# MIB 2019

## The Danish National Research Foundation's Center for Music in the Brain

MIB Annual Report 2019

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

Annual Report 2019

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# WORDS FROM THE DIRECTOR

The year 2019 was an extremely productive year at Center for Music in the Brain (MIB) in terms of publications, international collaborations, and outreach. We published a high number of peer reviewed papers (see full list on page 74) with an increasing impact on the field of neuroscience and music and an increasingly strong effect on decision makers with regards to strategies for the use of music within the educational and health care systems in Denmark.

Central to the MIB research is the tenet that music, structured around the unifying theme of prediction, can advance our understanding of prediction as a fundamental brain principle across a range of functional domains, as expressed in our Predictive Coding of Music (PCM) model. In 2019, the model was featured in a review paper in the prestigious journal, Trends in Cognitive Science, and presented orally at The Predictive Brain Conference in Marseille in September.

Through the process of studying PCM as the basis of perception, action, emotion, and learning at the individual level, a new direction of research has emerged at MIB, which focuses on understanding the predictive mechanisms involved in how music becomes meaningful when it is communicated between humans. Hence, in 2019 we suggested a new oscillator-based model for understanding perception/action brain processes related to interpersonal synchronization, which applies successfully to people tapping together and the related brain responses. In a more ecologically valid context, we are using musical improvisation as a model for studying non-verbal communication as well as creativity through music analyses, mathematical modelling, and with behavioural and neuroscientific experiments; most often using jazz as the prime example.

At a greater scale we published a paper in the high impact journal eLife, which is now featured at videnskab.dk, showing how structure in music evolves over centuries, possibly millennia, partly through the process of intergenerational transmission, “adapting” to the brains of its users, i.e. transmitters and receivers. We are furthermore using a novel social entrainment video paradigm to show how music can provide a meaningful context for social interactions and hereby strongly influence the experience of social closeness even though participants may not be aware of this effect. These findings suggest that how much we enjoy a musical context is more relevant for the influence of temporal social cues on affective social bonding than how familiar we are with this context.

These basic research studies feed into our clinically oriented research branch, with the work on understanding music as an interpersonal

## 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.

phenomenon bearing great potential for being translated into clinical applications. One of the highlights of 2019 was our publication in Nature Communications showing that by moving beyond the state-of-the-art and developing a completely data-driven Hidden Markov Model (HMM), it is possible to characterise the spatiotemporal complexity of whole-brain networks and state transitions. Here, we used a prediction-based method to discover the dynamic choreography of different whole-brain networks across the wake-sleep cycle and are in the process of translating this knowledge into our research on the role of music listening for sleep disorders. Other important clinical applications include listening interventions to improve mood and mental health and to alleviate pain perception and cancer-related anxiety. We are also involved in active rehabilitation interventions in patients diagnosed with chronic lung disease and in patients with Parkinson's disease, and we record brain activity mapping out the music-related hearing capabilities of cochlear implant users.

MIB values international collaborations, and during the year, we have hosted a number of doctoral, postgraduate and undergraduate students from abroad and prominent guest speakers and collaborators, such as professors Martin Lotze, Petri Toiviainen, Edward Large, Eckart Altenmüller and Mari Tervaniemi. 2019 also saw new national and international collaborations, e.g. as an outcome of our work on cortical feedback mechanisms in relation to musculoskeletal pain in musicians, recently funded by the Lundbeck foundation and performed together with Danish National Research Center for Neuroplasticity and Pain (Aalborg University). We also initiated collaborations with Anne Caclin and Barbara Tilmann, University of Lyon in which we are recording EEG in amusics, and with Bob Knight at UC Berkeley, where we use intracranial recording to understand the underlying brain mechanisms of music memory.

This year saw the successful PhD defenses of Ole Adrian Heggli and Maria Celeste Fasano, who were part of the first brood of PhD students hired at MIB back in the beginning in 2015. Ole continues in a postdoc position at MIB, while Maria Celeste has been employed as postdoc at the Psychology Department at Aarhus University. In December, David Quiroga defended his thesis and was subsequently hired to continue his post-doctoral research at MIB. As a new addition to our postdoc group, we welcomed Alexandre Celma-Miralles from University Pompeu Fabra. Since September 2019, Prof. Marcus Pearce had to move back to the UK for family reasons, but he remains an important collaborator and PhD supervisor at MIB.

In the spring of 2019, the scanners and technical staff of CFIN moved to Aarhus University Hospital in Skejby, and shortly after, MIB and the rest of CFIN moved to another building at Nørrebrogade – the oldest building at the old "Kommunehospitalet". After a short period with minor turbulence, we have now settled in at the new facilities, and the collaboration with the technical staff in Skejby works seamlessly.

Together with the Mariani Foundation lots of effort has gone into organising the upcoming Neurosciences and Music Conference taking place in Aarhus June 2020. To support the conference we were happy to receive 300.000 DKK from the Lundbeck Foundation. Also, the planning of the Aarhus Summer School was a focus point this year, and we are now ready with an impressive lineup of renowned speakers, including Professors Robert Zatorre, Virginia Penhune and David Huron, and exciting hands-on workshops to welcome national and international PhD students in Aarhus. Unfortunately, both events have been postponed to 2021 due to the Covid-19 epidemic.

In December we received the wonderful news that MIB will be granted a second period by DNRF from 2021-2025.

With this annual report, we wish to highlight the scientific progress and key events in 2019 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

# PERCEPTION

*Peter Vuust, Elvira Brattico, Morten L. Kringelbach*

**By Boris Kleber**

Our previously reported refinements of the Musical Multifeature (MuMUFE) paradigms aimed at changing the predictability of acoustic feature violations, making them more musical sounding to test context dependent effects of musical expertise, and creating a shorter and thus more efficient no-standard version[1]. In 2019, this new version has been used for the first time with children. It features six types of unexpected acoustic deviations: pitch, slide, omission, intensity, and two timbre deviants, namely flute and violin. In the "orchestral musical training in school project" (OrkesterMester), a large population of 7-8 years old school children participated (see Learning, pages 30-33). The aim was to assess how playing an instrument in an orchestra may develop central auditory perceptual skills. Specifically, if playing would enhance perceptual discrimination of timbre deviants related to the instrument of training. That is, violin players were expected to show stronger neural responses to deviants composed of violin sounds than to sounds of other instruments. Similar effects have been demonstrated in cross-sectional studies with adult musicians[2].

Baseline measurements yielded encouraging results, demonstrating the feasibility of obtaining robust mismatch responses (MMR) with the non-standard MuMUFE paradigm in the context of realistic school settings. These children are now entering the training phase, which is followed by post-training measurements.

Taking a broader view on music perception, postdoc Marina Kliuchko investigated the impact of cultural differences on predictive processes in melody perception between Danish and Chinese participants[3]. This study was based on the notion that passive exposure to culturally defined musical traditions may shape the development of perceptual (e.g., melodic) expectations, which are encoded as internal models in the brain and incorporate the statistical and structural regularities of melodic patterns. The neural responses to melodic pitch violations in Danish and Chinese non-musicians were captures with MEG while listening to culturally familiar and unfamiliar folk melodies. The analysis first focused on identifying notes with a high information content (IC; e.g., low probability notes) using a computational model (IDyOM). Neural responses to IC notes were then assessed as a function of cultural familiarity with the musical content. Preliminary results supported the notion that high IC notes modulate the mid-latency components (N1 and P2), yet cultural effects were not detected. This may indicate that high information content might reflect melodic expectations more generally and independent from cultural familiarity.

Perceptual music preferences, on the other hand, can also be captured by changes in salient perceptual features that compose the sound of recorded music. In fact, many people are able to tell the representative era of a song when they hear it. Postdoc Jan Stupacher and colleagues investigated this phenomena by examining the evolution of acoustic features in music from the Billboard Hot 100 charts from 1955 to 2016[4]. They found that the songs were not only becoming louder over the years while their dynamic range decreased, but they also revealed that the largest increases involved the bass range. Even when controlling for overall intensity, spectral flux increased most strongly in the lowest frequency bands (0–100 Hz), suggesting that the chart-toppers may be so successful because they are better at synchronizing movements through bass-driven rhythms (e.g., foot-taping, head-nodding, and dancing).

Indeed, music activities are able to engage the motor system and trigger the urge to move just by listening to the beat, which suggests a biological basis of musical rhythm processing. In order to determine the mechanisms by which the brain extracts temporal properties from music, many studies focus on the concepts of beat and meter. The beat provides a stable periodicity within a stimulus sequence as a reference point to categorize the perception of acoustic events, whereas the meter hierarchically organizes these events in strong and weak positions. According to neural resonance theory (NRT), brain oscillations are synchronized to the frequency of an external periodic stimulus through nonlinear coupling between oscillating neural systems. This gave rise to the notion that beat perception may occur from the entrainment of neural populations at the beat frequency, with harmonics reflecting the subdivision level. The "frequency tagging" approach is a method that captures how neural oscillations are frequency-locked to the beat and meter through analyzing the frequency domain of EEG recordings.

Postdoc Alexandre Celma Miralles used frequency tagging to examine (i) if subdivisions of a beat are an emergent property of the oscillating neural system and (ii) if neural entrainment favors certain (binary) subdivisions[5]. In his experiment, musicians and non-musicians listened repeatedly to an isochronous beat, a subdivision of this beat (duplet, triplet, quadruplet or quintuplet), and again the isochronous beat followed by the same subdivisions while tapping the isochronous beat (Fig. 1).

Results revealed that when subjects listened to the subdivisions, the neural synchronization to the frequency of its beat increased in the EEG recordings. Sensorimotor integration (i.e., tapping to the beat) was more consistent in musicians than in non-musicians, and better for duplets, triplets and quadruplets than for quintuplets, as indicated by enhanced neural entrainment (Fig. 2). This suggests that neural entrainment to the beat and its first harmonic may indeed support beat perception. Moreover, this could also explain why specific subdivisions enhance tapping

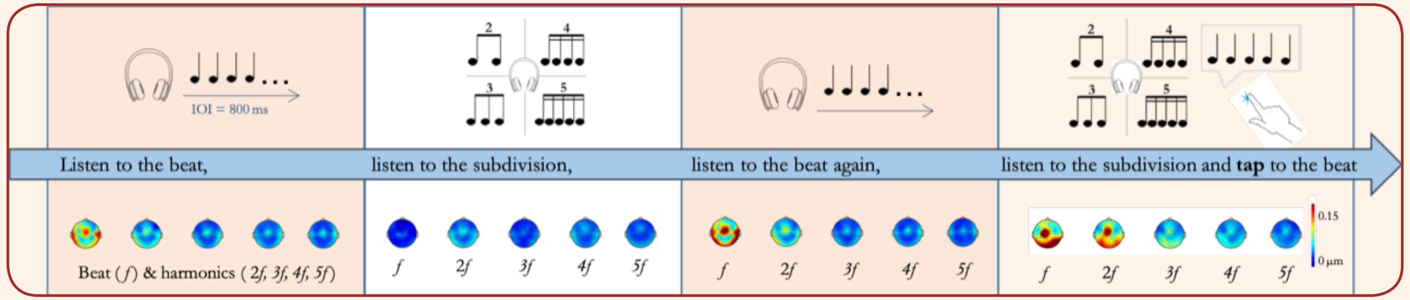
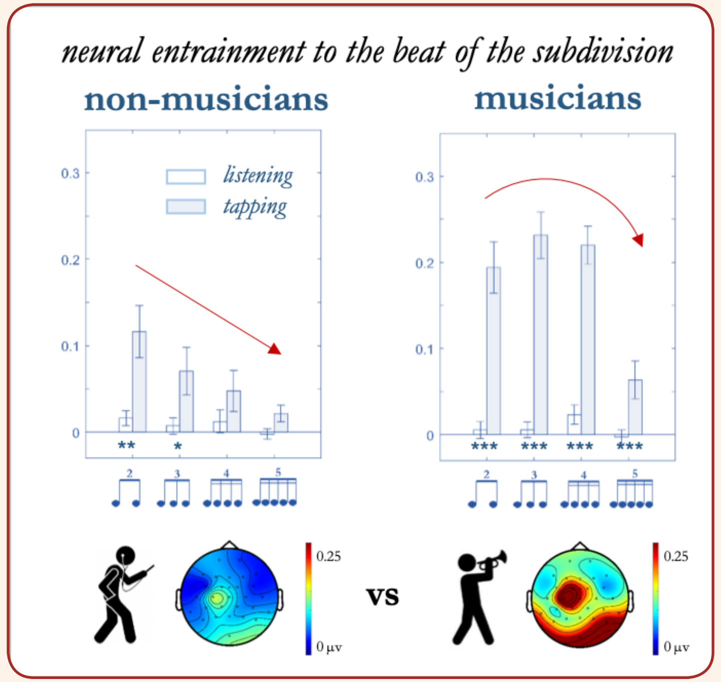



*Figure 1. Study design and topographies. All participants listened to continuous auditory sequences that presented the beat* **(1)***, one of four subdivisions* **(2)***, the same beat again* **(3)** *and the same subdivision again* **(4)***. In the fourth section, participants had to tap along the beat of the subdivision. The topographies below show the averaged neural entrainment to the beat (f) and its harmonics, representing the duplet (2f), the triplet (3f), the quadruplet (4f) and the quintuplet (5f). Of notice is the increase in beat entrainment in task 3, after participants listened to the different subdivisions.*




performance independent from musical training, thus emphasizing a critical role of perception in motor processes.

In a follow up, postdocs Cecile Møller, Jan Stupacher, and Alexandre Celma Miralles used frequency tagging to test how high-level conscious beat perception can arise from low-level sensory input though the interpretation of temporal regularities. To this end, the interpretation of perceptually ambivalent 3:4 polyrhythm was manipulated by first presenting either isochronous triple-beat or quadruple-beat drum sounds to established a metrical context. Preliminary analyses of these data showed that the metrical context can influence the interpretation of the subsequent polyrhythm, as indicated by changes in neural entrainment, suggesting that predictive processes

*Figure 2. Neural entrainment to beat during listening to the subdivisions. The bar plots depict the amplitudes of beat entrainment for each subdivision and group during the task 2 and 4. Tapping the underlying beat of the subdivisions increased the amplitudes in both groups, but especially duplets, triplets and quadruplets in musicians. The topographies roughly illustrate the contralateral motor entrainment and ipsilateral cerebellar entrainment to the beat, which was greater in musically-trained than in musically-naïve participants.*



were activated that may boost the temporal expectation of upcoming events.

Assist. Prof. Massimo Lumaca and colleagues investigated how the brain deals with different levels of temporal complexity in sound[6] by relating neural prediction error, as indicated by the mismatch negativity (MMN), to the information content of rhythmic sequences. Participants listened to standard five-tone rhythms with three levels of entropy that varied with respect to the number of unequal interval durations (zero, two, or four) and the size of prediction error by occasionally moving the fourth tone either 100ms or 300ms forward in time. Results showed that higher entropy is more difficult to model for the brain, yet only for small timing deviants. Larger timing deviants modulated the neural activity in the opposite direction (N1 component), indicating that temporal prediction errors occur as a function of rhythmic complexity.

Moving from basic processes to transfer effects, current evidence suggests that enhanced perceptual abilities in musical experts may be linked to mental speed, a measure of how quickly we can process information and make decisions based on it. In a big-data study (N=1000), postdoc Cecilie Møller and colleagues aimed to determine if music sophistication may also affect cognitive function in the general Danish population by combining self-report data based on the Goldsmiths Music Sophistication Index (Gold-MSI) with performance data, such as the mistuning perception test (MPT) as well as auditory and visual reaction time (RT) tests. Results yielded a significant effect of music sophistication on mental speed (as measured by visual RTs), which was fully mediated by self-reported as well as objectively measured perceptual skills. Together, results suggest that enhanced mental speed may in fact not only be an exclusive result of musical training but could rather be more commonly related to music perceptual skills across the population.

Lastly, postdoc David Quiroga-Martinez performed a series of related MMN experiments to reveal if melodic expectations in the brain are hierarchically organized, using realistic musical stimuli and computational methods. More details on this fascinating work are found on pages 62-63.

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# PERCEPTION

## Modulatory effects of musical consonance on probabilistic decision-making

**By Christine Ahrends**

As opposed to traditionally presumed linear models of decision-making, it has been shown that humans do not always make optimal decisions in a given context[1]. Instead, their decision-making is often irrational and subject to perceptual and cognitive noise[2]. Ecological environments in which individuals make decisions are noisy, and this is especially true for auditory noise. In slot machines, online games, or casinos for instance, gambling is usually accompanied by music. However, the few previous studies on auditory noise during gambling have only identified generally distracting or motivating effects of sounds[3-4], but failed to systematically link it to the information content of the sounds, thus neglecting the cognitive aspects of auditory processing.

In our study, we aimed at investigating whether the content of musical sounds can systematically bias decision-making. We used a probabilistic gambling task with either high or low uncertainty that we developed based on the Card Deck Paradigm[5-6] (Fig. 1). While participants were making decisions about the outcome of their gamble, we played tone sequences that had been randomly sampled from consonant, intermediate, and dissonant interval clouds. These stimuli were shown to elicit positive, ambiguous, and negative valence ratings, respectively[7]. Importantly, the musical stimuli were irrelevant to the decisions at hand. In line with previous studies on increased weighting of sensory input under perceptual uncertainty and the free energy principle[8, 9], we hypothesised that participants would use the information from the sounds despite their irrelevance in an attempt to reduce uncertainty in the high uncertain gambling conditions. To complement the behavioural study, we collected fMRI data of participants performing the task. We then used both amplitude and dynamic functional connectivity analyses[10] to identify functionally specialised areas and describe interactions between auditory processes and probability weighting in the brain.

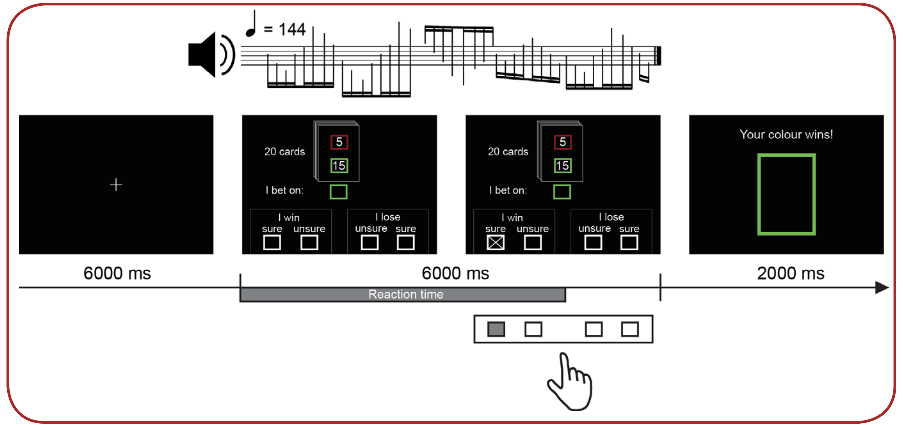


*Figure 1* *Decision-making task. Musical stimuli of different levels of consonance are played while participants make a decision about the outcome of a gamble.*





Our results show that participants change their decisions when musical stimuli were played compared to visual alone trials. However, as opposed to our initial hypothesis, we could observe this effect only in the gambles with low uncertainty, but not in the highly uncertain conditions (Fig. 2a). Using data from 78 healthy participants performing this task, we could build a model that successfully predicted decisions at 74.3% accuracy (above the chance-level of 50%) based on both the given probabilities and the level of consonance in the sounds, as well as individual variability (Fig. 2b and Fig. 2d). As an additional exploratory analysis, we then showed that the directional effect of consonance on the decisions is best described by a Bayesian model that uses a positive effect of consonant and a negative effect of dissonant sounds as a prior (Fig. 2c). This showed that the effect of music is indeed systematic based on the content of the sounds: Participants are more optimistic about their outcome in trials with consonant sounds and more pessimistic in trials with dissonant sounds.

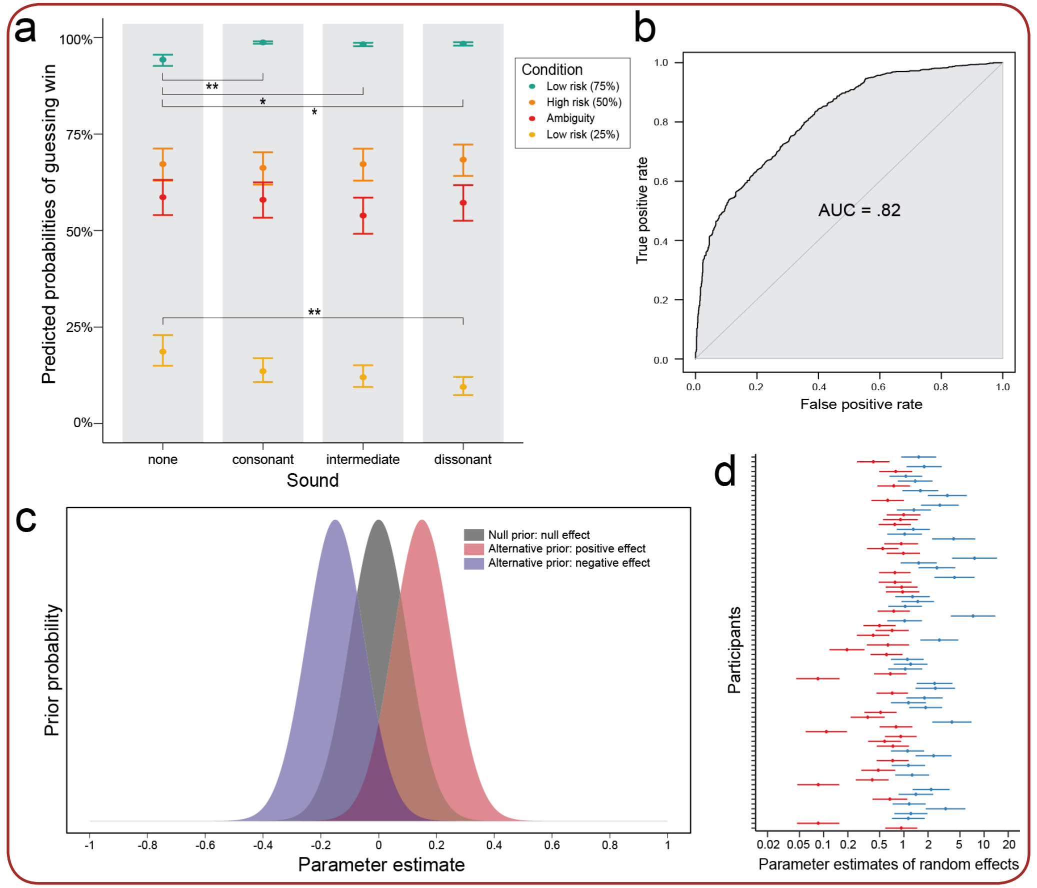


*Figure 2* *Models of decision-making behaviour. a) Predicted probabilities of a GLM modelling the interaction effect of sounds and uncertainty on the outcome. b) ROC-plot of model performance. c) Priors used for Bayesian analysis. d) Random subject intercepts included in all models.*

Based on these findings, we then identified brain areas associated with these different task conditions (Fig. 3a). First, we found that activation in areas involved in impulse-inhibition and decision-making, such as the anterior cingulate

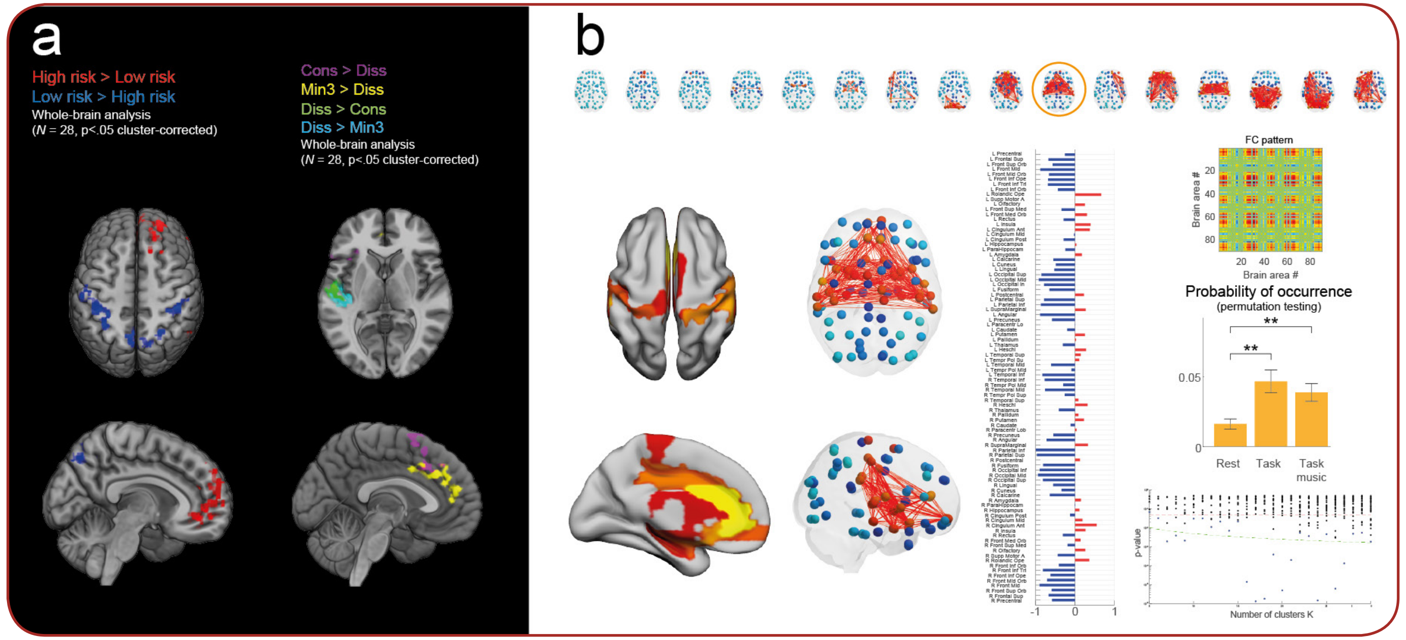


*Figure 3.* *Patterns of brain activation and dynamic functional connectivity during the decision-making task. a) GLM-analysis of condition-specific brain activation. b) Modelling of a dynamic functional connectivity network with higher probability of occurrence during the decision-making task.*

cortex and frontal gyrus, is increased during high uncertainty, while activation in sensory-motor regions is decreased. We could also observe functionally distinct areas related to the level of consonance in the musical stimuli: the dissonant stimuli showed a pattern of activation centred on the superior temporal gyrus, while a more caudal cluster in the anterior cingulate was active during intermediate stimuli and the medial region of the superior frontal gyrus during consonant stimuli.

While these results gave a detailed picture of functional specialisation of brain areas related to the different task conditions, it seems unlikely that either one of these areas alone will be responsible for the complex process of decision-making ultimately leading to the bias we observed in the behavioural data. Instead, we can conceptualise the interplay of processes necessary for decision-making in a noisy environment as communication between several nodes that changes over time.

From this perspective, we described the dynamic functional connectivity patterns of our fMRI-data, from which a single network reliably emerged as task-specific brain state (Fig. 3b). Interestingly, this network consisted of the same areas we identified in the previous analysis with the anterior cingulate cortex, the “decision-making area”, as central and most strongly connected hub. From a methodological point of view, it is particularly noteworthy that we were able to show substantial overlap across solutions between a data-driven analysis and the hypothesis-driven analysis reported above. This indicates that results from both approaches can be meaningfully combined to interpret brain processes. In the case of auditorily biased decision-making, we show that nodes specialised to process uncertainty and musical consonance synchronise and form a dynamic brain state during the task.

Decision-making in a noisy environment is not a straightforward process. While it was established that sounds can be distracting, we now show that musical content such as consonance systematically biases decision-making. This effect occurred despite participants explicitly knowing the probabilities of winning in the task and the sounds being irrelevant to the outcome. In the affected decisions, consonant sounds led participants to be more optimistic about the outcome, while dissonant sounds made them more pessimistic. However, contrary to what we expected, the participants seemed to be biased by the musical stimuli only in conditions with low uncertainty. In line with decision-making[11] and attentional bottleneck theories[12], in highly uncertain situations, participants seem to be able to focus only on the relevant information instead of using available, but irrelevant auditory information to resolve uncertainty. This is likely a more effortful, but adaptive process to ensure that harder decisions are done well. Under low uncertainty, however, there would be no need to apply this cognitively more demanding strategy, so that the irrelevant auditory information could bias the more intuitive decisions. This interplay of decision-making and auditory processes in the brain can be described as an interaction of functionally specialised nodes, using the anterior cingulate cortex as a central hub. As a next step, we aim to use characteristics of these dynamic brain states to understand individual differences in susceptibility to decision-making bias.

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# ACTION

*Peter Vuust*

Music is a social phenomenon, in that we make, listen and dance to music together. Its unique capacity to create and strengthen social bonds amongst members of a group relates to providing a rhythmic framework that facilitates synchrony and mutual adaptation. The Action strand is based on the key PCM idea that the processes underlying perception and action are coupled such that perception minimizes prediction error by updating the predictions, whilst action reduces prediction error by engaging motor systems to resample the environment. In line with the novel MIB research plan and the upcoming Neuromusic conference – connecting with music across the lifespan, this strand increasingly focuses on music interaction through rhythm.

In 2019, we published a number of studies elucidating how people interact with and communicate through music. This research was centered around four different topics: interpersonal synchronization, social entrainment, cultural transmission of music, and musical improvisation. To study interpersonal synchronization postdoc Ole Adrian Heggli used our highly cited dual-tapping paradigm (see page 58). He asked dyads of musicians to tap together with either matching or conflicting metric models while recording dual-EEG. He showed that musicians adapt differently to each other depending on their underlying internal predictive model and instrumental expertise[1]. Differences in dyad tapping behaviour – e.g. exhibiting a leader-follower, mutual adaptation or leader-leader relationship - could successfully be modelled using one internal and one external Kuramoto-oscillator per person. This is consistent with how predictive coding theories of brain processing describes bottom-up and top-down influences on neural processing[2] and simulates coupling between action and perception. Experimentally, the EEG-data showed that dyads exhibiting mutual adaptation behaviour engaged action-perception brain networks to a higher degree than leader-leader dyads. These dyads also had a stronger emphasis on the external oscillators parameters when their tapping data was fitted to the 4-oscillator model. Because of the simplicity and scalability of the Kuramoto-model, we are currently trying to extend our research into synchronization behaviour for larger ensembles.

When people interact with music, they do not only synchronize their motor output and behaviour, but also communicate, interact socially and build up social relations including trust and cohesion. Our groove experiments have comprehensively elucidated the inverted U-shaped relationship between syncopation and the pleasurable sensation of wanting to move. We the relationship between groove and dancers' movement accuracy[4], in individuals with different cultural backgrounds[5], brain responses to groove[6], and the interaction between rhythmic and harmonic complexity[3] (Fig. 1).



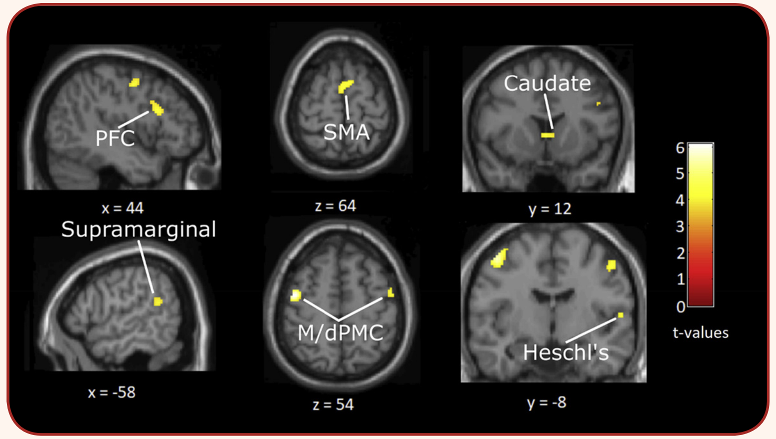


***Figure 1.*** *Motor system activation in musicians compared to non-musicians when listening to groovy rhythms ( M/dPMC, motor/dorsal premotor cortex; PFC, prefrontal cortex; SMA, supplementary motor area).*

In extension of these studies, postdoc Jan Stupacher used his social entrainment video paradigm[7] to study the influence of groove music on social connectedness (see page 18). In three behavioural experiments (under review) we showed that participants felt closer to a virtual other when a virtual self and other were moving synchronously. When the context-providing music was more familiar, social closeness was higher independent of movement synchrony. When the music was more enjoyed, social closeness increased strongly with a synchronized virtual other, but only weakly with an asynchronized virtual other. This suggest that how much we enjoy a musical context is more relevant for the influence of temporal social cues on affective social bonding than how familiar we are with this context.

Investigating musical interaction in a broader context, Assist. Prof. Massimo Lumaca used his multi-generational signalling games (MGSGs) paradigm, in which music material conveying emotional meaning is passed on from senders to receivers in transmission chains of generations of individuals to study cultural transmission of music. Using auditory and resting-state functional magnetic resonance imaging (fMRI) with MGSGs, we found that the degree of interhemispheric resting state functional connectivity within fronto-temporal auditory networks predicts learning, transmission, and structural modification of melodies from an artificial tone system[8].

This study introduces neuroimaging in cultural transmission research and points to specific neural auditory processing mechanisms that constrain and drive variation in the cultural transmission and regularization of musical systems. Importantly, these studies are highly integrated with and contribute to the development of the theoretical framework of MIB[9]. Consistent with PCM, we used Causal Modelling (DCM) on fMRI data acquired during the presentation of complex auditory patterns in the MSGS study. We showed that learning of complex auditory patterns is associated with changes in the excitatory feedforward connections encoding prediction errors and in the intrinsic connections that encode the precision of these errors and modulate their gain[10].

A particularly important form of musical interaction and meaningful communication during playing take the form of improvisation. This is integral to non-Western styles of music, as

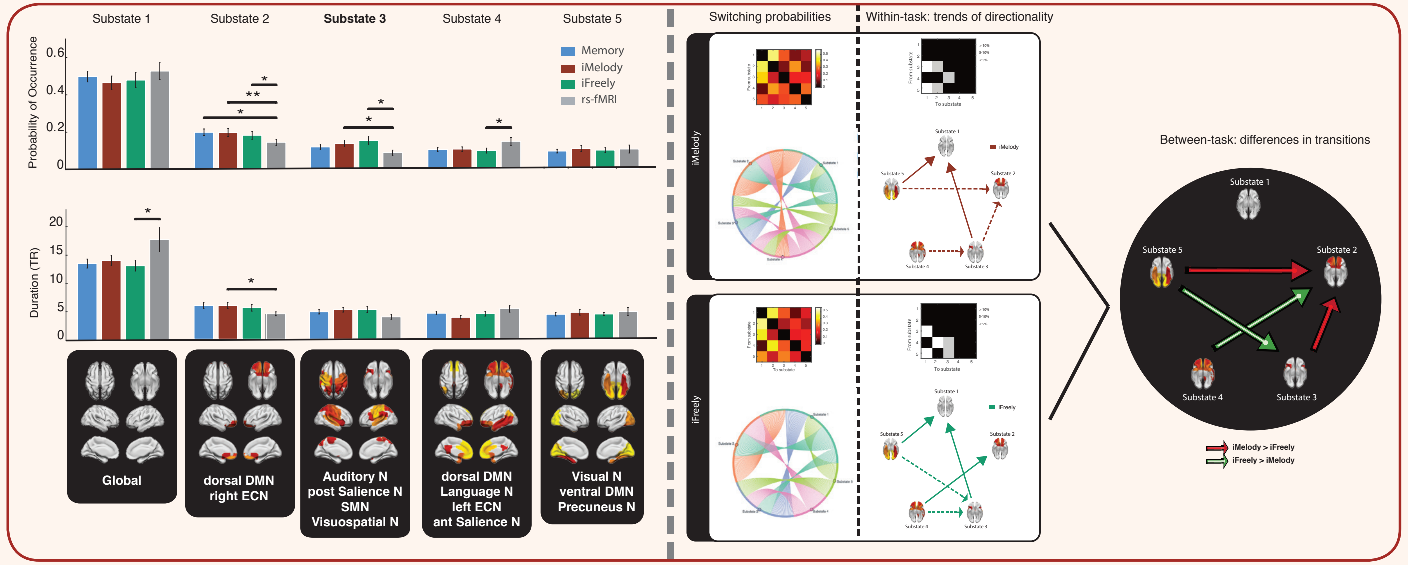


***Figure 2.*** *Neural correlates of musical improvisation. Repertoire of metastable brain states and respective probabilities of occurrence estimated using LEiDA for improvisation and non-improvisation conditions (left). Brain state switching profiles for the improvisation conditions (right).*

well as to blues or freestyle rap and in particular to jazz. In collaboration with the Emotion and Perception strands, we use musical improvisation as a model for studying non-verbal communication. Currently, we are studying the neural correlates of improvisation combining structural and functional neuroimaging data with connectomics and whole-brain computational modelling.

PhD student Patricia da Mota has used MRI to scan expert jazz piano players while they improvised over a well-known jazz song. The conditions included a) playing the melody by heart, b) sight-reading an unknown melody, c) improvising a similar melody, and d) freely improvising. Preliminary analyses of brain connectivity dynamics indicate different probabilities of occurrence of brain states in improvisation conditions compared to non-improvisation. Despite the musical output being more similar between modes of improvisation, differences in terms of brain state probabilities of occurrence and transition profiles were found, with free improvisation having to rely more strongly on an auditory-motor network, and less on default mode, executive control and salience networks (Fig. 2).

In a similar improvisation paradigm, using MIB's unique technical competences in fMRI of overt singing[11], we are currently trying to distinguish between effects related to motor skill (singers vs. non-singers) and improvisation expertise (jazz vs. classical vs. non-singers). Such studies in different musical populations and in non-musicians[12-14] contribute to





our goal of translating our basic research, grounded in the predictive coding of music hypothesis, into applications relevant for music education.

The research in the Action strand is equally important to MIB's clinical studies[15-20], especially to those that involves motor systems in the brain. We have recently acquired exciting data showing a different U-shaped relationship between degree of syncopation and wanting to move in patients with Parkinson's diseasewhich will have direct implications for guidelines concerning the use of music in rehabilitation efforts in these patients (in submission). In another approach together with the Perception strand[21] and CNAP,  Aalborg University, we study cortical feedback mechanisms in relation to musculoskeletal pain in musicians, using fMRI, TMS and behavioural measures. While uncovering underlying brain mechanisms related to pain, these studies may also provide knowledge of importance to rehabilitation efforts in these populations.

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# ACTION

## Social entrainment with music

**By Jan Stupacher**

Music is predominantly performed in groups and oftentimes for groups to induce bodily movements and to emotionally unite people[1]. In social interactions, music facilitates coordination by increasing the predictability of another person's behavior and mood. Accordingly, it has been argued that human musicality might have partly evolved to facilitate social living[2].

Social bonds have long been associated with enhanced mental and physical health and well-being[3]. How well we connect with another person depends, among others, on our cultural background, individual preferences, and the context of a given situation. Music provides a social context by introducing temporal and affective frameworks, which increase behavioral synchrony and emotional harmony. Individuals collectively synchronize their movements with rhythmical features of the music on a temporal scale down to milliseconds. This type of temporal framework provides a shared understanding of a group's behavior by increasing the predictability of others' movements, for example in dance. In addition, by listening to the same music, people share common contextual information and establish joint attention, ultimately building up a collective affective experience driven by cooperation and affiliation. The synchronization of movements is usually referred to as temporal social entrainment and the sharing of emotional experiences as affective social entrainment[4].

Temporal social entrainment is observable in the tendency to synchronize movements and behavior in everyday interactions such as walking[5]. These and other expressions of interpersonal movement synchronization have been shown to promote affective social entrainment in form of affiliation and cooperation[6]. In two previous studies, we found that the prosocial effects of temporal entrainment seem to be particularly strong when moving together with music[7,8], suggesting that music adds a powerful social context to interpersonal interactions.

How temporal and affective levels of social interactions with music are connected and how they are modulated by cultural familiarity and individual musical preferences remain open questions. In three studies[9], we operationalized the affective aspects of social interactions as ratings of interpersonal closeness between two walking stick-figures in a social entrainment video paradigm developed by Stupacher and colleagues[8] (Fig. 1). In the videos, two figures were walking side by side. One figure represented a virtual self and the other figure a virtual other person. The temporal aspects of social interactions were manipulated by movement synchrony: While the virtual self always moved in time with the beat of instrumental music,



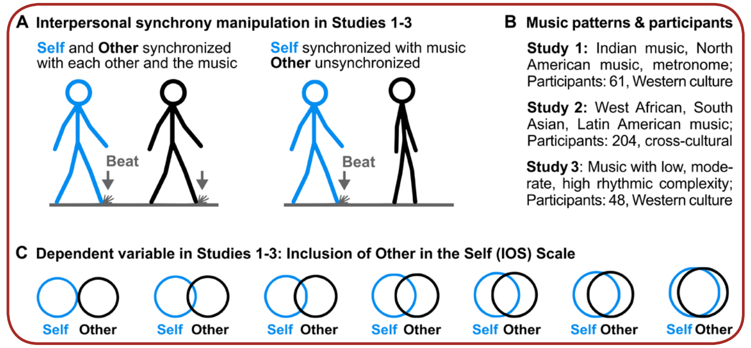


*Figure 1. A) Participants watched two walking stick figures and imagined that one of the figures represents themselves and the other figure represents an unknown person. Synchronized steps were aligned with the quarter beat of the music. A stylized dust cloud additionally marked the steps and the beat. B) Different musical stimuli used in the three studies and participant samples. C) Adapted Inclusion of Other in the Self scale10 on which participants rated the interpersonal closeness between virtual self and other on a continuous slider.*

the virtual other moved either synchronously or asynchronously. In Studies 1 and 2, the musical context was provided by instrumental music typical for different topographical regions. Participants rated the familiarity with and enjoyment of this music. In Study 2, participants additionally rated the beat clarity of the music. In Study 3, we directly manipulated the rhythmic complexity of the musical context and evaluated the effect of beat clarity on interpersonal closeness in synchronous and asynchronous movement interactions.

In all three studies, we showed that participants felt closer to a virtual other person when self and other were moving synchronously with music. Additionally, interpersonal closeness increased when the musical context of these interactions was more familiar. Importantly, this increase of interpersonal closeness was independent of movement synchrony. Furthermore, we demonstrated that enjoyment of the music is associated with strong increases of interpersonal closeness when moving with a synchronized virtual other, but only weak increases of interpersonal closeness when moving with an asynchronized virtual other. This interaction effect indicates that with less enjoyed music, movement synchrony is less relevant for social bonding than for highly enjoyed music. Taken together, these findings suggest that the influence of movement synchrony on social bonding during musical activities is less affected by what music we are familiar with but more affected by what music we enjoy.

Similar to the effect of enjoyment of music, increased beat clarity was associated with more widely separated ratings of interpersonal closeness with a synchronously compared to asynchronously walking other person. When the perceived beat clarity was higher, interpersonal closeness increased strongly with a synchronized virtual other, but only weakly with an asynchronized virtual other. From our previous findings, we know that music can strengthen interpersonal closeness by providing a meaningful context for social interactions, which can increase temporal and affective self-other overlaps. The current beat clarity results suggest that for this context to become meaningful, a clear perception of the temporal structure of the music is crucial. Without perceiving such a clear structure, temporal self-other overlaps are reduced and social bonding decreases.

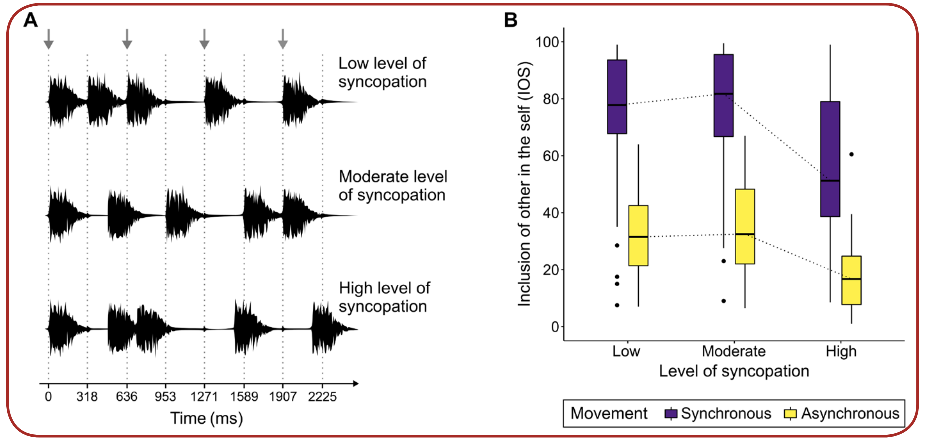


*Figure 2:* ***A)*** *Waveforms of the three different musical stimuli with low, moderate, and high levels of syncopation. The dotted grey lines represent the eighth-note level. Grey arrows on top mark the strong metric positions at the quarter-note (beat) level. In the stimulus with low syncopation, four of five onsets fall on the strong metric positions, compared to two in the moderately syncopated and one in the highly syncopated stimulus.*
***B)*** *Inclusion of Other in the Self ratings for videos with synchronously or asynchronously moving figures accompanied by musical stimuli with three different levels of rhythmic complexity.*

When directly manipulating the level of syncopation, we found that a certain amount of rhythmic complexity might actually be favorable for social bonding when moving together with music. When compared to complex rhythms with high levels of syncopation, low and moderate syncopation levels resulted in higher interpersonal closeness (Fig. 2). This finding might relate to the inverted U-shaped relationship between syncopation, pleasure, and body movement previously demonstrated by MIB researchers: Rhythms with moderate levels of syncopation are more enjoyed and induce more movement than rhythms with low and high levels of syncopation[11].

Syncopation is only one of many musical features inducing pleasure and movement – or inducing groove. Other temporal and sonic features associated with the experience of groove include beat salience, repetitiveness of the rhythm, percussiveness, density of sounds, dynamic variability, and energy in bass frequencies[12]. Over the last decades, musicians and producers made more and more use of these features – especially loud bass frequencies (Fig. 3)[13] – as the experience of groove is one of the most direct ways that music can capture individual listeners and groups of people synchronizing their movements in dance. Musical pieces with high "danceability" are more likely to end up at a high chart position[14]. These findings demonstrate our preference for music that makes us move, enables us to anticipate the movements of others, and facilitates the sharing of affective states.

In future experiments, we will adapt the social entrainment video paradigm to further investigate the tight links between temporal and affective levels of interpersonal movement synchronization. We will find out how social entrainment is related to empathy and whether we can alter ratings of social connectedness by administering oxytocin. Another future perspective is the use of social entrainment with music to improve social communication in people with autism spectrum disorder.



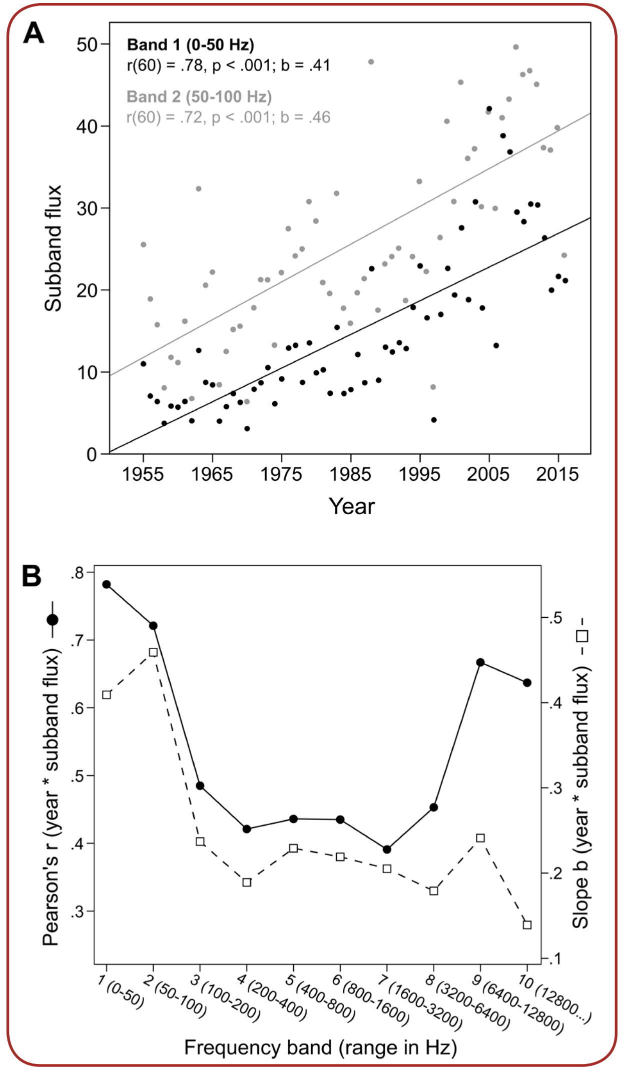


***Figure 3:*** *Analyses of the spectral flux (i.e., fluctuations in the frequency content of an audio signal) across frequency bands for the top two songs from every year-end Billboard Hot 100 Chart from 1955–2016. A) Depicts the striking increase of spectral flux in the two lowest frequency bands (0-50 and 50-100 Hz) over time. B) Depicts the correlation coefficients (•) and regression slopes (□) between year and spectral flux in all frequency bands. The most prominent increases are in the low-frequency bands.*

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# EMOTION

*Morten L. Kringelbach*

Music is a highly meaningful pleasure that arguably brings more joy than other pleasures such as coffee or chocolate[1]. Our research continues to explore the intimate links between music, emotion and eudaimonia, the life well-lived[2, 3]. The research is facilitated by the strong collaborative links between MIB, Oxford and Barcelona, which have allowed us to develop new groundbreaking whole-brain computational models with Prof. Gustavo Deco, based at Universitat Pompeu Fabra. As such this enable us to study music with methods from many disciplines including psychology, neuroscience, physics, engineering and computer science to create groundbreaking science.

Music has a unique ability to be meaningful in and of itself – as well as becoming meaningful by bringing people together as seen for example in the vital relationship between infants and caregivers, which we are exploring in the ERC CAREGIVING project.

Another example is how adolescents use music as a tool for connecting with others and promoting emotion regulation. Postdoc Maria Celeste Fasano describes on pages 60-61 the dynamics of brain activity in whole-brain networks responsible for music processing in early adolescence and shows how the orbitofrontal cortex plays a key role – similar to that seen when experiencing other pleasures.

Equally, the interactions between musicians must play a role in their experience of making meaning through music. On pages 58-59 postdoc Ole Heggli describes how strategies for interpersonal synchronisation change in musicians. In his doctoral research he used a combination of behaviour, modelling, and neuroimaging to map how musicians are able to synchronise, while at the same time adapting and anticipating each other's actions.

Yet, such studies are all conducted when awake, which is only one of many possible brain states, where for instance various sleep stages take up about a third of our lives. It is well-known that music plays a key role in other states of consciousness including sleep and psychedelics, but the underlying mechanisms are not yet clear. On pages 26-29 PhD student Christine Ahrends and postdoc Angus Stevner propose that the underlying predictive coding mechanisms of music change with different brain states. Taking this into account will allow for the formulation of new testable hypotheses regarding the neural systems supporting wakeful cognition, perception, and action. More generally, the study of music processing in altered states of consciousness will help us to expand predictive coding to the full spectrum of human experience.



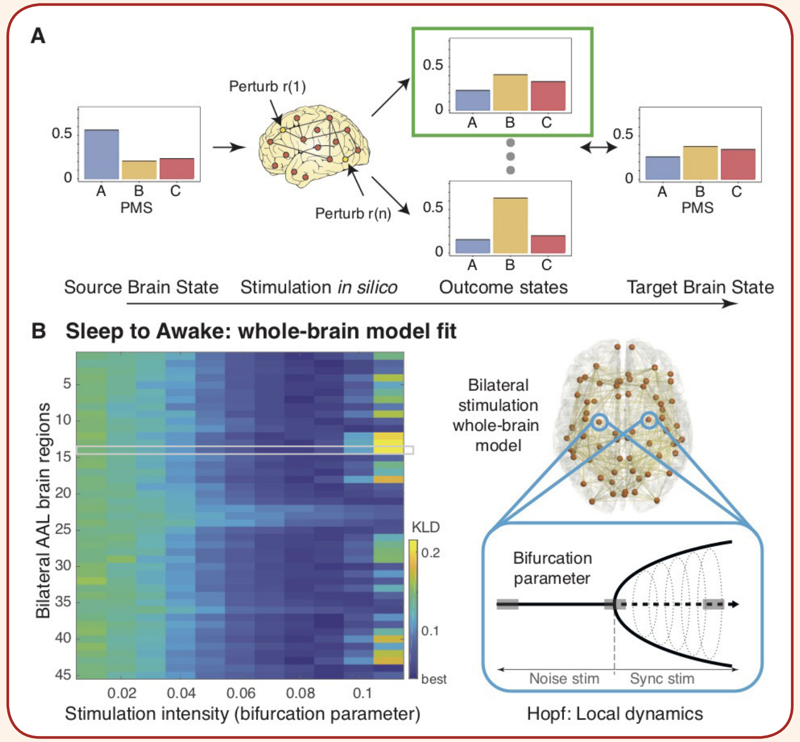


*Figure 1. Schematic of strategy for forcing transition between source and target brain states. A) The brain regions in the whole-brain model of the source state can be systematically stimulated and the results can be compared to the target state (top row). Specifically, in the local region Hopf model, it is easy to perturb the model by simply changing the bifurcation parameter[7]. B) The stimulation intensity, i.e. the strength of the perturbation, is directly related to the amount of shifting the local bifurcation parameter (bottom row, right, see[8]. The composite results are shown bottom left of stimulating the whole-brain EC model bilaterally. We show the KL-distance obtained for brain state transition fitting when perturbing separately each of the 45 regions (using bilateral stimulation) with different stimulation intensities in source state (deep sleep). Here we have highlighted one region in a grey region, which is being stimulated while the other regions are kept at their normal bifurcation parameter. The colour scale for the results shows the level of fitting with the target state (wakefulness), ie. lower values (deep blue) correspond to the most effective transitions.*

But how does the brain change between different brain states? Here we highlight our new findings (published in PNAS[4]) which show in principle how to create a whole-brain model of wakefulness and sleep and how to force a transition between them. This research has already had direct implications on music research, where MIB PhD student Patricia da Mota has used similar principles to show the causal brain networks involved when musicians are improvising using different strategies.

**Forcing transitions between brain states**

A fundamental problem in systems neuroscience is how to force a transition from one brain state to another by external driven stimulation in, for example, wakefulness, sleep, coma, or neuropsychiatric diseases. This requires a quantitative and robust definition of a brain state, which has so far proven elusive. We provided such a definition, which, together with whole-brain modeling, permits the systematic study in silico of how simulated brain stimulation can force transitions between different brain states in humans. Specifically, we used a unique neuroimaging dataset of human sleep to systematically investigate where to stimulate the brain to force an awakening of the human sleeping brain and vice versa. We showed where this is

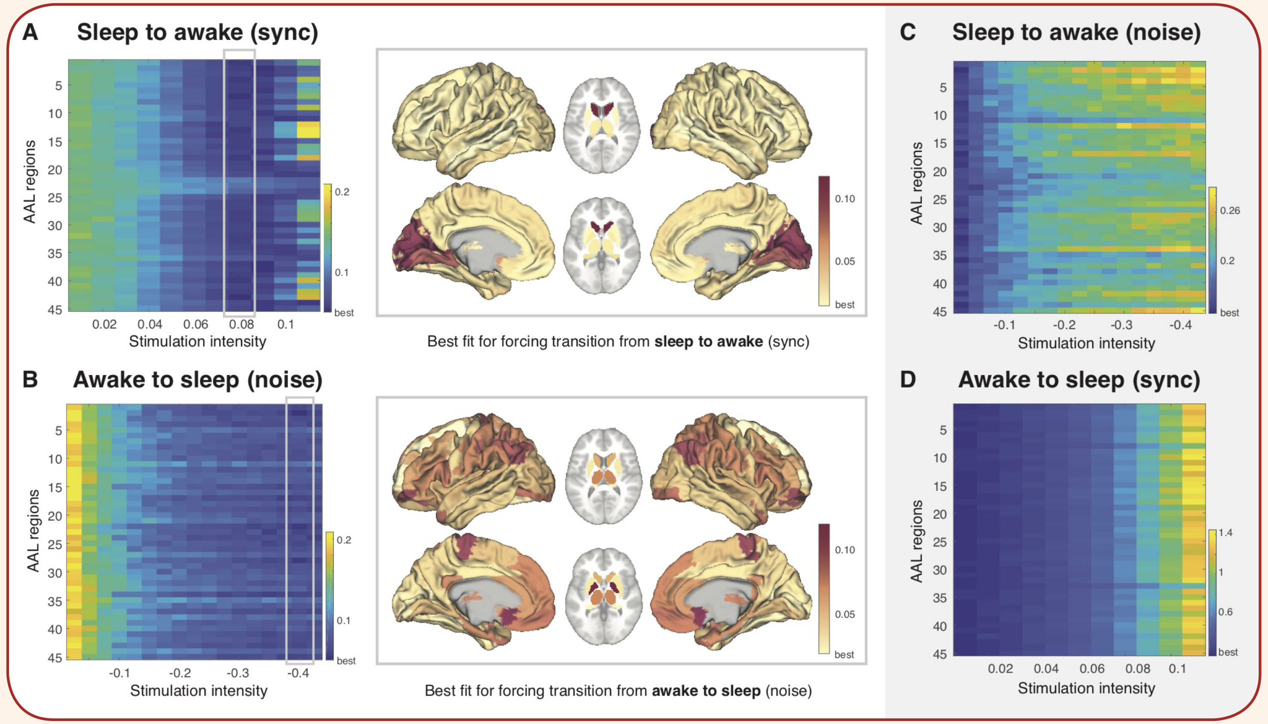


***Figure 2**. Main results of forcing a transition between brain states. We used two different protocols for external stimulation, synchronisation (sync) and noise, which shifted the local bifurcation parameter to positive and negative values, respectively.*
***A)** Showing the results of forcing a transition from source state (deep sleep) to target state (wakefulness) using a synchronisation protocol (left panel) where positive values of the local bifurcation parameter force local oscillations that promote the possibility of more synchronisation across the whole brain. The colour scale indicates the KL distance between source and target state with lower values indicating a better fit (more blue). As can be seen, a transition from deep sleep to wakefulness is promoted when perturbing most brain regions with sufficient stimulation intensity (a=0.08). In the right panel we show the ability of brain regions to promote transition at this stimulation intensity. It is clear from the results that while many regions are able to promote a transition (given sufficient stimulation), other regions are less suitable for this (see burgundy areas).*
***B)** Showing the results of forcing the opposite transition from source state (wakefulness) to target state (deep sleep) using a noise protocol (left panel), where negative values of the local bifurcation parameter force local oscillations that promote the possibility of more noise and less synchronisation across the whole brain. The results show more specificity for making the wakeful brain move to deep sleep than for the inverse, with the right panel showing the ability of brain regions to promote transition at the stimulation intensity of a=-0.4 (note the increase in burgundy areas). Please also note how the noisy protocol needs larger absolute values than the synchronisation protocol.*
***C)** In contrast, transitions are not always possible such as when using the opposite protocols for forcing transitions. In particular, when using the noise protocol to force a transition from deep sleep to wakefulness increases in stimulation intensity lead to higher KL distances, i.e. poorer fit, indicated by an increase in the colours to more yellow from blue. Please also note that the colour scale is different between A and C, with the first column in each figure having the identical numerical KL distances (corresponding to the non-perturbation case) but appearing in different colours due to different colour scales.*
***D)** Similarly, it is not possible to force a transition from wakefulness to deep sleep when using the synchronisation protocol, as shown by the monotoc increase in KL distance.*



possible using a definition of a brain state as an ensemble of “metastable substates,” each with a probabilistic stability and occurrence frequency fitted by a generative whole-brain model, fine-tuned on the basis of the effective connectivity. Given the biophysical limitations of direct electrical stimulation (DES) of microcircuits, this opens exciting possibilities for discovering stimulation targets and selecting connectivity patterns that can ensure propagation of DES-induced neural excitation, potentially making it possible to create awakenings from complex cases of brain injury.

Overall, the methods and results may eventually allow us to build causative whole-brain models that can characterize all brain states, including levels of consciousness, disease and states related with music. In particular this could have great clinical utility given that it could provide a principled way of discovering how to force a transition between two brain states. In addition, ongoing research by PhD student Patricia Da Mota is demonstrating that this technique may even provide a handle on the brain networks responsible for musical improvisation.

## Continued development of novel methods

The dynamic effects of music on emotion are complex to untangle and we are continuing to develop sophisticated new methods help with this. For this purpose we have developed whole-brain computational modelling to reveal the underlying causal brain mechanisms[5]. These developments will help us identify how music evokes emotion and how music can best help emotion regulation. Taken together, such findings provide the necessary novel tools that could be used to reveal the underlying mechanisms by which music can elicit emotion, change lives and contribute to a flourishing life[6].

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

## Predictive Coding of Music in altered states of consciousness

**By Christine Ahrends & Angus B.A. Stevner**

As a foundation of MIB, the predictive coding of music theory (PCM) has allowed us to study and describe the hierarchy of processes involved in music listening (Fig. 1, from[1]). However, so far, we have only tested our theory in normal wakefulness, which is only a fraction of states that we experience as humans. Additionally, music might play a particularly important role in other states of consciousness: While sleep has long been thought to be characterised by a lack of processing of external stimuli, there is growing evidence that properties of auditory stimuli are still processed to considerable degrees in sleep[2]. Reduced consciousness, like sleep, is only one side of the story though. In neuroscience, there is a renewed interest in the psychedelic state as a state of consciousness[3]. The link between psychedelics and music has been described across history and cultures.

Some evidence already exists that predictive coding changes in sleep and the psychedelic state. Low-level prediction error signals were seen to be preserved in sleep, while higher-order predictive coding vanished[2]. Along similar lines, low-level prediction error signals have been shown to become blunted in the psychedelic state[3]. It has been hypothesised that this effect is caused by decreased precision-weighting of higher-level priors. However, common to these approaches is that they have targeted either very low or very high levels of the processing hierarchy. From a cognitive perspective the psychedelic state is evidently highly diverse, and, albeit to a lesser extent, the same can be said of sleep. It is likely that several different recombinations of the processing hierarchy take place within each of these different states of consciousness.

Employing PCM paradigms, such as the MuMuFe[4] or the extended musical syntax paradigm[5], allows us to target specific levels of the PC hierarchy resulting in a more detailed mapping of the mechanisms and ultimately a better understanding of the cognitive states. As a new perspective to the PCM theory, we are therefore now looking to study music in altered states of consciousness.

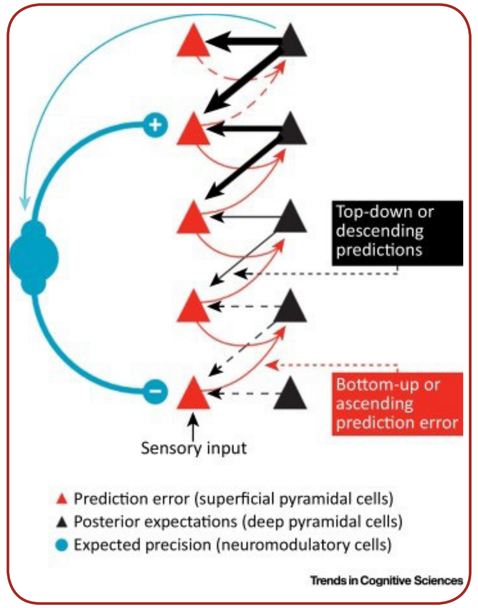


*Figure 1. Predictive coding of music. The PCM describes a hierarchical processing of ascending prediction errors (red arrows), descending priors (black arrows), and modulating precision-weighting (blue).*

Changes in consciousness imply a fundamentally different brain configuration. An influential perspective on the hierarchic architecture of consciousness in the brain is described by the Global Neuronal Workspace Theory (GNWT[6]). This view posits that a single global workspace, i.e. a group of highly interconnected regions in the brain, interacts with specialised subsystems, such as perceptual, memory, or attentional processors (Fig. 2). The top-down direction allows for conscious control of subconscious processes (signals directed from the global workspace to select input), while the bottom-up direction is a subconscious stream that constantly competes for access to the global workspace. For example, to guide attention to auditory stimuli, the global workspace can select the relevant module (auditory inputs), which then becomes conscious, while the other perceptual modules do not enter the workspace.

The way in which the conscious global workspace communicates with subconscious modules is likely fundamentally altered both during the psychedelic state and sleep (Fig. 2). The residual processing of basic sensory features in sleep without the ability to consciously access this information can be thought of as a heightened threshold of accessing the global workspace for information from lower levels of the hierarchy.[2]. In the psychedelic state,

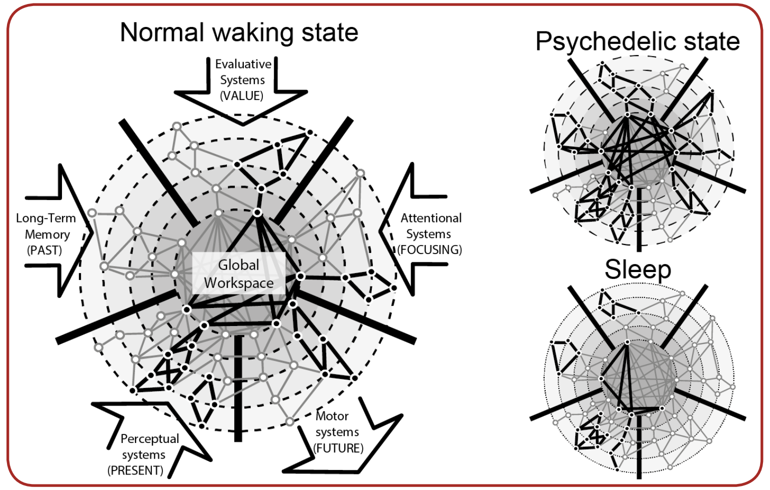


*Figure 2. The Global Neuronal Workspace and hypothesised changes in different states of consciousness.*

the relaxation of higher-level priors may be reflected in the Global Workspace perspective as a faster and less selective ignition where all levels can similarly access and influence conscious processing.

Using a new method, the normalised directed transfer entropy (NDTE) framework[7], we have recently shown that it is possible to build a functional model of the hierarchical global workspace and its neural correlates. This method will allow us to probe the theoretical scenarios of sleep and psychedelics above (Fig. 2).

The information-theoretic measure of entropy has been suggested as a physical manifestation of differences in hierarchical processing in different states of consciousness. In this view, the brain is conceptualised as a dynamical system whose spatiotemporal patterns can be described both

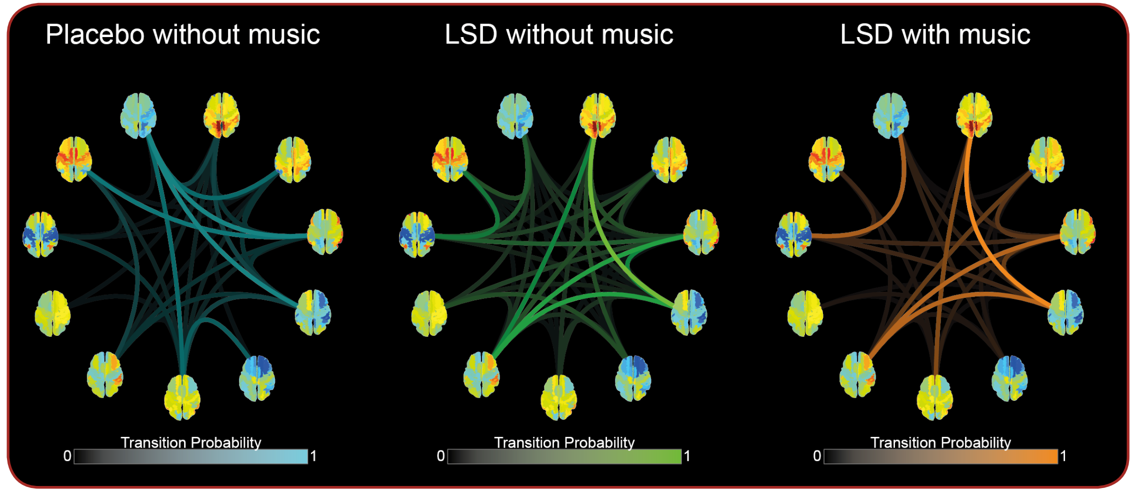


*Figure 3 .Whole-brain state transition patterns under placebo, LSD, and LSD with music (preliminary results)*

qualitatively and quantitatively. A highly entropic system will move through a theoretical state space randomly, while a system with low entropy will be highly predictable, because its underlying state space has strong attracting tendencies, i.e. it will settle into certain states with a significantly higher probability. Additionally, a highly entropic system will be susceptible to perturbation whereas the opposite is true for a system with low entropy[8]. Surrogate measures of entropy have been shown to decrease in sleep[9] and increase in the psychedelic state[3].

How brain dynamics change in these states can be simulated using computational models[10]. While entropy and state space are theoretical measures, we have analysis methods that allow us to approximate both. As such, Hidden Markov models of continuous fMRI recordings are able to resolve whole-brain network configurations and their behaviour over time[11]. The transition dynamics captured by these models are likely to be sensitive to varying degrees of entropy in brain state landscapes, and as such will allow us to probe the global determinants of hierarchical inferences in sleep as well as the psychedelic state. We have previously applied this method to estimate whole-brain transition patterns of sleep[12]. Now, we are using the same approach on fMRI-data of subjects under the influence of LSD while listening to music, adding evidence from the psychedelic state (Fig. 3).

Both the GNWT and the entropic brain hypothesis relate back to the hierarchy involved in PCM. The computations guarding the transfer of predictions through the processing hierarchy of PCM, such as bottom-up prediction errors, top-down priors, and precision weighting, may recombine and change the rules of access to the global workspace (Fig. 4, top panel). Precision weighting, as an example, is known to be sensitive to the action of the brain's



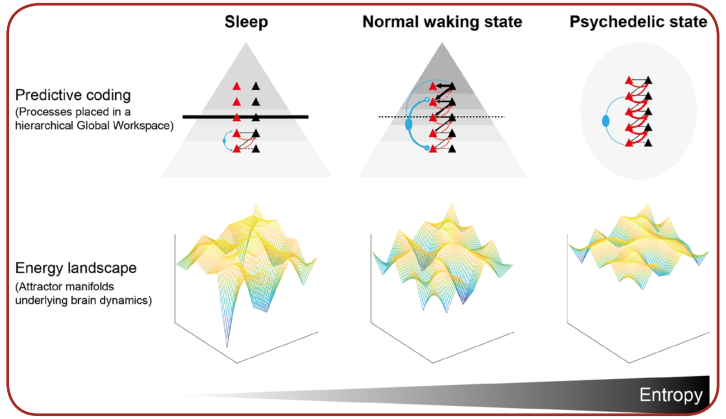


*Figure 4. Predictive coding placed in hypothesised Global Workspace hierarchies of different levels of consciousness and their corresponding energy landscapes.*

key neurotransmitter systems. This is relevant, since all main neurotransmitters undergo large fluctuations in concentration from wakefulness to non-REM sleep and again to REM sleep[13], while agonism of the serotonin system, specifically, is known to underlie the psychedelic experience[3]. At the level of whole-brain dynamics, mechanisms of hierarchical inference have been suggested to be manifested in the landscape of brain states (Fig. 4, bottom panel). The differences in the underlying landscape, in which predictive processes are taking place, could then explain how the brain and mind quickly switch between different states, like under psychedelics, or settle and "get stuck" in the same state for a longer time, like during deep sleep.

An interesting implication of describing music through mechanisms of predictive coding is that it allows for the formulation of several testable hypotheses regarding the neural systems supporting wakeful cognition, perception, and action. By studying the processing of music in altered states of consciousness, we may not only expand PCM to the full spectrum of human experience, but also begin to understand how different levels of the predictive hierarchy are involved in the control of consciousness itself.

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# LEARNING

*Elvira Brattico*

## Measuring the learning brain for real

Studying how the predictive brain learns new sound patterns and makes sense of incoming auditory information is the challenge we take very seriously. In the past year, we simulated situations in the neuroimaging laboratory where our typical participants, namely healthy students from European/American universities listened without interruption to musical pieces in which sound patterns repeat naturally and become motifs, hence acquiring their own specific meaning. After this listening exposure, we asked participants to perform a task and recognise the already heard patterns in the midst of new unfamiliar ones. Thanks to ongoing magnetoencephalography (MEG) measurements and to utilising anatomical brain images for neural source reconstruction, we can thus infer the brain mechanisms allowing the formation of musical meaning over the course of continuous learning and memorisation of sounds over shorter or longer spans of time (see pages 36-37). With our typical participants (the healthy European/American university student), we also simulated learning and transmission of audiovisual codes and found out that these are governed by intraconnectivity in auditory regions (see pages 34-35)[1].

While these studies are crucial to identify the neural architecture without which prediction, learning and transmission of musical sounds would not occur, they miss most of the excitement: the largest part of learning in daily life happens outside, not inside, the lab. And most typically it happens with children inside schools. Another major fact that would be ignored when limiting research within the lab and Western participants, is that the largest population of humans is Asian. In the following, I will illustrate our efforts to study children with neuroimaging measures up to bringing the brain recording devices inside schools, and to expand our research to understanding how musical cultures are acquired and how they affect perception even in Chinese individuals.

**Studying children in the neuroimaging lab**

Since 2016, we have worked intensively to be able to measure healthy children in the delicate period just preceding adolescence, when music becomes highly important and rewarding, with an expensive neuroimaging device such as functional magnetic resonance imaging (fMRI). Our goal was to obtain data that would allow us to understand how the maturing adolescent brain is affected by music, which brain network responds to reward and pleasure from music listening and whether, with music training, we can help the brain balance between the subcortical pleasure circuit and the cortical cognitive system.

To our knowledge, at MIB we have been the first ones in Denmark to implement an fMRI protocol on healthy children. This protocol was inspired by the one tested in Nadine Gaab's lab at the Children's Hospital in Boston[2], one of the few fMRI children labs around the world, and then adapted to our lab specificities thanks to several pilots with helpful young volunteers. The final protocol involves an experimenter and a team of at least 3 research assistants (typically students of Psychology at Aarhus University) who welcome the child, help her to feel at ease by showing the lab and allowing the reassuring presence of a parent or friend, and then instruct the child carefully on how to behave (especially how to minimise movements) by means of cartoons and an toy incentive. Thus far, we count three manuscripts ready for submission and two doctoral theses (one already defended by Maria Celeste Fasano in 2019 and another one by Pauline Cantou scheduled for July 2020). In summer 2019, Andrew Moore, a Fullbright award recipient, joined the children fMRI team, and is writing a fourth paper together with Ida Lorenzen, student of Psychology at AU, also writing her thesis on the same topic. In sum, after three years of piloting and measuring, the lab procedures for measuring fMRI in children during music-related tasks are well tested and running.

The next step is to obtain dedicated funding to expand this line of research further towards a full picture on music-skill learning in the brain and the body of youngsters, and towards understanding how the special sensitivity for music in adolescence develops and stabilises toward a self-identifiable musical taste in young adulthood.

**Taking the lab to the schools**

Some years ago, we were contacted by Danish Culture and Music Schools association ("Danske Musik- og Kulturskoler") about collaboration on a community program involving thousands of children across Denmark. This program is called Orkestermester and was generously funded first by Nordea Fonden and then by the Ministry of Culture to acquire orchestral instruments (e.g., violins, cellos, flutes) for children located in up to 20 Danish schools, with the goal of forming school orchestras and performing at the end of the year together with the prestigious DR orchestra in Copenhagen. We enthusiastically offered our collaboration for assessing the outcomes of this large-scale music program intervention and decided to focus on the development of fine perceptual skills in children after one year of joining the instrumental training program.

The children who participated in this community-based music program were located in several schools across the country, the closest one to Aarhus being in Silkeborg. Knowing from our children fMRI studies how hard it is to convince parents and children to participate within Aarhus, even when offering weekend dates for lab measurements, our reasonable option was not to ask them to come to the lab but to bring the lab to them. After obtaining ethics permission from the local Institutional Review Board, we took our 20 kg "portable" electroencephalography (EEG) equipment to Silkeborg and set up a silent room at Hvinningdal public school. Upon informed consent of the parents and the children, and coordinating

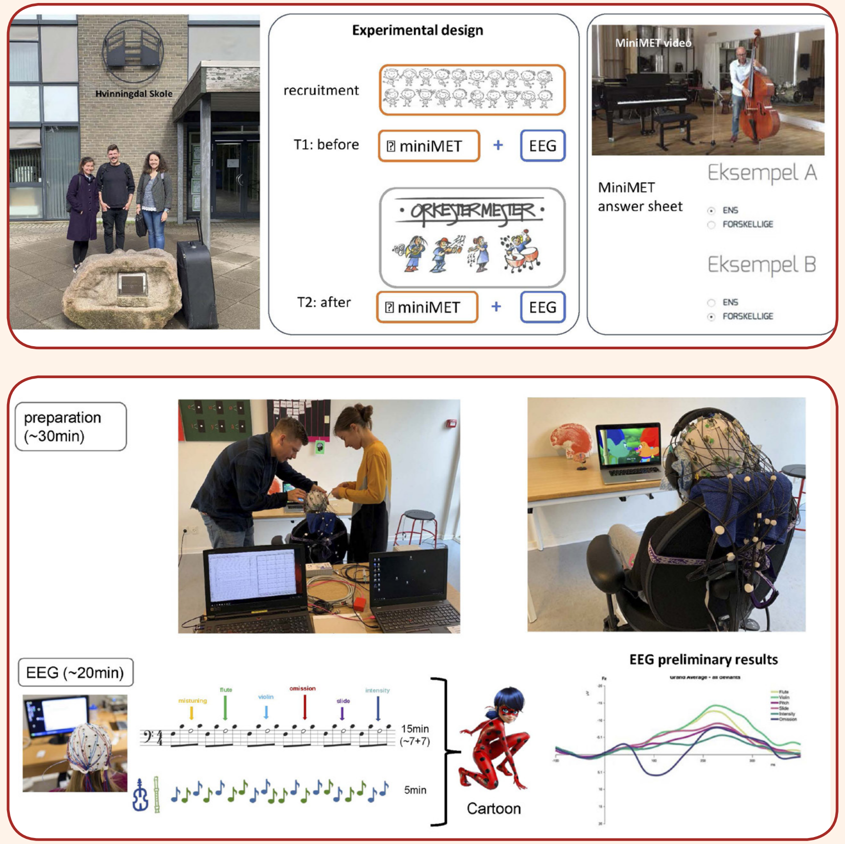


*Figure 1 + 2. Experimental design of the OrkesterMester project.*

our actions with the school headmaster, pedagog and teachers, we measured 37 children with EEG while they concentrated on watching a cartoon and they heard sounds in the background. At the end of the EEG session, children also performed a child-friendly version of the MET listening test developed at MIB, for assessing individual musicality attitudes[3]. For these measurements experimenters had to solve practical issues such as sweaty or even rain-soaked kids, coordination with school schedule, and noisy environment. Several tricks were adopted such as ventilating the room, placing the EEG equipment as far as possible from power lines, and so on. Overall, the kids were nice and in a good mood, happy to participate and watch cartoons (Fig. 1 and 2).

A second measurement session was planned for May 2020 (but postponed), when the Orkestermester program will reach its ending for 2019/2020, with the goal to investigate how perceptual skills have developed in children and in their young brains thanks to orchestra training. Remarkably, considering that there are no studies so far investigating brain prediction error responses to musical sounds in school-age children, we are preparing two manuscripts for the first already-completed measurement session also capitalising from increased human resources in our team (Silvia Bruzzone joining as trainee, and Pætur Zachariasson and Sarah Foss writing their master's theses with us), and from recent development of an analysis approach for isolating individual brain responses[4].

**From Denmark to the world**

Learning to predict the environment is not restricted to a specific place and culture. It is a mechanism that allows us humans to adapt to any new situation and to form new meanings



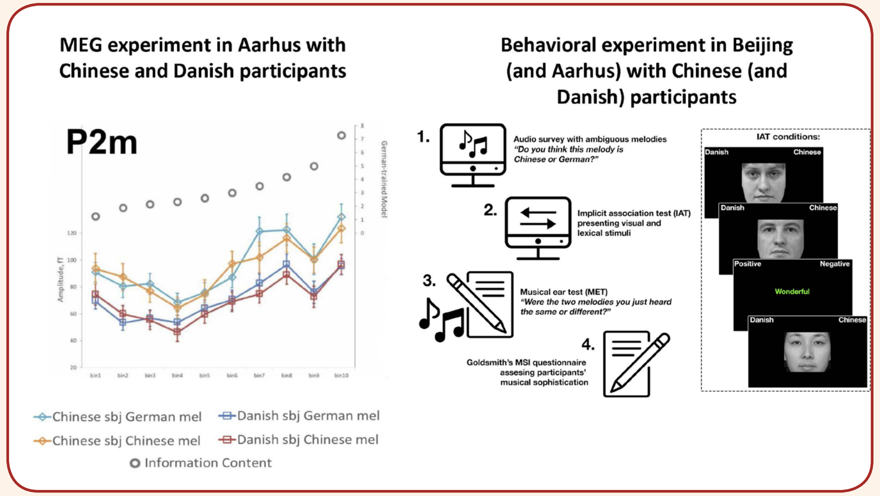


*Figure 3. Preliminary results of Chinese-Danish MEG study and behavioural experiment.*

and ultimately to build new cultures and transmit them among humans and across generations. We strive to understand how these processes manifest in the behavior and brains in the world. For that, we profited from the expertise of Prof. Marcus Pearce in modelling the local expectancy of melody pitches based on a Chinese or a German corpus and conducted as a MEG study in Aarhus with Danish and Chinese participants. Preliminary findings show that long-term knowledge of a musical culture does not affect the auditory-cortex responses to each sound (Fig. 3). Moreover, we initiated two collaborative studies, one behavioral and one MEG, with Prof. Yi Du from the Institute of Psychology of the Chinese Academy of Sciences thanks to Mathias Klarlund, a Master's student of the Sino-Danish Programme in Neuroscience. Thus far, 100 Chinese participants have been tested in Beijing with a listening paradigm and psychological tests. For this study, 40 Danish participants will be tested in Aarhus too. Moreover, MEG measurements are planned for another 50 participants in Beijing. Challenges have been the coordination of protocols among distant labs. To make things even more difficult, the medical situation forced us to postpone the start of recordings. Other two studies have been planned with Prof. Fengyu Cong at Dalian Technical University and are on hold. All these will be launched as soon as circumstances allow.

To conclude, our MIB research on Learning is moving at a fast pace towards ecological validity and high generalisability to offer knowledge that in the near future can be translated and applied to guide educational strategies for music teaching and for research.


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# LEARNING

## (Neuro)biology matters: Differences in interhemispheric connectivity may explain how music diversity originated

**By Massimo Lumaca**

One striking aspect of human culture is the rich variability in musical forms and features observed across the world's populations. The origins of music diversity has fascinated researchers for more than a century. Up to now, most attention to this issue has come from historical- and ethno-musicology, and has focused on the way music is shaped by socio-cultural and aesthetic factors.

In our study, we showed that a fraction of this diversity can be explained by functional and structural differences in our brains. Music, like language, is a complex cultural construct that is preserved over time through cultural transmission across many generations of music learners and transmitters. Intergenerational transmission of culture is far from being accurate, due to learning constraints. This mechanism may introduce new 'variants' in cultural systems. The question we asked here is whether individual constraints in learning and transmission are grounded in our brains. Are there aspects of brain function and structure that may distinguish a faithful 'transmitter' from an 'innovator'?

Here, we addressed this question with behavioural and neuroimaging methods. In our experiment, 52 human volunteers underwent functional MRI scanning while presented with standard and deviant five-tone auditory sequences. Resting-state and diffusion images were also acquired in the same session. Later on, the same participants underwent a behavioural test of so-called intergenerational transmission similar to the 'Game-of-Telephone', where the participants represent one 'generation' through which artificial musical stimuli are learned and passed on (Fig. 1a).

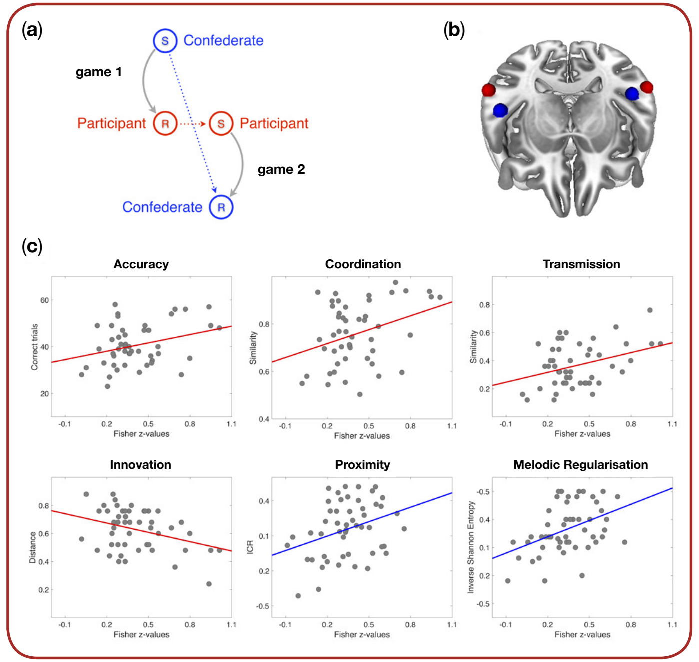


*Figure 1. Experimental design and correlation results (a) Experimental transmission design whereby the participant played first as receiver and then as sender. (b) Seeds for the resting-state connectivity (rs-FC) in the posterior superior temporal gyrus (red spheres) and in the primary auditory cortex (blue spheres). (c) Pearson's correlations between rs-FC and behavioural performance and structural modification.*



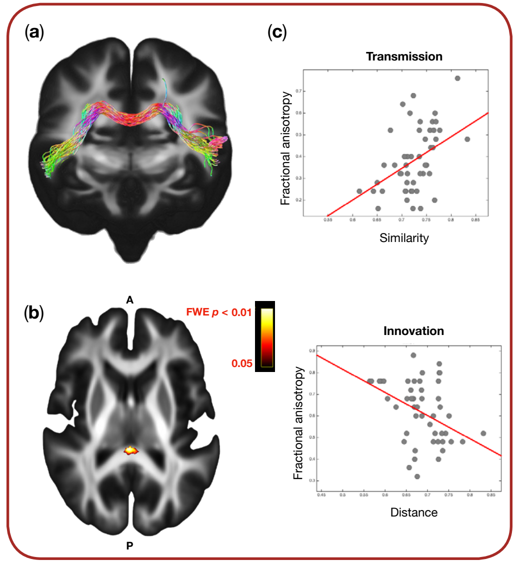


*Figure 2. (a) The auditory interhemispheric pathway. (b) Statistical results of multiple-regression analysis. Voxel-wise fractional anisotropy increases as a function of transmission performance and decreases as a function of innovation. (c) Pearson's correlations between fiber cross-section metrics in splenium and behavioural performance.*

In one study, now published in the scientific journal eLife [1], we showed that tiny differences across individuals in auditory brain function - differences in how strongly cortical regions of a fronto-temporal auditory network are connected when measured at rest - are linked to how they learn, transmit, and regularize musical sounds (Fig. 1). Specifically, a stronger connectivity between bilateral auditory cortices, and between auditory cortices and frontal areas, was associated with a better capacity to retain and transmit melodic sounds (Fig.1b-c). This study was the first to show that specific brain characteristics of individuals can distinguish faithful transmitters from innovators in the cultural transmission of music. This work further points to the corpus callosum - the bundle of neuronal fibres connecting the two sides of the brain - as a putative structural 'ground' for this effect.

Preliminary analysis of diffusion data supports this hypothesis. In Study 2, we combined fractional anisotropy - a local measure of white matter integrity - with fixel-based analysis, more tract-specific. Figure 2 shows the results. Compared to innovators, individuals who transmitted the artificial sounds more faithfully displayed a cluster of significantly higher fractional anisotropy on midsagittal area of the splenium - the posterior subdivision of the corpus callosum that contains axons involved in interhemispheric auditory transfer. Higher fractional anisotropy in this area might entail better interhemispheric communication and processing of musical sounds.

Historically, research on the sources of music diversity has mainly focused on cultural phenomena such as the fusion of musical variants from different musical cultures - for instance, the importation of Asian musical characters into Western music by composers such as Debussy. Our findings suggest that also individual (neuro) biology matters. Variability across individuals' brains in interhemispheric functional and structural connections may provide a source of variants in symbolic systems like music and language.

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# LEARNING

## The predictive coding of complex musical patterns recognition: evidence from magnetoencephalography

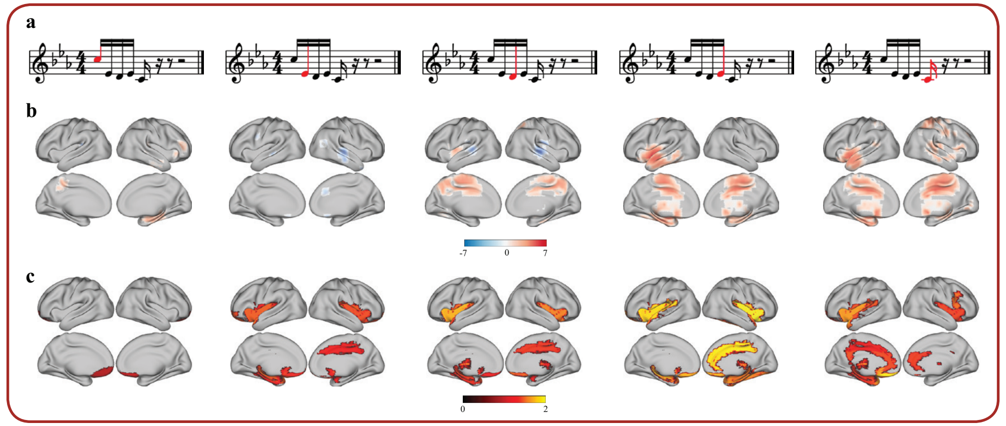
**By Leonardo Bonetti**

Predictive coding (PC) is one of the main theories developed by the neuroscientific field in the past decades. PC considers the brain as a generator of mental models of the environment that are continuously updated by processing external stimuli. Specifically, the brain is thought to produce predictions of the incoming stimuli with the aim to anticipate their occurrence. The mismatch between the predictions and the actual stimuli is constantly used to refine the models[1].

Among several neuroscientific sub-fields, PC has been successfully applied to the auditory domain, leading to relevant discoveries. For instance, PC has been used to construct a model of auditory repetition suppression, a phenomenon that happens when brain activity decreases because of the repetition of the same stimulus[2]. Other studies used mismatch negativity (MMN) as a tool to explore the predictions made by individuals exposed to melodic[3] and rhythmic[4] violations. Additionally, MMN has been used to differentiate the more accurate predictions of musicians over non-musicians[5].

The growing interest in the relationship between predictive coding, auditory neuroscience and music was summarized by a key recent paper authored by Koelsch, Vuust and Friston[6]. This work presented the remarkable case of music, which can be considered a perfect example of PC within complex cognitive processes. In their paper, authors suggested that minimizing the precision-weighted prediction error during music listening may return insights about how music becomes meaningful for the brain. However, the major part of the studies focused on elementary musical elements to highlight the brain basis of predictions in auditory domain. Thus, within the PC framework, less is known about higher cognitive processes responsible for music processing such as melodic recognition occurring through connectivity between auditory cortex and other brain regions.

Therefore, in our study, we assessed the brain activity and connectivity during conscious recognition of musical patterns that were previously learned by participants. We asked participants to listen to a whole prelude by Johann Sebastian Bach trying to memorize it as much as possible. Then, we extracted 5-tone excerpts from the musical piece that we called Bach's original and we created some variations of them (Bach's variations). Those excerpts were presented to participants during magnetoencephalography (MEG) recording. Participants were asked to recognize the excerpts and categorize them as Bach's original or variation. We analysed the data in terms of both brain activity and connectivity, by employing state-of-the-art techniques such as phase synchronization analysis, graph theory and machine learning. Brain activity analysis returned a strong activation of Heschl's gyrus, superior temporal gyrus and insula for both musical excerpt categories. This activity decreased over time. Furthermore, connectivity results showed a large network of brain areas involved in the task, such as Heschl's and superior temporal gyri, insula, hippocampus, basal ganglia, frontal operculum, cingulate gyrus and orbitofrontal cortex. Additionally, the connectivity patterns became stronger over time. Both the activity and centrality within the whole brain network of those areas were more pronounced for Bach's original than for the variation.




***Brain activity and connectivity underlying the recognition of musical sequences composed by Johann Sebastian Bach.***
*__a__ – Musical score representation of one melodic sequence composed by Johann Sebastian Bach that was used in the experimental task. Red notes show the progression of the sequence over time. __b__ – Contrasts (t-values) over time between brain activity underlying recognition of Bach's original (red) vs variation (blue). __c__ – Significantly central brain areas (t-values) within the whole brain network associated to the recognition of Bach's original musical sequence vs rest.*

According to PC, our study suggests a double prediction made by the brain while participants continously listened to sounds. First, the prediction of the individual upcoming sounds forming the musical sequence and resulting in a progressive decrease of auditory cortex activity. Second, the prediction of the whole musical pattern, highlighted by the increase over time of brain activity and connectivity among several brain areas related to high-level ognitive functions occurring when listeners correctly recognized the known musical excerpts. This increased activity and connectivity might be interpreted as the mechanism responsible for matching incoming sounds with the predictions formed for the whole musical piece.

Future studies are called for to better understand this phenomenon and precisely describe the brain mechanisms that allow individuals to recognize astonishing musical patterns.

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# CLINICAL APPLICATIONS OF MUSIC

*Kira Vibe Jespersen*

In 2019 WHO published a report synthesizing the evidence on the role of the arts in improving health and wellbeing[1]. The report covers a vast amount of studies and more than 200 reviews in the field, including MIB publications. It supports the growing focus on how music and the other art forms can be used in prevention and promotion of health and well-being as well as in management and treatment of diseases and disorders.

At MIB we aim to contribute to the field of clinical applications of music both through basic and clinical research. Our basic research can inform clinical research, and research in the clinical fields may in turn feedback relevant knowledge to basic research. As an example, the theory of predicitive coding of music is at the core of MIB research. Studies with clinical populations can refine and broaden our understanding of this theory by shedding light on how predictive processes may be altered in relation to neurodegeneration (e.g. Parkinsons' disease), atypical development (e.g. autism spectrum disorder) or altered states of consciousness (e.g. sleep and psychedelics). Furthermore, we aim to bridge basic and applied sciences by using the knowledge and methods from basic research to thoroughly evaluate music interventions for international health care challenges such as COPD, pain[2], cancer[3] and insomnia[4]. In addition, we use some of our basic research paradigms to increase our understanding of how perceptual, motor and emotional processes may be altered in clinical populations such as people with Parkinsons' disease, Autism spectrum disorder and Cochlear Implants[5].

In 2019, MIB researchers have particularly contributed to an increased understanding of the relationship between music and pain. Sigrid Juhl Lunde finished her PhD on music-induced analgesia and placebo, and she continues her work as postdoc at the Department of Psychology. In a 2019 review, she and her colleagues outline the potential musical and non-musical mechanisms underlying music-induced analgesia[2], and her work also included an experimental evaluation of whether dopamine and opioid systems underlie the pain relieving effects of music[6].

The mechanisms underlying music-induced analgesia has also been the focus of PhD student Victor Pando-Naude. In a recent study, he and his colleagues investigated the neural correlates of music-induced analgesia in patients with fibromyalgia. The results showed that music-induced analgesia was significantly correlated with decreased functional connectivity between the angular gyrus, posterior cingulate cortex and precuneus, and increased functional connectivity between amygdala and middle frontal gyrus[7] (Fig. 1) The authors discuss how these areas are related to autobiographical and limbic processes, as well as auditory attention, suggesting that music-induced analgesia may arise as a consequence of top-down modulation, probably originated by distraction, relaxation, positive emotion, or a combination of these mechanisms.

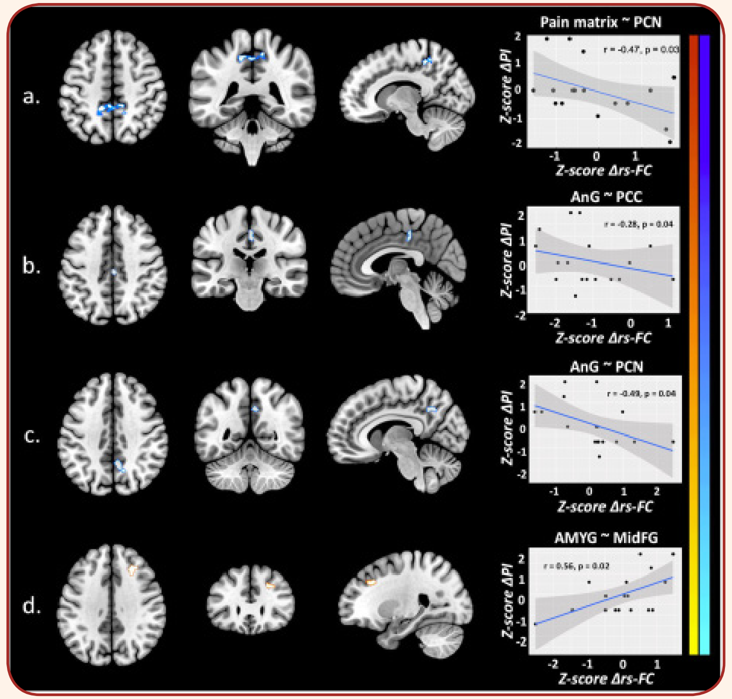


***Figure 1.*** *Functional connectivity (rs-FC) of music-induced analgesia in fibromyalgia. Higher analgesic effect of music (ΔPI) is correlated with rs-FC decrease between the pain matrix and precuneus (a), rs-FC decrease between posterior areas of the DMN (b,c), and rs-FC increase between amygdala and middle-frontal gyrus (d).*

Another 2019 contribution to the field of music and pain is the work by postdoc Anna Zamorano and Assist. Prof. Boris Kleber using resting-state fMRI to study how experience-dependent neuroplasticity in trained musicians can modulate the effects of chronic pain on insula-based networks. Contrary to previously published studies in the general population, musicians with chronic pain showed decreased insula connectivity relative to healthy musicians, as well as lower pain-related inferences with daily activities[8]. The authors conclude that although music-related sensorimotor training and chronic pain, taken in isolation, can lead to increased insula-based connectivity, their combination may lead to higher-order plasticity in chronic pain musicians, engaging brain mechanisms that can modulate the consequences of maladaptive experience-dependent neural reorganization.

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# CLINICAL APPLICATIONS OF MUSIC

*Alberte Seeberg, Monica Ipsen, Andreas Højlund, Bjørn Petersen*

## Music in the lives of cochlear implantees

**"With every mistake we must surely be learning"**[1]. The song line by Harrison nicely paraphrases the essence of the predictive coding theory. Our understanding of the world is to a large degree based on erroneous presumptions made right. For patients with a hearing loss who must learn to listen through a cochlear implant (CI) this is particularly true, as every sound must be perceived, recognized and understood anew. This includes the sound of music which for many CI users is a long-lost life ingredient that they hope to be able to enjoy again. At MIB, researchers have a long history of studying music and CIs, recently reporting on a novel MMN-paradigm that can estimate musical discrimination abilities and thresholds in CI users[2]. Here, we report on behavioral and qualitative data also collected as part of the study.

**A tiny window of opportunity**
The transmitted frequency range of a CI is approximately ~200 Hz to ~8500 Hz. This limited range negatively impacts music perception, especially impeding perception of pitch and timbre. Hence, CI users' ability to identify musical instruments[3] shows great variance and a performance which is generally poorer than that of normal hearing controls[4,5].

Another reported deficit is the reduced ability to discern dynamics or intensity in music, which is ascribed to the high level of compression in the CI-signal. This issue affects the ability to perceive the emotional effects of music, such as a dramatic buildup with a crescendo[5].

The missing ability to distinguish pitch differences, intensity levels and timbral cues makes it hard to segregate the musical properties, and these will become a blur of noise. Some studies, however, have reported increased music discrimination ability following musical training, most promisingly within musical instrumental recognition, indicating a plastic potential[6,7].

**Who, what & with which?**
Twelve recently implanted CI users (CIre, $M^{age}$: 60.5y, range 34-80; f = 3) and 15 experienced CI users (CIex, $M^{age}$: 54.6y, range 18-77; f = 10) took part in the study. The mean CI experience was 63 mths. for CIex and 0.7 mths. for CIre.

The CI-users' music discrimination skills were measured with a three-alternative forced choice task (3-AFC) in which a 4-tone musical pattern was presented twice in the standard and once in the deviant condition. In the deviant condition, the standard third note was randomly violated by an intensity, pitch, timbre or rhythm deviant at four different levels of magnitude (1, 2, 3, 4; see MIB annual report 2017 p. 42 for an illustration). The deviant could randomly occur in either of the three patterns and the participants were instructed to click the deviant pattern on a computer screen. The hit rates were converted to percent correct scores for each deviant level. All participants received the sound through a direct audio input, bypassing microphones and ruling out any residual hearing.

Moreover, all participants filled out a questionnaire, mapping different aspects of their relationship with music such as musical background, music enjoyment, music listening habits and rating of the sound of music with their implant.

To investigate if any demographic or music-related factors predicted the participants' discrimination accuracy, we applied a mixed-effects logistic regression approach. All models in the analysis included the participants' binary responses (correct or incorrect) as the dependent variable and participant IDs as a random effect.

**How low can you go...**
... in magnitude of the deviation and still be able to discriminate? While no remarkable differences were found between groups in discrimination of deviation magnitude in neither pitch or rhythm, experience with the CI seems to positively affect discrimination of intensity and timbre deviants (Fig. 1). For the intensity deviant, the group difference also tends to increase with increasing magnitude, reflecting the lack of differentiation in the CIre group. For CIex the discrimination threshold is reached at the smallest deviant level, at which the group average is at chance level. By contrast, for the timbre deviant, experience

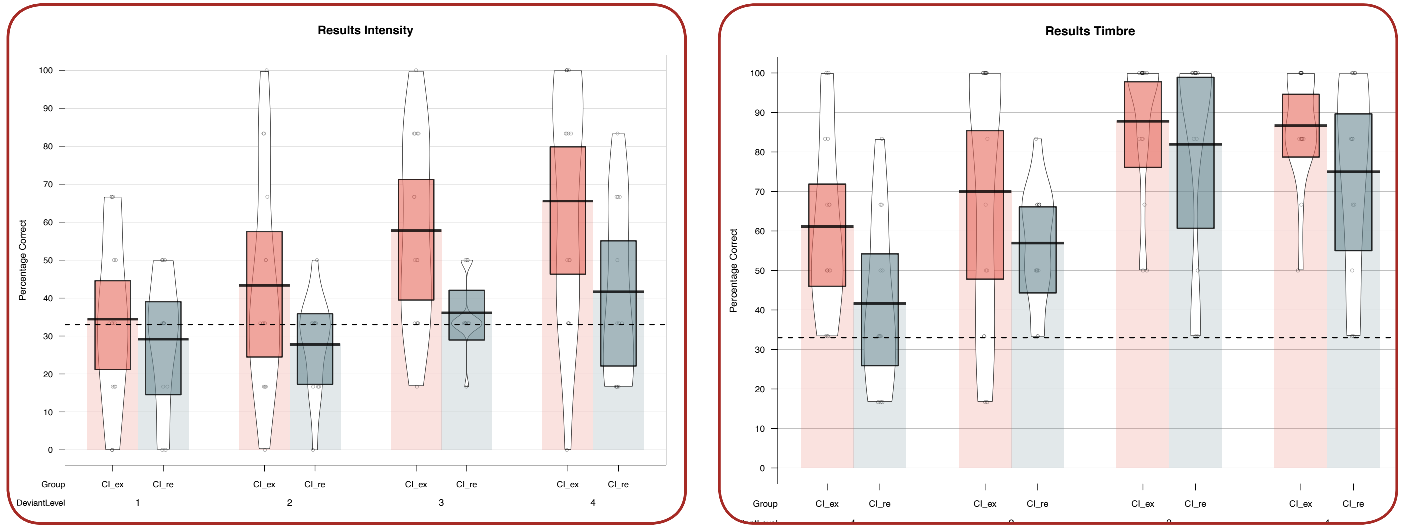


*Figure 1. Violin plot showing discrimination accuracy for both groups and all deviant levels in the intensity deviant (left) and the timbre deviant (right).*

appears advantageous at all levels of deviation, albeit most prominently at the two smallest levels of deviation.

Apart from more CI-experience, the participants in the CIex group may also benefit from optimized individual mappings of the sound processor algorithms. Given the short adaptation period, it is likely that participants in the CIre group will not yet have acquired personalized and well-adapted mappings, which again may reduce perception of the dynamic and timbral properties of music in particular. Interestingly, despite very little experience, the recently implanted participants scored on par with the experienced in discrimination of the different levels of the rhythm and the pitch deviants. This confirms a) that the high temporal resolution, reflected in recurring reports of near normal rhythm discrimination[5], is established very quickly after switch-on and b) that even though some discrimination of pitch is possible, potential progress is constrained by the poor representation of frequencies in the CI[2].

### Just keep listening

Listening habits, i.e. the extent to which the CI-users choose to listen to music, showed a robust effect on overall discrimination accuracy (Fig. 2). The effect, however, was only prominent for participants listening to music for 9 or more hours per week. This indicates that CI-users who report a very high degree of music listening also seem to most optimally be able to identify fine-grained details in music.

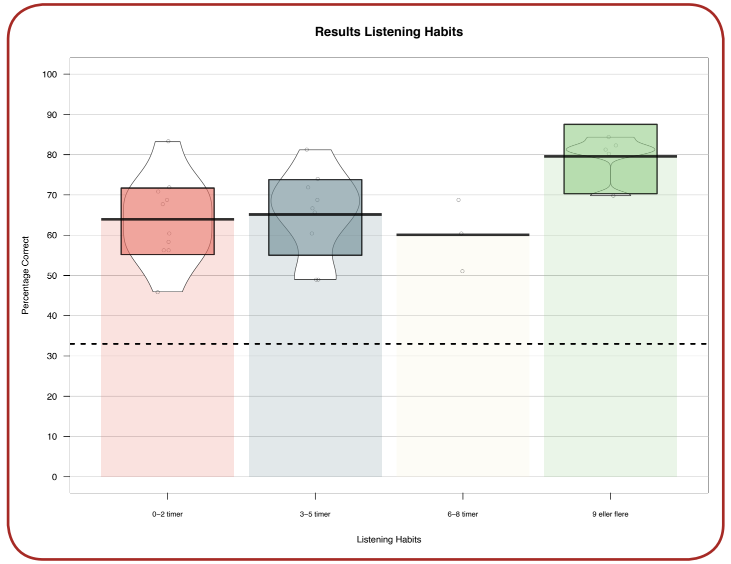


*Figure 2. Discrimination accuracy in percentage across groups for different levels of listening habits, measured as hours of listening to music per week.*

The result reflects a classical hen and egg case, in which it is unclear if it is the music listening efforts that improve the discrimination skills or it is a generally better implant outcome that improves the quality of music, and thus the inclination to listen to music. If it is the former, it could support the recommendation to include music-training in CI-recipients' rehabilitation measures[8]. Not only could this positively affect the ability to perceive salient properties of music, potentially improving music appreciation, but it might also generalize to other challenging listening tasks, such as speech perception in background noise and perception of emotional prosody[9].

Surprisingly, we saw no difference in discrimination accuracy between CI-users who

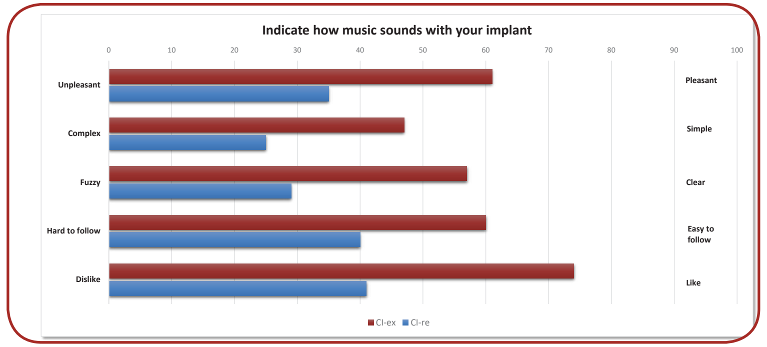


*Figure 3. CIre (blue) and CIex (red) ratings of the quality of the sound of music through their CI as indicated on a VAS scale of 0-100 with bipolar adjective descriptors. The average rating was 40 for CIre and 61 for CIex.*

report no or very little music listening and those who choose to listen between 2-8 hours per week. This suggests that other factors in music such as rhythm and lyrics may also determine CI-users' inclination to listen to music.

### How do you like the sound of music?

In addition to reporting music listening habits and level of music enjoyment, the respondents were required to report the quality of the sound through their implant. The CI-users rated their level of satisfaction on a VAS scale by a value of 0-100 between two bipolar adjective descriptors with 0 being the most negative and 100 the most positive. The results suggested that at this level of detail, CI experience has a significant positive effect on perception of musical sounds, with CIex rating an average of 61 and CIre rating an average of 40 (Fig. 3).

### Stylistic preferences

The CI-users were asked to state which styles of music they enjoyed listening to. Pop, rock, blues, jazz and classical music were preferred by the most respondents, while heavy metal was only preferred by one listener. Unexpectedly, one of three CI-listeners found joy in listening to rap and hip-hop, which may be subscribed to the strong focus on rhythm and lyrics in this genre.

### As heard through the grapevine

The questionnaire gave the respondents the opportunity to comment on the different music-related questions, which many chose to do. The comments reflect a vast range of music enjoyment from great enthusiasm over disappointment to mere disgust, confirming previous findings. Diversity aside, a large proportion of the respondents tended to agree that 1) familiarity with a song is a determining factor for music enjoyment, 2) repeated listening of a particular song or piece gradually improves the listening experience, 3) the presence of lyrics adds significantly to the musical outcome, 4) a hearing aid combined with a CI makes the sound richer and more satisfying.

This may indicate that music enjoyment is enhanced by increased top-down processing. While music perception is normally predominantly based on bottom-up processing, familiarity with a song and the presence of lyrics might assist the brain in making meaning of the CI-sound by using existing recollections of what a song used to sound like. One participant commented: "Music is best when I play or sing myself[...]". This may suggest a positive effect of haptic memory for music, in which the brain's prediction of certain sounds is based on bodily sensations, thereby enabling this information to be used for top-down processing.

To illustrate the different views, we have compiled a number of comments from respondents when invited to elaborate on questions.

"Had a really nice experience in the Berlin Opera." (Man, 50-55y, CI exp. 5 mths)
"I listen to music everyday. On my stereo, in the Radio or Spotify on my smartphone (w. streamer)." (Woman, 60-65 y, CI exp. 4.2 y)
"It sounds just fine. Maybe the bass could be a bit better." (Man, 55-60y, CI exp. 8.5 y)
"Today, music sounds more natural than 10 years ago." (Woman, 60-65y, CI exp. 13.5 y)
"There is a great difference between the sound of musical instruments. The guitar and saxophone sound very beautiful." (Woman, 50-55 y, CI exp. 4.4 y)
"I always listen to music in the car and on TV. E.g. X-factor UK."(Woman, 35-40y, CI exp. 1 mth.)
"The sound is 10 times better than with hearing aids." (Man 15-20y, CI exp. 1y)
"It has taken some time to learn to listen to music with CIs but it is fine now. I play CDs at home but it is a limited and flat experience. Concerts are MUCH better." (Woman, CI exp. 2y)
"Just recently begun hearing music and it was wonderful." (Woman 60-65y, CI exp. 1.5 mth.)

"Not all forms of music sound good. One of the genres that sounds significantly better after CI is opera. On the other hand music with a lot of bass sounds strangely toneless." (Woman, 60-65y CI exp. 4y)
"Music sounds pretty spacy…. as if all the midrange tones are on helium." (Man, 55-60y, CI exp. 3mths)
"I listen to Abba's Super Trouper - it is unpleasant but I detect the rhythm! (Man, 75-80y, CI exp. 14d)
"Everything sounds like bells."( Man, 30-35y CI exp?)
"Through speakers the music sounds horrible whereas music has a clear sound when it is not electric." (Man, 50-55y, CI exp. 5m)
"Music is best when i play or sing myself but it sounds a bit as if played in a bucket." (Man, 30-35y, CI exp. 4m)

"I cannot hear music." (Man, 65-70y, CI exp. 10d)
"It would be completely pointless and unpleasant to take the chance with a concert." (Man, 80-85y, CI exp. 4.5 mths)
"No pleasure but it can be recognized." (Man, 70-75y, CI exp. 14d)
"I never listen - all I hear is noise." (Man, 80-85y, CI exp 6 mths)
"Simultaneous musical instruments sound like cats' music."(Woman, 70-75y, CI exp. 4.5 m)
"Trying (to listen to music) is risky business." (Man, 80-85, CI exp. 6m)
"My guitar stands in a corner unused. If I sing, I hear myself singing wildly out of tune" (Man, 80-85y, CI exp. 6m)





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Assist. Professor Bjørn Petersen presenting his and MIB/CFIN colleagues' recent work on CI at CI2019: 16th Symposium on Cochlear Implants in Children in Hollywood, Florida. Bjørn had both his abstracts accepted for podium presentation, sceduled in two sequential. talks: one reporting on the results from two novel EEG-paradigms tested with experienced cochlear implant users and one conveying preliminary findings in MMN-experiments with recently implanted CI users. Subsequently, both works were presented at the 2019 Conference on Implantable Auditory Prostheses (CIAP), Lake Tahoe, California.

# METHOD DEVELOPMENT

*Niels Trusbak Haumann*

## New insights and accurate measures of brain activity with spike density component analysis

### Surveying neural activity

When we sense and think, agnetoencephalography (MEG) sensors and electroencephalography (EEG) electrodes placed outside the head can measure related electrical activity generated by neurons in the brain. MEG/EEG is widely applied to measure healthy sensing and cognition in the brain and effects of illness and recovery in patients. However, these measures are not yet used for clinical routine, since the electrical brain activity is very weak, and it needs to be isolated from many interfering signals[1]. Imagine if the human brain was a large city with ten million talking people. EEG electrodes and MEG sensors would then correspond to an array of microphones placed outside a city wall, which are applied to reveal a message told by one out of ten million talking inhabitants . A specific neural signal can be isolated from the overlapping activity by using state-of-the-art experimental designs, signal averaging, and component analysis methods, however, with a lack of accuracy[1]. In 2019 MIB developed a novel data analysis method, the spike density component analysis, which isolates neural signals from different brain regions by modelling their shape in time[2] (Fig. 1).

### New insights into the timing of neural activity

When we hear a sound or perceive another sensory stimulus, neural electrical signals propagate through the peripheral sensory system and up through sensory regions in the cortex of the brain. The early lower stage neural signals are characterized by millisecond precise clock-like synchronous neural activity[3]. Later, approximately fifty milliseconds after stimulation, large groups of neurons in the upper cortex respond to sounds or other stimuli. The response in the group of cortical neurons can best be characterized by probabilistic timing distributions[4]. Imagine if certain news is spread in the aforementioned city: The exact time when the news arrive to an individual is uncertain, but the arrival of the news varies systematically around an expected time point.

Over the past 60 years, probabilistic timing distributions have been successfully applied in neuroscience research to describe the electrical signals of individual neurons in cortical brain regions, but only based on invasive studies, where electrodes are placed inside the brains of animals or humans[5]. Also, only little is known about the nature of the neural timing distributions[5]. MIB's novel spike density component analysis (SCA) method is the first which can decompose neural activity measured with non-invasive MEG/EEG into probabilistic timing distributions (by

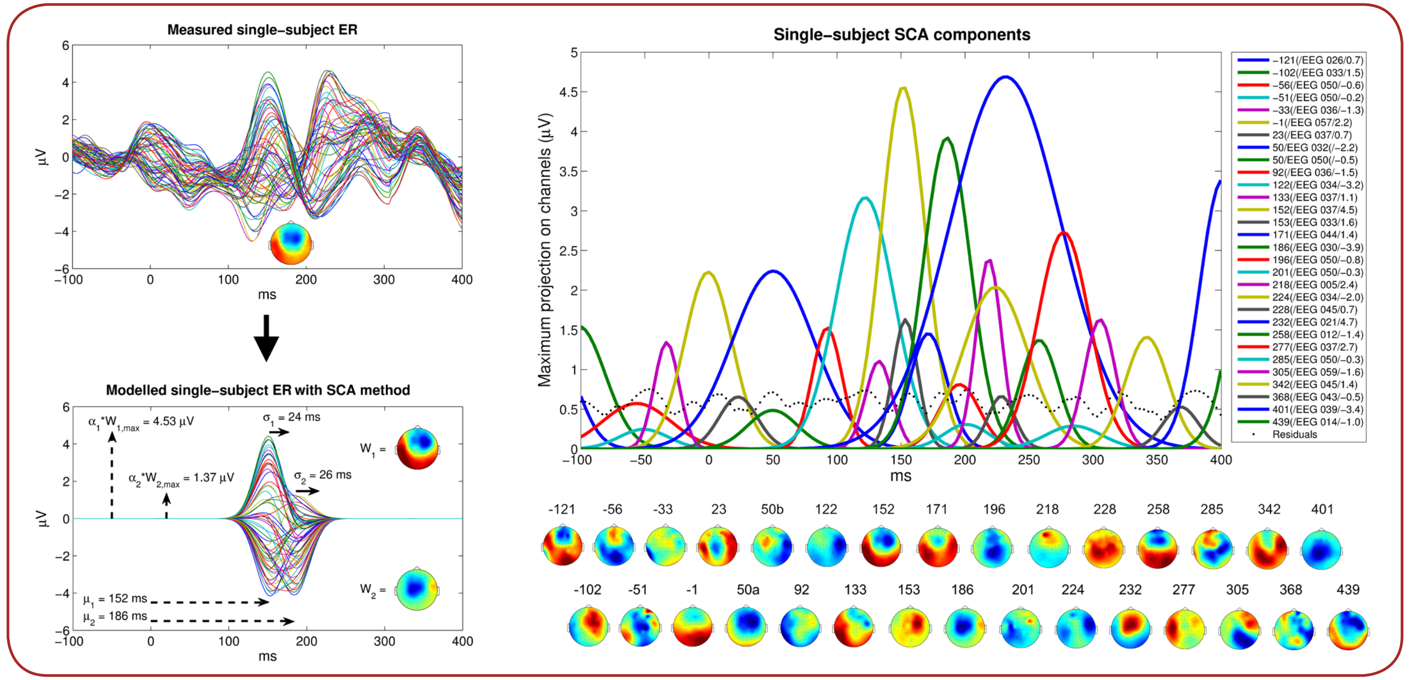


*Figure 1. Spike density component analysis. Neural activity from different brain regions is modelled by separating neural activity into specific shapes in time (in milliseconds, ms). (2)*

placing electrodes/sensors outside the head). Our ongoing studies verify that the SCA method can model neural activity more accurately than was previously possible with non-invasive MEG/EEG methods[2]. Moreover, the SCA method might in the future aid in providing new insights into how and why neural activity in cortical regions is distributed over time.

### Ongoing studies on sound perception

The first SCA study was conducted in a collaboration between MIB and the BioMag Laboratory at Helsinki University Hospital and was supervised by Professor Elvira Brattico and first-authored by Niels Trusbak Haumann. The first results showed that the novel SCA method succeeded modelling nearly all neural activity measured with 60 EEG electrodes and 306 MEG sensors placed on 94 human study participants (median 99.7%-99.9% variance explained in individual MEG and EEG waveforms) and accurately isolated weak neural MMN signals from the cortex related to sound perception[2]. We have replicated these initial SCA modelling findings in seven subsequent and ongoing EEG studies. In a collaboration with Oticon Medical and Aarhus University Hospital we succeeded in decomposing MMN responses to deviant

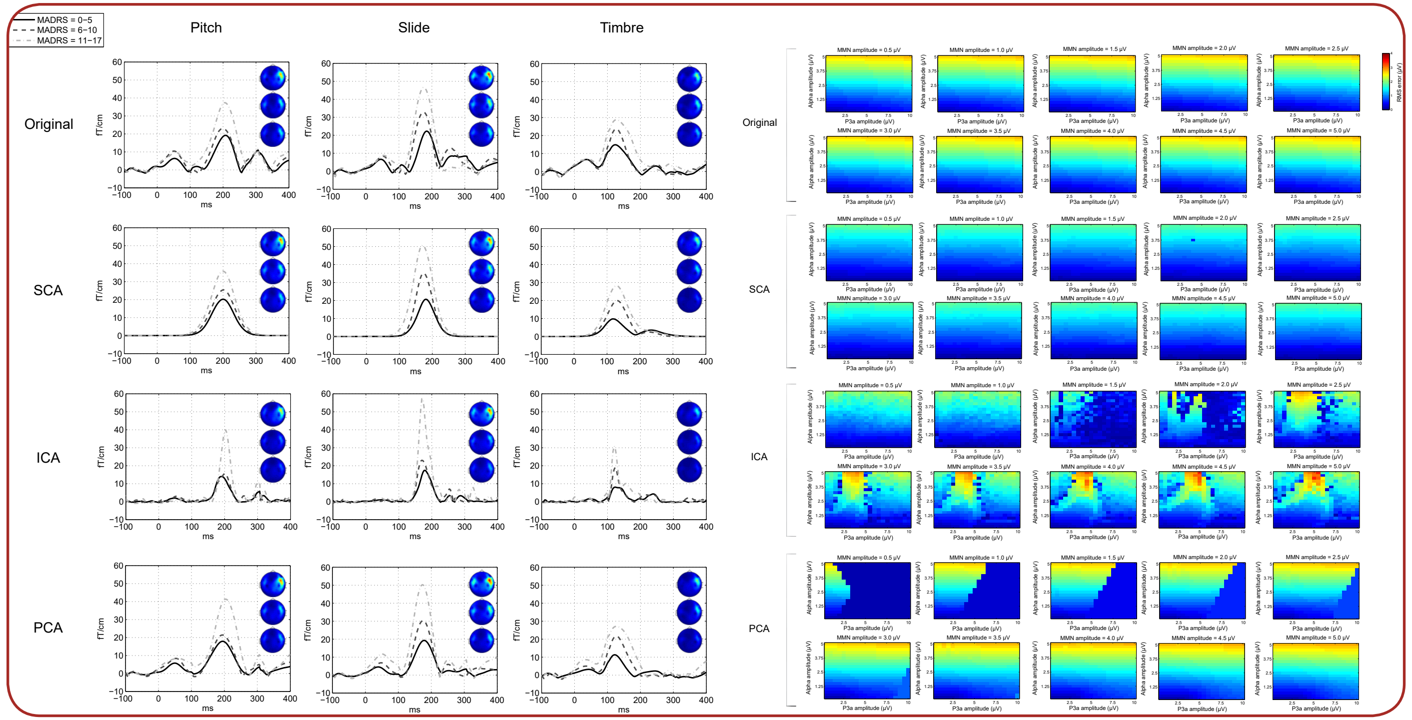


*Figure 2. Improvement of single-patient MEG/EEG analysis with SCA. Interindividual variance in MMN responses to sound deviants related to depressive traits (left). Errors (warm colours) in isolating specific neural signals from interfering activity based on 12000 computer simulations of individual EEG (right).[2]*

sounds in the auditory cortex of young adults, older normal hearing listeners, and older cochlear implant (CI) patients[6]. Also, we were able to decompose and extract P1/N1/P2 responses to complex naturalistic music stimuli from the auditory cortex of young adults, older listeners, and older CI patients.

Furthermore, in a recently initiated international collaboration with postdoc Marina Kliuchko and intern Silvia Bruzzone we succeeded in applying the new SCA method to isolate P1/P2/N2 responses to music instrument sounds in the auditory cortex of Danish six- to eight-year-old children, while they are learning to play a music instrument.

**Translating basic research into clinical applications**
Most of the new developments in basic MEG/EEG research are difficult to translate into clinical applications, mainly because of the problem with isolating specific neural signal from the overlapping neural activity. In basic research the problem is commonly solved by analysing the average neural signal across a group of study participants (thereby using signal averaging to increase the signal-to-interference and noise ratio). However, this solution is not possible in clinical applications where only MEG/EEG of the individual patient is available. Our current results suggest that single-patient MEG/EEG analysis can be improved with SCA (Fig. 2).

For example, a previous study by Bonetti and colleagues[7] showed that MMN responses to spectral deviations, related to emotion expression in music, increase in relation to the individual level of depression symptoms. It turned out that these interindividual differences in MMN responses, related to depressive traits, were more accurately detected after applying the SCA method[2]. Also, in an ongoing study we succeeded in isolating individual patients' MMN responses in both experienced and newly operated CI users[6]. In another collaboration with associate professor Brian Hansen at Center of Functionally Integrative Neuroscience, Aarhus University, we created 12,300 computer simulations of realistic EEG data. The results of the computer simulations showed that SCA was the most accurate available method for isolating neural signals from the overlapping neural activity[2]. Based on these positive findings we expect that the novel SCA approach will be of general importance to future basic and clinical MEG/EEG research.

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# EDUCATIONAL ACTIVITIES

*Elvira Brattico and Bjørn Petersen*

**Educating nationally**
Continuing the good practices of previous years, MIB personnel, from professors to PhD students, has contributed to teaching and supervising local students both at RAMA and Aarhus University.

The year started with such activity on the 3rd and 4th of January at RAMA, namely the annual seminar on "Musik og Læring", congregating 300+ Danish music teachers. This year's seminar focused on two themes: The optimal music-learning environment ("gode musikalske læringsmiljøer") and The music pedagogue on discovery ("musikpædagogen på opdagelse"). Prof. Brattico contributed with a lecture on "When learning is successful".

Moreover, Prof. Brattico was invited to teach a module on "Music, Art and the Brain" for the Graduate Neuroscience Course at Aarhus University. Also, postdoc Kira Vibe Jespersen was invited to give a lecture as part of a symposium on "Music Interventions and Neurochemistry" at University of Copenhagen, Department of Drug Design and Pharmachology.

At RAMA, Assist. Prof. Bjørn Petersen as part of his responsibilities for the academy's R&D-activities organized a research course titled "Project development – from idea to application". The course was aimed at RAMA teachers and Prof. Peter Vuust and Assoc. Prof. Torben Westergaard, Kirstine Heebøll and Margrethe Langer Bro gave presentations which accounted for different aspects of scientific, artistic and pedagogical research. Subsequent workshops in smaller groups dealt with the implementation of the presented topics and approaches into actual research ideas.

Supervision of master theses are a priority at MIB. For example, Bjørn Petersen supervised a Master's project by Clara Chill, RAMA student of electronic music composition. In strong alignment with the Music and Health strategies at MIB, the project developed an interactive musical sensory device (IMSD) that served as a sensory integration method for children with autism. Subsequently, Chill was one of five nominees for the Young Talent Award 2020 at DMEA, Europe's largest trade show for digital solutions for the healthcare sector. Other examples are Postdoc Kira Vibe Jespersen's supervision of two Master's projects. The first project, carried out by Karen Vestergaard Pedersen and Sune Aaes, Department of Musicology, Aarhus University, entitled "Sleep music" investigated both musical and clinical perspectives on the common practice of listening to music at bedtime. The second project was a pilot study on music interventions for sleep improvement in a neuro-rehabilitation setting carried out by Emil Grønbæk Nielsen, Department of Communication and Psychology, Aalborg University in collaboration with Vejlefjord Neuro-rehabilitation center.

*Professor Elvira Brattico speaking at RAMA*

**… and internationally**
In 2019 visiting fellows funded from Erasmus or comparable intra-European exchange grants were Francesco Carlomagno, Virginia Fedele, Gülce Isil Göcke, Agata Patyczek, Johanna Rösch, Sarah Foss, Ana Teresa Queiroga, Francisca Assuncao, and Pedro Ferreira. Additionally, since August, MIB hosted a Fullbright scholar, Andrew Moore from University of Oklahoma (USA). His stay was planned to last a full academic year but had to be interrupted in March 2020 due to the coronavirus pandemic crisis.

At MIB, we have also acted as external evaluators for several bachelor's, Master's and PhD theses, for instance a Master's thesis from University of Oslo (Brattico), a PhD thesis from the Chinese Academy of Sciences in Beijing, China/Sino-Danish Center (Brattico) and another PhD thesis from University of Gothenburg (Kringelbach).

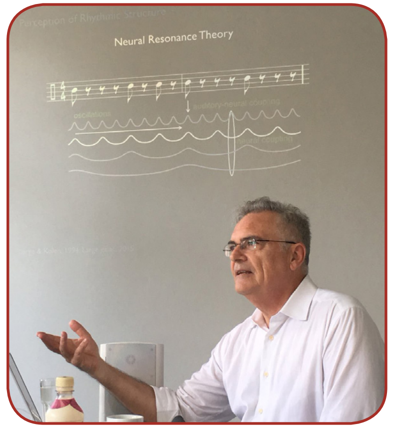
Furthermore, MIB continued its involvement with the Empowering Talent program at Aarhus University, supporting the career development of junior researchers, with a particular attention to female foreigners.

**Summer educational days in Aarhus and abroad**
In May, Prof. Brattico proudly contributed to teaching young students from Spanish high schools how women can successfully combine work and family life, at the First international Day of Women in Inclusive Sound and Music Computing Research in Malaga.

Preparations for the First Summer Course on the Neurosciences of Music tightened in 2019, landing on an excellent program featuring all the top scientists around the world in the field (Robert Zatorre, David Huron, Virginia Penhune, Isabelle Peretz, Simone Dalla Bella, Maria Ruiz Herrojo, as well as MIB's own Morten Kringelbach and Boris Kleber). The Summer Course was organized as a PhD course in collaboration with the Graduate School of Health at AU and planned to run at RAMA and AUH facilities in the week leading up to NMVII. Unfortunately, by March 2020 the pandemic crisis forced us to hold our horses and postpone the summer course to June 2021.

**International guest speakers**
Since its launch in 2015, MIB has had a strong tradition of inviting international guest speakers to Denmark – ranging from upcoming researchers to renowned established experts in the field. 2019 was no exception, offering a program of 19 presentations, within the CFIN/MIB seminar series (in collaboration with CFIN Prof. Yury Shtyrov), which discussed topics spanning from music-based rehabilitation interventions and brain imaging to sleep and the psychedelic brain. A full list is provided on the next pages.

**...and in-house speakers**
Finally, the weekly internal MIB lab meetings have experienced a remarkable increase in in-house presentations. The development is by large the result of postdoc Cecilie Møller's organising efforts and skills and has resulted in a considerable growth in knowledge-sharing and exchange of ideas. Furthermore, it has given visiting students the opportunity to share their work and receive feedback in a well-structured and constructive environment.




*Professor Ed Large*

## Guest speakers 2019

Drs Teppo Särkämö and Noelia Martinez Molina
University of Helsinki, Finland
Clinical efficacy and neural mechanisms of music-based interventions in stroke and traumatic brain injury rehabilitation and dementia rehabilitation

Senior lecturer Nicholas Furl
Department of Psychology, Royal Holloway, University of London, UK
Social information from others' faces: Computations spanning vision to decisions

Professor Martin Lotze
University of Greifswald, Germany
Brain imaging of sensorimotor integration in musicians and chill responses to music.

Professor Petri Toiviainen
University of Jyväskylä, Finland
The chronnectome of musical beat.
Dr Daniela Dentico
Italy
Sleep: A Privileged Window into the Neuroscience of Meditation.

Dr Sabine Grimm
Cognitive and Biological Psychology (BioCog), Leipzig University, Germany
Memory representations for random pitch patterns: the roles of attention and stimulus variability as measured in the EEG



Associate professor Michael Pitts
Reed College, Portland, USA
Isolating neural correlates of conscious perception

Dr Patrick Fisher and Dr Martin Korsbak Madsen
The Neurobiological Research Unit (NRU), Copenhagen,
The Psychedelic Brain: Neuroimaging psilocybin effects in humans

Professor Markus Müller
Center for Science of Complex Systems, UNAM, Mexico
Multiple scaling behaviour and nonlinear traits in music scores

Professor Edward Large
Music Dynamics Laboratory at University of Connecticut, USA
Get the groove, baby: Modeling rhythm learning, perceptual narrowing, and enculturation

Professor Eckart Altenmüller
Hannover University, Germany
Dysfunctional sensory-motor learning in musicians: lessons from Musician's Dystonia

Dr. Elena Boto
University of Nottingham
Wearable magnetoencephalography

Lindsey Redmore
The Ohio State University's School of Music, USA
Timbre in the brain: semantics and cross-modal perception

*Associate professor Rebecca Schaefer*

Senior scientist Julien Valette
l'Energie Atomique - MIRCen, Fontenay-aux-Roses in France
Diffusion-Weighted NMR Spectroscopy In Vivo to Probe Brain Cell Structure… and Beyond

Professor Dmitry Nivokov
Department of Radiology at NYU Langone Health
Imaging tissue microstructure with MRI: Bridging across scales

Associate professor Rebecca Schaefer
Leiden University
Moving to music: Neural, cognitive and kinematic findings

Research Director Mari Tervaniemi
University of Helsinki, Finland
Music, learning, and development – what MMN can tell us and what it can't.

# MIB/RAMA COLLABORATIONS

*Bjørn Petersen*

The partnership between The Royal Academy of Music (RAMA) and MIB provides a rare opportunity to combine the musical performative and creative expertise of RAMA's teachers and students with the diverse scientific expertise of MIB's researchers. In 2019, four of these collaborative projects were selected for presentation at the now postponed Neuroscience and Music VII conference in Aarhus. The projects reflect the heterogeneity of the research that takes place at RAMA, including empirical research as well as artistic and pedagogical research. Brief descriptions of the four projects are found in the following.

## Mental Practice

**Kristian Steenstrup, Boris Kleber, Carles Camarasa Botella, Niels Trusbak Haumann & Bjørn Petersen**

Trumpet Professor at RAMA Kristian Steenstrup is the author of two books on brass technique (Teaching Brass, 2007; Blow your Mind, 2017) and an internationally acclaimed master class teacher. In this project, Steenstrup investigates the potential benefits of applying mental strategies in the daily practicing routines of brass players in particular and musicians in general.

One of these strategies is "Motor and auditory imagery (MAI)" in which the player mentally rehearses a musical performance without physically engaging in the actual action. MAI has recently been established as a potentially efficient tool in the acquisition of musical competency. A different strategy, also involving mental resources, is the use of "absolute solmization (SOL)" in which a piece is learned through singing, using a set of attributed syllables.

Fifty academy level trumpet students at 6 different institutions in 4 European countries have been recruited for the study. The participants were given 3 minutes to practice a short piece and randomly assigned to apply one of five different strategies: Physical Practice (PP), MAI, SOL, a combination of PP, SOL and MAI (COM) or no practice (NP). Performances were recorded before and after practice. To identify intervention effects, three experts, blinded to the data origins, made individual evaluations of the recordings on parameters such as accuracy of pitch and rhythm as well as quality of musical expression, intonation and sound.

Preliminary results indicate that physical practice is most efficient in achieving pitch accuracy with COM Background. coming out as close number two. Interestingly, the COM strategy outperforms all of the other strategies on quality of musical expression. Further analyses will look into how individual demographic factors and musical background may affect these results.

## Forming performing

**Søren Rastogi & Bjørn Petersen**

Søren Rastogi is an internationally renowned and sought-after professional concert pianist and accompanist as well as an associate professor at RAMA. In this artistic research project, he has monitored and reflected on the process of learning the previously not performed piano concert by Paul von Klenau.

Background and methods. The cognitive processes involved in mastering a classical musical piece at a professional level are difficult to access via traditional research methods, as it entails a complex blend of analytical strategies, automated motor learning expertise and emotional and imaginative involvement. With this project, Rastogi has systematically used first-person methods such as self-observation and reflection in order to search for categorization and conceptualization of important aspects of the learning process. The method involved in his investigation was primarily observation of video recordings of his own piano practice. Around 70 hours were recorded and subsequently reviewed and analyzed applying critical reflection, leading to a set of derived conceptualizations. Some of the videos, including synchronized on-screen analyses, were published on YouTube. Furthermore, the results were published in an e-book.

Key findings: Unconscious strategy changes appear rapidly, resistance in the learning process is often resolved covertly and several techniques were developed which increased the speed of learning, such as conscious attention shifts between perception and action as well as self-awareness strategies. The project demonstrates the validity of using a first-person perspective in order to gain new insights directly relevant for professional musicians but also as a way of gaining a better understanding of the cognitive processes involved in advanced level musical practice.

## Evaluation of musical outreach programs

**Karsten Aaholm & Bjørn Petersen**

Karsten Aaholm is a professional guitar player and composer and an associate professor at RAMA. Aaholm has BA in Anthropology and an MA in Educational Anthropology. With this project, Aaholm aims to get behind the discussion of El Sistema-inspired musical outreach programs. Background. In the last ten years, there has been an increasing awareness of musical programs aimed at socially marginalized children and adolescents. Many of these programs have been influenced by the El Sistema program (founded in Venezuela in 1975 by Venezuelan educator, musician, and activist José Antonio Abreu). However, there seems to be very different perceptions of the programs and their effect.

The purpose of the research project is to contribute to the encouragement of applying reliable, objective evaluations of such initiatives and hence obtain results that can form the basis for new initiatives. It may also help professional music educators to gain a more realistic view of what music can and cannot do. In this way, the study will be a relevant contribution to the discussion whether music should be judged on its intrinsic values or on its derivative effects.

Methods. Based on the research question 'how are the programs evaluated?' the study reviews academic literature (in English, German and Scandinavian languages), published within the last ten years, that evaluate such programs. Results. The literature seems to reflect very opposing positions. This lack of consensus also reflects a wide range of evaluation methods and different priorities in the choice of the observed parameters. The findings suggest that the application of a transparent set of evaluation methods may improve the validity of the research within the field.

### Marimba, Mallet and Mind – Enhancing the Marimba Sound by Ki-aikido Approach

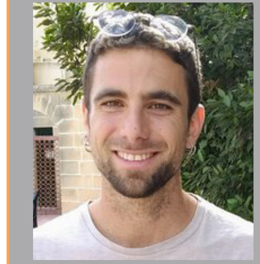
**Henrik Knarborg Larsen, Ole Adrian Heggli and Bjørn Petersen**

Henrik Knarborg Larsen is a professional percussion artist and internationally acclaimed master class teacher. At RAMA he is an associate professor and director of the classical percussion department. In this study Larsen examined the application of a physico-mental method from the Japanese martial art Ki-aikido to marimba playing, aiming at enabling the player to produce a more varied spectrum of sounds and express more nuances in the music.

Methods. Twentyfour percussion students were randomly assigned to two groups. The experimental group played a short exercise on marimba before and after a Ki-aikido instruction. The control group played the same exercise before and after a control instruction. To measure possible group differences in sound quality, the amplitude in three prominent partials were inspected and compared between groups by use of Fourier analysis. Furthermore, recordings of the performances were subjectively rated by ten international marimba experts who were blinded to the type of intervention.

Results. The result of the spectrum analysis showed a significant effect of the Ki-aikido intervention, indicated by a lowering of the relative amplitude in the third and fourth harmonic, thus enhancing projection of the fundamental frequency and higher harmonics. By contrast, the expert ratings showed no effect on the musical parameters resonance and overtones, whereas the ratings of the parameter synchronized attack suggested an overall effect of the control instruction. Perspectives. As indicated by spectrum analyses, the physico-mental awareness provided by the Ki-aikido instruction may significantly change the harmonic distribution in the instrument's timbre, thus providing room for a warmer, clearer and more open sound. Whereas the objective analysis constitutes a solid and consistent platform for measurements, the subjective approach was flawed by several inconsistencies and thus less reliable. The study highlights the potential of taking Ki-aikido strategies into consideration in the general approach to teaching and production of sound on percussion instruments.

### NEW FACE AT MIB



Alexandre Celma-Miralles is new postdoc at MIB. He will work on rhythmic perception and production, extending his methodological scope from EEG and behavioral paradigms to MEG and fMRI measures. He is interested in the hierarchical organization of the beat (i.e. meter) and he musical notes (i.e. tonal harmony). He is currently seeking the hierarchical tonal-harmonic structures of music and the effects of neural entrainment to beat subdivision on motor production.
After a Music Professional degree on violin (2010) and a BA in Catalan Philology (2012), he pursued a MA in Cognitive Science and Language (2014) and a MSc in Brain and Cognition (2015). Then he pursued a PhD in Biomedicine in the Center for Brain and Cognition at the Universitat Pompeu Fabra (Barcelona). His thesis is entitled "Neural and Evolutionary Correlates of Rhythm Processing through Beat and Meter". The neural correlates were observed through frequency analyses of the electroencephalographic recordings, while the evolutionary bases of rhythm were studied on rats' behavior. The human studies focused on the role of modality, attention and formal music training in rhythmic perception. The animal studies focused on isochrony detection, rhythm recognition and tempo-pitch-timbre modulation.

# PHD FEATURE

*Ole Adrian Heggli*

## Strategies for interpersonal synchronization in musicians: Behaviour, modelling, and neuro-imaging

Interacting with other people is not just an important aspect of everyday life, but also a key part of what makes us develop and flourish as humans. In fact, many psychiatric disorders, such as ADHD or social anxiety disorder, predominantly manifests as abnormal social functioning[1]. A particularly interesting aspect of social interactions is that they often lead to synchronization[2]. In music, the ability to synchronize to other musicians is critical. In my PhD I focused on exactly how musicians are able to perform such synchronization, while at the same time adapting and anticipating each other's next action. To explore this, we designed a joint finger tapping experiment, wherein highly skilled musicians tapped a simple rhythm together in pairs. While this may sound like a trivial task, it results in complex behaviour[3].

We found that most pairs of musicians synchronized using a strategy called "mutual adaptation". This means that both members of a pair continuously adapt to each other on a tap-by-tap basis[3]. However, some of the musicians achieved similar synchronization levels, while using a completely different strategy. These musicians were predominantly drummers and did not exhibit much adaptation to each other. We called this new synchronization strategy "leading-leading"[4].

In our work to explore the dynamics of synchronization strategies we used computational modelling. We created a Kuramoto-based coupled oscillator model where we abstracted each interacting musician as a unit of two intercoupled oscillators, serving as proxy for auditory perception and motor action. When we coupled two such units together, we found the model produced mutual adaptation if they were strongly coupled and leading-leading if they were weakly coupled[5]. This work shows that even complex human behaviour may be modelled using simple mathematical processes.

We have currently adapted our oscillator model to run on a single-board microcontroller. This allows us to design experiments where participants tap along the model in real-time, while we measure how synchronization strategies change over time. In addition, we have extended the model to work with more than two interconnected units. This enable us to simulate synchronization dynamics in larger ensembles such as symphony orchestras or jazz quartets. We look forward to investigating how different types of musical groups interact in terms of synchronization.

In the joint finger tapping experiment, we also recorded EEG. Here we found that mutually

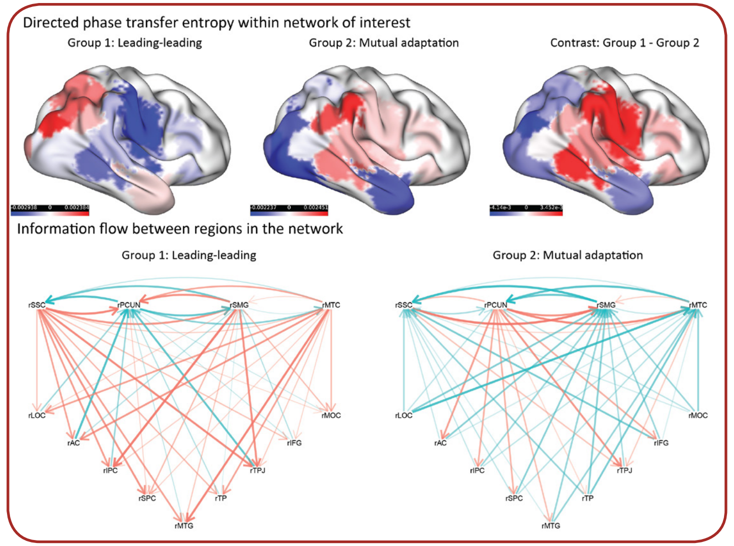



***Figure 1.*** *Illustration of information flow as measured with directed phase transfer entropy, within the network of interest. On top, directionality of the regions is shown on the cortex. Here, red indicates that an area is predominantly transmitting, and blue indicates predominantly receiving. On the bottom we see the network connections, with four significantly different regions listed at the top. A red line indicates information outflow, a blue line indicates inflow.*

adapting musicians exhibited a more frequent occurrence of phase-locked activity within an action-perception related brain network as compared to the leading-leading group. Using a new analysis method based on directed phase transfer entropy, we identified parietal and temporal brain regions within this network that significantly differed in the directionality of information flow between the groups (Fig. 1)[6]. Of particular interest here is the right precuneus. It has been linked to processes of integrating external and self-related information and in leading-leading the precuneus acts as a sink in the network. This means that while it receives information from many other regions in the network, it does not transmit much information. This relationship is reversed in mutual adaptation. We are now planning follow-up studies to better isolate and investigate the role of this network in the dynamics of synchronization strategies.

In summary, the work performed as part of my PhD project has led to new insight into how musicians synchronize and to the development of a versatile computational model. It has also contributed to understanding the neural correlates of interpersonal synchronization. My current work focuses on developing a theoretical model that integrates my findings with theories of general brain functioning. Such a theoretical model will allow us to better understand interpersonal synchronization both behaviourally and in terms of brain dynamics.

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# PHD FEATURE

*Maria Celeste Fasano*

## From pleasure to learning: The motivational power of music in children and adults

The scientific community unanimously describes music as a strongly pleasurable activity able to recruit the brain's pleasure system. One of the brain areas associated to music pleasure is the orbitofrontal cortex (OFC), also important for emotion regulation and cognitive control. The tendency of adolescents to use music as a tool for promoting emotion regulation and the recent studies showing a positive effect of collective music training on inhibitory control highlight the need of further exploring the potential regulatory power of music.

The overall aim of my PhD project was to investigate the neural underpinning of music pleasure and its interactions with the process of learning in children and adults. We pursued this aim by using behavioural and neuroimaging methods.

In the first study, we explored for the first time the dynamics of brain activity in whole-brain networks responsible for music processing in early adolescence, investigating how they are modulated by individual sensitivity to musical pleasure[1]. We addressed this question by using the Leading Eigenvector Dynamics Analysis (LEiDA)[2] and investigated whether there are specific network patterns of dynamic phase coherence (PC states) that differentiate between music listening and no music in young adolescents. Our analysis showed a significantly increased tendency to access a reward PC state involving OFC during music listening compared to no music (Fig. 1). Moreover, the

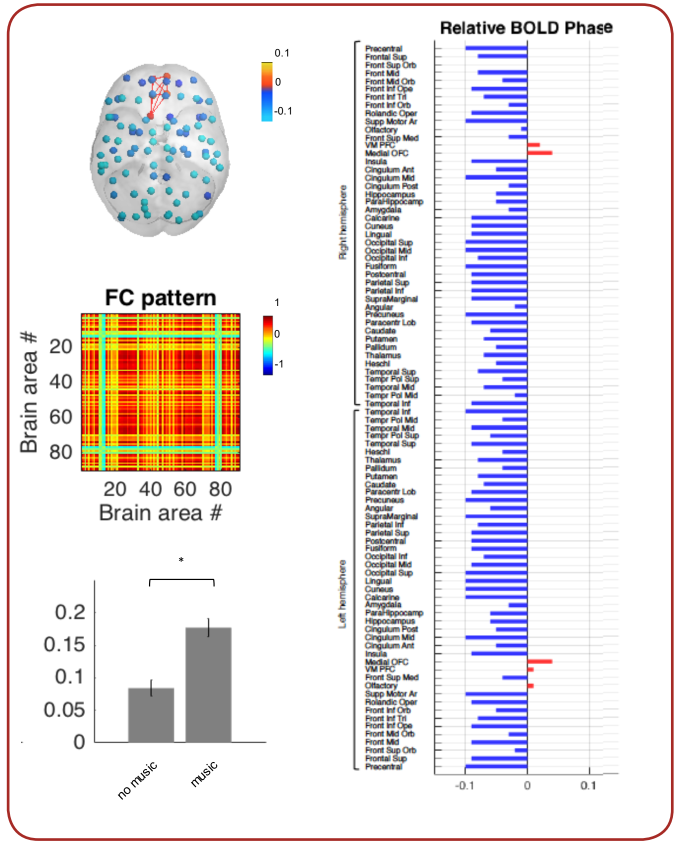


*Figure 1. The PC state occurring significantly more often during music listening than no music corresponds to a network involving OFC bilaterally.*

*Figure 2. One of the lessons of the short orchestral music training provided to the experimental group for 3 months (musicaingiocobari.wordpress.com).*

young adolescents with higher music reward sensitivity switched more frequently from a PC state, involving bilateral insula and rolandic operculum, to the OFC reward PC state. The top-down control function of the OFC in the emotional network and the frequent recruitment of a PC state involving this region during music listening, may provide a hypothesis for the recurrent adolescents' use of music listening as one of their most important coping strategies for emotion regulation. Moreover, it seems reasonable to speculate that the capability of music listening to stimulate and recurrently attract the reward OFC network during adolescence, when OFC is not yet fully matured, might make music a tool able to modulate the development and the function of top-down reward regulation of this brain area.

In the second study, we carried out a longitudinal behavioural study to assess near- and far-transfer effects of short orchestral music training on inhibitory control, hyperactivity, impulsivity, and inattention. Using a repeated measure design and comparing an experimental group undergoing the music program (Fig. 2) with a control group, we found a significant effect of the three-months music training on inhibitory control and hyperactivity-impulsivity[2]. The results suggest that collective music training may be an efficient tool for improving inhibitory control and reducing hyperactive behaviours in children.

Finally, in the third study we investigated whether optimal performance in playing a piece by heart after one month of training and motivation to learn it are linked to the shared recruitment of specific brain structures, including the reward network[3]. For this purpose we combined functional magnetic resonance imaging (fMRI) with behavioural data. Our results showed that the best performers and the most motivated pianists to learn the sonata were similarly activating brain regions of the reward brain system and the dorsal-stream.

Taken together, the present PhD dissertation contributes to an increased understanding of the neural bases of pleasure and modulatory power of music in young and adult populations. The results suggest that music may be used as facilitator of behavioural and neural changes in clinical and academic contexts.

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# PHD FEATURE
*David Quiroga*

## A hierarchy of melodic expectations in the brain

Music is a rich auditory signal. At the surface, there is an acoustic wave that reaches the ear, but at deeper levels music is an intricate combination of auditory objects with different degrees of abstraction unfolding in time. Therefore, it is remarkable that we are equipped with the neural machinery to perceive, appreciate and get moved by music. In my PhD, I aimed to unveil the inner workings of such machinery. Specifically, I aimed to understand how the brain encodes the expectations that we create about how a musical piece will unfold. To do so, I focused on musical stimuli that are more complex and realistic than those typically studied in neurophysiological research, hoping they would reveal a more accurate picture of music perception as it happens in daily life. In the following, I will discuss three key findings arising from these efforts, which together reveal a hierarchy of expectations that mirrors the depth and complexity of music itself.

In an early processing stage, neurons in the primary auditory cortex encode sound acoustics. Here, a phenomenon known as stimulus specific adaptation (SSA) occurs in which neurons respond less to subsequent presentations of acoustically similar sounds[1]. In our research, we found evidence that SSA plays an important role in melodic listening. Using a computational model (IDyOM), we found that tone expectedness—as derived from the statistics of a corpus of Western tonal music—predicted the amplitude of the N1 component of the sound-evoked brain magnetic field. Thus, it would be tempting to think of the N1 as encoding stylistic musical expectations. However, further analyses suggested that the pitch distance between consecutive sounds—which correlated with expectedness—was a more likely explanation of the effect. This is interesting because, in our

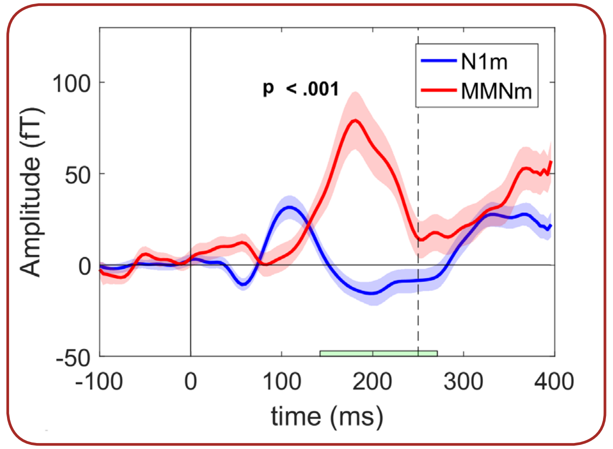


*Figure 1.* *Magnetic (m) N1 effect (i.e. large - small inter-tone distance) and MMN (deviant - standard) effect. Note how the MMN was larger and peaked later than the N1 effect, thus indicating a higher-order level of processing. Green horizontal lines indicate the times when differences between components were significant. Shaded areas depict 95% confidence intervals. Displayed activity corresponds to the average of the four left temporal magnetometers with the strongest N1 modulation. Dashed vertical lines indicate tone onsets.*





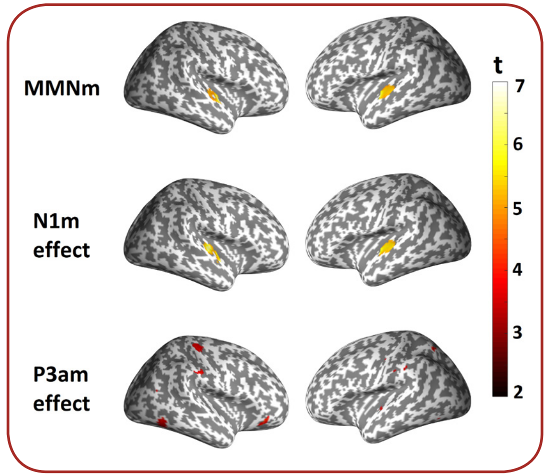


*Figure 2.* *Source estimates of the magnetic (m) N1, MMN and P3a effects. Colored areas represent statistical t-maps of the sources that were consistently identified over subjects, thresholded at 0.05 after multiple comparisons correction, in the case of the MMN and N1; and at 0.0005 without multiple comparison corrections for the P3a.*

stimuli, the smaller the pitch distance between two tones, the closer they were in their spectral content. This points to SSA as the true driver of the effect and suggests that musical styles may be highly constrained by the underlying acoustics.

In a second stage, the brain extracts regularities from the recent past and generates predictions about future sounds. In our experiment, regularity violations elicited a response known as the mismatch negativity (MMN). Crucially, the MMN was not a mere acoustic response like the N1 (Fig. 1), but instead reflected the violation of abstract regularities in a constantly changing auditory stream. This was most evident for pitch deviants, which violated the tuning system, a clearly abstract musical entity. Moreover, MMN responses were stronger for musicians than nonmusicians[2] and for predictable than less predictable melodies[3], which suggests a higher sensibility of the MMN to top-down influences.

Finally, in a third stage higher-order expectations are deployed, which may reflect stylistic musical knowledge. In our work, when the pitch distance was held constant, proper sound expectedness—as estimated with IDyOM—modulated a late response that resembled the P3a, a component linked to the orientation of attention and the tracking of higher-order regularities[4]. Moreover, the source of this response was localized in frontoparietal regions, which contrasts with the sources of the N1 and the MMN, which were restricted to temporal auditory areas (Fig. 2).

In sum, our research suggests that the brain keeps track of melodic expectations at different hierarchical levels and indicates that the neural processing of music is heavily shaped by the depth, richness and complexity of music itself.

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# PHD FEATURE

*Margrethe Langer Bro*

## Resonance – music as adjuvant for cancer treatment

Cancer affects all aspects of life, both in terms of somatic, psychological, and social dimensions. These multidimensional problems may be complex and require interdisciplinary approaches to meet the patient's needs. During the last decade music has been proposed as a supplement to cancer treatment. A couple of reviews have reported positive effects of music, reducing level of anxiety, increasing quality of life, reducing depression, improving mood and reducing pain[1-2]. However, methodological limitations in the included studies did not allow for final conclusions. Broad inclusion criteria, small sample sizes, various cancer diagnoses, different disease stages and lack of information on the patient´s background and the actual music applied were among factors contributing to the low quality of evidence. Based on this critique, my PhD was formed into three studies, supervised by Peter Vuust (MIB), Niels Abildgaard (Dept. of Haematology, OUH), Christoffer Johansen (Danish Cancer Society Research Center) and Jeppe Gram (Dept. of Endocrinology, SVS).

In study one[3], we conducted a systematic review and metaanalysis to identify the psychological and physical effects of music interventions in active cancer treatment. The Checklist for Reporting Music-Based Interventions[4] was used to evaluate the music applied and quality of the studies. We included 25 RCTs of which 20 were eligible for the meta-analysis (n=1565). Music reduced anxiety [SMD -0.65, 95 % CI -1.20 to -0.11], pain [SMD -0.88, 95 % CI -1.45 to -0.32], and improved mood [SMD -0.55 [95 % CI, -0.98 to -0.13]. However, studies were hampered by high heterogeneity (I2) 73% (54 % - 96 %), and the quality of the studies ranged from very low to low. The most effective mode of music intervention appeared to be passive listening to self-selected, recorded music in a single session design.

In study two[5-6], we performed a 3-armed multicenter randomized controlled trial on patients with lymphomas undergoing first-line chemotherapy treatment, offering either patient-preferred live or CD music compared to standard care. The primary outcome was anxiety measured by The Spielberger State Anxiety Inventory (STAI). Secondary outcomes included pulse rate, blood pressure, nausea and vomiting, serum catecholamine levels pre and post intervention to measure arousal levels and patient-reported health related quality of life (EORTC-30-QOL). The Goldsmith Musical Sophistication Index (GOLD-MSI) and The Musical Ability Test (MET) was used to link musical background, preference and ability to psychological and physical results.

The intervention consisted of the patient's favorite music genre, special pieces of music/songs with an average tempo of 60–80 beats per minute. Musicians from the Danish National Academy of Music (SDMK) participated, representing various genres; classical, pop, rock, blues, folk, and jazz. To ensure the intervention quality in group I, the musicians had attended SDMK's hospital project for at least 2 years. In order to make the two intervention groups comparable, the musicians and the patients were informed to limit the communication during the intervention.

*Live music during chemoherapy treatment*

A total of 143 patients with Hodgkin and Non-Hodgkin lymphomas were included. They were randomly assigned into three groups receiving either 30 minutes of patient-preferred live music (n=47), 30 minutes of patient-preferred recorded music (n=47) or standard care (n=49) during outpatient chemotherapy. Each patient received up to 5 sessions separated by 1-2 weeks.

Surprisingly, baseline scores of anxiety (STAI) were low across groups (live music, 33.4; recorded music, 35.6; controls, 33.1). Nevertheless, when adjusting for age, sex, diagnosis, number of sessions, and baseline anxiety, we found a 7% decrease in anxiety in the live music group compared to standard care ($p = 0.05$) whereas no effect was seen in the recorded music group ($p = 0.18$).

In study three, we explored whether positive responders across intervention groups were determined by musical background (GOLD-MSI) and musical ability (MET-test), age and gender. We found that musical ability and background, adjusted for age and gender did not influence the effect of music intervention.

This thesis provides new insights on physical and physiological effects of music interventions in active cancer treatment and contributes to evidence based and targeted music intervention.

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# MIB ANNUAL RETREAT 2019 - SKANDERBORG

*Make Time to Think*



The retreat took place at Skanderborg Hus


Talks by center leader Peter Vuust and Associate Prof Micah Allen


Making time to think






Social activities: Polyrhythm workshop, sailing on Skanderborg Lake and concert

The winners of our Make Time to Think Competition:
Davide Ligato, Kira Vibe Jespersen, Margrethe Langer Bro and Mette Kaasgaard.
The title of the winning project was ”Sound Asleep”.

# PEOPLE

Peter Vuust
Professor
Director
Principal investigator

Elvira Brattico
Professor
Principal investigator

Morten Kringelbach
Professor
Principal investigator

Marcus Pearce
Professor

Line Gebauer
Associate professor

Bjørn Petersen
Assistant professor

Boris Kleber
Assistant professor

Henrique Fernandes
Assistant professor



Manon Grube
Assistant professor

Massimo Lumaca
Assistant professor

Alexandre Celma-Miralles
Postdoc

Angus Stevner
Postdoc

Cecilie Møller
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David Quiroga
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Jan Stupacher
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Joana Cabral
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Kira Vibe Jespersen
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Ole Adrian Heggli
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Christine Ahrends
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Selen Atasoy
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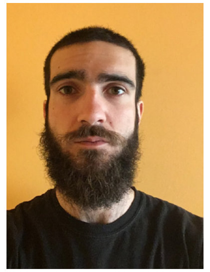
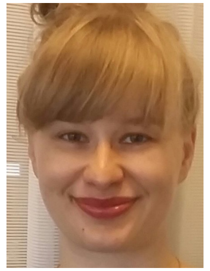

Davide Ligato
PhD student


Maria Celeste Fasano
PhD student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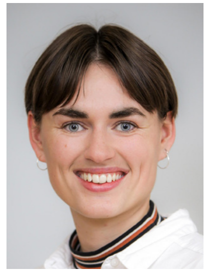
Hella Kastbjerg
Centre secretary



Laura Vestergaard
Student helper

## INTERNATIONAL GUEST RESEARCHERS

- Agata Patyczek
- Alexandre Celma Miralles
- Ana Teresa Queiroga
- Andrew Moore
- Francesco Carlomagno
- Francisca Assuncao
- Gülce Isil Göcke
- Johanna Rösch
- Mattia Rosso
- Pedro Ferreira
- Sarah Foss
- Virginia Fedele

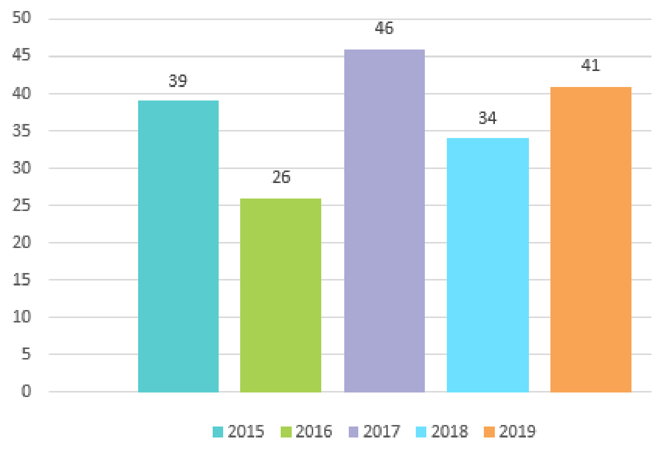
## PRIZES

MIB post doc Kira Vibe Jespersen won the prize for Best Poster at the annual Neuroscience Day at Aarhus University.

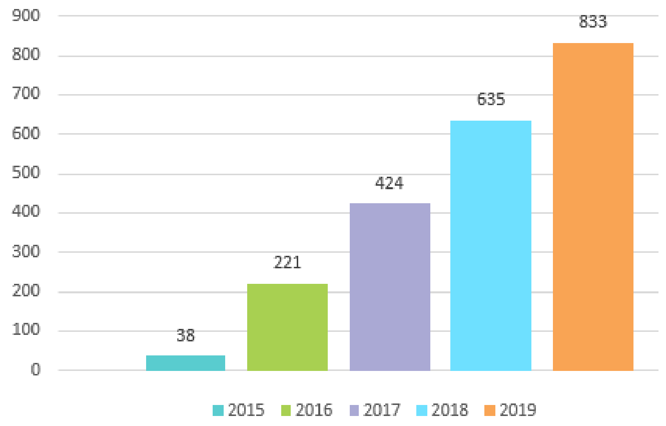

MIB post doc Jan Stupacher was awarded The Outreach Henry Prize at a ceremony during the annual joint MIB & CFIN Christmas Dinner.

# PUBLICATIONS 2019

Number of peer-reviewed articles




Number of citations




## Peer-reviewed articles

Brattico, Elvira; Varankaité, Ulrika. Aesthetic empowerment through music. Musicae Scientiae, Vol. 23, No. 3, 09.2019, p. 285-303.

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Bro, Margrethe Langer; Johansen, Christoffer; Vuust, Peter; Enggaard, Lisbeth; Himmelstrup, Bodil; Mourits-Andersen, Torben; Brown, Peter; d'Amore, Francesco; Andersen, Elisabeth Anne Wreford; Abildgaard, Niels; Gram, Jeppe. Effects of live music during chemotherapy in lymphoma patients: a randomized, controlled, multi-center trial. Supportive care in cancer: official journal of the Multinational Association of Supportive Care in Cancer, Vol. 27, No. 10, 10.2019, p. 3887-3896.

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Deco, Gustavo; Cruzat, Josephine; Cabral, Joana; Tagliazucchi, Enzo; Laufs, Helmut; Logothetis, Nikos K.; Kringelbach, Morten L. Awakening: Predicting external stimulation to force transitions between different brain states. Proceedings of the National Academy of Sciences of the United States of America, Vol. 116, No. 36, 03.09.2019, p. 18088-18097.

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Proceedings of the National Academy of Sciences of the United States of America. Vol. 116, No. 42, 2019, p. 20813-20814.

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Stevner, A. B.A.; Vidaurre, D.; Cabral, J.; Rapuano, K.; Nielsen, S. F.V.; Tagliazucchi, E.; Laufs, H.; Vuust, P.; Deco, G.; Woolrich, M. W.; Van Someren, E.; Kringelbach, M. L. Discovery of key whole-brain transitions and dynamics during human wakefulness and non-REM sleep. Nature Communications, Vol. 10, No. 1, 1035, 2019.

Stupacher, Jan. The experience of flow during sensorimotor synchronization to musical rhythms. Musicae Scientiae, Vol. 23, No. 3, 09.2019, p. 348–361.

Zamorano, Anna M.; Montoya, Pedro; Cifre, Ignacio; Vuust, Peter; Riquelme, Inmaculada; Kleber, Boris. Experience-dependent neuroplasticity in trained musicians modulates the effects of chronic pain on insula-based networks – A resting-state fMRI study. NeuroImage, Vol. 202, 116103, 15.11.2019.

## PhD theses

Margrethe Langer Bro
Resonance – music as adjuvant for cancer treatment

Ole Adrian Heggli
Strategies for interpersonal synchronization in musicians: Behaviour, modelling, and neuroimaging

Maria Celeste Fasano
From pleasure to learning: The motivational power of music in children and adults

David Quiroga
The neural responses to auditory surprise in complex and realistic musical contexts.

## Book chapters (selected)

Brattico, Elvira The neuroaesthetics of music: A research agenda coming of age. In: The Oxford Handbook of Music and the Brain. ed. / Michael Thaut; Donald Hodges. Oxford University Press, 2019.

Heggli, Ole Adrian; Vuust, Peter; Kringelbach, Morten L. Please Please Me! The Pleasure of Music in the Brain. In: The Routledge Companion to Music, Mind and Well-being. Abingdon, Oxon, UK: Routledge, 2019. p. 205-218.

Morrison, Steven; Demorest, Steven; Pearce Marcus Cultural Distance: A Computational Approach to Exploring Cultural Influences on Music Cognition. In: The Oxford Handbook of Music and the Brain. ed./Michael Thaut, David Hodges. Oxford University Press, 2019

Sedghi, Nader Alessandro; Brattico, Elvira. Musik og evolution. In: Mennesket, kultur, evolution: et biokulturelt perspektiv. ed. / T.K. Nielsen; C Andersen; A.R. Kratschmer; M Clasen. Aarhus : Aarhus Universitetsforlag, 2019. p. 201-214.

## Conference abstracts in proceedings

Høgholt, Nadia Flensted; Kringelbach, Morten L Treating pregnancy-related insomnia with music and light: A neuroimaging study. / . Frontiers Abstract Book. Frontiers Media SA, 2019. p. 62-64.

Niranjan, Dipankar; Toiviainen, Petri; Brattico, Elvira; Alluri, Vinoo. Dynamic Functional Connectivity in the Musical Brain. Brain Informatics: 12th International Conference, BI 2019 Haikou, China, December 13–15, 2019 Proceedings. ed. / Peipeng Liang; Vinod Goel; Chunlei Shan. Cham : SPRINGER, 2019. p. 82-91 (Lecture Notes in Computer Science, Vol. 11976 LNAI).

## Posters/Abstracts (selected)

Ajaj, T; Blankertz, B; Alter, K; Grube, Manon. Event-related EEG correlates of the processing of a metrical beat: in search for components of entrainment and prediction.
Annual Meeting of the German Neuroscience Foundation , Göttingen, Germany.

Alexander Kleber, Boris. The neural correlates of musical improvisation in trained and untrained singers.
Organization for Human Brain Mapping (OHBM) Annual Meeting 2019, Rome, Italy.

Brandl, S; Trusbak Haumann, Niels; Brattico, Elvira; Vuust, Peter; Grube, Manon. Tracing rhythmic regularity processing in EEG and MEG.
Engineering in Medicine & Biology Conference (EMBC).

Brandl, S; Trusbak Haumann, Niels; Brattico, Elvira; Vuust, Peter; Grube, Manon. Chasing auditory rhythmic regularity processingin the EEG – and now MEG.
MEG Nord, Jyväskylä, Finland.

Brandl, S; Trusbak Haumann, Niels; Brattico, Elvira; Vuust, Peter; Grube, Manon. Chasing auditory rhythmic regularity processingin the EEG & MEG.
The Predictive Brain Conference, Marseille, France.

Celma-Miralles, Alexandre; Pagès-Portabella, Carlota; Toro, Juan. Musical syntax: can tonal functions elicit metrical structure?
Society for Music Perception and Cognition, New york, United States.

Fasano, Maria Celeste; Cabral, Joana; Stevner, Angus; Cantou, Pauline; Vuust, Peter; Siemens Lorenzen, Ida; Brattico, Elvira; Kringelbach, Morten L. Music attracts orbitofrontal reward brain network in early adolescence: An fMRI study.
Neuroscience Day 2019, Aarhus, Denmark.

Grube, Manon; Kumar, S; Smith, F; Slater, H; Griffiths, TD. Neural substrates of auditory sequence processing and language skill in early-to-mid adolescence. /
Annual Midwinter Meeting of the Association for Research in Otolaryngology (ARO), Baltimore, United States.

Jespersen, Kira Vibe; Stevner, Angus; Fernandes, Henrique; Sørensen, Stine Derdau; Van Someren, Eus; Kringelbach, Morten L.; Vuust, Peter. Altered brain connectivity in Insomnia Disorder.
Neuroscience Day 2019, Aarhus, Denmark.

Kaasgaard, Mette; Andersen, Ingrid Charlotte ; Vuust, Peter; Hilberg, Ole; Løkke, Anders; Bodtger, Uffe. Heterogeneity of Danish lung choirs and their singing leaders – a study of performance, experiences, and attitudes in an emerging field.
Dansk Lungemedicinsk Selskab Årsmøde/Kongres 2019, Odense, Denmark.

Kaasgaard, Mette; Andersen, Ingrid Charlotte ; Vuust, Peter; Hilberg, Ole; Løkke, Anders; Bodtger, Uffe. Heterogeneity of Danish lung choirs and their singing leaders – a study of performance, experiences, and attitudes in an emerging field.
European Respiratory Society (ERS) International Congress 2019, Madrid, Spain.

Kliuchko, Marina. The role of musical enculturation on building melodic expectations in the brain.
Brain, Music and Cognition 2019, Jerusalem, Israel.

Lumaca, Massimo; Vuust, Peter; Dietz, Martin. Dynamic causal modelling of effective connectivity during music perception.
Organization for Human Brain Mapping (OHBM) Annual Meeting 2019, Rome, Italy.

Lumaca, Massimo; Trusbak Haumann, Niels; Brattico, Elvira; Grube, Manon; Vuust, Peter. Weighting of neural prediction error by rhythmic complexity: A predictive coding account using Mismatch Negativity.
Organization for Human Brain Mapping (OHBM) Annual Meeting 2019, Rome, Italy.

Lund, Helle Nystrup; Kreutz, Gunter; Jespersen, Kira Vibe Music and sleep: Improving mental health.
European Congress of Psychiatry, Warsaw, Polen, 6.-9. april 2019.
Mårup, Signe Hagner; Møller, Cecilie; Vuust, Peter Simultaneous performance of rhythm and beat: A bodily hierarchy.
Brain, Music and Cognition 2019, Jerusalem, Israel.

Møller, Cecilie; Højlund, Andreas; Bærentsen, Klaus B.; Hansen, Niels Chr.; Skewes, Joshua; Vuust, Peter.
You get what you need: individual differences in visually-induced amplification of the auditory mismatch negativity.
Neuroscience Day 2019, Aarhus, Denmark.

Niklassen, Andreas Steenholt; Ovesen, Therese; Fernandes, Henrique; Fjaeldstad, A. Danish Validation of Sniffin' Sticks Olfactory Test for Threshold, Discrimination, and Identification.
Dansk Selskab for Oto-rhino-laryngologi, Hoved-Halskirurgi: DSOHH årsmøde, Nyborg, Denmark.

Petersen, Bjørn; Friis Andersen, Anne Sofie; Trusbak Haumann, Niels; Højlund, Andreas; Dietz, Martin; Brattico, Elvira; Michel, Franck; Kamaric Riis, Søren; Vuust, Peter. The Sound of Music – Two Novel EEG-Paradigms for Measuring Discrimination of Music in Cochlear Implant Users.
CI2019 Pediatric: 16th Symposium on Cochlear Implants in Children, Hollywood, FL, United States.

Petersen, Bjørn; Friis Andersen, Anne Sofie; Trusbak Haumann, Niels; Højlund, Andreas; Dietz, Martin; Brattico, Elvira; Michel, Franck; Kamaric Riis, Søren; Vuust, Peter. Objective Measurements of Music Discrimination in Individual Experienced and Recently Implanted Cochlear Implant Users.
CI2019 Pediatric: 16th Symposium on Cochlear Implants in Children, Hollywood, FL, United States.

Petersen, Bjørn; Friis Andersen, Anne Sofie; Trusbak Haumann, Niels; Højlund, Andreas; Dietz, Martin; Brattico, Elvira; Michel, Franck; Kamaric Riis, Søren; Vuust, Peter. The Sound of Music: Two Novel EEG-Paradigms for Measuring Discrimination of Music in Cochlear Implant Users.
Conference on Implantable Auditory Prostheses (CIAP), Lake Tahoe, United States.

Petersen, Bjørn; Friis Andersen, Anne Sofie; Trusbak Haumann, Niels; Højlund, Andreas; Dietz, Martin; Brattico, Elvira; Michel, Franck; Kamaric Riis, Søren; Vuust, Peter. Objective Measurements of Music Discrimination in Individual Experienced and Recently Implanted Cochlear Implant Users.
Conference on Implantable Auditory Prostheses (CIAP), Lake Tahoe, United States.

Petersen, Bjørn; Friis Andersen, Anne Sofie; Trusbak Haumann, Niels; Højlund, Andreas; Dietz, Martin; Brattico, Elvira; Michel, Franck; Kamaric Riis, Søren; Vuust, Peter. Beat based entrainment in the brain and the question of its relevance to auditory perception of rhythmic patterns.
AU Neuroscience Day 2019.

# OUTREACH 2019

## Talks at international conferences

**Bjørn Petersen**
CI2019 Pediatric: 16th Symposium on Cochlear Implants in Children, Miami, USA

**Boris Kleber**
PEVOC - The Pan European Voice Conference, Copenhagen Denmark
SysMus - The International Conference of Students of Systematic Musicology, York, UK
XXVII Pacific Voice Conference EU Poland edition, Krakow, Poland
International Conference on Musician's Health, Murcia, Spain
X Encuentro de ROCE, Grenada, Spain

**Cecilie Møller**
AIAS joint conference: Multimodality: Illusion, Performance, Experience. Aarhus, Denmark

**Elvira Brattico**
16th Sound and Music Computing Conference, Malaga, Spain
TEAP 2019 Tagung Experimentell Arbeitender Psychologen, Holloway Campus, London Metropolitan University, UK
MEG Nord, Jyväskylä, Finland
First International Day of Women in Inclusive Sound and Music Computing Research, Institute of Communication Engineering, University of Malaga, Spain.
"Voci di Dentro e di Fuori", Conservatory "Cesare Pollini" of Padova, Italy
X Encuentro ROCE - Música Y Neurociencia, Granada, Spain
Apulian Mini-symposium on Music Psychology, Education, & Neuroscience, Department of Education, Psychology, Communication, University Aldo Moro of Bari, Italy

**Jan Alexander Stupacher**
CIM19 - Conference on Interdisciplinary Musicology, Graz, Austria

**Kira Vibe Jespersen**
Nordic Music Therapy Student Conference: Brain, body and surroundings, Aalborg, Denmark
European Music Therapy Conference, Aalborg, Denmark
Danish Sound Day, Copenhagen, Denmark

**Leonardo Bonetti**
MEG Nord, Jyväskylä, Finland

**Marina Kliuchko**
The 5th Learning and Plasticity Meeting: Music: Neurocognition and Therapeutic Applications, Ylläs, Finland

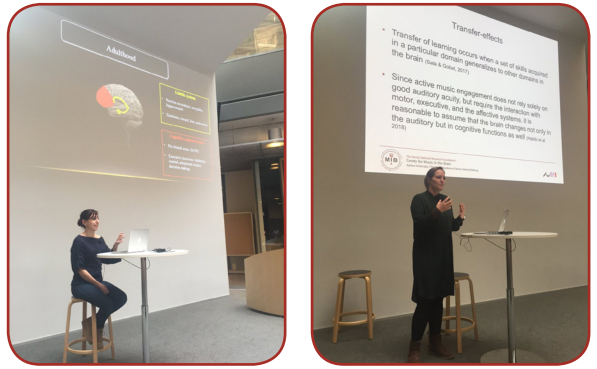
**Manon Grube**
MEG Nord, Jyväskylä, Finland

**Morten Kringelbach**
Luminous Conference, Oxford, UK
Science of Consciousness Conference, Interlaken, Switzerland
10th ISAD conference – International Society of Affective Disorders, London, UK
IAS 'On Laughter' conference, London, UK
School of Sound International Symposium, Barbican, London, UK

**Ole Adrian Heggli**
Rhythm Production and Perception Workshop 17, Traverse City, Michigan, USA

**Pauline Cantou**
Brain Awareness Week 2019, Helsinki, Finland





*MIB PhD students Pauline Cantou and Stine Derdau speaking in Helsinki during the Brain Awareness Week about how the child's brain is influenced by music training.*

**Peter Vuust**
The predictive brain conference, Marseilles, France
The Society for Music Theory Annual Meeting, Ohio, USA
School of Sound International Symposium, Barbican, London, UK
Nordic Song Festival 2019, Trollhättan, Sweden

**Sànder Celma Miralles**
The 2019 Biennial Meeting of the Society for Music Perception and Cognition, New York, USA
2nd Conference of the Timing Research Forum, Queretaro, Mexico

**Stine Derdau Sørensen**
Brain Awareness Week 2019, Helsinki, Finland

## Other talks (selected)

**Boris Kleber**
IVACON – Institute for Vocal Advancement, 2019, Baden, Austria
Hörfest Wiesbaden 2019 - das Labyrinth des Hörens, Frankfurt, Germany
Simposio Internacional Educando la Voz con Ciencia y Tecnología, Barcelona, Spain

**Elvira Brattico**
Gothenburg Science Festival
39th Conference of the Italian Society of Pharmacology, Firenze, Italy
Oxford Music and Science Day, Hedonia Group, University of Oxford, UK
Workshop "Musik og Læring", RAMA, Aarhus, Denmark
Festival delle Arti per l'Inclusione, Bitonto (Bari), Italy
Primary School Secondo Circolo Didattico "Giovanni XXIII", Triggiano (Bari), Italy
Brain Awareness Week, Aarhus University, Denmark
Annual Research Meeting of the Department of Clinical Medicine, Aarhus University, Denmark
University of Jyväskylä, Finland

**Kira Vibe Jespersen**
Dansk Selskab for Søvnmedicins konference, Aarhus, Denmark
Drug Research Academy, University of Copenhagen, Denmark
CareWare Conference, Aarhus, Denmark

**Leonardo Bonetti**
University of Bologna; Italy
McGovern Institute for Brain Research, Massachusetts Institute of Technology (MIT), Boston, USA
The University of Sassary, Italy
Department of Psychiatry, University of Oxford, UK

**Massimo Lumacca**
Interacting Minds Center, AU, Denmark

**Mette Kaasgaard**
Dansk Vokalforening/Danish Vocal Society, Copenhagen, Denmark
Lungeforeningen, Copenhagen, Denmark

**Morten Kringelbach**
Department of Psychiatry, University of Oxford, UK,
BBC/Nova, UK
Pembroke College, Oxford, UK
Danish National Research Foundation, Denmark
Carlsberg meeting, Oxford
Gotheburg University, Gothenburg, Sweden
Folkeuniversitet, Aarhus, Denmark
Oxford Synoptics FHS lecture, UK
Charité, Berlin

**Ole Adrian Heggli**
Interacting Minds Center, AU, Denmark

**Peter Vuust**
Svendborg Musikskole, Denmark
Grenå Gymnasium, Denmark
Ledelseskonference BUPL Storkøbenhavn, Denmark
Enhed for Patientsikkerhed og Patientjura, Region
Hovedstaden, Denmark
Brønderslev Gymnasium, Denmark
Draaby Kirke, Denmark
Hjerneugen, Copenhagen, Denmark
Gl. Holte Kirke, Denmark
Sankt Annæ Gymnasium, Copenhagen, Denmark
Holstebro Gymnasium, Denmark
Parkinsonsforeningen Århus, Denmark
Landskonference for sundhedsplejersker, Svendborg, Denmark
Køge Musikskole, Køge, Denmark
Continence Days, Copenhagen, Denmark
Københavns Voksenuddannelsescenter, Denmark
Gymnasieskolernes musiklærerforenings generalforsamling,
Fredericia, Denmark
Møde m. DMF bestyrelsesmedlemmer, Kerteminde, Denmark
Folkesundshedsdage 2019, Nyborg, Denmark
Aktivitetscenter Fredenshjem, Brørup, Denmark
Kulturværftet; Helsingør, Denmark
Det Medicinske Selskab, Copenhagen, Denmark
Fagligt Selskab for Anæstesi-, Intensiv- og
Opvågningssygeplejersker, Svendborg, Denmark
Depressionsforeningen, Odense, Denmark
Lemvig Gymnasium, Denmark
Musikudvalgsmøde i Roskilde Kommune, Denmark Esbjerg
Sygehus´ intensiv afdeling, Denmark
Vækst med Kultur-konference, Copenhagen, Denmark
Lægeforeningen, Middelfart, Denmark
Psykiatriens forskningsdag, Fredericia, Denmark
Auditory Research Group Zurich, Switzerland

Victor Pando
Neuroscience Day 2019, Aarhus University, Denmark
Annual Research Meeting of the Department of Clinical
Medicine, Aarhus University, Denmark

## Participation in TV, radio and podcasts (selected)

**Alexandre Celma-Miralles**
Spanish Radio Longitud de Onda

**Elvira Brattico**
BBC World Service's CrowdScience podcast
Ladies of Folk podcast

**Kira Vibe Jespersen**
P4 Østjylland
Kulturen på¨P1
P1 Morgen

**Morten Kringelbach**
BBC Science Radio
BBC Sounds Crowdscience
BBC Inside Science Podcast

**Peter Vuust**
P6 Beat
P1 Brinkmanns Briks
Kulturen på P1
Science Stories Podcast
P4
Radio 4
TV2 Go'morgen Danmark
Videnskab.dk's Brainstorm podcast

## Interviews in printed media/web (selected)

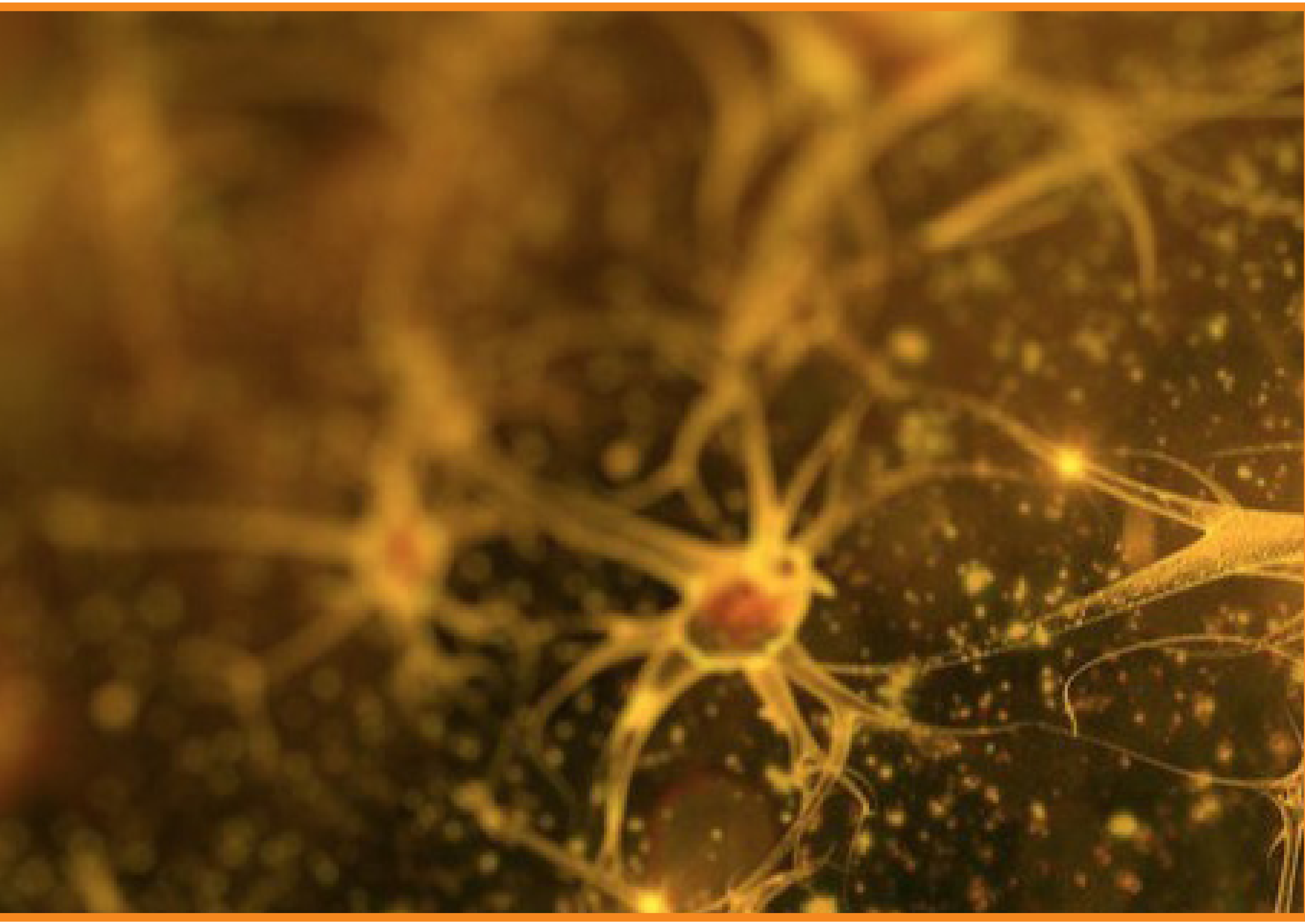
**Angus Stevner**
www.videnskab.dk

**Jan Stupacher**
www.physicsbuzz.physicscentral.com

**Kira Vibe Jespersen**
Chicago Jazz Magazine
Welfaretech

**Morten Kringelbach**
Politiken
La Repubblica
Discover Magazine
The Guardian
www.tv2.dk
Daily Mail
Business Insider
Gizmodo
Chicago Jazz Magazine
Eating Well

**Peter Vuust**
Information
Jyllands-Posten
www.videnskab.dk
BT
Dagbladet Ringkøbing-Skjern
www.dr.dk
Kristeligt Dagblad
Politiken



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