Stevner, Angus; Deco, Gustavo; Kringelbach, Morten L. Neural plasticity in human brain connectivity: the effects of deep brain stimulation. In: The Rewiring Brain: A Computational Approach to Structural Plasticity in the Adult Brain. Elsevier, 2017. p. 527-546.

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## Posters/abstracts (selected)

Bodak, Rebeka; Witek, Maria; Stephan, Marianne; Penhune, Virginia; Vuust, Peter; Lauren Stewart Can listening to sounds train motor skills? A between subjects study
The Neurosciences and Music VI - Music, Sound and Health, Boston, United States.

Bonetti, Leonardo; Haumann, Niels Trusbak; Kliuchko, Marina; Vuust, Peter; Brattico, Elvira. Mild depression enhances auditory pitch discrimination in the brain as indexed by the Mismatch Negativity
The Neurosciences and Music VI - Music, Sound and Health - Havard Medical School, Boston, United States

Bonetti, Leonardo; Haumann, Niels Trusbak; Vuust, Peter; Kliuchko, Marina; Brattico, Elvira. Mismatch Negativity to sound pitch deviants as a possible screening tool for depression.
International Health Conference - St Hugh´s College, Oxford University, Oxford, United Kingdom

Bonetti, Leonardo; Haumann, Niels Trusbak; Brattico, Elvira; Kliuchko, Marina; Vuust, Peter; Näätänen, Risto. Working memory performance predicts the neural discrimination of sound deviants as indexed by frontal mismatch negativity: an MEG study.
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Bonetti, Leonardo; Haumann, Niels Trusbak; Brattico, Elvira; Kliuchko, Marina; Vuust, Peter; Näätänen, Risto. Working memory regulates frontal Mismatch Negativity to sound intensity and slide deviants.
Neuroscience Day - Let's rethink memory 2017, Aarhus, Denmark.

Fasano, Maria Celeste; Glerean, Enrico; Gold, Benjamin; Sheng, Dana; Sams, Mikko; Rauschecker, Josef; Vuust, Peter; Brattico, Elvira. The brain correlates of engagement in music performance: A behavioral and fMRI study.
The Neurosciences and Music VI - Music, Sound and Health, Boston, United States.

Fasano, Maria Celeste; Glerean, Enrico; Gold, Benjamin; Sheng, Dana; Sams, Mikko; Rauschecker, Josef; Vuust, Peter; Brattico, Elvira. Neural changes after multimodal learning in pianists - An fMRI study.
Aarhus University Graduate School of Health, PhD Day 2017, Aarhus, Denmark.

Heinonen-Guzejev, Marja; Kliuchko, Marina; Vuust, Peter; Tervaniemi, Mari; Brattico, Elvira. Studying noise sensitivity on the brain level.
12th ICBEN Congress on Noise as a Public Health Problem, Zurich, Switzerland.

Jespersen, Kira Vibe; Otto, Marit; Kringelbach, Morten L.; Van Someren, Eus; Vuust, Peter. The effect of music on insomnia - a randomized controlled trial.
The Neurosciences and Music VI - Music, Sound and Health, Boston, United States.

Petersen, Bjørn; Friis Andersen, Anne Sofie; Højlund, Andreas; Dietz, Martin; Haumann, Niels Trusbak; Brattico, Elvira; Ovesen, Therese; Vuust, Peter. Music Listening in Electric Hearing -designing and testing two novel EEG paradigms for measuring music perception in cochlear implant users.
15th symposium on Cochlear Implants in children, San Francisco, United States.

Quiroga Martinez, David Ricardo; Hansen, Niels Christian; Højlund, Andreas; Brattico, Elvira; Vuust, Peter. Perceptual processing of a complex musical context: Testing a more realistic mismatch negativity (MMN) paradigm.
MEG NORD 2017, Aarhus, Denmark and European Society for Cognitive Sciences Of Music (ESCOM), 2017, Ghent, Belgium.

Quiroga Martinez, David Ricardo; Hansen, Niels Christian; Højlund, Andreas; Brattico, Elvira; Vuust, Peter.
A new multifeature mismatch negativity (MMN) paradigm for the study of music perception with more real-sounding stimuli.
Donders Discussions 2017, Nejmegen, Netherlands.

Photo: Hella Kastbjerg

Quiroga Martinez, David Ricardo; Hansen, Niels Christian; Højlund, Andreas; Brattico, Elvira; Vuust, Peter.
Perceptual processing of a complex auditory context : testing a new dichotic multifeature mismatch negativity (MMN) paradigm.
The Neurosciences and Music VI, Boston, United States.

Ross, Suzi; Brattico, Elvira; Herrojo Ruiz, Maria; Stewart, Lauren. Predicting pitch from action in expert musicians.
Aarhus University Graduate School of Health, PhD Day 2017, Aarhus, Denmark.

Sørensen, Stine Derdau; Petersen, Bjørn; Ross, Suzi; Wallentin, Mikkel; Heggli, Ole Adrian; Haumann, Niels Trusbak; Brattico, Elvira; Vuust, Peter. The miniMET - A novel tool for measuring musical abilities in children.
The Neurosciences and Music VI - Music, Sound and Health, Boston, United States.

# OUTREACH 2017

## Invited talks/talks at international conferences

**Bjørn Petersen**
Cochlear Nordic Symposium 2017, Stockholm, Sweden
EURO-CIU Symposium, Helsinki, Finland

**Boris Kleber**
14th Christmas meeting at the Instituto de Neurociencias de Alicante, Spain
VIII Annual COST related Symposium & VII World Voice Consortium Congress, Copenhagen, Denmark

**Elvira Brattico**
European Society for Cognitive Sciences Of Music (ESCOM), Ghent, Belgium
La musicoterapia ascolta le neuroscienze, Padua, Italy
Leitourgia Annual Conference, Aarhus, Denmark
Neuroscience Day 2017, Aarhus, Denmark
MEG Nord Conference, Aarhus, Denmark

**Lauren Stewart**
The Systematic Musicology 10th International Conference, London, UK

**Massimo Lumaca**
Inaugural Conference of The Cultural Evolution Society, Max Planck Institut, Germany

**Mette Kaasgaard**
Forskningens Døgn, Copenhagen, Denmark

**Morten Kringelbach**
Brain Prize, Middelfart, Denmark
3rd International Conference on Architecture, Research, Care and Health, Aalborg University Copenhagen, Denmark
Organization for Human Brain Mapping, Vancouver, Canada
13th International Infant Cry Workshop, Trento, Italy
Biannual Meeting of the British Sleep Society, Brighton, UK
Delwart Symposium, Brussels, Belgium

**Peter Vuust**
The Symphony of Modern Neuroscience, Marseilles, France
International Workshop on Cross-disciplinary and Multi-cultural Perspectives on Musical Rhythm III, Abu Dhabi, United Arab Emirates
Neuroscience and Music – VI, Boston, USA
The 13th International Symposium on Computer Music Multidisciplinary Research, Porto, Portugal

**Rasmine Mogensen**
International conference on autism, Skive, Denmark

**Rebeka Bodak**
The Systematic Musicology 10th International Conference, London, UK


*Peter Vuust speaking in Boston*





## Other talks (selected)

**Elvira Brattico**
Caffescienza, Italy
CFIN and Neurophysiology Symposium, Aarhus, Denmark
Seminar of the Neurology Department, Aarhus University Hospital, Denmark.
Odder Music School, Denmark

**Kira Vibe Jespersen**
Annual meeting of Dansk Selskab for Søvnmedicin, Denmark
Søvnmøde Region Midt, Denmark
Aalborg University, Denmark

**Lauren Stewart**
Cheltenham Science Festival, London, UK

**Leonardo Bonetti**
University of Bologna, Cesena, Italy.
University of Bologna, Bologna, Italy.
International Health Conference, Oxford University, UK.

**Morten Kringelbach**
Tel Aviv University, Israel
Tel Aviv Hospital, Israel
Oxford ScandSoc, UK
Cosmic People, Copenhagen, Denmark
Brain Prize annoncement, Denmark
Oliver Sacks Memorial, Oxford, UK
Lecture at Open University, Psychological Society på Warwick University, UK
Carlsberg, Politiken, Copenhagen, Denmark
Royal Institution of Great Britain
Firmenich, Geneva
Summer School Oxford, UK
Scars of War Foundation, Oxford, UK
Oxford University Museum of Natural History, UK
Trygfonden, Copenhagen, Denmkar
Brain Matters Seminar, Wits, South Africa

*Elvira Brattico speaking at the CFIN & Neurophysiology Symposium*

**Peter Vuust**
Cairos, Denmark
Slagelse Musikskole, Denmark
6. Nordiske Konference, Center for Høretab i Fredericia, Denmark
Odense University Hospital, Denmark
Forskningens Døgn 2017, Denmark
Seminar on children's music, Denmark
Struer Kommune, Denmark
FOFs Sommerhøjskole, Denmark
Pori Jazz Festival, Finland
Innovationssommerskole in Vejle, Denmark
Conference "Støj og Musik på intensivafdelingen", Aarhus University Hospital, Denmark
Seminar i Klinisk Socialmedicin & Rehabilitering, Skanderborg, Denmark
Conference "Kunst, kultur og sundhedsfremme", Copenhagen, Denmark
TL Fagfestival, Fredericia, Denmark
Neurodagen, Copenhagen
Arbejdsmiljøkonference, Herning, Denmark
Sejergaardsskolen, Tølløse, Denmark
Farum Bibliotek, Denmark
Rambøll, Denmark
FOF Odense, Denmark
Vejle Symposium, Denmark

**Stine Derdau Sørensen**
Brain Awareness Week 2017, Denmark

## Participation in TV and Radio (selected)

**Bjørn Petersen**
TV2 Syd: Interview about the Mass Experiment
P4 Østjylland: Experiment at SPOT Festival

**Cecilie Møller**
P4 Østjylland: Experiment at SPOT Festival

**Lauren Stewart**
BBC Radio 4: About earworms
The Guardian: Podcast on how music affects the brain

**Morten Kringelbach**
DR P1 Radio: Forældrehjernen
DR TV: Featured expert in Four part TV documentary ”Nydelse”
Aeon.com: TV interview about ’Pleasure and the good life
DR Morgen Radio: Pleasure cycles and the Brain Prize
DR2 Dagen: TV Interview on ’Reward from Brain Prize’
TV2 News: Interview on ’Brain Prize’

**Peter Vuust**
DR2 Morgen TV: Mass Experiment
TV2 Nyheder: Mass Experiment
DR P1 Radio: Mass Experiment
P2 Radio: Mass Experiment
TV2: Musik kan være en nøgle til at forstå hjernen
Magisterbladet.dk: The book ”Musik på hjernen”
TV: DR2 Dagen: The book ”Musik på hjernen”
Radio P4: The book ”Musik på hjernen”
TV2 Go´Morgen Danmark: The book ”Musik på hjernen”
DR1 Sundhedsmagasinet: Kan musik helbrede?
P2 Radio: About the book ”Musik på hjernen”
P4 Radio: Music and the brain
P1 Radio - Bagklog: Music and the brain
P1 Radio - Supertanker: Music and the brain
TV2 Go´Morgen Danmark: About Christmas songs

## Interviews in printed media/web (selected)

**Bjørn Petersen & Cecilie Møller:**
Jyllands-Posten: Experiment at SPOT Festival

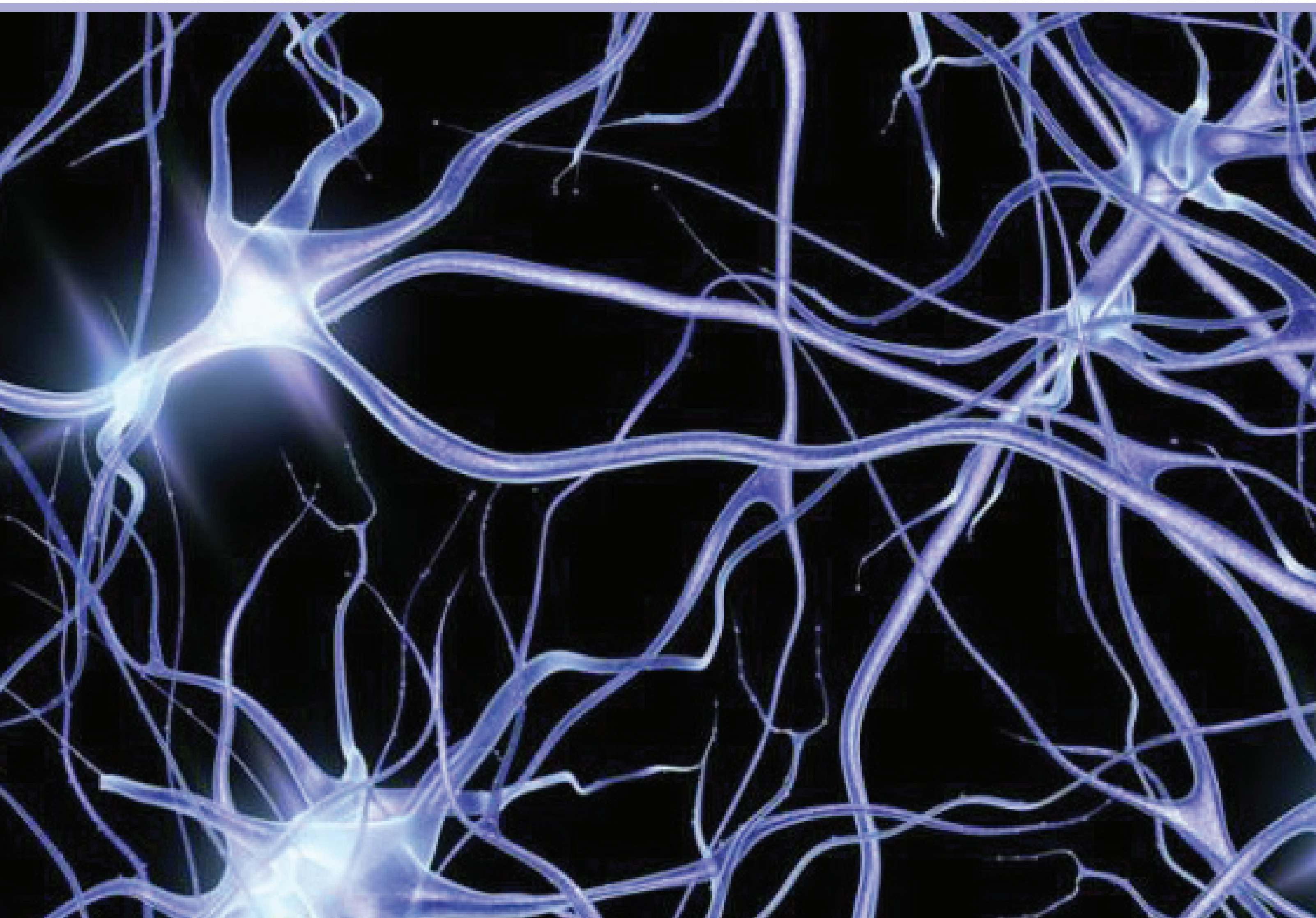
**Elvira Brattico**
Biotechniques.com: Genes, Music and the Brain
www.cerveauetpsycho.fr: La musique a-t-elle toujours un effet sur notre humeur?

**Massimo Lumaca**
Magazine Mente e Cercello: Il senso della musica

**Morten Kringelbach**
Live video stream talk: Det nydelsesfulde menneske
Podcast debate: Hvad sker der i den nydelsesfulde hjerne?
OX Magazine: The Traumatised brain
New York Times: A Baby Wails, and the Adult World Comes Running
Politiken : Forskere afslører hemmeligheden bag dyb hjernestimulation
Magazine El Dia: La estimulación cerebral profunda alivia los síntomas del párkinson’
Magazine Redacción Médica: La estimulación cerebral profunda alivia los síntomas del párkinson’
Medical Xpress: The wiser brain: Insights from healthy elders
Information: Gyserfilm
The Guardian: Put on your party shoes – it’s time for political hedonism
Weekendavisen: Små djævle
Dr.dk: Gys og smerte hænger sammen med nydelse
Dr.dk: Vi er skabt til at nyde mad, sex og samvær
Videnskab.dk: Prisvindende forskning: Vi lærer gennem belønning
Dr.dk: Forskning i hjernens belønningscenter vinder millioner

**Peter Vuust**
netudgaven.dk: Husker du soundtracket til dit første kys?
tv2fyn.dk: Mass Experiment
Politikken: Mass Experiment
Jyllandsposten: Mass Experiment
dr.dk: Mass Experiment
Jyllandsposten: The book ”Musik på hjernen”
Politikken: The book ”Musik på hjernen”
Magisterbladet.dk: The book ”Musik på hjernen”
Kristeligt Dagblad: The book ”Musik på hjernen”
Weekendavisen: The book ”Musik på hjernen”
Fyns Amts Avis: Musik pirrer hjernen
Magasinet Frie Skoler: Musik og læring handler om forventninger
Musikeren: Musik handler om sex & stoffer
Magasinet Lime: Lyt dig lykkelig
Kristeligt Dagblad: Vi køber os til stilhed
Erhvervsmagasinet Dental: Rytmen tager smerten

*Center for Music in the Brain.* *Photo: Hella Kastbjerg*



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