MIB 2022

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

MIB Annual Report 2022

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

Annual Report 2022

Center for Music in the Brain
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WORDS FROM THE DIRECTOR

In 2022 we accelerated the pace from 2021 in terms of publications totaling 70 peer-reviewed papers with 30 of those published in journals with an impact factor of 5 or more. In particular, we take pride in our review in Nature Reviews Neuroscience, which cements our Predictive Coding of Music (PCM) hypothesis in the neuromusic field as the main comprehensive theory of how music is processed by the brain. We wrote this together with Prof. Karl Friston, which is one of the most cited researchers in cognitive neuroscience, and who has contributed greatly to develop the theoretical foundation of MIB, and who was keynote speaker the year before at our international Neuroscience and Music conference in Aarhus. PCM remains the fundamental theoretical framework on which the research of the center is based. This directly influences the paradigms developed by MIB, such as the inverted U-shape of groove, which is now the focus of research at many other groups and institutions worldwide, and underlies groundbreaking new results such as the bodily hierarchy discovered in the work of PhD student Signe Hagner.

Adding to PCM's success, Prof. Morten Kringelbach published a number of theoretical papers in high-ranking journals on dynamical models which are used at MIB to analyse structure–function relationships in brain networks. These and other state-of-the art analysis methods are at the core of the scanning experiments which form the majority of MIB's work. This is true for Leonardo Bonetti's work, which uses magnetoencephalography and brain network analyses to elucidate how musical processing evolves from note to note while the brain is trying to figure out whether it knows the melody or not. Noteworthy is also Associate Prof. Massimo Lumaca's Network Analysis of Human Brain Connectivity in relation to musical interaction in signaling games (also known as Chinese Whispers) a unique paradigm he has developed to show the mechanisms as well as the structural and functional brain processing underlying how music is transmitted from person to person over time, from generation to generation.

With the new research plan for the last four years of the center much of the research is now directed towards such experiments emphasizing music interaction in the light of the predictive coding theory. Pioneering this work is newly appointed Prof. Peter Keller, who is world leading in this field with a career as former leader of a Max Planck group in Leipzig, and former Director of research at the Marcs Institute for Brain Behavior and Development in Sydney, Australia. Bringing experimental expertise on combined neuroimaging, computational modelling of behavior, motion capture and modelling of joint interaction in music, he is key to the future of this line of

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.

research at MIB. This fortifies MIB's ambition of understanding the brain mechanisms underlying music's ability to unite people, which may be the evolutionary function of music, and where we in 2022 through dual EEG experiments performed in collaboration with the IPEM center in Belgium, proposed beta-band bursts as candidate mechanisms underlying joint tapping.

This research taps into the most fundamental questions in the biological study of music which was already theorized about by Charles Darwin in his famous second book "the Descent of Man" from 1871. Why do we have music in the first place? Animals only have parts of the cognitive abilities for making and understanding music. In the beginning of the year, we were very happy to be joined by one of the leading experts in this field, Associate Prof. Andrea Ravignani, a long-term collaborator of MIB, as a 20 % professor. Ravignani's seminal work on the evolutionary and biological bases of rhythm cognition and flexible sound production, and the role they played in the origins of music and speech in our species is a perfect fit for MIB and broadens the scope of our research towards the more fundamental biological questions about music.

At MIB, we put a lot of efforts in translating the insights from basic research into brain processing of music into a more clinical context. This is evidenced by our 2014 White Paper entitled "Music interventions in health care" which was subjected to a major update revision in 2022. This book covers a wide range of interventions from the use of music for pain relief and improving insomnia to music interventions in the rehabilitation of Parkinson's patients or for improving sports performance and will help guide health care personnel as well as policy makers in the use of music in health care. This paper complements our experiments in music and health care, using patient populations suffering from chronic lung disease, Parkinson's, insomnia, and pain.

In June 2022, Nadia Høgholt defended her thesis on changes in brain and behaviour after becoming a parent. Afterwards she has continued her clinical career as a medical doctor at Regionshospital Randers. Later in June, Mette

Kaasgaard defended her thesis about Singing in Pulmonary Rehabilitation of Patients with Chronic Obstructive Pulmonary Disease (COPD), and her paper in European Respiratory Journal received substantial interest. Here, in a cluster randomized trial design, she showed that choir singing may outperform or at least be as good as standard physical training. She is continuing her research in a postdoctoral position at Næstved Sygehus. We also said goodbye to long-term employee Ole Adrian Heggli, who had been at MIB from the beginning of the centre, but who re-located back to Norway in 2022 for family reasons.

In 2022, we welcomed two new PhD students: Ana Teresa Queiroga and Pelle De Deckere, who are now studying musical improvisation and the neurochemistry involved in the experience of musical groove.

Postdoc Leonardo Bonetti was awarded the Lundbeck Talent Prize which is given to five scientists under the age of 30 who have made or contributed to original discoveries leading to the advancement of science, resulting in a better understanding, or improvement, of health and biomedical sciences in the broadest sense.

Again in 2022, MIB received generous external funding of which we are extremely thankful. One of the grants came from Horizon Europe Marie Skłodowska-Curie Actions for the Lullabyte project on music and sleep which will take place at several European universities, including MIB. Assistant Prof. Kira Vibe Jespersen will be the Danish PI. Additionally, Asscociate Prof. Boris Kleber was awarded a Semper Ardens from the Carlsberg Foundation – an Accelerate grant for a project on inducing self-related emotional experience by modulating the speaking voice.

All these developments bode well for the future of MIB. With this annual report, we wish to highlight the scientific progress and key events in 2022. We also wish to highlight MIB's new research plan, by structuring this annual report according to the new themes introduced in the plan: 1) refining and developing Predictive Coding of Music, 2) multimodal theme, 3) music interactions theme, 4) meaning of music theme. While this means underemphasizing some of the core research from the first research plan still taking place at MIB, we hope that this may give the reader a fresh look at our research and help ourselves to further conceptualize these new lines of research at the center.

We finally wish to thank MIB and CFIN scientists and collaborators, The Danish National Research Foundation, Central Denmark Region, 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 Center for Music in the Brain
Peter Vuust

PREDICTIVE CODING OF MUSIC

Peter Vuust

One of the overall goals of MIB's second research plan is to refine and develop the predictive coding of music (PCM) hypothesis. We focus on how brain processes underlying musical meaning can be described in terms of minimizing precision-weighted prediction error in the context of multi-modal processing and interpersonal interaction.

Alongside a number of theoretical papers related to brain organization in general[1-4], a major step towards a more explicit understanding of PCM was our 2022 Nature Reviews Neuroscience (NRN)[5], which views brain processing of music through the lenses of predictive coding and active inference. It summarises the literature on music and the brain of the last couple of decades and points towards the future for the field of neuroscience and music. Below, I will make a résumé of this paper and relate it to some of our findings in 2022.

First, the review shows that music perception, action, emotion and learning all rest on the human brain's fundamental capacity for prediction — as formulated by the PCM model. This model states that when we listen to music with melody, harmony and rhythm, the brain deploys a predictive model — based on prior experience — that guides our perception. In the review, we take the example of a repeated syncopated rhythm, a rhythm wherein one beat feels displaced by a fraction. Here, we experience an error at the unexpected, syncopated note as proposed by the PCM model. This may drive an impulse for action in the form of enforcing the beat by tapping the foot. This active listening process forms the basis of emotional responses to music and musical learning, which updates our underlying predictive model over time. Listening to musical rhythms will thus over time lead to more precise expectations for certain rhythmic continuations (veridical expectations) but also a stronger general sense of the musical pulse, subdivisions of the pulse and accentuation of beats (schematic expectations provided by the meter). In 2022, we published a number of predictive coding related rhythm studies[6,7] and a meta-analysis explicating how musical learning changes predictive coding in musicians' brains[8].

Similarly, for melody and harmony, an unexpected note or chord may cause the listener to switch attention and maybe respond by moving the body or by looking up. Listeners, even without explicit musical training, have implicit knowledge of the statistical regularities of melodies of their own culture[9]. This knowledge is constantly applied to form musical expectations by comparing a given note to the given statistical distribution. Similarly, to the meter, which is a mental predictive model underlying rhythm processing in the brain, the tonality provides a statistical distribution and hence a predictive model, which underlies melody and harmony expectations. In 2022, we published a review of the empirical evidence for predictive coding of pitch formation, detailing basic pitch-related auditory patterns, more complex regularity processing extracted from basic patterns and long-term expectations related to musical syntax[10]. Extending these ideas, postdoc Leonardo Bonetti's used magnetoencephalography, to show how veridical memory for musical melodies changes global but not local processing of notes 3, 4 and 5 in learned compared to unknown melodies, involving more widespread and higher order networks for processing known melodies compared to unknown melodies[11]. This shows the information flow from lower to higher order brain regions and reveals the differential involvement of slow and faster predictive whole brain processing associated with learned versus novel auditory sequences.

The NRN review shows how music can be used as a powerful tool for studying the predictive brain, owing to the way its structure licenses anticipation and how it creates a natural test bed for studying brain plasticity and learning. In that respect, cross-sectional and longitudinal studies of musicians and musical learning have shown how the heightened demands on audio–motor coupling in music performance shapes brain structure and the ability to form music-related predictions with high precision. These studies shed light on how the complex relationship between factors such as musical training, culture, listening history, music-stylistic preferences, context, personality, and genotype significantly influences the precision and ensuing amplitude of the explainable prediction error, as well as how the brain infers a predictive model from the musical context. In 2022, we showed enhanced processing of prediction error in musicians[12] and the involvement of higher-level brain regions such as cingulate cortex, inferior frontal gyrus, and the supplementary motor area for computing early cognitive errors in these participants[13], an association between musical abilities and enhanced cognitive abilities[14] and an effect of mental practising on music memorization[15].

Going forward, the review considers more complex musical phenomena, which integrate melody, harmony and rhythm and exemplify the crucial role of precision-weighted prediction error. Here, the experience of musical groove (or the "Pleasurable Urge to Move to Music (PLUMM)" as it will now be termed) is known to follow an inverted U-shape as rhythms become increasingly syncopated. This U-shape, which was discovered by Witek and colleagues at MIB in 2014, can be modelled as the product between the metrical predictability (precision) and the stimulus deviations from the meter. This is now a key concept in the burgeoning field of groove perception, and has led to a wealth of cross-disciplinary papers, from a lot of research groups around the world, and an internationally organized workshop of which the first was held in January 2023 (https://sites.google.com/view/groove-workshop/home).

In 2022, we produced an optimal short paradigm for obtaining the inverted U[16] discussed the influence of social relations on groove[17] and showed that higher empathy is associated with stronger social bonding when moving together with music[7]. Adding an interesting layer to our understanding of the inverted U of groove, Tomas Matthews showed a stronger relationship between perceived synchrony and groove ratings than measured synchrony and syncopation and found this effect to be strongest for medium complexity rhythms.

The NRN review continues by describing how musical emotion, pleasure and musical expertise can be understood in the light of PCM and the last part is dedicated to a discussion about how music and the PCM model can be extended to encompass the role of communication in dyadic interactions and hierarchical organization in groups. Musical interactions rely heavily on prediction. While playing we continuously make predictions about the sensory consequences of our own actions that we generally use to attenuate predicted sensations and amplify those caused by others. This selective attention and attenuation is found throughout the animal kingdom but the more advanced ability for shared predictive processing — needed for the full experience of music — has only so far been found in humans. Joint action may thus be best understood within a predictive coding framework, where the emphasis is on establishing a shared narrative and mutual predictability. Recent studies have leveraged this perspective looking at musical interactions in different paradigms e.g., when two individuals tap together. In 2022, in collaboration with researchers at IPEM in Belgium, we found a putative mechanism (beta-band bursts) that on one hand facilitates our own tapping while at the same time enables us to track and predict the tapping of others, even if their tapping is out of sync with our own[18].

One of the basic assumptions of predictive coding and hence the PCM model, is that the brain makes inference about the causes of its input from the outside world based on its priors. These priors can relate to innate capabilities of the human brain, such as the limitations of the auditory system or can be acquired over time through implicit and explicit learning, but in many cases it is hard to distinguish between nature and nurture. A particularly interesting case is the surprising musical phenomenon, which was discovered in a series of ground-breaking studies from Signe Hagner Maarup's PhD of which the first was published in 2022[19]. As it turns out, there is a bodily hierarchy (1) mouth – 2) left hand – 3) right hand – 4) right foot – 5) left foot), in which it is much more difficult to keep the beat in a higher orders limb, and a rhythm in a lower ordered limb than vice versa, coupled with activity in higher order brain areas. Future studies may shed light on whether this is an innate property of the human brain, learned or a combination of predisposition and learning.

The NRN review received quite substantial international attention, and several refinements and alternatives to PCM have already been put forward and discussed by other international research groups[20,21]. In August, Savage and colleagues published a comment in NRN in which they proposed to extend the PCM framework to encompass the perception of music — and music listeners —from cultures beyond the Western tradition[22]. As Savage and Fujii rightly point out, there are music genres outside of the Western tradition that do not include harmony — being often based on musical modes other than the major and minor modes — and music pieces that are non-isochronous or/and unmetered. Hence, the traditional predictive models we usually consider to be underlying music perception in Western music—tonality and meter—may not suffice. We will much look forward to seeing and evaluating future evidence from empirical neuroscientific investigations within the exciting field of cross-cultural neuroscience of music[23].

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PREDICTIVE CODING OF MUSIC

Tomas Matthews

Prediction based learning drives the pleasurable urge to move to music

The predictive coding of music (PCM) has proven to be a highly influential framework, leading to key insights into the processes underlying the perception, production, and enjoyment of music. As outlined in a recent review[1], PCM emphasizes the role of internal models of musical features which are continuously fine-tuned to maximize their congruence with the musical input. In the context of musical rhythm, the internal model reflects the meter, which is the pattern of strongly and weakly accented beats that structures how a rhythm is perceived and understood. These accent strengths can be operationalized in terms of probabilities such that a stronger accent reflects a higher probability (i.e., a stronger prediction) that a note will occur at that position. In real music, some rhythms follow the meter exactly while others deviate, leading to discrepancies between probabilistic predictions and input (i.e., prediction errors), and thus uncertainty about the current metrical model. One such discrepancy is syncopation, which is when a note is shifted to a weaker metrical position, leaving a gap on the stronger metrical position where one strongly expects a note. The strength of a syncopation and the resulting prediction error is determined by the metrical position at which it occurs. Conveniently, the number and strength of syncopations can be quantified for a given rhythm, giving us a measure of prediction error and the resulting metrical uncertainty. With this relatively simple yet ecologically valid framing, musical rhythm provides a crucial testbed for investigating PMC, as well as the role of predictive processes in shaping the perception and affective response to music more generally.

The PCM framework has had a particularly large impact on our understanding of the pleasurable urge to move to music (PLUMM). In a seminal study carried out at MIB[2], participants listened to rhythms of varying degrees of syncopation and rated their experienced pleasure and urge to move. Plotting these ratings as a function of syncopation results in an inverted U-shaped pattern, with moderately syncopated rhythms receiving the highest ratings, and both non-syncopated and highly syncopated rhythms receiving relatively low ratings. This fits well with PCM, which suggests that the inverted U occurs because moderately syncopated rhythms diverge from the meter in a way that maximizes the number of strong prediction errors. This leads to a strong drive to reduce the metrical uncertainty. This drive is manifested as an urge to move along to the rhythm as synchronized movements add proprioceptive input that fill in the gaps created by syncopations, increasing the match between meter and input.

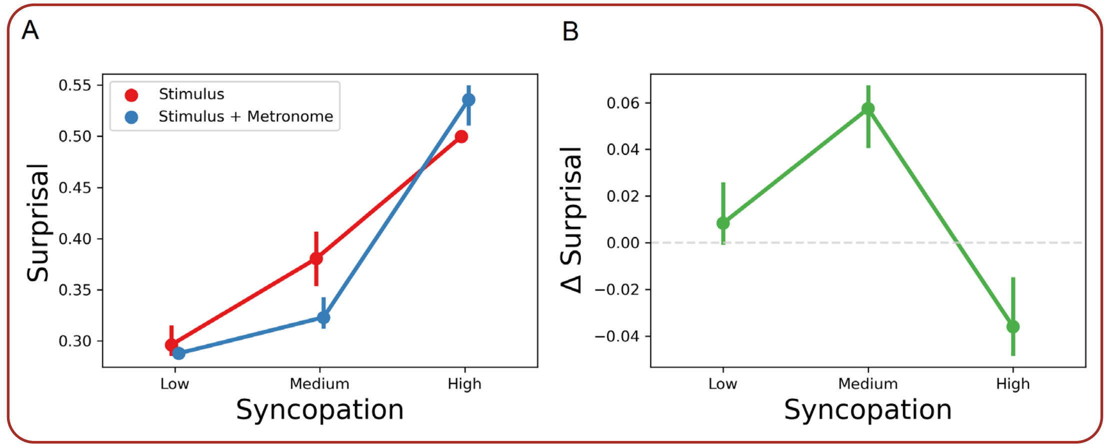

*Figure 1. Simulation results supporting the role of prediction error minimization in PLUMM. Simulations were carried out with a computational model that uses a Bayesian process to infer which of two underlying probabilistic meters (4/4, uniform) is active while listening. Prediction error was operationalized as Bayesian surprisal. Prediction error minimization was modeled as the difference in Bayesian surprisal (Δ Surprisal) between rhythms with and without a metronome, which served as a proxy for synchronized movement. **A)** Surprisal increases as syncopation increases with and without a metronome. **B)** Δ Surprisal is maximal for moderately syncopated rhythms as they maximize the surprisal that can be reduced by adding a metronome.*

The inverted U has now been replicated in several studies with different stimuli, with the predictive coding of music remaining the dominant framework. However, several open questions remain, including those surrounding the exact psychological and neural mechanisms linking prediction error and uncertainty reduction to PLUMM. In two recent review[3] and perspective papers[4], we proposed refinements to PCM to emphasize the role of the intrinsic motivation to learn. This was inspired by the learning progress hypothesis[5], which suggests that organisms are intrinsically motivated to seek out stimuli and activities that maximize learning. Here, learning is operationalized as model improvement via prediction error and uncertainty minimization.

Therefore, stimuli that maximally afford learning are those that are just beyond the predictive capacities afforded by one's current internal model such that the model is challenged, but can still be leveraged to meet these challenges, and thus to learn.

Accordingly, only rhythms that provide the potential for learning via prediction error and uncertainty minimization will lead to PLUMM. In this context, moderately syncopated rhythms not only maximize strong prediction errors, they maximize *reducible* prediction errors. Conversely, rhythms that are too far beyond the predictive capacities afforded by the current model or that are too predictable, thus offering no opportunity to learn, will be considered aversive or boring. Therefore, it is not a specific level of rhythmic complexity or novelty that maximizes PLUMM, but rather the potential for learning given the current state of one's internal model. This is supported by ongoing work using computational simulations showing that strong prediction errors (operationalized as Bayesian surprisal) alone do not lead to the inverted U over syncopation (Fig. 1A). Instead, it is the reduction in prediction errors via movement (operationalized as a metronome) that lead to an inverted U pattern over syncopation (Fig. 1B). The emphasis on the intrinsic motivation to learn also strengthens the explanation for the pleasurable component of PLUMM. As learning is intrinsically rewarding, rhythms that afford learning via model improvement will elicit greater pleasure than those that do not.

As suggested above, this refinement to PMC leads to the prediction that there is not an optimal level of syncopation that will maximize PLUMM for ever person or in every context. Instead, the shape of a listener's inverted U will depend on their current metrical model, which results from a combination of interindividual and contextual factors, including listening history, musical training, neurological health, and degree of attention. This is supported by recent and ongoing work showing that musical training and Parkinson's disease lead to enhancement and dampening of the inverted U, respectively. Musicians have stronger and more flexible metrical models[6] and show higher urge to move ratings for moderately syncopated rhythms compared to non-musicians[7] (Fig. 2A). Parkinson's disease involves dopamine dysregulation due to cell loss in subcortical brain networks that are implicated in the predictive processes thought to underlie PLUMM. Parkinson's patients show a relatively flat pattern of ratings compared to healthy controls, possibly due to weaker metrical models and/or reduced ability to leverage their models to reduce prediction errors[8] (Fig. 2B). Ongoing computational work corroborates the influence of metrical model strength in determining the shape of the inverted U. This, along with the intrinsic motivation to learn, provide a mechanistic account of how interindividual differences in predictive capacity can influence PLUMM.

Incorporating the intrinsic motivation to learn into PMC suggests a link with curiosity, which can be defined as the intrinsic motivation for information gain. Since information gain can be framed in terms of increasing the match between model and input, we predict a link between curiosity and PLUMM. This is currently being investigated by Assistant Prof. Jan Stupacher. Preliminary results suggest that participants are more curious about how moderately syncopated rhythms will unfold over time compared to non-syncopated or highly syncopated rhythms. Since moderately syncopated rhythms afford the greatest opportunity for model improvement and thus information gain, participants are more intrinsically motivated to keep listening to accomplish this improvement. Further, this effect is stronger for participants with greater motivation for information gain, thus supporting a link between PLUMM and both state and trait curiosity.

Finally, this refinement to PMC clarifies the potential role of dopamine in PLUMM and music reward processing more generally. Long-standing models suggest that dopamine encodes reward prediction errors, that is, when a stimulus is better or worse than expected. However, for more abstract rewards such as music, it is not clear

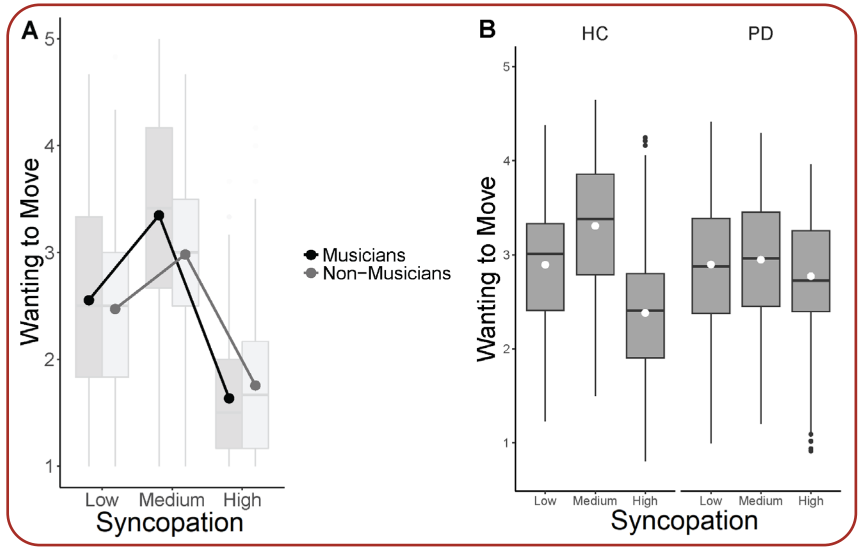

Figure 2. Effects of musical training and Parkinson's disease on the inverted U. ***A)*** *Musicians show higher ratings for moderately syncopated rhythms compared to non-musicians.* ***B)*** *Parkinson's patients (PD) show a flatter pattern of ratings compared to age-matched healthy controls (HC) who show the inverted U.*

what can be considered better or worse. Instead, in the current context, dopamine may signal reducible, and thus salient prediction errors, in turn activating noradrenergic systems to mobilize attentional and memory resources to maximally exploit the learning opportunity. This aligns with recent work making a causal link between dopamine, music liking, and memory[9]. Ongoing work by MIB PhD student Pelle De Deckere will use a similar intervention approach to investigate the causal role of dopamine in PLUMM, while future work will investigate the role of noradrenaline using pupillometry.

In sum, by incorporating the intrinsic motivation for learning, we have refined and developed PMC to clarify the psychological and neural mechanism underlying PLUMM and affective responses to music more generally. This has led to clearly defined, testable predictions, many of which are undergoing current investigation at MIB. Going forward, this ongoing feedback loop between theory and data will help us better understand the processes that imbue music with the power to move us, both physically and emotionally.

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MULTIMODAL THEME

Boris Kleber

In the second funding period, Center for Music in the Brain (MIB) is embarking on a new journey to explore the multifaceted nature of musical experiences by delving into the realm of multimodality. Building upon the groundbreaking achievements and insights from the first grant period, MIB aims to broaden our understanding of the intricate relationship between music and the human brain, transcending the boundaries of unimodal perception. The study of multimodality holds great significance and potential impact in the broader context of perception and sensorimotor integration research, enabling us to gain a more comprehensive and nuanced understanding of how the brain seamlessly integrates and processes complex sensory information from multiple sources. This approach ultimately provides crucial insights into the underlying neural mechanisms that shape our rich and diverse experiences of the world around us. Consequently, MIB will expand the predictive coding of music (PCM) model to account for multimodal prediction. In this report, we will discuss key studies and projects that highlight the importance of multimodal research in understanding music and the brain.

Aligning with MIB's new multimodal theme, a recent study[1] emphasizes the importance of examining the complex interplay between various modalities in understanding emotion evaluation and the brain's processing of music and other sensory information. The team of MIB researchers investigated the distinction between likability and pleasantness in early stages of multimodal emotion evaluation. Using behavioral measures, they explored how participants evaluated likability and pleasantness while experiencing audiovisual stimuli. The results revealed that these two dimensions are processed differently, with likability involving cognitive appraisal and attention, while pleasantness is associated with a more automatic, sensory-driven process. These findings contribute to the development of a more comprehensive understanding of how multimodal processing shapes our experiences and perception of music and emotions.

Furthermore, in a recent project conducted at MIB and the Department of Electrical and Computer Engineering at Aarhus University, researchers investigated neural processes associated with different perceptual experiences of ambiguous polyrhythms. The study employed electroencephalography (EEG) to examine metrical interpretation in the brain by comparing neural amplitudes at beat-related frequencies, 1.5 Hz (two-beat) and 2.25 Hz (three-beat). Participants listened to 2:3 polyrhythms, which were either presented alone or preceded by a priming period with drums and speech to reinforce the two-beat or the three-beat. Subsequently, a tapping period allowed participants to indicate the beat perceived in each trial. The motor tapping as a proxy for auditory perception provided a more naturalistic multimodal setting for investigating the neural correlates of beat perception. The results revealed a significant interaction between frequency and tapping type, with larger EEG amplitudes at 1.5 Hz for trials where participants perceived the two-beat and larger amplitudes at 2.25 Hz for trials where participants perceived the three-beat. This provides direct evidence of the endogenous nature of beat perception and highlights the potential of using single-trial frequency tagging analysis to account for individual differences in beat perception.

In another study, titled ”Feel the Beat and Improve the Groove: Multimodal Rhythm Perception in Cochlear Implant Users”, MIB PhD student Alberte B. Seeberg and collaborators will investigate rhythm and groove perception in individuals using cochlear implants (CI). Specifically, this study examines the potential benefits of concurrent rhythm-specific electro-haptic stimulation (EHS). While CIs effectively restore hearing abilities for those with severe sensorineural hearing loss, they often struggle to convey musical nuances, impacting users' quality of life. This translational neuroscience project delves into the largely unexplored realm of complex musical rhythm perception in CI users and the possible enhancement of rhythm perception through rhythm-specific EHS. In the study, participants listen to drumbeats of varying rhythmic complexity and instrumentation under three conditions: audio only, EHS only, and a combination of audio and EHS. The researchers assess participants' ”wanting to move” and ”experienced pleasure” ratings, their ability to tap along to the rhythm, and the neural correlates of rhythm and groove perception using EEG frequency-tagging. The study hypothesizes that lower rhythmic complexity will improve CI users' tapping accuracy, EHS will enhance groove perception and tapping accuracy, and the amplitude of the EEG signal will align with anticipated behavioral results.

Collaborations play a crucial role in MIB's success by offering access to diverse expertise and resources, particularly in interdisciplinary research. Associate Prof. Boris Kleber collaborated with the Center for Neuroplasticity and Pain at Aalborg University, leading to two groundbreaking studies on the effects of musical training on sensory perception and pain modulation, directed by Assistant Prof. Anna Maria Zamorano and Prof. Graven Nielsen.

In the first study, published in the European Journal of Pain[2], researchers found that musicians had enhanced nociceptive cortical responses (i.e., nociceptive N200 event-related potentials - ERPs), which were linked to higher activation of sensorimotor network regions. Faster reaction times to non-nociceptive stimuli correlated with higher N140 ERPs amplitudes, which were linked to increased activation of brain regions within the salience network. Interestingly, the activation pattern for the nociceptive stimulation was reversed in musicians compared to non-musicians,

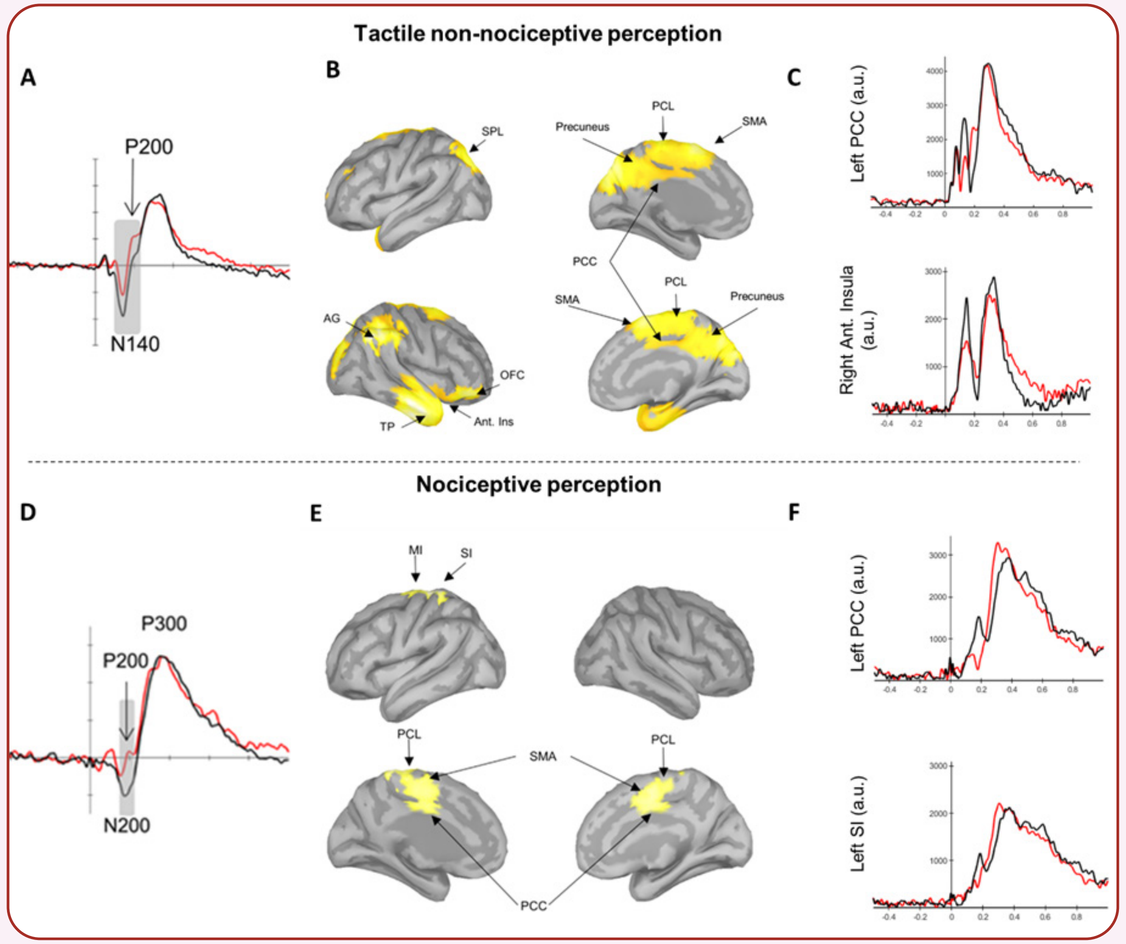
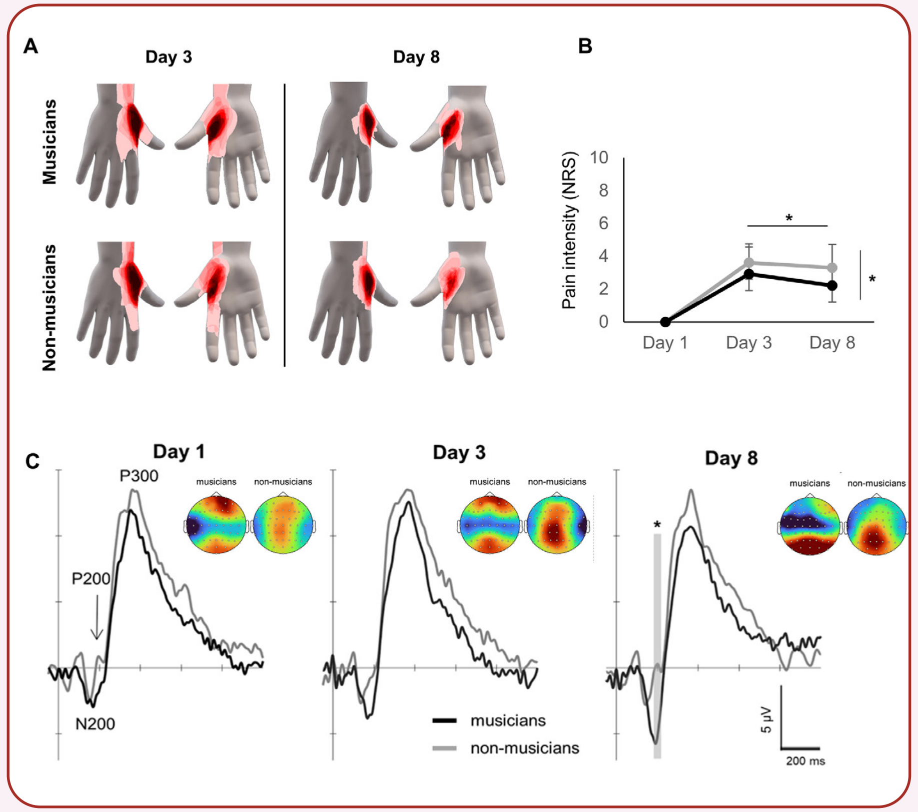


Figure 1. Evoked responses (A and D), sources (B and E), and time courses of the neural sources in (C and F) of non-nociceptive and nociceptive stimuli, respectively. Musicians are represented in black lines and non-musicians in red lines. Adapted from Zamorano et al., 2023a.

indicating that the mechanisms by which extensive sensorimotor training promotes use-dependent plasticity in multisensory neural structures may also shape pain processing in healthy individuals. The second study, published in the Journal of Pain[3], induced prolonged experimental muscle pain in the hands of musicians and non-musicians, measuring their pain sensitivity and cortical responses before and during pain development. The findings revealed that musicians developed secondary hyperalgesia and enhanced nociceptive cortical responses, but reported feeling less pain

Figure 2. Effects of prolonged experimental muscle pain in the hands of musicians and non-musicians. A) pain distribution, B) pain intensity, and C) evoked responses to electrical nociceptive stimulation. Musicians are represented in black lines and non-musicians in grey lines. Adapted from Zamorano et al., 2023b.



during the experiment, implying better pain control. These results demonstrate that use-dependent plasticity associated with multisensory musical training can facilitate central changes in bottom-up perception and top-down cognitive control of pain, providing novel insights into repetitive sensorimotor practice's role in pain modulation.

In conclusion, MIB's research efforts in the second funding period have made significant strides in the realm of multimodality. These studies are not only deepening our understanding of the complex relationship between music, perception, and the brain but also highlight the potential impact of multimodal research in various aspects of human experience, such as emotion, rhythm perception, and pain modulation. As MIB continues to explore the intricate connections between music and the human brain, our findings will ultimately enrich our understanding of how we experience and interact with the world around us through music.

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MULTIMODAL THEME

Signe Hagner Mårup

Behavioral and neural evidence for a hierarchical organization of rhythm and beat in body and brain

One of the core components of music is the rhythm and the steady underlying beat that supports it. When listening to music, people tend to reinforce their perception of a consistent beat by tapping their foot in synchrony with the music. This type of body movement has been shown to assist in extracting the beat of a rhythmic sequence[1], and recent research has linked the ability of beat extraction to the brain's natural desire to make predictions based on the input it receives[2]. When playing music, musicians often coordinate different body parts to keep a beat and perform a rhythmic sequence. An example of this is when vocalists sing while playing the guitar or piano. Here, the voice often performs intricate and varied rhythms while the instrument maintains the underlying beat or repeats a rhythmic pattern. When doing so, each body part takes on either a conductive role (the rhythm) or a supportive role (the beat). Interestingly, to perform interlimb coordination with an opposite distribution of the roles, i.e., vocalize a steady beat while clapping a complex rhythm, can seem almost impossible. The preferred distribution of roles between effectors raises questions about whether it follows a specific pattern in interlimb coordination, how challenging it is to reverse these roles, and how the brain processes such a task. Understanding the mechanisms underlying interlimb coordination in music can have implications for learning and rehabilitation in various fields, including music education and neurorehabilitation.

To investigate the relationship between different body effectors during the simultaneous performance of rhythm and beat and the neural correlates of these actions, three studies were conducted:

In Study 1[3], a total of 60 participants, consisting of non-musicians, amateur musicians, and professional musicians, were asked to tap three short rhythmic patterns of varying difficulty along with their underlying beat using different combinations of voice, hands, and feet. Each trial was assessed by two musically trained raters, and the results indicated a bodily hierarchy between effectors, consisting of 1) left foot, 2) right foot, 3) left hand, 4) right hand and 5) voice (Fig. 1). This meant that task execution was more accurate when the rhythm was performed using an effector occupying a higher level in the hierarchy compared to the effector responsible for keeping the beat. For example, combining the right hand and voice resulted in higher error rates if the right hand performed the rhythm while the voice kept the beat than vice versa. However, when combining the right hand and left foot, the error rates were lower when the right hand performed the rhythm, while the left foot tapped the beat than vice versa. Therefore, the hierarchical organization implies that when engaging in simultaneous performance of rhythm and beat, a certain effector did not always prefer to take on a certain role; performance accuracy depended entirely on the relative position in the hierarchy of the effector with which it was paired. Our observations suggest that the preferred direction of effector combinations is not solely determined by differences in dexterity. Rather, it appears to be influenced by the perceptual roles of rhythm and beat. Specifically, we found that the preferred direction was evident not only when the rhythmic pattern was faster than the beat (i.e., with shorter inter-onset intervals), but also when it consisted of fewer notes with longer inter-onset intervals than the beat. These findings suggest that bodily hierarchy is shaped by multiple factors beyond dexterity, and that the interplay between rhythmic and perceptual cues can play a crucial role in determining motor responses.

In Study 2[4], we used functional magnetic resonance imaging (fMRI) to examine the neural processing related to this bodily hierarchy by scanning 41 musicians performing a similar task. The effector combinations in question were limited to voice and right hand (V+RH), right hand and left hand (RH+LH), and left hand and right foot (LH+RF). Using a full-factorial general linear model, we assessed the neural activations associated with the differences between going with and against the bodily hierarchy. The behavioral

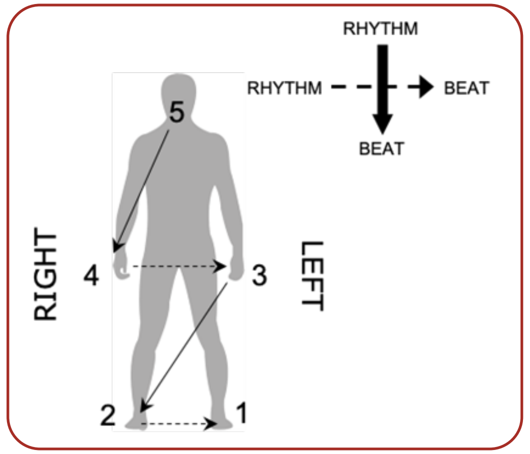

Figure 1. In the bodily hierarchy, the voice (V) is positioned at the top (5), followed by the right (4) and left (3) hand (RH and LH), and the right (2) and left (1) foot (RF and LF) (adapted from Mårup et al., 2022). The difference between the scores of conditions with and against the bodily hierarchy is larger in the vertical dimension (non-homologous effectors) than the horizontal (left-right) dimension.

tapping results replicated Study 1, with higher error rates observed when participants performed against the bodily hierarchy than with the bodily hierarchy. Whereas these behavioral differences between hierarchical directions were similar across effector combinations, the difference in neural activity between hierarchical directions was most pronounced in the V+RH effector combination compared to both the RH+LH and LH+RF. Interestingly, the additional neural activity associated with going against the bodily hierarchy were not limited to motor regions but also involved regions associated with perceptual and cognitive processes. Specifically, going against the hierarchy in the V+RH combination activated areas such as the supplementary motor area, cerebellum, and insula, which are related to top-down sensorimotor control and bottom-up feedback processing, while going with the hierarchy activated areas related to the default-mode network and emotional processing. Additionally, a similar pattern was revealed in the RH+LH and LH+RF combinations at a less strict significant threshold.

Finally, in Study 3 we conducted a seed-to-voxel-based analysis on the dataset of Study 2 and identified significantly stronger functional connectivity between auditory cortices and other brain regions when going against the hierarchy compared to going with it across all conditions. These regions included frontal areas, supramarginal gyrus, inferior lateral occipital cortex, and left lingual gyrus, which indicates that stronger auditory-motor coupling is used when going against the hierarchy. As with the GLM-analysis of the dataset, we found larger differences in functional connectivity between the hierarchical directions in the V+RH conditions than in the other effector combinations.

Taken together, the bodily hierarchy identified and investigated in our studies suggests that the coordination of rhythm and beat is not only shaped by differences in dexterity but also by the perceptual roles of rhythm and beat. This is supported by the neural findings showing that to go against this hierarchy, neural activation increases in areas that govern higher level motor control and that are involved in complex rhythm perception and production. Specifically, compared to performing with the bodily hierarchy, performing against it engages brain regions associated with prediction error processing and sensory feedback integration, coupled with an increased functional connectivity in areas related to auditory and sensorimotor coupling. On the other hand, the opposite contrast revealed increased activation in areas associated with automatized processes, i.e., the default mode network. The extent to which this bodily hierarchy is innate or learned remains an intriguing and open question. Additionally, it would be necessary to conduct future studies to distinguish the impact of task difficulty from effects related to beat extraction, rhythmic complexity, and their interaction with the direction of performance using different effector combinations.

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Prediction errors of inharmonic sounds: the effects of spectral entropy

In the summer of 2022, visiting researcher Krzysztof Basiński and MIB researchers Alexandre Celma-Miralles, David R. Quiroga-Martínez and Peter Vuust designed and ran an oddball-roving paradigm using EEG to study how the brain makes predictions of an important feature of pitch: harmonicity. This auditory process occurs early on and it is fundamental for object identification and categorization, from human voices to environmental sounds. Sounds like animal vocalizations or musical instruments are harmonic: complex tones that comprise a fundamental frequency (f0) and integer multiples of it called harmonics (e.g. 2f, 3f…). In contrast, in inharmonic sounds, the harmonics are not integer multiples (Fig. 1a). To elicit pre-attentive mismatch negativities (MMN, i.e. prediction errors), participants watched a muted video while harmonic and inharmonic sounds were presented separatedly in 3 blocks: (b1) harmonic pitch deviants in a harmonic context, (b2) inharmonic pitch deviants in an inharmonic context in which the spectral content of each sound was constant, and (b3) inharmonic pitch deviants in an inharmonic context in which the spectral content of each sound was jittered (see Fig. 1.b). The preliminary analysis of the mismatch negativities revealed that all deviants elicited prediction errors, but that the MMN in b3 were significantly weaker than the others (Fig. 1c). Importantly, the MMN of inharmonic sounds in b2 were similar to the MMN of harmonic sounds in b1, though their peak occurred slightly later. Different P300 amplitudes were found in each block, which may reflect differences in the update of the predictive model depending on the contextual spectral entropy. In short, our brain seems to construct a reliable pitch percept with inharmonic sounds when their spectral content is consistently jittered.

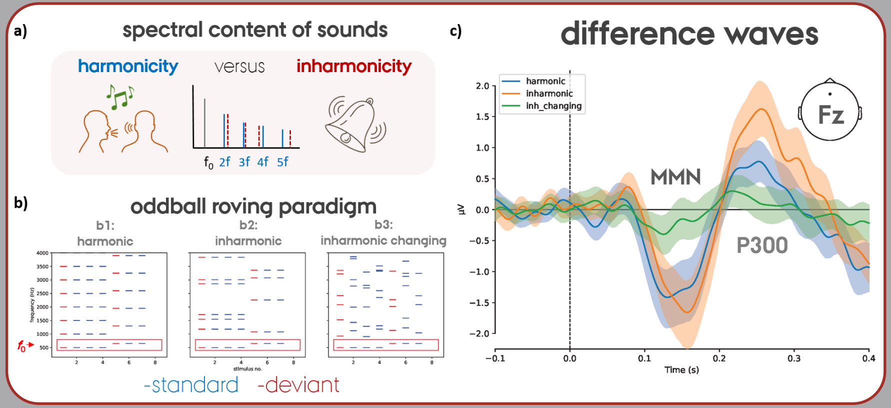

Figure 1. *Methods and preliminary results of the EEG study on pitch harmonicity. a) Example of the spectral content of harmonic (blue) and inharmonic (red) sounds. b) Representation of the stimuli in the three blocks following a roving oddball paradigm, in which a deviant sound changing in pitch (f0, red) becomes a standard (blue) after some repetitions. c) Difference waves at the Fz electrode calculated by subtracting the ERPs of the averaged standard tones from the ERPs of averaged deviant tones. MMN and P300 time windows to find the peak amplitudes are approximately depicted.*

MUSIC INTERACTIONS

Peter Keller

Human musicality likely evolved to fulfill social functions related to interpersonal bonding and nonverbal communication. Fully understanding the musical brain therefore necessitates investigating how humans interact in musical contexts. MIB research on musical interaction follows three branches: (1) Interpersonal synchronization, (2) Social entrainment, and (3) Improvisation and Communication.

Interpersonal synchronization

Our research on interpersonal synchronization targets the psychological processes and brain mechanisms that allow individuals to coordinate with precision in the millisecond range while maintaining the flexibility required for varying expressive intentions. As a theoretical foundation, the predictive coding framework that formerly guided research at the individual level has been extended to account for musical interactions[1].

On this account, interacting individuals use predictive models of their own actions, others' actions, and joint action outcomes to control their performance in a manner that aims to minimize discrepancies between predicted and actual events. Such minimization relies on sensory-motor and cognitive 'ensemble skills' that allow co-performers to anticipate, adapt, and attend to each other's actions while monitoring the overall, integrated sound[2, 3]. These skills can be influenced by knowledge about the music and familiarity with co-performers' playing styles, as well as by goals, strategies, and social–psychological factors including personality[4]. Complementary computational modelling approaches shed light on the interplay of ensemble skills[5-7] and novel experimental paradigms enable modulatory effects of higher-level cognitive and social processes to be interrogated.

This approach has proven fruitful in studying the balancing of self-other priorities during ensemble performance. Coordination in musical groups requires the merging of psychological representations of 'self' and 'other' while maintaining a degree of self-other distinction[8]. It has been proposed that internal models that represent self, other, and joint action outcomes regulate this balancing of self-other integration and segregation[9]. An fMRI study in collaboration with the Max Planck Institute for Empirical Aesthetics addressed this hypothesis by varying co-performer knowledge and goals while pianists performed in duos, with individuals taking turns to play in the scanner[10]. Co-performer knowledge was manipulated by varying whether pianists were familiar with each other's parts, and temporal goals were manipulated by varying the congruence of the tempi at which they were instructed to play. Results revealed a subregion of the cerebellum that was sensitive to these manipulations, possibly reflecting the reconfiguration of internal models of self and other due to varying task demands (Fig. 1A).

Related 'hyperscanning' research used electroencephalography (EEG) to record brain activity simultaneously from multiple individuals. Previous studies have shown that EEG spectral power at the performance tempo is correlated with interpersonal keystroke synchrony in piano duos[11], and that alpha oscillations (~10 Hz) play a role in establishing leader-follower relations by balancing the focus of attention internally on self-related information versus externally on others[3,12,13]. Oscillations in higher frequency bands have been implicated in diverse sensory-motor and cognitive processes, but their involvement in musical interactions has been less well documented.

A study in collaboration with IPEM in Belgium addressed this gap by recording dual-EEG as paired participants performed a joint finger-tapping task while visual and auditory coupling were varied[14]. When participants were coupled, recurrent periods of synchronized dyadic behavior were accompanied by modulations in the power of beta band oscillations (~20 Hz). These beta-band bursts provide a potential neurophysiological mechanism for co-regulating timing by enabling mutual adaptation and anticipation. Going a step further, a dual-EEG study with piano duos[15] suggested that oscillations in the gamma band (~30-40 Hz) may come into play when endogenously

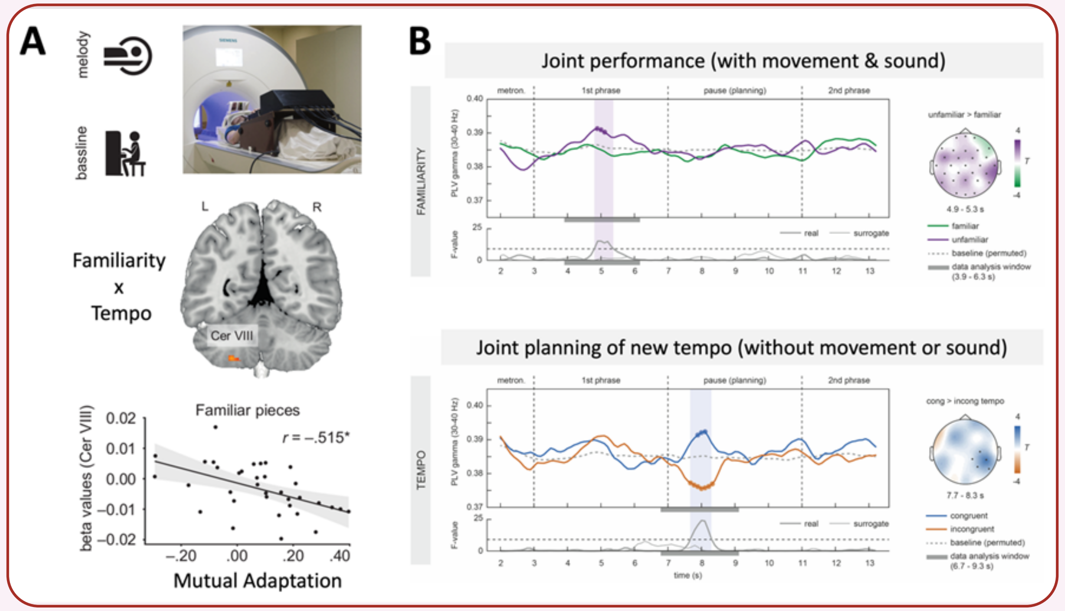

*Figure 1. **(A)** An fMRI study of piano duos varied co-performer knowledge and goals as one member of each duo was scanned (10). When pianists were familiar with each other's parts but were playing at slightly incongruent tempi (induced by devious instructions), increased activation in a subregion of the cerebellum was observed, with stronger activation associated with reductions in the degree of mutual adaption to each other's timing. This cerebellar subregion may control the interaction of internal models of self and other. **(B)** Implementing the same task in a dual-EEG paradigm (15) revealed higher interbrain synchrony in the gamma band (30-40 Hz) when pianists were unfamiliar with each other's parts, and they hence had to attend more closely to the joint outcome. During a silent pause between musical phrases, gamma-band interbrain synchrony was higher when co-performers were planning to play at the same tempo, and the degree of this neural synchrony predicted how well their subsequent performance tempi matched. Since the familiarity effect occurred despite similar sensorimotor information and the goal congruence effect occurred when not actually playing, these results highlight the role of endogenous cognitive processes in interpersonal synchrony.*

driven cognitive functions related to action planning and joint attention are required (Fig1B).

Social entrainment

The synchronization of body movements and sounds during musical interaction facilitates the alignment of thoughts and feelings, and this social entrainment promotes interpersonal bonding and cooperative behavior, even uniting us in times of crisis[4,16,17]. However, the mechanisms linking interpersonal synchrony and prosociality remain opaque.

A hypothesis under investigation at MIB is that concept of groove—the "Pleasurable Urge to Move to Music (PLUMM)"—may be informative regarding this link[18]. A relevant fMRI study conducted with the D'Or Institute for Research and Education in Brazil found close correspondence between the perception of differing degrees of synchrony and ratings of wanting to move and feelings pleasure while listening to samba ensemble rhythms[19]. Consistent with previous research[20], increases in these subjective correlates of groove were accompanied by increased activation of the motor system. Furthermore, listeners who reported strong emotional responses to samba music in daily life had especially strong activations in the subgenual cingulate, a brain region associated with pro-social feelings.

Another research stream has identified links between specific aspects of personality and social entrainment. The empathic capacity to understand others' thoughts and feelings has emerged as a powerful explanatory construct mediating these relations[21]. For example, a study by Jan Stupacher found that higher empathy was associated with stronger social bonding in video presentations of a virtual self and other walking with accompanying music, especially when the two avatars' movements were temporally aligned[22].

From a broader perspective, musical interaction can be seen as a microcosm of social interaction to the extent that it draws on psychological processes that support collective behaviour more generally in everyday life[4,16]. Studying such natural interaction has been facilitated by technological developments in computer vision that allow research to be conducted outside the lab. Research with the Italian Institute of Technology demonstrated the feasibility of this approach by using automatic pose estimation algorithms to analyze ensemble coordination in conventional videos[23] (Fig 2). A new frontier for applying related techniques is dance, as in a project by PhD student Olivia Foster Vander Elst that seeks to identify factors influencing leader-follower dynamics between salsa partners.

Improvisation and Communication

Musical interaction is often spontaneously improvised, which highlights the capacity for creativity in human communication. Related MIB research elucidates brain mechanisms behind the invention of new musical material and the transfer of musical information across individuals via cultural transmission.

An fMRI study by PhD student Marie Dahlstrøm investigated the neural bases of musical creativity

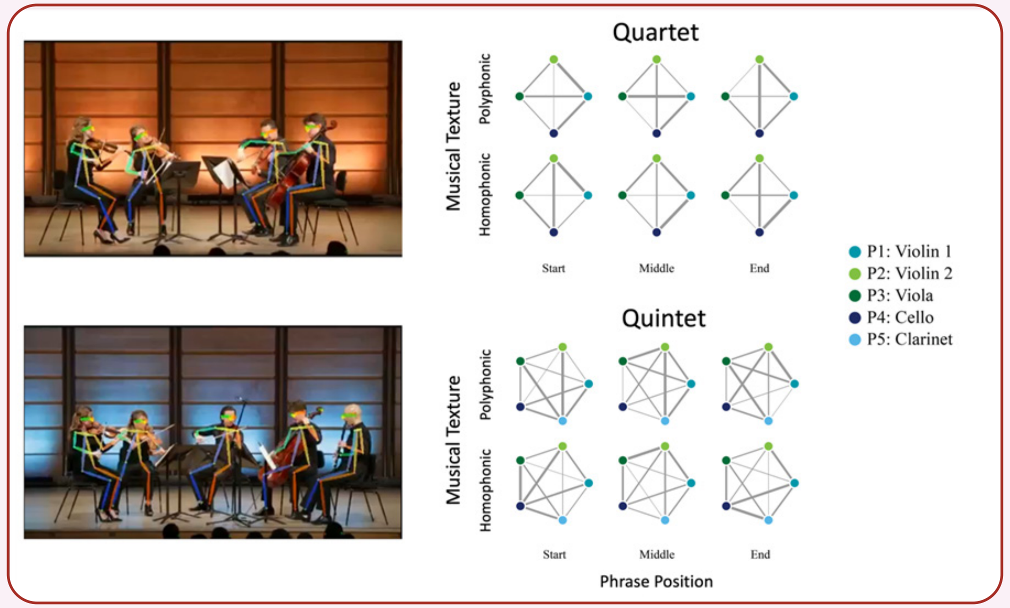

Figure 2. *Automatic pose estimation techniques were applied to video recordings of concert performances by a professional instrumental ensemble playing two musical pieces: a string quartet (top) and a quintet for strings with added clarinet (bottom) (23). Analysis of phase-relations between co-performers' head motion revealed that interpersonal coupling was stronger (thicker lines in network plots) for polyphonic textures (with no fixed leader) than homophonic textures (clear melodic leader), and this difference was greater in early portions of phrases than endings (where coordination demands are highest). This study provides proof-of-principle that automatic pose estimation is sufficiently sensitive to detect subtle modulations of interpersonal coupling in standard video recordings recorded under naturalistic performance conditions.*

by comparing brain activations before and after a course of singing improvisation training. New PhD student Ana Teresa Queiroga is examining the distinction between neural processes associated with improvising versus imitating melodies generated by another individual. A PhD project by Atilla Vrasdonk from the RITMO Centre in Oslo crosses the boundary between music and dance by analyzing improvised interactions between members of flamenco duos comprising a dancer and guitarist.

Although music's impact on society formation and cultural evolution unfolds over long timescales, these large-scale processes are fundamentally constrained by fine-grained biological predispositions. Massimo Lumaca has combined neuroimaging with an iterated learning paradigm to examine how the organization of brain networks constrains the transmission of musical information[24], with extensions of this work addressing the bias for simple ratios musical rhythm production. Taking a cross-cultural perspective, PhD student Mathias Klarlund is exploring the effects of cultural background, specifically the dimensions of collectivistic and individualistic values, on musical coordination and communication in a study spanning Denmark and China.

Overall, the MIB program of research on musical interaction broadly contributes to furthering our understanding of how human musicality buttresses society and enriches culture. Emerging findings on the brain bases of relevant sensory-motor mechanisms and social-cognitive factors have implications in domains ranging from health to the arts.

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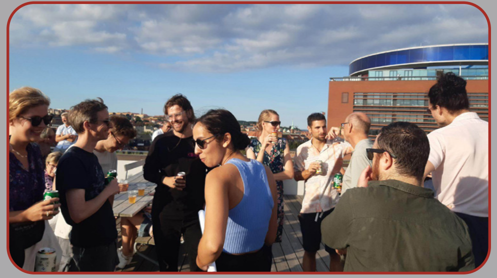
MAKE TIME TO THINK

The annual MIB retreat was this year a one day event at the Scandic Aarhus City Hotel. The theme was ”How to write good papers” and included talks and group work. The day ended with a treasure hunt around Aarhus finishing at the rooftop of The Royal Academy of Aarhus with a wonderful view to the Rainbow of Aros.



BOAT TRIP

A windy afternoon in September a boatful of brave MIBers cruised around the Aarhus bay area for a couple of hours under expert guidance from captains Møller & Petersen.

CONFERENCE IN JAPAN

Finally able to travel again after the pandemic, three MIB researchers went all the way to Japan for The 9th Mismatch Negativity conference in Fukushima.

MUSIC INTERACTIONS

Jan Stupacher

Empathy increases social bonding in interpersonal interactions that feature music

All around the world, music is predominantly performed *in* groups and *for* groups. Music induces bodily movements and unites people in social gatherings. In many of these gatherings, music provides a shared temporal structure that enables the coordination of body movements between individuals, for example in dance. This shared structure allows people to jointly express their attitudes and emotions, as eloquently described by the sociologist Émile Durkheim:

"*Probably because a collective emotion cannot be expressed collectively without some order that permits harmony and unison of movement… gestures and cries tend to fall into rhythm and regularity, and from there into songs and dances*"[1]

The social nature of music makes it apparent that certain personality traits, such as empathy, are important for understanding and expressing affect in shared sounds and movements. Empathy is a complex construct that involves comprehending and sharing the perspectives and emotions of others. It is an important aspect of social functioning and is associated with prosocial behavior[2] and a reduced tendency towards social prejudice[3].

While some studies have indicated that individuals with higher empathy are more synchronized in joint music-making tasks[4], other studies have suggested that the relationship between empathy and interpersonal movement synchronization in musical contexts is less straightforward. For example, one study found that dancing pairs in which both partners had high trait empathy were perceived as less similar and less interactive than dancing pairs in which one partner had high and the other low trait empathy[5]. These conflicting results suggest that the impact of empathy on social bonding when moving to music remains a controversial topic.

We therefore examined whether people with higher empathy feel a stronger sense of interpersonal closeness when engaging in movement interactions with music. We utilized our own social entrainment video paradigm[6], in which participants rated their perceived interpersonal closeness towards a virtual partner who moved synchronously or asynchronously with music or a metronome (see Fig. 1A-E and Fig. 2A-D). Trait empathy was measured with the B-IRI, a standardized self-report measure of disposition to empathic responsiveness[7]. In Study 1 with 146 participants, the musical stimulus consisted of an excerpt from a jazz trio piece. Study 2, with 162 participants, included three musical excerpts from the genres pop, funk, and jazz to test the generalizability of the results.

In general, our findings indicate that synchronous movements between virtual self and other lead to stronger social bonding. This beneficial impact of

coordinated movement was observed when virtual self and other were engaging with either music or a metronome and aligns with prior research that has demonstrated a positive association between interpersonal movement synchronization and prosocial behavior[8,9].

Our results also suggest that music has a unique influence on movement in social contexts. In both studies, videos featuring virtual self and other moving to music received higher scores for social closeness than those with metronomes. Moreover, both studies demonstrated that when participants were engaging with music, a greater level of empathy was associated with increased social bonding between virtual self and other.

Additionally, our findings revealed two distinct interactions with empathy. In Study 1, participants with higher empathy experienced higher interpersonal closeness in virtual movement interactions that featured music, whereas participants with lower empathy experienced higher interpersonal closeness in virtual movement interactions that featured a metronome (Fig.1F). In Study 2, higher empathy was associated with strong increases of social bonding when interacting with a synchronized virtual other, but only weak increases of social bonding when interacting with an asynchronized virtual other (Fig. 2E). To put it differently, when it comes to social bonding in interpersonal movement

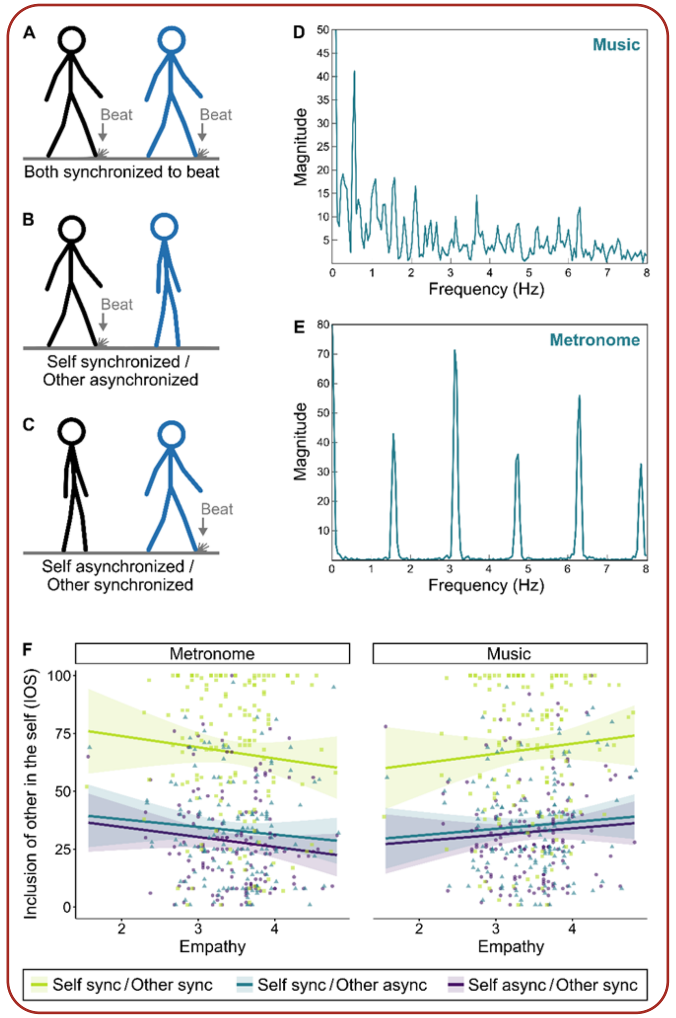


Figure 1. Methods and results of Study 1. A – C: In the video paradigm, participants were instructed to imagine themselves as the black figure and the blue figure as an unfamiliar person. The videos featured three levels of movement synchronization: A) Both figures synchronized with the beat of the music / the metronome, B) Self synchronized and Other asynchronized with the beat, and C) Self asynchronized and Other synchronized with the beat. D and E: Frequency spectra of the note-onset interval series for the music ("Elevation of Love" by Esbjörn Svensson Trio) and metronome stimuli detected by 'mironsets' in the MIR toolbox[10] for MATLAB (MathWorks, Natick, MA). The beat of the audio stimuli and the synchronized step frequency of the visual stimuli was 94 bpm / 638 ms / 1.57 Hz. The asynchronized step frequency was 80 bpm / 750 ms / 1.33 Hz. F: Individual data points and linear predictions of interpersonal closeness as measured by IOS in relation to participants' trait empathy. Shaded areas represent 95% confidence intervals.

interactions, individuals with low empathy may exhibit less distinction between synchronized and asynchronized others than individuals with high empathy.

One possible reason why the empathy × music interaction was significant in Study 1 but not in

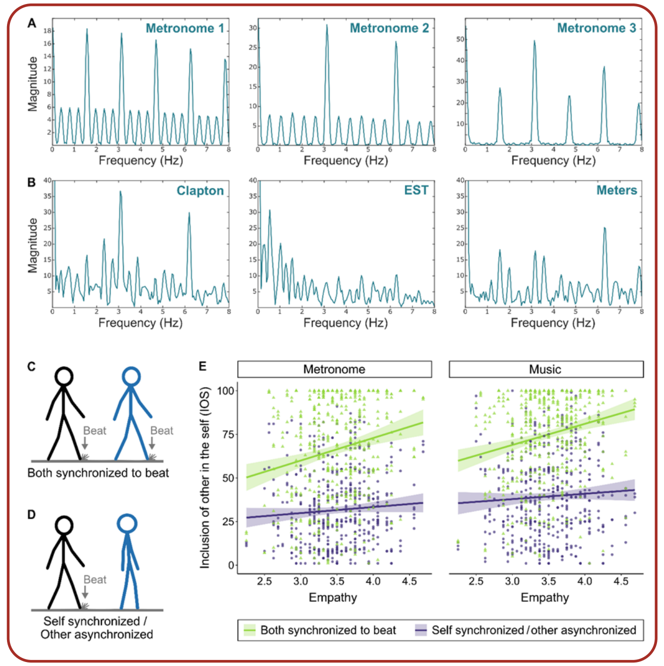


*Figure 2. Methods and results of Study 2. **A** and **B**: Frequency spectra of the note-onset interval series of the three metronome stimuli and the three music stimuli ("My Father's Eyes" by Eric Clapton, "Elevation of Love" by Esbjörn Svensson Trio, and "Thinking" by the Meters). **C** and **D**: The two different movement synchronization levels of the video paradigm. As in Study 1, participants were instructed to imagine themselves as the black figure and the blue figure as an unfamiliar person. In contrast to Study 1, asynchronized figures started to walk with a step frequency of 78 bpm / 769 ms with a 233 ms delayed first step, sped up to 86 bpm / 698 ms, and slowed down to the start step frequency again. E: Individual data points and linear predictions of interpersonal closeness as measured by IOS in relation to participants' trait empathy. Shaded areas represent 95% confidence intervals.*

Study 2 is due to the selection of musical excerpts. Study 1 only used the rhythmically driving but melancholic piece, "Elevation of Love" by the Esbjörn Svensson Trio. In contrast, Study 2 included a wider variety of musical excerpts, including the groovy "Thinking" by The Meters and the standard pop/rock song "My Father's Eyes" by Eric Clapton, in addition to "Elevation of Love." Therefore, the empathy × music interaction observed in Study 1 may reflect the influence of empathy on social bonding with melancholic music specifically. However, for music in general and for more uplifting music, this effect may be weakened. Huron and Vuoskoski suggest that people who enjoy sad music more than others may have a particular pattern of trait empathy that allows them to experience pleasure through compassion and empathy[11]. In our study, higher empathy was linked to greater enjoyment of the "Elevation of Love" excerpt, suggesting that participants with higher empathy may have felt more compassion through the music, which in turn could lead to stronger feelings of social closeness.

The insights gained from empirical studies, such as the current ones, can be applied to educational programs and clinical interventions that use joint musical activities to enhance empathy and strengthen social bonding. One example are individuals with autism spectrum disorder (ASD), who typically exhibit deficits in empathy. In a study that involved a beat-based communication task, neurotypical participants showed increased cognitive empathy towards a synchronous partner compared to an asynchronous partner, whereas participants with ASD did not[12]. This aligns with our finding that participants with low empathy rated their social closeness to synchronized and asynchronized virtual others similarly, whereas those with high empathy rated their social closeness to the synchronized virtual other significantly higher than the asynchronized virtual other.

A promising avenue for future research is to investigate the physiological and psychological benefits of social musical activities that involve synchronized movements for individuals with low trait empathy. As we could show in our study, the type of music used in these social musical activities has to be carefully considered: Clear beats may be better suited to promote sensorimotor and social synchronization in individuals with low empathy.

In both aforementioned studies, individuals with higher empathy enjoyed the musical pieces more. These findings support previous research indicating that trait empathy is linked to increased activity in the prefrontal and reward regions of the brain while listening to music[13] and a greater level of enjoyment while dancing[14]. Higher empathy might therefore not only increase social bonding when moving to music with others, but also promote the pleasurable urge to move to music per se. We have tested this hypothesis in a pilot study with 30 participants ranging from low to high trait empathy as measured with the B-IRI7. Participants with higher trait empathy reported a stronger pleasurable urge to move to drum rhythms with different levels of rhythmic complexity than participants with lower trait empathy. In the coming year, we will investigate these effects in a larger sample and with behavioral measures, such as synchronization accuracy and velocity when tapping in time with the beat of the rhythms.

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MEANING OF MUSIC

Elvira Brattico & Morten Kringelbach

Making sense of sounds and the human fascination for dissonance

The way music acquires sense is highly individual. Differently from language, in music meaning is less defined, and this semantic instability makes music more a form of art than a cognitive function. Indeed, the same song can mean close to nothing for one listener or can have the deepest meaning to another one, when it is related to the inner self or to the dearest memories of a lost beloved one or suddenly transports oneself in time and space to the childhood home. Such variability of meaning or semantic instability in music is closely dependent on predictive processing. Our past research has established how each person shapes their own predictive models for music, such as tonal centers or meters, according to individual experiences, listening biography, memories, preferences and personality. Even when individuals interact musically, such as when dancing or playing together in an ensemble, such interaction strictly depends on the compatibility of each individual's predictive models.

The research of this first year of the second MIB period has tackled how musical meaning emerges in presence of highly complex sounds and how this process is affected by musical or even non-music-specific priors that are continuously learned and updated. Learning here is conceptualized as the process of creating and changing these priors within and across generations, ultimately leading to the rules and conventions that make up a musical culture. From this viewpoint, the atonal classical contemporary musical style (CCM), which is highly unpredictable due to the aesthetic decisions adopted by composers favoring the absence of a tonal center and metric periodicity and overall sounding unpleasant or dissonant to the inexpert ear but receiving enthusiastic appraisal by a consistent group of aficionados, well suits the study of listening expertise in the predictive processing framework and aesthetic specialization[1,2].

Importantly, the process of learning and updating priors for minimizing errors of our brain in the continuous struggle to understand the external world does not end in the isolated listener. It expands across people and generations. We at MIB have designed an original way to objectively test this process without waiting the century-long amount of time that would be needed to observe the evolution of a musical culture. We do this in the laboratory, during a single experimental session in which a dyad of participants interact with each other through a signaling game (transmission chain), learn from each other, transmit sets of totally unfamiliar musical codes (short sequences of Bohlen-Pierce scale tones associated with images), ultimately creating a common musical "culture". Via learning those initially novel and meaningless codes acquire sense, and such sense emerges and is shared in a laboratory-recreated cultural evolution process. Our research confirms and expands the cultural evolution theory by demonstrating that individual neuroanatomical constraints, such as the intra-hemispheric connectivity and the anatomical left-right asymmetry of the primary auditory cortex, are what guides the emergence of population-based patterns and conventions in a musical culture[3].

These studies capturing vertical, phylogenetic mechanisms of prediction in a small and short-duration scale require the adoption of artificial sounds and fixed images. To increase their validity, we need to understand all about the predictive processes in relation to the highly complex sounds constituting real music in a horizontal, ontogenetic dimension.

Making sense of the dissonance outside us

Sound combinations that are pleasant or consonant are often sounds that are most frequently chosen by composers, although the rough, dissonant sound combinations which by their dynamic nature create tension and ask for a resolution, are typically used by composers to induce emotions, in varying degrees over historical epochs. In a wide multidisciplinary account of research on dissonance/consonance perception[4], we summarize robust evidence linking auditory roughness with distress/danger and hence, with defensive behaviour and neural responses indicating aversion. Think of the strong and immediate affective brain reaction to infant cries characterized by distinctive acoustic roughness and inharmonicity, first in the brainstem (in the periacqueductal grey) after 50 ms[5] and later in the orbitofrontal cortex at around 130 ms from sound onset[6]. This neural activity is followed by widespread differences around 800-1000 ms in the extensive networks involved in parenting[7]. The attractive nature of consonance, in turn, remains more elusive, although this is likely to also involve networks centered on the orbitofrontal cortex. Along with dissonance/consonance, another feature that is robustly associated with expression and induction of discrete emotions by music is the musical mode, that is, the selection of scale pitches governed by distinct conventions of music behavior and organization[8].

Our MEG/EEG studies focused on the neural mechanisms underlying our capacity to learn and predict complex sounds, including those that are unpleasant and dissonant, lacking a clear tonal center and even a metric[9,10], (for a review, see[11]). In these studies, we introduced stimulation paradigms and analysis approaches (exploiting knowledge from computational fields such as Music Information Retrieval and information theory models of melodic expectancy, namely IDyOM) that allowed us to identify prediction-error responses from highly uncertain contexts including CMM during a realistic music listening situation[12].

Previous findings with music following tonal conventions showed that the auditory cortex predicts in a less effective way an error in the pitch of a melody when such error occurs in melodies characterized by high uncertainty, suggesting that the salience of unexpected events and the related neural responses are modulated by the certainty and precision of the predictions. However, when using CCM that is completely atonal, all learned predictions are nullified since tones tend to occur with equal probability. This is visible in the behaviour with less confident error detection responses and less memorization for musical patterns embedded in atonal vs. tonal music, but not in the brain responses which do not distinguish between acoustic errors embedded in tonal or atonal context. These findings were obtained with non-musicians, whose brains might simply focus on the superficial features of the melody sounds. For musicians, the absence of a clear predictive model of the sounds in atonal CCM style might by itself be a source of pleasure: We propose that the exploratory behaviour and the human need to reduce uncertainty in a novel and complex environment by continuously seeking knowledge might be particularly acute in CCM experts[1]. Initial empirical support for this hypothesis came from an interview study with eight CCM and eight romantic-classical music experts. Textual content analysis revealed that CCM experts typically expect surprises in the music; hence they adopt an exploratory attitude and enjoy the perceptual insight and the path to this insight, making their aesthetic experience qualitative distinct from that of the non-CCM expert[2].

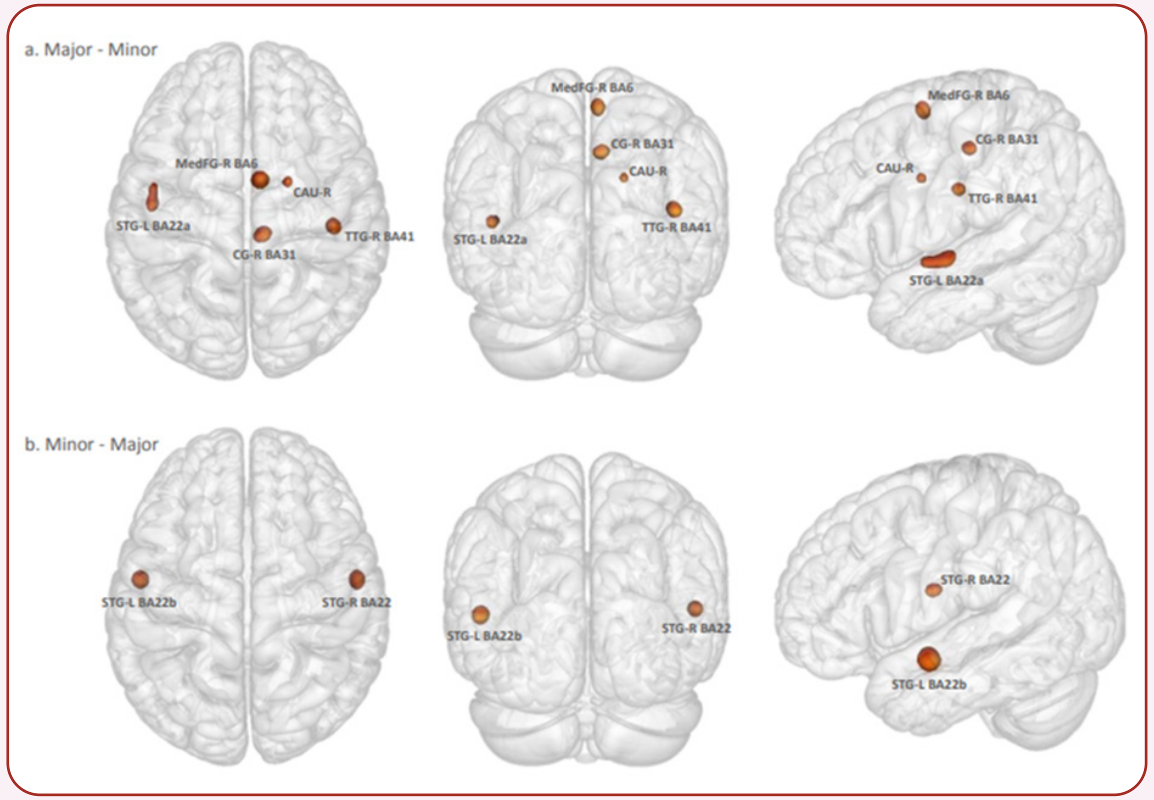

Figure 1. *Results of the coordinate-based meta-analysis of the neuroimaging studies comparing listening to music in major vs minor mode. STG-L BA22, left superior temporal gyrus; MedFG-R BA6, right medial frontal gyrus; TTG-R BA41, right transverse temporal gyrus; CG-R BA31, right cingulate gyrus, CAU-R, right caudate.*

Looking at how predictions for atonal vs. tonal music are formed in the brain, functional connectivity analyses in the source space of the MEG/EEG experiments highlight the emergence of cortico-hippocampal interactions during the formation of memories for more predictable, tonal sequences as opposed to less predictable and dissonant atonal sequences[10]. These results contribute to the understanding of the brain mechanisms underlying auditory encoding and prediction in uncertain contexts.

The dissonance and consonance within us

MIB findings indicate that our brain, while thirsty for novelty and prone for exploration, cannot rely on the connections needed to make sense of complex, dissonant sounds, especially when those sounds are not sufficiently familiar. The chaotic succession of neural events in presence of dissonance could be seen as a metaphor of the altered neural communication underlying a neurological or psychiatric disease. In a systematic review we evidenced how a disruption in both top-down connectivity processes (associated with memory intrusion and difficulty of inhibition) and bottom-up processes (associated with the sensory areas involved in perception) might even produce sensory hallucinations in neurodegenerative patients[13]. In turn, psychotropic drugs such as LSD and psilocybin can result in aberrant sensory experiences, by causing turbulence in hierarchically organized neural communication, with LSD directly impacting on primary visual-sensory areas and psilocybin with stronger effect on high-level brain networks[14,15]. In healthy individuals, neural communication between brain networks in fast frequency bands also seems to drive the individual differences in fluid intelligence[16]. Interestingly, our iScience paper demonstrated that brain network behaviour is related to functional mutations of BDNF and COMT genes[17].

Music appears to help restore such aberrant neural communication[18], hence restating balance within us[19]. In an fMRI study[20] with 17 preadolescent children (10-11 y.o.), it was pinpointed how the motivational drive to listen to and play music relies on time-varying neural connections within the medial orbitofrontal and ventromedial prefrontal cortices, brain regions previously associated with reward processing in other contexts[21]. Such motivational value of music indeed emerges just before adolescence hits the ground, and seems to depend on individual empathy traits, as put forward in a behavioural study with 48 preadolescents (9-11 y.o.)[22]. Our ongoing longitudinal studies investigate how the rewarding power of music combined with embodied efforts of learning to play an instrument in the orchestra[23] can shape children's brains towards making them more intelligent, self-disciplined, confident, and, in a word, flourishing adults[24,25].

Overall, music can drive meaning-making in the brain. Through a number of experimental paradigms exploring the consonance and dissonance found in music (and in our brain networks), we are starting to make important progress in understanding the evolution in spatiotemporal brain connectivity driving meaning-making not just in music but possibly even more generally.

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PRIZES 2022

Leonardo Bonetti receives the Lundbeck Foundation Talent Prize

Photo: Alessandro Orefice Campogrande

Postdoc Leonardo Bonetti, who holds master's degrees in both classical guitar and psychology as well as a PhD degree in health science, uses music to examine the brain's cognitive processes – e.g. attention, memory and emotions.

The Talent Prize is awarded to five scientists under the age of 30 who have made or contributed to original discoveries leading to the advancement of science, resulting in a better understanding, or improvement, of health and biomedical sciences in the broadest sense.

Alexandre Celma-Miralles wins the Dolby Barcelona Scientific Paper Award

The "Dolby Barcelona Scientific Paper Award 2022" was awarded to postdoc Alexandre Celma-Miralles for his research article "Detecting surface changes in a familiar tune: exploring pitch, tempo and timbre".

Celma-Miralles wrote the paper in collaboration with colleagues from the Language and Comparative Cognition Group of the Center for Brain and Cognition at Universidad Pompeu Fabra, and it was published in the journal Animal Cognition.

Alberte Seeberg awarded prize for Best Research Pitch

The very first Eriksholm Summer School, a four-day event with the overall theme 'Translational research' was organized and hosted by Eriksholm to facilitate networking among the PhD students and postdocs tied to Demant.

MIB PhD student Alberte Seeberg won with her group first prize for their "Translational Research Pitch".

MEANING OF MUSIC

Gemma Fernández Rubio & Leonardo Bonetti

Insights from the fast-scale brain dynamics of auditory recognition

Music is built upon a diverse combination of pitches and rhythms that can evoke powerful emotional responses and convey meaning. For this reason, it provides an excellent opportunity to investigate the brain underpinnings of complex cognitive processes. A unique strategy to understand how the brain makes meaning of music consists of studying the neural mechanisms underlying musical memory. The human brain has complex neural mechanisms which allow for encoding (i.e., memorizing) and recognizing sensory stimuli. The hippocampus plays a crucial role in memory encoding[1], while a network of interconnected regions in the medial temporal lobe supports subsequent recognition memory processes[2].

In the past, studies on musical memory have benefitted from the high spatial resolution of functional magnetic resonance imaging and highlighted the involvement of motor, cognitive, memory and limbic areas during processing and recognition of music[3,4]. More recently, researchers from MIB combined high temporal resolution magnetoencephalography (MEG) with magnetic resonance imaging (MRI) and showed that a widespread cortico-subcortical brain network is involved in recognizing musical sequences[5,6]. However, when it comes to making music meaningful, the complexity of the music can significantly impact neural and behavioral mechanisms.

According to the predictive coding of music theory, music processing is bound by hierarchical Bayesian rules, wherein the brain compares auditory information with its internal predictive model in an attempt to generate musical expectations and reduce prediction errors[7]. As music complexity increases, predictability decreases, leading to more prediction errors. This is the case of atonal music, a musical system that is characterized by hierarchical instability and the absence of a tonal center[8]. Such features can make atonal music rather unpredictable and difficult to process. Conversely, tonal music, which is most popular in Western countries, has a high predictive value and is associated with fewer prediction errors[8].

In 2022, we published a study describing an auditory memory paradigm with both tonal and atonal music[9]. Seveny-one participants performed an old/new auditory recognition task while their brain activity was recorded using MEG. First, participants actively listened to and memorized two musical pieces: the right-hand part of Johann Sebastian Bach's Prelude No. 1 in C Major, BWV 846 and an atonal version of the prelude. Both pieces were identical in terms of their main musical features except for their tonality/atonality: the tonal piece was in the key of C major, whereas the atonal piece did not have a musical key. After memorizing the pieces, participants were presented with 40 musical sequences that were part of the original pieces (i.e., memorized musical sequences) or with 40 new musical sequences (i.e., novel musical sequences) and were asked to classify the sequences as 'memorized' or 'novel'.

The results showed clear differences in recognition of tonal and atonal sequences. Overall, participants' reaction time and accuracy were significantly higher when identifying memorized tonal sequences than memorized atonal sequences. Furthermore, using source reconstruction analysis, we found that their neural activity was stronger in memory processing areas in the right hemisphere when correctly classifying tonal sequences as 'memorized' and in auditory processing regions in the left hemisphere when correctly identifying memorized atonal sequences.

Predictive mechanisms rely on familiarity, memory functioning, and listening strategies to create musical expectations[7]. In our case, the diminished predictability of the atonal piece led to a higher number of errors and slower responses (Fig. 1). We hypothesize that a mismatch between auditory information and the internal predictive model of the brain occurred when listening to the atonal sequences, which increased the prediction errors. Conversely, the predictability and familiarity associated with tonal music was responsible for the high accuracy and faster reaction times (Fig. 1). However, since we did not measure prediction

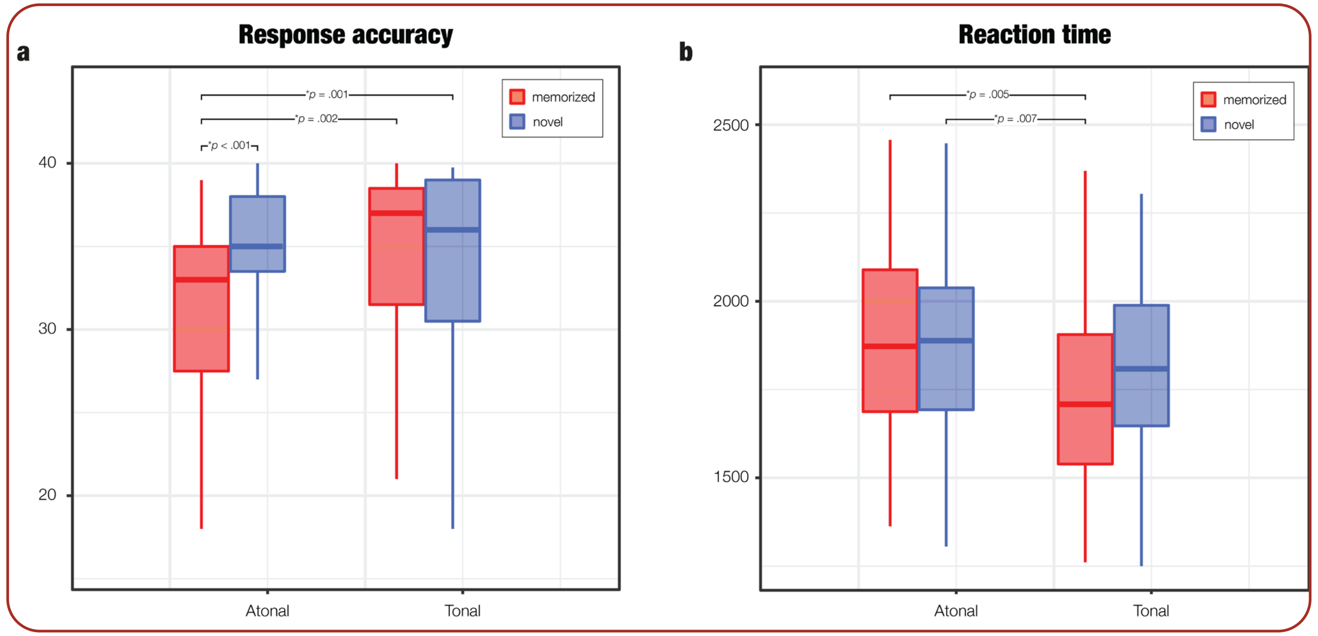

Figure 1. *Behavioral results. Boxplots show the median and interquartile (IQR, 25–75%) range of the distributions of tonal and atonal memorized and novel sequences in response accuracy (a) and reaction time (b; in milliseconds).*

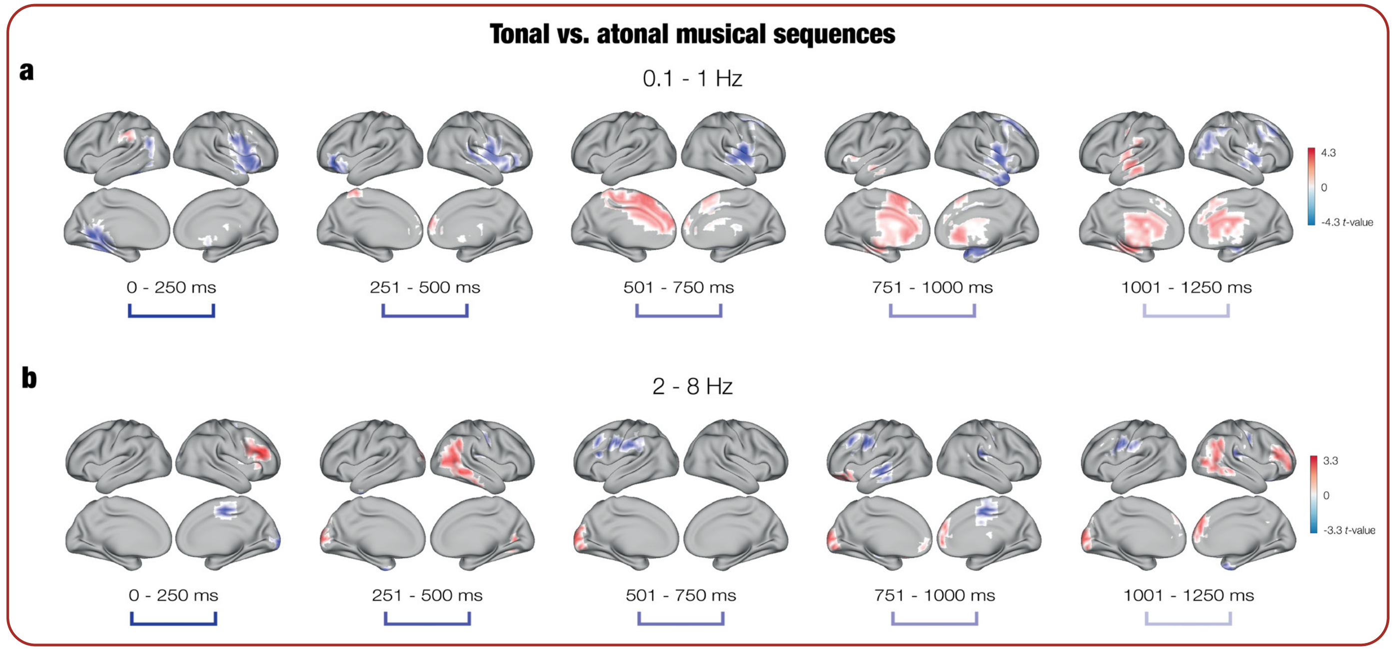

Figure 2. *Brain activity results.* ***a.*** *In the 0.1 – 1 Hz frequency band, the contrast between memorized tonal and memorized atonal sequences resulted in stronger brain activity in left memory processing areas in the last three notes of the tonal sequences (in red) and in right auditory processing areas throughout the atonal sequences (in blue).* ***b.*** *In the 2 – 8 Hz frequency band, the contrast between memorized tonal and memorized atonal sequences resulted in scattered and weak brain activity. Overall, the brain activity was stronger for memorized tonal sequences (in red) in the frontal gyrus (notes 1, 4, and 5), temporal gyrus (notes 2 and 3), and occipital gyrus (notes 2 – 5), and for memorized atonal sequences (in blue) in the supplementary motor area (note 1), frontal gyrus (notes 3 and 4), middle temporal gyrus (note 4) and postcentral gyrus (note 5).*

errors, future studies are invited to replicate and expand these results.

With respect to previous research on the neural underpinnings of memory recognition, the brain activity observed in this study confirmed the involvement of a widespread brain network including auditory regions such as the superior temporal gyrus and Heschl's gyrus, and memory recognition regions such as the cingulate gyrus and medial temporal lobe structures [5,6]. Furthermore, the brain activity was clearly distributed in two frequency bands, with a slow band (0.1 – 1 Hz) linked to the recognition of the whole auditory sequences (Fig. 2a) and a faster band (2 – 8 Hz) associated with the processing of the individual notes (Fig. 2b). Previous work by researchers from the Center for Music in the Brain pointed to the involvement of these two frequency bands and guided the analyses conducted in this study[5,6].

Regarding the differences in brain activity underlying recognition of tonal and atonal sequences, we observed distinct neural pathways when identifying the two types of auditory stimuli. On the one hand, recognition of tonal sequences primarily recruited the cingulate gyrus and hippocampus in the right hemisphere at the 0.1 – 1 Hz frequency band. On the other hand, recognition of atonal sequences was mainly associated with a sustained, slow activity in the left auditory cortex, superior temporal gyrus, and Heschl's gyrus in the same frequency band (Fig. 2a). Finally, the contrast between recognition of memorized tonal and memorized atonal sequences at the 2 – 8 Hz band highlights the relevance of this frequency range for processing individual notes, rather than recognizing the sequences as a whole[5,6]. Thus, few differences were observed in brain activity between memorized tonal and memorized atonal sequences at this frequency band (Fig. 2b).

In conclusion, this study provided new insights into the neural activity involved in recognizing musical sequences of different levels of complexity. The findings suggest that the brain uses distinct neural pathways to process and recognize tonal and atonal music and highlight the relevance of complexity for making meaning of music. Beyond advancing our understanding of music cognition, these findings have implications for clinical and educational contexts. For example, further research could explore how music complexity affects brain development in children and whether music-based interventions could help individuals with neurological disorders improve their cognitive functioning. Additionally, understanding how the brain processes different types of music could inform the development of personalized music therapy approaches that optimize the therapeutic benefits of music for individuals with diverse musical backgrounds and preferences. Overall, this study underscores the importance of studying the neural basis of processing music characterized by different levels of complexity to unlock new insights into brain function and potentially improve human health and well-being.

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MEANING OF MUSIC

Katarina Jerotic

Music in Ayahuasca Rituals of the Santo Daime

Human use of psychedelics can be traced as far back as 8600 BC in Peru, where the first anthropological evidence of mescaline use through the San Pedro cactus was noted[1]. Many aboriginal cultures, such as Alaskan Yupik Eskimos, Australian aboriginals, and Amazonian tribes, continue to use psychedelics within rituals and healing ceremonies today[2]. The examination of psychedelics in modern science originated in the 1950s but was quickly ceased due to the classification of psychedelics as drugs of abuse with "no recognised medical value"[3]. The last three decades of modern research into psychedelics have highlighted the effectiveness of psychedelic-based therapy in the treatment of depression, anxiety[4], and addiction[5] leading to persistent interest in these compounds within the scientific research community.

Set and setting are widely recognised as being key drivers of the psychedelic experience. Set refers to an individual's internal state at the time of embarking on the experience, while setting refers to the environment within which the experience takes place[6]. Participant openness to the music presented during a psychedelic therapy session, has been found to directly relate to improved short and long-term outcomes following the session[7]. Researchers suggest that such an interaction between psychedelics and music may be observed from two perspectives. On the one hand, the presence of the psychedelic influences the perception of the music. To this point, prior research has found that LSD administration in healthy individuals leads to changes in the neural response of brain regions supporting both lower- and higher-level music processing[8]. On the other hand, research has also shown music to be important in encouraging therapeutically meaningful emotions and mental imagery as well as guidance during the "trip"[9]. Furthermore, music listening in the absence of psychedelics has previously been found to occasion altered states of consciousness including groove, flow-like states and trance[10]. Given music's posited critical role in reaching altered states of consciousness in the absence of psychedelics, its effects in combination with psychedelics must be considered more thoroughly.

Music has been found to be a fundamental component of psychedelic ceremonies globally, including in Mazatec Indian mushroom ceremonies, Native American peyote ceremonies[10], and most notably for our current research, in Ayahuasca ceremonies of the Santo Daime[6]. The Santo Daime is one of three major religious groups (others include the Uniao do Vegetal, and the Barquinha) originating in Brazil, whose practices include the regular use of Ayahuasca[1]. The Santo Daime is a syncretic church which incorporates elements of Roman Catholicism, Afro-Brazilian rituals, European spiritualism, and Amazonian shamanism. As part of their practice, members of the church take part in regular – usually biweekly – ayahuasca rituals. These rituals are music ceremonies, with set Icaros (or songs) being used to achieve specific predetermined goals.

Figure 1: *Santo Daime religious ritual. Source[23]*

Ayahuasca is a psychedelic brew originating from the Amazonian basin, created through the concoction of a tea, commonly composed of two plants: baanisteriopsis caapi and psychotria viridis. P. viridis contains the main psychoactive component N,N-dimethyltryptamine (DMT), while b. caapi contains beta-carbolines, monoamine oxidase A inhibitors (MAOIs), which block the breakdown of DMT in the gut, allowing it to enter the blood stream and cross the blood brain barrier. Ayahuasca has been used for at least 1000 years, as was previously determined through the discovery of a small pouch in a cave in southwestern Bolivia – a pouch thought to belong to a Shaman[12]. Tribes of the Amazonian basin use ayahuasca to achieve a variety of positive outcomes, including healing physical illnesses, improving mental health, solving social issues within the community, and more broadly gaining knowledge. Regular as well as one-off use of ayahuasca has been associated with a variety of positive mental health outcomes such as having anxiolytic[13] and antidepressant[14] qualities, as well as lowering rates of substance abuse[15] and resulting in overall improved mental wellbeing[16].

"[Among the Santo Daime] the symbiosis between ayahuasca and music is a passport to the sacred and to revealed truth, untranslatable in ordinary language or states of consciousness"[17].

Center for Music in the Brain (MIB) collaborated with Prof. Jan Ramaeker's lab in the University of Maastricht to collect neuroimaging data from 24 members of the Santo Daime church in the Netherlands. fMRI data was collected on two separate days, in the presence and absence of the acute effects of ayahuasca. On both days resting state data was collected as well as data during a music listening paradigm. Dr Christine Ahrends from MIB designed the music paradigm which was played to participants while in the scanner. The paradigm consisted of a 2 x 2 design in which individuals were played four song; they were played music that is relevant to their ritual and that they are familiar with as well as music that is consistent in structure and design to their music but is fabricated, and therefore unfamiliar to the listener. This separation has been made to examine

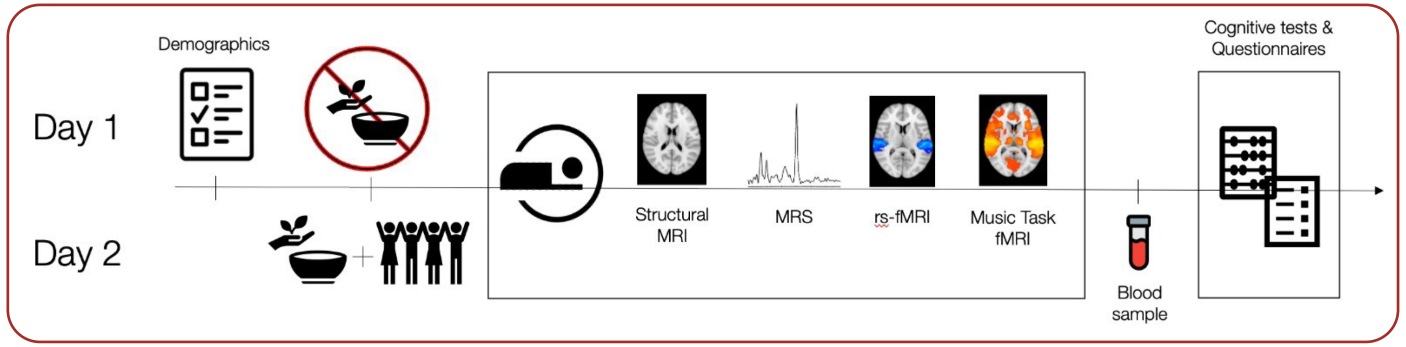

Figure 2: *Timeline of testing days with members of the Santo Daime Church in the Netherlands.*

the role of music familiarity on brain activity. Furthermore, each of these songs were additionally manipulated to lower their predictability, allowing for more direct examination of the effect of ayahuasca on predictive processing in the brain[18].

The mechanisms of psychedelic action on large-scale brain activity is still in the process of discovery. The current pervasive theory of psychedelic action is the Relaxed Beliefs Under Psychedelics (REBUS) model which stipulates that psychedelics help flatten the dynamic landscape of the brain, lowering the brain's functional hierarchy, and increasing entropy[19]. Mediano et al examined the effects of environmental factors present during a psychedelic experience on neural dynamics. Their work found the presence of both music and visual stimuli while under the influence of the psychedelic to have strong effects on brain entropy levels as measured through Lempel Ziv[20]. As part of my DPhil, I am applying exciting thermodynamics-based measures of non-reversibility (entropy production and therefore hierarchical processing) in the brain to this dataset[21,22]. The aim of this work is to shed light, not only on the role of psychedelics in flattening the hierarchical landscape of brain dynamics, but the effects of the interaction between music and psychedelic on said dynamics among the Santo Daime. We hope that this research will help us better understand the importance of music in the neural response to psychedelics, as well as improve understanding of how to optimise the psychedelic-therapy environment, through more informed music choice.

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CLINICAL APPLICATIONS OF MUSIC

Kira Vibe Jespersen

In 2022, MIB has contributed to the progression of research in the field of Clinical Applications in several ways. One of the major contributions is the update of the 2014 White paper on Music Interventions in Health Care[1]. This work was led by Assistant Prof. Kira Vibe Jespersen as a collaboration project with a grant from the Danish Sound Cluster including business partners from Oticon Medical, WS Audiology and SoundFocus[2]. The White paper maps the field of music interventions in health care presented to a layman audience and links this to an overview of basic research in music neuroscience to highlight the mechanism by which music may facilitate beneficial effects. Thus, the first part of the White paper provides an overview of the building blocks of music as well as an outline of the various ways music is processed in the brain. This leads to the second part, which includes a review of the existing evidence of the effects of music within a wide range of somatic and psychiatric disorder as well as domains related to general well-being (Fig. 1). In addition to updating the existing topics with the newest research, we have included a number of new topics where substantial scientific evidence has emerged. These new topics include the effect of music in COPD rehabilitation, multiple sclerosis, dental procedures, pain management, ADHD, pregnancy and birth. Another important new feature is the implementation of the guidelines from Oxford Centre for Evidence-based Medicine in the evaluation of the level of the evidence for each topic. These clear criteria make the evaluation transparent and enables the comparison with other clinical fields. Interestingly, level 1 evidence, i.e. systematic reviews of randomized controlled trials, exist for 12 of the 20 included topics (Fig. 1). These findings reflect a maturation of the field with more high-quality clinical music studies being conducted following the gold standards of health research. The White paper was presented by Peter Vuust and Kira Vibe Jespersen at a webinar hosted by the Danish Sound Cluster on September 14, 2022, with a broad audience including health care clinicians, researchers, musicians and people from the sound industry.

	INTERVENTION MECHANISMS					
	Audition	Cognition	Rhythm/Motor	Arousal	Emotion	Level of evidence*
Somatic disorders						
Operations	■	■		■	■	Level 1
Cancer	■	■		■	■	Level 1
COPD				■	■	Level 1
Stroke		■	■		■	Level 1**
Dementia		■		■	■	Level 1***
Parkinson's			■		■	Level 1
Multiple sclerosis			■		■	Level 2
Tinnitus	■	■			■	Level 2
Cochlear disorders	■				■	Level 3
Dental procedures		■		■	■	Level 1
Pain management		■		■	■	Level 1
Psychiatric disorders						
Depression					■	Level 2
Insomnia		■		■	■	Level 1
Autism	■		■		■	Level 2****
ADHD				■	■	Level 3
Well-being						
Cognitive enhancement		■		■	■	Level 2
Exercise			■	■	■	Level 1
Pregnancy and birth		■		■	■	Level 1
Stress reduction				■	■	Level 1
Healthy ageing			■		■	Level 2

*Based on the Oxford Centre for Evidence Based Medicine guidelines for treatment benefits.
**Level 1 evidence for improvements in gait function. Level 2 evidence for upper limb rehabilitation and cognition.
***Level 1 for reduction in depression. Level 2 for other outcomes.
****Level 2 evidence for improvements in social communication. Level 3 evidence for other language outcomes.

Figure 1. *Overview of the topics included in the 2022 White paper on music interventions in health care. The proposed mechanisms underlying the effect are marked for each topic and in the far-right column is the evaluation of the level of the evidence.*

MIB research has also progressed in the field of Cochlear Implants (CI). Here, PhD student Alberte Seeberg has published a paper on the early development of music-discrimination abilities in CI users together with MIB researchers Bjørn Petersen, Niels Haumann, Elvira Brattico and Peter Vuust[3]. In continuation of this research, Alberte has conducted a survey investigating the impact of instrumentation and rhythmic complexity on the sensation of groove in both healthy controls and CI users. The stimuli have been developed in collaboration with postdoc Tomas Matthews building on the longstanding line of groove research at MIB[4-5]. The survey results will be used for creating the stimuli for an upcoming EEG study on the enhancement of rhythm perception in CI users via haptic stimuli.

The role of rhythmic complexity has also been investigated in relation to rehabilitation strategies for Parkinson's patients. In 2022, postdoc Victor Pando-Naude has conducted a study in which Parkinson's patients walked to rhythmic auditory stimuli of varying complexity. The preliminary results confirm previous findings showing more pleasurable urge to move with low-complexity rhythms in Parkinson's patients compared to a preference for medium complexity rhythms in healthy control participants[6] (Fig. 2a). For the gait measurements, the results suggest improvement in cadence (number of steps per minute) with more

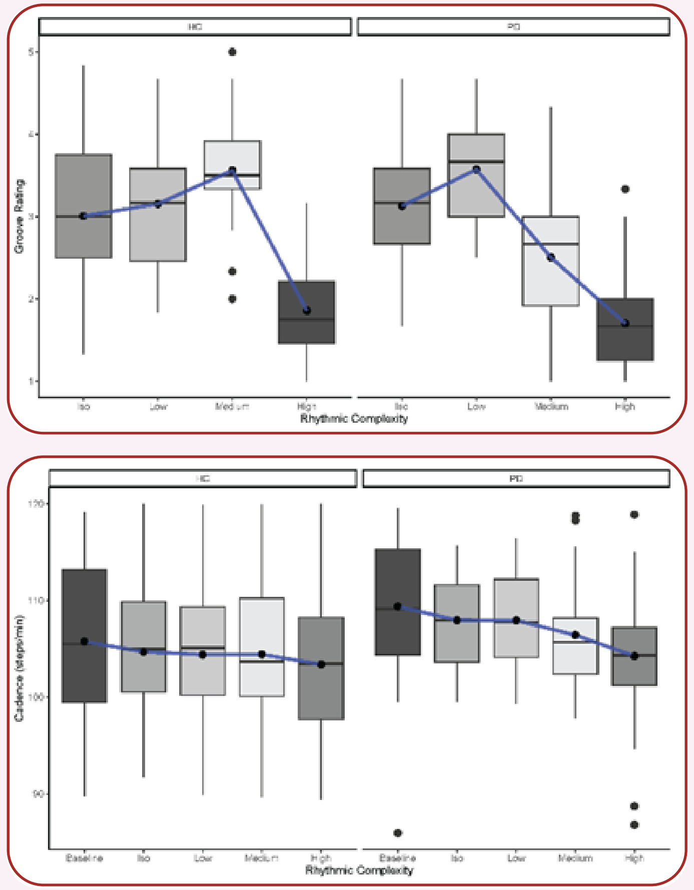

Figure 2. A) *Healthy controls (HC) and Parkinsons' patient's (PD) rating of groove defined as the pleasurable urge to move.* ***B)*** *Measurements of cadence for HC and PD participants in the various conditions.*

complex rhythms (Fig. 2b), but no difference in pace or step length.

In the line of insomnia research, the data collection by PhD student Nadia Høgholt was completed for an online randomized controlled trial (RCT) on music for pregnancy-related insomnia. In this study, first-time pregnant women with sleep difficulties were randomized to either music listening at bedtime combined with sleep hygiene advice or sleep hygiene advice alone. The results are currently being analysed. Similarly, Assistant Prof. Kira Vibe Jespersen finalised data collection for an RCT on music for sleep-onset insomnia. This study evaluates both the effects of music on subjective and objective sleep measures and investigates the underlying psychological and neurophysiological mechanisms using EEG. One proposed mechanism is the promotion of EEG slow waves through neural “entrainment” to the beat of the music. This hypothesis is tested together with postdoc Alexandre Celma-Miralles using a frequency-tagging approach[7] (Fig. 3).

Importantly, the research on music and sleep has been strengthened in 2022 through a 2,468,844 Euro grant from the EU Horizon Marie Curie Doctoral Network for the “Lullabyte” project by Kira Vibe Jespersen together with nine European researchers in the fields of musicology, sleep research and data science. The grant will be used for ten PhD projects of which one will be based at MIB (read more at www.lullabyte.org).

Other contributions to the line of insomnia research include the publication of a new Cochrane review on listening to music for insomnia in adults by Kira Vibe Jespersen together with MIB researchers Victor Pando-Naude and Peter Vuust[8] (see page 46). In addition, Kira summarized the effect of music on sleep in hospitalized patients in a systematic review based on the bachelor thesis of medical student Maria Hauge Hansen[9]. The results show that music can be an effective intervention to improve sleep quality in patients hospitalised at both intensive care units and general hospital wards. Also, Kira published a book chapter on the use of music as sleep aid in the book “The musical neurons”[10].

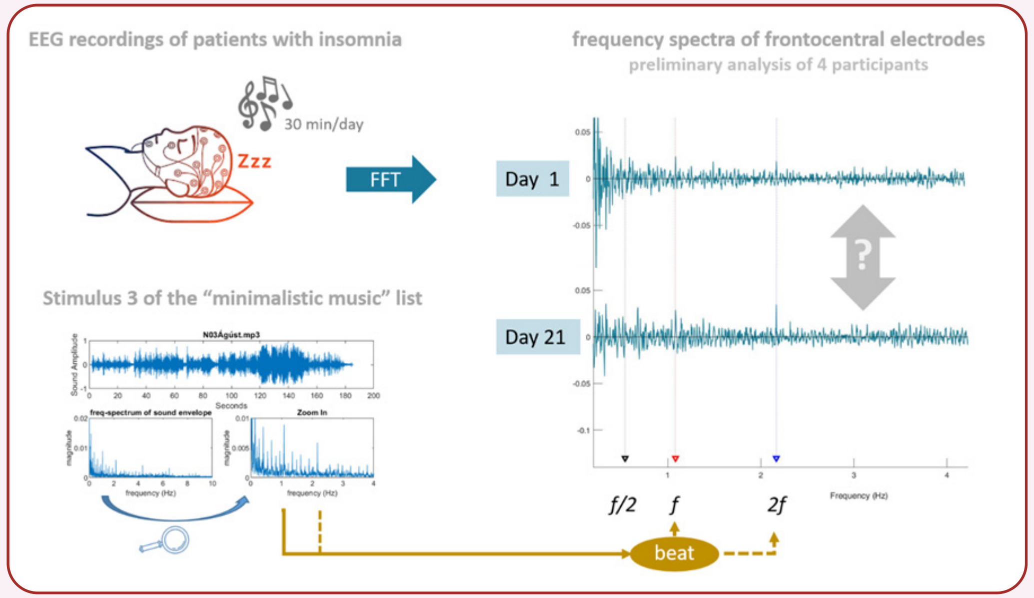

Figure 3. *Example of the methods used to explore neural synchronization to the beat of naturalistic songs in participants with insomnia. Participants listen to music for 30 minutes every night at bedtime for 28 days with collection of EEG measurements before and after this intervention period. We calculate the neural responses at the frequencies related to the beat of the music, using a fast Fourier transform. Analyses of the full dataset will allow us to assess the presence of neural changes in response to the intervention and link these to sleep outcomes and see if the “entrainment” to the beat of a slow soothing music facilitates the transition from wakefulness to sleep.*

A new field that has emerged at MIB in 2022, is the field of age-related changes in music perception and cognition. One study led by Dr., Niels Trusbak Haumann looked at age-related changes in central auditory system responses to high and medium naturalistic auditory stimuli. They found that age-related changes were smaller with highly naturalistic stimuli compared to medium naturalistic stimuli[11]. These findings open new avenues for including naturalistic stimuli in the investigation of age-related central auditory system disorders. Similarly, PhD student Gemma Fernández Rubio compared auditory short-term memory, long-term memory and working memory in young and older adults and investigated the influence of musical training. The results showed that musical training was associated with enhanced short term memory for melodic sequences and better identification of new pieces in a long-term memory task[12]. These findings suggest that music in some cases can serve as a protection against age-related decline in auditory memory.

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CLINICAL APPLICATIONS OF MUSIC

Kira Vibe Jespersen

Listening to music for insomnia in adults

Within clinical research, systematic reviews of randomized controlled trials are considered the highest level of evidence when evaluating the effect of an intervention. The Cochrane Collaboration is a global not-for-profit organisation dedicated to publishing high-quality systematic reviews to provide the best research evidence assisting informed decision-making in health care. In 2022, we published a Cochrane review on the effect of listening to music for improving sleep in adults with insomnia[1].

Insomnia as a global health challenge

Insomnia refers to the subjective complaint of poor sleep in the presence of adequate opportunity and circumstance for sleep[2]. This includes difficulties falling asleep, staying asleep or poor quality sleep. Unfortunately, this condition is very common, affecting around 1/3 of the general population[3]. Persistent insomnia can have a negative impact on physical and mental health and as such, it is costly for both individuals and society[4]. Many people report listening to music when they have trouble sleeping, and the aim of this systematic review was to assess the effect of this strategy.

We searched electronic databases to identify relevant studies using a randomized controlled trial to evaluate the effect of music on sleep in adults with a complaint of insomnia. Through a thorough assessment procedure, we identified 13 studies that matched the inclusion criteria, which is more than double the number of studies identified in a previous review from 2015[5](Fig. 1). The studies compared the effect of listening to music to treatment as usual or no treatment, including a total of 1007 participants. Participants in the intervention groups listened to prerecorded music between 25 to 50 minutes daily. The intervention period varied from three days to three months with most studies implementing the intervention in the homes of the participants. One trial was conducted in a sleep lab[6], and two were conducted in a rehabilitation setting[7-8]

Quality assessment

To evaluate the quality of the evidence, we used the Cochrane Risk of Bias assessment[9] to evaluate risk of bias in the included studies and the GRADE approach to summarize the quality of the evidence for each outcome[10]. The risk of bias within the studies varied, with all studies being at high risk of performance bias, because of limited possibilities to blind participants to the music intervention. In addition, some studies were at high risk of detection bias or other bias (Fig. 2). We used the risk of bias information in the GRADE assessment evaluating the quality of the evidence for each outcome as high, moderate, low or very low.

Improved sleep quality

Ten of the included studies reported the effect of listening to music on sleep quality, and combining these results showed moderate quality evidence for a beneficial effect of the music (Fig. 2). The results did not show any difference between those who listened for one or two weeks compared to those who used the music for more than three weeks. Similarly, we did not see any differences in the effect between participants suffering from age-related insomnia, insomnia related to a chronic medical condition or pregnancy-related insomnia, or those who had been diagnosed with insomnia disorder[1].

Some of the studies also reported other sleep outcomes such as total sleep time, sleep-onset

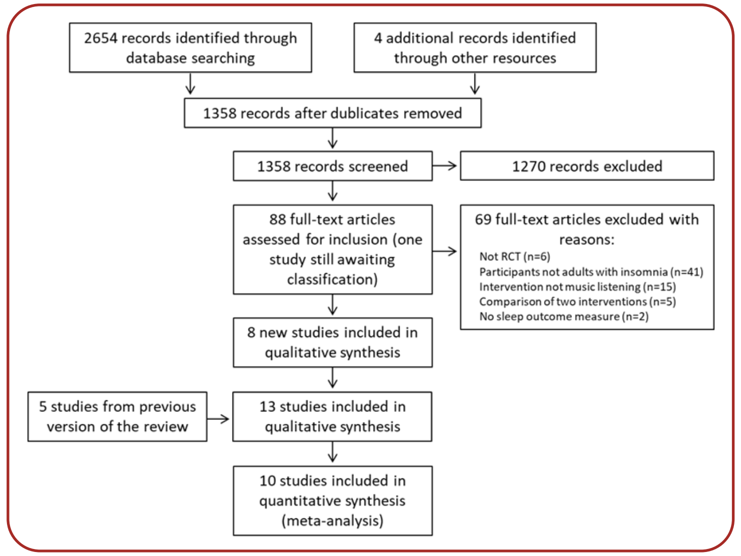

Figure 1. *Flow chart of the study selection process.*

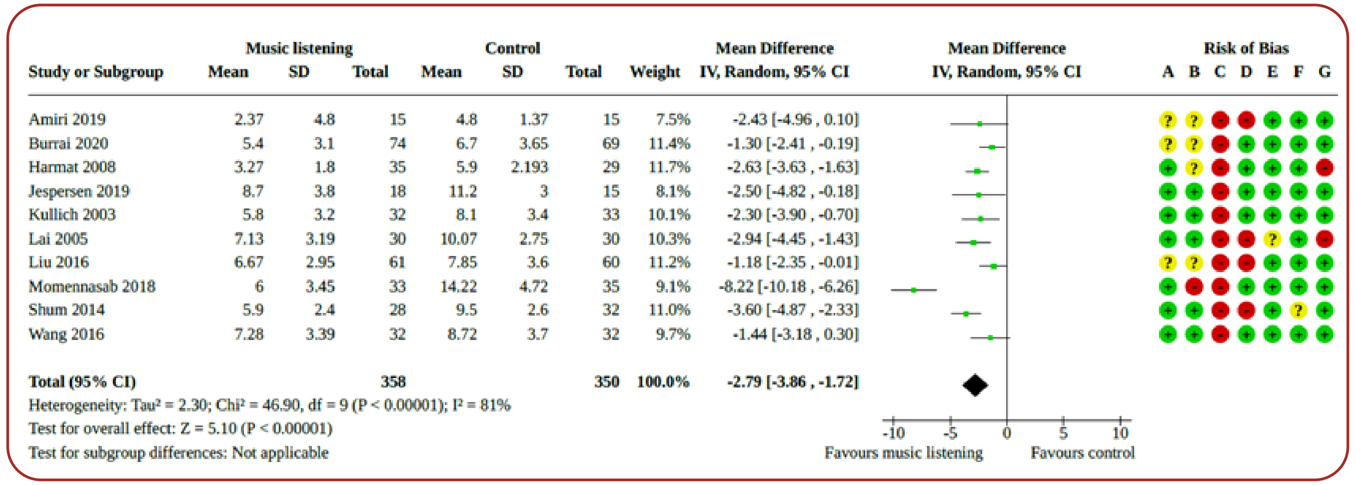

Figure 2. *Forest plot of the meta-analysis on sleep quality. Ten studies reported on sleep quality using the Pittsburgh Sleep Quality Index (PSQI). The PSQI measures the degree of sleep problems, and higher scores indicates more sleep problems. The meta-analysis shows a consistent reduction in sleep problems across all studies and a highly significant positive effect of the music intervention. The risk of Bias assessment evaluates* ***A)*** *Random sequence generation,* ***B)*** *Allocation concealment,* ***C)*** *Blinding of participants and personnel,* ***D)*** *Blinding of outcome assessment,* ***E)*** *Incomplete outcome data,* ***F)*** *Selective reporting and G) Other bias.*

latency and insomnia severity. However, because there were few studies reporting these outcomes, the results are less reliable. Listening to music may improve experienced sleep-onset latency (how quickly a person falls asleep) (MD –0.60, 95% CI –0.83 to –0.37; 3 studies, 197 participants), sleep duration (MD –0.69, 95% CI –1.16 to –0.23; 3 studies, 197 participants) and sleep efficiency (amount of a time a person is asleep compared to the total time spent in bed) (MD –0.96, 95% CI –1.38 to –0.54; 3 studies, 197 participants). However, the studies measuring sleep objectively with polysomnography (EEG, EOG, EMG) did not show any changes in these outcomes.
A few studies measured depressive symptoms, anxiety and quality of life, and a meta-analysis combining these results showed low certainty evidence for a medium effect size reduction of anxiety (SMD –0.52, 95% CI –0.75 to –0.28; 3 studies, 294 participants) and improvement of quality of life (SMD 0.55, 95% CI 0.25 to 0.85; 2 studies, 177 participants) with the music intervention. Importantly, none of the studies reported any adverse events.

How can music alleviate insomnia?
The findings of this review provide evidence that music may have a moderate to large beneficial effect on sleep quality in different populations experiencing insomnia. Still, the specific factors underlying the effect remain unclear. All included trials used music that was characterised as sedative or relaxing. However, these included a number of different musical styles (e.g. classical, new age, jazz, etc.), and at this point, it is not clear if some types of music may be more effective than others[11]). Furthermore, the objective characteristics of the music interact with the subjective preferences of the individual listener, and future studies should help elucidate the neurophysiological and psychological mechanisms underlying the impact of music on sleep.

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NEW FACE: ANA TERESA QUEIROGA

Graduated in Biomedical Engineering at the University of Minho (Braga), Ana Teresa comes from Penafiel, Portugal.

After having visited MIB for about 9 months during the final year of her master's studies, during which she developed her thesis project entitled "Brain Fingerprints of Musical Complexity during Jazz Improvisation" under the supervision of Henrique Fernandes (MIB) and Prof. Victor Alves (UMinho), she is now back as a PhD student.

Extending on her previous work, Ana Teresa will continue to focus on the improvisation paradigm, seeking to adopt a multimodal approach (neural, behavioural and physiological measures) to study the intra- and inter-brain neural effects that emerge when individuals interplay during music improvisation.

Ana Teresa considers herself a science enthusiast drawn to multidisciplinary projects and is therefore very excited to see what the next 3 years have in store, and how she will be able to further broaden her areas of interest in the music and neuroscience field.

NEW FACE: PELLE DE DECKERE

Pelle first joined MIB in November 2021 as a research intern for 9 months as part of his master's program at the University of Antwerp. He wrote his master's thesis entitled "An fMRI study: Inducing self-related Emotion Evaluation by Modulating the Speaking Voice" under the supervision of Prof. Dr. Debby Van Dam and MIB Associate Prof. Boris Kleber. In July he successfully defended his master's thesis with greatest distinction before the jury in Belgium and was awarded a master's degree in Biomedical Sciences with a specialization in Neuroscience.

After a short summer break, Pelle returned to MIB as a PhD student. During his PhD, he will continue his project with Associate Prof. Boris Kleber and start up a new project with Prof. Peter Vuust. This new project will focus on the neurochemistry underlying the influence of music on the cognitive, emotional, and behavioral networks in the brain.

With a passion for both neuroscience and music, Pelle finds combining the two very exciting and looks forward to being part of the MIB team for the next 3 years.

NEW FACE AT MIB: ANDREA RAVIGNANI

Andrea Ravignani in a Parisian street not *named after him.*

Why are we musical animals? If you ask anybody "Do you like music?", most answers will range from appreciation to extreme love for music. It is rare to hear the sentence "I despise music!". Most morphological, cognitive and behavioural traits we see in humans and other species seem to have an obvious biological ultimate function. From cortisol to color vision, from bipedal gait to tool use, most human traits are easily explainable by Darwin's theory of evolution by natural selection. Music, however, seems paradoxical: so extremely common in our species, but not directly functional in many ways. Andrea Ravignani's research employs a broad range of methods – including those from psychology, ethology, neuroscience, anthropology and computer science – to try to understand why, when and how we became musical animals.

Andrea joined Center for Music in the Brain as Associate Professor in January 2022. Andrea has studied, researched and worked in several areas, including mathematics, biology, speech sciences, musicology, computer science and cognitive psychology - this multidisciplinarity is mirrored in the research teams he attempts to put together. Andrea has also been a W2 Independent Group Leader at the Max Planck Institute for Psycholinguistics, where he led the Comparative Bioacoustics Research Group. Andrea's research group at the MPI was highly interdisciplinary, featuring 10 scientists from many areas, including cognitive neuroscience, ethology, experimental psychology, linguistics, communication sciences, computer science, AI, bioacoustics, primatology and marine mammalogy.

Andrea's work tries to address some big-picture questions about the evolution of human cognition and behaviour. Who's got rhythm? Why are we such chatty animals? Human music and speech are peculiar behaviors from a biological perspective: Although extremely common in humans, at first sight they do not seem to confer any direct evolutionary advantage. Many hypotheses try to explain the origins of acoustic rhythm capacities in our species, but few are empirically tested and compared. Because music and speech do not fossilize, and lacking a time machine, the comparative approach provides a powerful tool to tap into human cognitive history. Notably, homologous or analogous building blocks underlying human rhythm can be found across a few animal species and developmental stages. Hence, investigating rhythm across species is not only interesting in itself, but it is crucial to unveil music-like and speech-like behaviors present in early hominids.

Andrea's current work tackles major hypotheses for the evolution of rhythmicity in humans and

The giant lemur Indri indri, one of the few singing mammals apart from humans. Only a few thousand of these animals exist, and the species may unfortunately become extinct very soon.

other animals, which link acoustic rhythms to vocal learning (a precursor to speech), gait, breathing or chorusing. To obtain a full picture and empirically testable predictions, he integrates approaches from ethology, psychology, neuroscience, modeling, voice sciences and physiology. Andrea's cross-species research focuses on some crucial mammals which are key to test alternative hypotheses on rhythm origins, with particular attention to the rhythm-vocal learning link. Rhythm research in aquatic mammals and primates – species partly neglected until now - can be particularly fruitful in shedding light on the evolution of rhythm and vocal learning. Andrea's results from pinnipeds and singing primates suggest that rhythm research in non-human animals can also benefit from ecologically-relevant setups, combining strengths and knowledge from human cognitive neuroscience and behavioral ecology. Andrea has also performed human work in experimental cultural evolution, where musical rhythm is created and evolves culturally due to cognitive and motoric biases. These transmission chain experiments show the importance of the interplay between biology and cultural transmission and the need to move away from simplistic nature-nurture dichotomies. Overall, Andrea's comparative work suggests that, while some species may share one or more building blocks of speech and music, the 'full package' may be uniquely human.

Since the end of his PhD in 2014, Andrea has written approx. 100 works (journal articles, book chapters, among others) published in Science, Nature, Nature Human Behaviour, Nature Communications, Music Perception, Cognition, PNAS, Current Biology, Trends in Cognitive Science, etc. Andrea is Associate Editor for BMC Research Notes, British Journal of Psychology, Frontiers in Auditory Cognitive Neuroscience, Journal of Zoology, and Methods in Ecology & Evolution.

Recently, Andrea has been awarded an ERC Starting Grant, a HFSP Grant and a Sapienza PI grant to investigate the origins of rhythm and vocal learning using a multi-species and multi-method approach. He firmly believes in both non-canonical academic paths and kindness in science.

Andrea swimming with a harbour seal (Phoca vitulina) in the Baltic Sea. Among the approx.20 species Andrea has worked with, harbour seals are the ones he worked with the most, investigating their capacities for both rhythm and vocal plasticity.

EDUCATIONAL ACTIVITIES & OUTREACH

Bjørn Petersen and Elvira Brattico

Weekly knowledge sharing

The weekly Monday morning lab meetings at MIB were continued in 2022. The meetings were held in a hybrid format, which enabled both attendees and speakers to participate and present remotely via Zoom whenever they were out of the lab for research or other reasons. Assistant Prof. Cecilie Møller organized a program consisting of 29 in-house presentations. These presentations are a vital activity at MIB, as they offer young researchers the chance to receive feedback from their colleagues on issues such as experimental design, test paradigms and statistical approaches. In some instances, senior researchers also share the results of recent publications, providing valuable inspiration and ideas to their fellow researchers. In many cases the presentations work as 'dress rehearsals' for researchers providing an opportunity to test upcoming talks whether it being for a conference or a presentation to the Scientific Advisory Board (SAB).

Outreach activities

MIB places a high priority on engaging with the general public as well as relevant groups of students and researchers. These outreach activities can take place on-site at MIB when hosting visiting groups or off-site at schools, libraries or similar venues both nationally and abroad.

In-house addresses

Again in 2022, MIB had the pleasure of welcoming a group of students from DIS, which is a non-profit study abroad foundation established in Denmark offering high-impact learning experiences for undergraduate students from distinguished North American colleges and universities. At the seminar, the DIS students were introduced to the research carried out by MIB researchers Cecilie Møller, Jan Stupacher and Alexandre Celma-Miralles on polyrhythms. The presentation included a pilot experiment in which the participants provided data which again were analysed on the fly and presented 45 minutes later. In addition, Associate Prof. Boris Kleber presented his research work with singers and non-singers improvising during fMRI scans.

On another occasion, MIB welcomed a group of 66 students from ESCP Business School in Paris, all of whom were Diploma students in International Business Management with a specialization in pharmaceutical and biotechnological management. The students had the opportunity to meet with three of MIB's expert researchers in their respective fields: Assistant Prof. Kira Vibe Jespersen, who spoke on the topic of ”Clinical Applications of Music”; postdoc Victor Pando Naude, who presented on ”Music in the Neurodegenerative Brain”; and Associate Prof. Boris Kleber, who gave a talk titled ”Singing in the Brain.” The French students were highly engaged and asked thoughtful questions, resulting in fruitful dialogues with the presenters.

Associate Professor Bjørn Petersen entertaining the French students.

At a slightly lower level, nonetheless very relevant, MIB entertains students from local high schools. Such an occasion took place in November where 28 students from Katedralskolen in Aarhus were introduced to the neuroscience of music and took part in an experiment, all brilliantly led by Assistant. Prof. Jan Stupacher and PhD student Rebecca Scarratt. The content was highly relevant because the students were specializing in music and math and were required to complete a major assignment that combines the two disciplines, making the neuroscience of music an ideal topic for exploration.

External public addresses

In addition to conference presentations, MIB researchers engage in a variety of public addresses. Examples of this are Assistant Prof. Kira Vibe Jespersen presenting her research to a local audience at Kolding library as well as a class of 9th grade grammar school children, and Associate Prof. Bjørn Petersen sharing his research on music and cochlear implants with two groups of senior citizens at the FO Senior Day School.

Prof. Brattico was also invited to give talks at two national conferences addressing both professionals and the general public, which were organized by the Conservatory of Bari and the Order of Psychologists, respectively, and which aimed to explain how music making can contribute to individual and collective flourishing.

A full list of external public addresses can be found on page 57.

Supervision

MIB reseachers have supervised a large number of Bacherlor's and Master's students - ranging from students at Aarhus University to international students visiting MIB for short or long internships. Below a few of the projects are highlighted.

Supervision of medical BSc students

The cooperation between MIB and AU on supervision of medical students doing either their BA thesis or an 8-week full-time research stay continued in 2022. And successfully so. A total of 11 students completed their empirical (9) or theoretical (2) projects under supervision of MIB researchers. Topping the list of research fields attracting most students was again projects under the “Music and sleep” umbrella led by Assistant Prof. Kira Vibe Jespersen who supervised one BA-project and two Masters' students, one of whom went on to successfully write her master's thesis based on the project.

Postdoc Tomas Matthews supervised a medical student in a project investigating the effects of age, musical training, and Parkinson's disease on the pleasurable urge to move to music (PLUMM). By combining data from multiple studies, the student measured differences in subjective ratings of PLUMM across a large number of participants. Results showed that Parkinson's and aging dampen the effect of rhythmic complexity on PLUMM, while musical training counteracts this effect, indicating a common underlying mechanism. The student produced a high-quality research paper summarizing the results, forming the basis of a future publication. This nicely demonstrates the mutual benefit that can arise from MIB's supervision agreement with the Department of Clinical Medicine.

Supervision of a Cognitive Science BSc student
In a parallel supervision agreement, PhD student Alberte Seeberg supervised a Cognitive Science BSc student's project on the effect of haptic stimulation on groove perception in cochlear implant users, using the commercial Neosensory Buzz device. The BSc student collected data from three normal-hearing controls and one CI user, providing a useful pilot for Seeberg's PhD project.

Organisation of courses and conferences
Royal Academy of Music Research
As in previous years, Associate Prof. Bjørn Petersen, who is responsible for the academy's R&D activities, organized a research course addressing his colleagues at RAMA. The one-day course was titled "Introduction to anthropological approaches to music and sound" and was arranged in cooperation with the Department of Anthropology at AU. RAMA's research committee had teamed up with Associate Prof. and anthropologist Nanna Schneidermann to lead the course. With the course, the research committee aimed to focus on various methods within anthropology and musicology, such as participant observation, participation in musical practice and field conversations. Twenty-four RAMA teachers took part in the course which included keynote talks, project presentations, workshops and experiments.

International conferences
Prof. Peter Keller co-organized a conference on the theme of music interactions titled "Social Bridges: The Biological Bases of Music" in Munich, Germany as well as a related symposium at the European Society for Cognitive Psychology (ESCoP) conference in Lille, France.

Prof. Elvira Brattico co-organized with Mari Tervaniemi (University of Helsinki) a symposium entitled "MMN Paste and Future", which was accepted for the hybrid event "The 9th Mismatch Negativity conference" in Japan.

Furthermore, Prof. Brattico had the opportunity to organize a concert conference for both scientists, students and the general public entitled "The power of Music – II Edition" in a gorgeous Art Deco theatre from Southern Italy (Kursaal Santa Lucia in Bari). This event attracted around 50 people, namely international and Denmark-based researchers, engineers and musicians, all united in the common effort to illustrate how music is learned, appreciated and transmitted among humans and even in the animal world. An audience, counting up to 300 participants, including children from middle schools, conservatory and university students, teachers and the curious laypersons, attentively followed the 3-hours-long event.

Planning of Aarhus Summer School in Music Neuro-science 2023
Following the success with Aarhus Summer School in Music Neuroscience in 2021, MIB was approached by AU's Aarhus Summer University organizers with a request of organizing a course as part of the annual AU Summer University. MIB agreed to the request to organize courses in 2023 and 2025. AU Summer University offers AU students as well as students from other universities the opportunity to take courses during the summer between the regular semesters. AU Summer University offers more than 100 courses from all five faculties and attracts over 2500 students each year.

Subsequently, an organizing committee headed by Prof. Elvira Brattico with Prof. Peter Keller, Associate Profs. Boris Kleber and Bjørn Petersen and centre administrator Tina Bach Aaen has met throughout 2022 to outline the 3-weeks course.

Associate Prof. Andrea Ravignani presenting at the conference in Bari, Italy

The target audience are students at Master's and advanced Bachelor's level whose topic of interest should be revolving around behavioural and brain science associated with music and sound cognition.

The course aims to provide the students with a fundamental overview of the trends and methodologies concerning research in the field of music and the brain and prepare them to take an interdisciplinary approach to research questions. The course is organized such that leading experts in the field present and discuss examples of their research in the mornings while MIB researchers are in charge of practical hands-on sessions in the afternoons. These sessions involve supervised teamwork and guided instructions in designing experiments as well as analysing and interpreting data using state-of-the-art software platforms. One day in the course is reserved for a visit to experience various brain research labs at Aarhus

University Hospital (Skejby). The course outline and content were accepted in September and published online in the course catalogue.

Supervision and teaching abroad
Also this year, some of MIB staffers gave lectures and even full courses at international universities. For instance, Prof. Brattico taught two full courses, respectively, on general psychology and psychology of learning and memory for undergraduate students of psychology and educational sciences and graduate students of philosophy and history at the University of Bari in Italy. She also taught a brief, advanced course of general psychology with practical sessions for psychologists at a psychotherapy school and introductory methodological courses on music psychology and neuroscience for music performance students of the Conservatory of Bari. Assistant Prof. Leonardo Bonetti also taught a course on Environmental Psychology at the University of Bologna in Italy.

Other teaching activities at IKM of Aarhus University
In 2022 Prof. Brattico contributed once again to graduate teaching at the Department of Clinical Medicine, AU by providing a lecture for the Neuroscience Graduate Course, reaching over 15 PhD students of the Graduate School of Health. Moreover, she organized and chaired the session Perception for the Interdisciplinary Summer School on Cognitive Neuroscience, led by Prof. Morten Overgaard, which was part of AU Summer University offering, and which provided 5 ECTS points.

Miscellaneous
MIB researchers are active in many ways and contexts. For instance, PhD student Ana Teresa Queiroga gave a talk titled "Decrypting the fingerprints of jazz improvisation" at the Tec2Med conference in Almada, Portugal organized by the NOVA School of Science and Technology. Postdoc Alexandre Celma-Miralles gave a flash talk entitled "Cochlear implant experience enhances the ability to track the musical beat" at the 5th Annual Research Meeting, Institute for Clinical Medicine, Aarhus University. Together with Assistant Prof. Cecilie Møller, Alexandre Celma-Miralles also gave a presentation entitled "Using musical rhythms to dissociate perceptual from sensory processes in the brain" for students at the Department of Dentistry and Oral Health. PhD student Alberte Seeberg did a podium presentation titled "Adapting to the Sound of Music — Development of Music Discrimination Skills in Recently Implanted CI Users" at the CI2022 international conference: Emerging Issues in Cochlear Implantation, Washington DC.

As part of a group of fellow PhDs and postdocs who were invited to a summer school on translational research funded by the William Demant Foundation, PhD student Alberte Seeberg presented a project pitch called "ADAPThearing". The project considered the potential for a more personalized treatment after getting a hearing aid, to increase the retention rate and user satisfaction of hearing aids overall. This was suggested to be done by developing a predictive model, predicting the individual's adaptation period based on personality traits as well as cognitive abilities.

The project was presented applying Seeberg's animation skills, and she as well as her fellow group members each won the first prize of 15,000 DKK.

International guest speakers in 2022
MIB has had a longstanding practice of inviting international guest speakers to Denmark ever since the centre was launched in 2015. These speakers have included both promising young researchers and well-known established experts in their field.

In 2022, MIB had the pleasure of hosting visits from the following researchers:

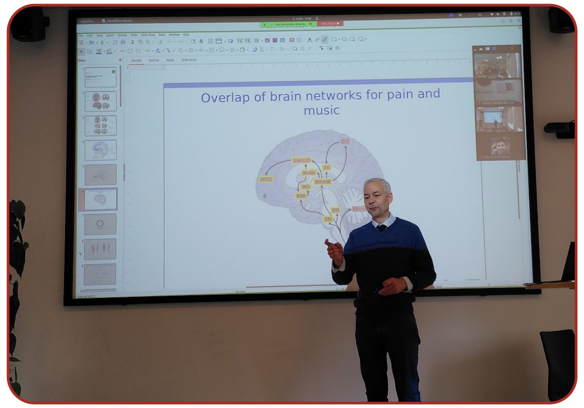
Dr Dobromir Dotov
Auditory Development Lab, McMaster University, Ontario, USA (Zoom)

Dr Fleur L. Bouwer
Department of Psychology, Amsterdam Brain & Cognition, University of Amsterdam (Zoom)

Dr Laura Bishop
RITMO - Centre for Interdisciplinary Studies in Rhythm, Time and Motion, University of Oslo

Professor Caroline Palmer
Department of Psychology, McGill University (Zoom)

Dr Laura Rai
Department of Psychology, Goldsmiths, University of London



Stefan Kölsch from Bergen University presenting his research at MIB.

Professor Stefan Kölsch
Department of Biological and Medical Psychology
University of Bergen

HENRY PRIZE

At the yearly MIB & CFIN Christmas Party, the Outreach Henry Prize was awarded to MIB PhD students Gemma Fernández Rubio and Alberte Seeberg.

PHD FEATURE
Mette Kaasgaard

Singing in pulmonary rehabilitation for patients with chronic obstructive pulmonary disease (COPD)

In June 2022, I defended my PhD thesis investigating effects and impact of singing in pulmonary rehabilitation for patients with chronic obstructive pulmonary disease (COPD)[1].

Background
COPD is often associated with cough, sputum, and dyspnoea (breathlessness) and with a vicious circle of low physical activity, social isolation, and impaired quality of life (QoL). To improve physical capacity and QoL, to support lifestyle-changes and to prevent further disease progression, COPD patients are offered pulmonary rehabilitation (PR), which consists of evidence-based activities with physical exercise training (PExT) as gold standard activity. However, a more personalized PR offer has been requested.

Singing has recently become increasingly popular worldwide for people with respiratory disease, either as leisure time activity or as structured activity aiming to improve wellbeing and health. However, the initial body of research is characterized by methodological heterogeneity, insufficient study sizes to detect change, and with contradictory findings in qualitative and clinical studies. Therefore, evidence has not yet been established.

Study 1: A survey-based study in current Danish lung choirs
Initially, I investigated how Danish lung choirs are performed in practice and conducted a survey-based study among Danish lung choir leaders (2017)[2]. The study included both a quantitative and a qualitative component and demonstrated heterogeneity concerning delivery and approach. The singing leaders did not apply any disease-specific methodological approach, lacked mutual network, and experienced feelings of isolation, inadequacy, and insecurity. However, the choirs were perceived as beneficial to both participants and singing leaders.

There is a need for an available, standardized, and disease-specific methodological framework including training and supervision of singing leaders in order to assess and evaluate the effect and significance of singing and to ensure homogenous and predictable outcomes for the participants.

Study 2 and 3: A randomized controlled trial investigating effects of singing in pulmonary rehabilitation for COPD
The main study was based on a multicentre, randomized controlled trial (RCT) within the framework of 10 weeks of community-based PR for COPD[3]. A total of 11 Danish municipalities and 270 COPD patients took part in the RCT which took place between 2017 and 2019. The current best-practice, disease-specific approach, ”Singing for Lung Health” (SLH), was applied and compared to standard PExT. SLH has been developed in the UK since 2008 and includes exercises for breathing, body, and voice, familiar and new songs, and games, movement and dancing along with singing, all specifically customized to meet the challenges of COPD. Assessments included standard objective and subjective outcomes within PR, including walking distance, lung function, respiratory muscle strength, dyspnoea, anxiety, depression, and QoL.

The study demonstrated that SLH provided relevant improvements on both physiological and psychological parameters, and that SLH was non-inferior to PExT in achieving improvements[3]. No factors were associated with effect, except for high adherence which significantly improved the odds for achieving the minimal important difference (MID) for both walking distance and QoL[4]. A post-hoc explorative study suggested that SLH was associated with improved respiratory muscle control and dyspnoea control in those who achieved MID, and that a larger proportion achieved MID in QoL than in walking distance[5]. SLH did not improve lung function. The primary results from the RCT were published in The European Respiratory Journal (IF:12.3)[3].

Conclusion and perspectives
My studies demonstrated that singing can be more than just a pleasant leisure activity. At least when delivered as a structured disease-specific activity, singing may provide measurable improvements on physiological and psychological parameters, relevant for people with COPD. Moreover, singing appears to be a safe and well-accepted activity. Further research is, however, needed before singing can be included in PR as a supplement to PExT.

Future research should include replication of the RCT in similar and ideal settings, investigation of the impact of singing on long-term effects, and elucidation of the underlying mechanisms of singing for people with lung diseases. Furthermore, preferred methodological delivery and approach should be explored.

There has been great interest in my research with around 70 features in the media, including national television and radio, and the RCT conducted during my PhD was winner of the category ”Best researcher-initiated trial” under the celebration of ”Best clinical trials of the year, 2023”: https://www.kliniskeforsoeg.dk/vinderne-kaares/”.

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PHD FEATURE

Nadia Flensted Høgholt

Perchance to sleep: Changes in brain and behaviour after becoming a parent

The 'parental brain' has been studied for several decades, and lately several models have emerged describing the underlying neural basis for attentive and caring parenting. Several networks of the brain have been found to be active when listening to infant vocalisations or when looking at infant pictures and videos. Further light is now being shone on this through the ERC-funded CAREGIVING project investigating the effects of caregiving on the male and female brain over time.

A crucial first step in sensitive caregiving is to pay closer attention to infant-related stimuli rather than oneself, despite the challenges of parenting including sleep-deprivation which is known to impact cognition. Over the years, the well-known self-prioritisation effect has been studied in different cognitive domains, showing that the brain is fine-tuned towards processing information regarding oneself over other stimuli. However, this has never been tested to include information regarding infants in non-parents and in new parents with and without the stressful challenges of sleep deprivation.

Crying is the most powerful tool the infant has for capturing our attention. A recent metaanalysis on infant cry perception in adults found several brain regions to be involved in this process, including the auditory system, thalamo-cingulate network, dorsal anterior insula, presupplementary motor area, dorsomedial prefrontal cortex, orbitofrontal cortex, inferior frontal gyrus, putamen, and cerebellum. However, the potential impact that sleep deprivation or lack of bonding with the infant might have on infant cry processing is yet to be understood.

Within the CAREGIVING project, the purpose of my dissertation was to understand 1) whether the self-prioritisation effect changed into an infant-prioritisation effect when becoming a parent for the first time; 2) if the self-infant-prioritisation in new mothers was influenced by the duration of night-time sleep; 3) which brain regions were active when listening to infant versus adult cries during magnetoencephalography, and whether this activity was modulated by duration of night-time sleep and/or the level of bonding with the infant.

To achieve these goals, I completed three different studies. Studies 1 and 2 measured self-infant-prioritisation with a modified version of the original perceptual matching task now including an 'infant' category. In this task, the participants were asked to remember five associations between geometric shapes and labels (e.g., you are represented by a circle, your infant by a pentagon, your mum by a square, your friend by a diamond, and a stranger by a triangle). Afterwards, the participants would be presented with a shape-label pairing and had to judge whether it was matched correctly or not. The outcomes of interest were reaction time and accuracy.

Study 1 first tested whether the self-prioritisation effect was replicated using the modified perceptual matching task in a group of young adults with no plans of becoming parents in the near future. The results confirmed this and found a strong self-prioritisation effect both regarding accuracy and reaction time. The second part of Study 1 consisted of a longitudinal study following couples before pregnancy and one year after birth-giving. The results showed that the self-prioritisation effect changed already when deciding to have a child and had changed into an infant-prioritisation effect one year postpartum with regards to reaction time.

Study 2 was a cross-sectional study testing whether the duration of night-time sleep (measured by means of wrist-worn actigraphy and sleep logs) altered the self-infant prioritisation effect in first-time mothers within the first year of postpartum. When analysing the data of all new mothers, a non-significant trend towards an infant prioritisation effect was seen. Further investigating this, I split the data into two groups with above or less than 7 hours of sleep. I found that the mothers sleeping on average above 7 hours of night-time sleep showed an equal self-infant prioritisation compared to all other categories (friend, mum and stranger), while the group with mothers sleeping less than seven hours showed a statistically significant infant-prioritisation effect both regarding accuracy and reaction time compared to all other groups; they even had the overall fastest reaction time in the 'infant' category.

Study 3 used a sample of the participants from Study 2 to test infant versus adult cry perception in a magnetoencephalography study. The results confirmed previous findings using the different technique of functional Magnetic Resonance Imaging and found activity in mentalisation and emotional networks. Importantly, I found a decrease in activity for key parental network regions which correlated with increased risk of impaired bonding (measured by means of the Postpartum Bonding Questionnaire) , thus potentially providing a brain signature for impaired bonding with the infant. However, there was no significant correlation between duration of night-time sleep and brain activity to infant cries.

To my knowledge, these were all new findings suggesting a protective mechanism ensuring the survival of the infant by assuring continued prioritisation of infant-related stimuli especially in the face of sleep deprivation. Future studies would need bigger samples in order to provide the numbers necessary for subsample analysis that could shed light on how factors such as gender, age, and level of bonding affect both the self-infant-prioritisation effect and the perception of infant cries. By expanding the experiments to clinical populations such as new mothers suffering from depression, I believe the findings could hold great potential for the development of future objective diagnostic tools, helping to ensure the best possible early intervention for vulnerable populations of parents and infants.

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PEOPLE

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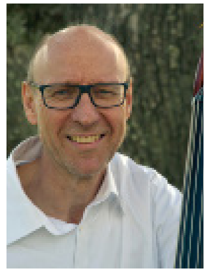

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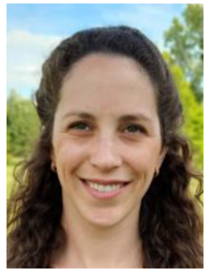

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INAUGURATION

May 12th 2022, Peter Keller was inaugurated as Professor of Neuroscience at the Department of Clinical Medicine, Aarhus University.

His inaugural lecture was entitled "Human Interaction Through Music: From Psychology to Neuroscience and Beyond" and contained an impressive overview of his groundbreaking research.

Photo: Wissenschaftcollege

Keller's research revolves around the perceptual and motor skills and neural mechanisms which enable people to interact and communicate in musical contexts.

Peter Keller holds Bachelor's degrees in music and psychology together with a PhD in psychology from the University of New South Wales in Australia. He came to MIB in November 2021.

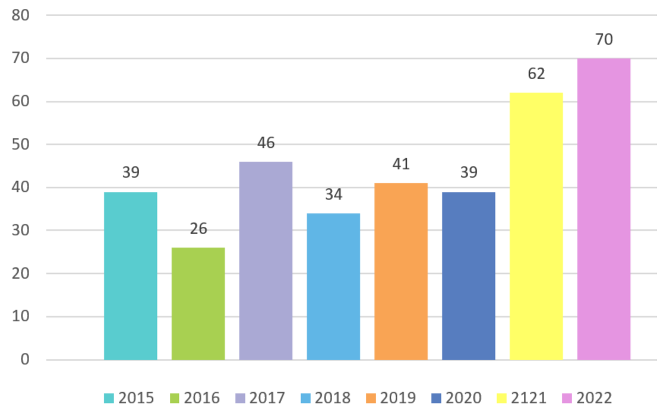
INTERNATIONAL GUEST RESEARCHERS

Aleksandra Pajdak
Alicja Szmidka
Ben Engler
Francesco De Benedetto
Krzysztof Basiński
Marc Barcelos
Nikita Joe
Pelle De Deckere
Ulvhild Færøvik

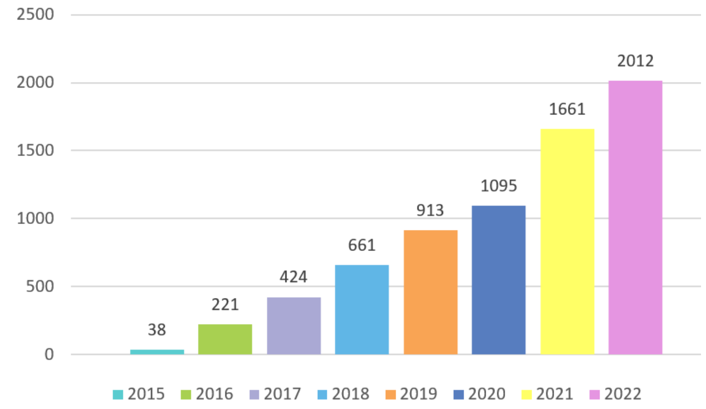
Assistant Professor Krzysztof Basinski from Medical University of Gedansk testing an EEG paradigm with MIB postdoc Alexandre Celma-Miralles.

PUBLICATIONS 2022

Number of peer-reviewed articles



Number of citations



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Kaasgaard, M. (2022). Singing in Pulmonary Rehabilitation of Patients with Chronic Obstructive Pulmonary Disease (COPD). Aarhus University.

Hoegfeldt, N. (2022). Perchance to sleep: Changes in brain and behaviour after becoming a parent Aarhus University

Books

Chemi T (editor), Brattico E (editor), Fjorback LO (editor), Harmat L (editor). Arts and mindfulness education for human flourishing. Taylor & Francis.

Jespersen K V, Gebauer L, Vuust, P. Music Interventions in Health Care: White paper. Center for Music in the Brain, Aarhus University.

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Other

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OUTREACH 2022

Talks at international conferences

Alberte Baggesgaard Seeberg
CI2022 DC Emerging Issues in Cochlear Implantation, Washington DC, United States
SysMus22 - International Conference Series of Students of Systematic Musicology, Ghent, Belgium

Ana Teresa Queiroga
Tec2Med Summit 2022, Almada, Portugal

Elvira Brattico
The 9th Mismatch Negativity Conference, Fukushima, Japan.
First International Conference, PLT (Psychology, Learning, Technology), Foggia, Italy
Social BRIDGES Conference, Munich, Germany
TeaP 2022 (Tagung Experimentell Arbeitender Psychologie), Köln, Germany
XXIII CIM Colloquio di Informatica Musicale, Ancona, Italy.
Conference: “Musical instrument and school inclusion”, Rome, Italy
Conference: “Radici comuni nel Mediterraneo – Echi di comPassione nelle musiche della Settimana anta”, Italy

Gemma Fernández Rubio
SysMus22 - International Conference Series of Students of Systematic Musicology, Ghent, Belgium

Jan Stupacher
Social BRIDGES Conference, Munich, Germany

Kira Vibe Jespersen
Conference of the International Association of Music and Medicine, Athen, Greece

Leonardo Bonetti
Sempre 50th Anniversary Conference, London, UK

Massimo Lumaca
Music Cognition Symposium: Music Cognition in theory and practice, online

Morten Kringelbach
Conference of the European Society for Cognitive and Affective Neuroscience (ESCAN), Vienna, Austria
Matchpoints Conference, Aarhus, Denmark
CFP: Interspecies Comparisons of Welfare, London School of Economics, London, UK
Neuro X Institute, Geneva, Switzerland

Niels Christian Hansen
Social BRIDGES Conference, Munich, Germany

Niels Trusbak Haumann
The 9th Mismatch Negativity conference, Fukushima Medical University, Fukushima, Japan

Ole Adrian Heggli
Social BRIDGES Conference, Munich, Germany

Peter Keller
22nd Conference of the European Society for Cognitive Psychology (ESCoP). Lille Grand Palais, Lille, France.
Conference of the European Society for Cognitive and Affective Neuroscience (ESCAN). Vienna, Austria.
Workshop on ‘Rhythm, Beat, and Oscillations in Music and Speech’, Universite Claude Bernard Lyon, Villeurbanne, France
23rd International Society for Music Information Retrieval Conference (ISMIR). Begaluru, India
International Workshop on the Neural and Social Bases of Creative Movement, Wolf Trap, Vienna, Virginia, USA

Peter Vuust
Social BRIDGES Conference, Munich, Germany
Matchpoints Conference, Aarhus, Denmark
Music Cognition Symposium: Music Cognition in theory and practice, online

Other talks (selected)

Alberte Baggesgaard Seeberg
International one-day seminar: Borderlands of living, Interacting Minds Centre, AU, Denmark

Alexandre Celma-Miralles
5th Annual Research Meeting, Institute for Clinical Medicine, Aarhus University, Denmark

Elvira Brattico
CBC Seminar at Center for Brain and Cognition, Universitat Pompeu Fabra, Barcelona, Spain
Workshop: Music analysis and cognitive processes. Conservatory of Bari N. Piccinni, Bari, Italy
Workshop: Musica e benessere psicologico, Ordine degli Psicologi & Conservatory of Bari N. Piccinni, Bari, Italy
Workshop; DSA e disabilità, l’inclusione nel sistema AFAM, Conservatory of Bari N. Piccinni, Bari, Italy

Kira Vibe Jespersen
Brain Awareness Week, Denmark
Sindslidendes Vilkår, Aarhus, Denmark
Kolding Bibliotek, Denmark
Vestre Skole, Aarhus, Denmark
Danish Sound Cluster, Denmark
Centre for Eudaimonia and Human Flourishing, University of Oxford, UK

Leonardo Bonetti
Linacre College, University of Oxford, UK
University of Geneva, Switzerland
Brain Awareness Week, Ukraine
Pinotsis lab, City, University of London, UK & Massachusetts Institute of Technology USA
The International High IQ Society, Italy

Mette Kaasgaard
Voice Study Centre, Bergholt Suffolk, UK

Morten Kringelbach
2022 Chevening Gurukul Fellows, Oxford, UK
Archbishop Tutu Leadership Programme Fellows, Oxford, UK
Young Global Pioneers, Oxford, UK
OUPS (Open University Psychological Society) Conference, Warwick, UK
Psychedelic Society of the University of Oxford, UK

Peter Keller
Lyon Neuroscience Research Center (CRNL), University Lyon 1, France
Interacting Minds Centre, Aarhus University, Denmark
Italian Institute of Technology, Rome

Peter Vuust
Karolinska Instituttet, Sweden
Columbia University, USA
New York University, USA
Hearts and Minds festival, Folkeuniversitetets Vidensfestival, Denmark
Oxford University, UK
Folkemødet, Bornholm, Denmark
Odense University Hospital, Denmark
DR P3, Denmark
6. Nationale Neurokonference, Denmark
Aros Festival, Denmark
Nationalt Videnscenter for Demens, Denmark
Odense Symfoniorkester, Denmark
Kunst og Kulturhøjskolen, Denmark
Sindets Dag, Odense, Denmark
Struer Hørecenter, Denmark
Dansk Neuropædagogisk Selskab, Denmark
Faglig Kongres – Kiropraktorernes Videnscenter, Denmark
Viby Amtsgymnasium: Denmark
Høreforeningen København, Denmark
Gramkom Østjylland, Denmark
Dalgas Skolen, Denmark

Participation in TV, radio and podcasts (selected)

Alberte Baggesgaard Seeberg
Podcast: Research * Clinical Practice: Explainable AI at the Borderlands of Living

Alexandre Celma-Miralles
Wall Street Journal: Rats Move to Musical Beat as Humans Do, New Study Suggests

Jan Stupacher
Deutschlandfunk – German national radio broadcasting (DLF)

Kira Vibe Jespersen
Podcast: Videnskabskanonen - Episode 9 ”Musik - kuren mod søvnløshed?”
P4 Radio Kraniebrud
P2 Foyeren

Niels Chr. Hansen
TV2 Go’ Aften Live
P3 Radio Påstand mod påstand

Peter Keller
Podcast: The Bulletproof musician
ABC Radio, Australia: National Weekend Evenings

Peter Vuust
TV2 Nyhederne
Novo Nordisk Podcast: Lyden af Videnskab
BJKS Podcast: Peter Vuust: music in the brain, predictive coding, and jazz
Trommernes Sjæl podcast: Peter Vuust - Rytmer på Hjernen
Inspiratio Podcast: Musikalske læreprocessor
WDR German Radio – 7 shows
Brainstorm podcast: Hvorfor får man irriterende sange på hjernen
Radio 8 Jazz
Radio 4 Kulturmagasinet Kræs
Radio 4
Radio P1
Radio 4 Kraniebrud podcast
DR3
P1 Hjernekassen: Komposition
Radio 24-7
Newstalk Irish radio

Interviews in printed media/web (selected)

Kira Vibe Jespersen
Videnskab.dk: Tre råd: Sådan kan musik hjælpe dig med at falde i søvn

Mette Kaasgaard
Lungeforeningen: Sangtræning giver dig pusten tilbage

Morten Kringelbach
Descopera.ro: Muzica ne ajuta sa întelegem cum functioneaza creierul uman
Forbes: Music And The Brain: Predictions And Expectations
EurekAlert: Great expectations - Music helps us understand how the brain works
TheBody.com: The Science Behind Music and Sex

Olivia Foster Vander Elst
Guardian UK: Watch Strictly, eat sauerkraut, win at Monopoly: expert tips for hacking your happy hormones

Peter Vuust
Heartsandminds.fuau.dk: Peter Vuust: Ambitionen er at forstå, hvordan hjernen behandler musik
www.bt.dk: Er du én ud af 10.000?
djoefbladet.dk: Her er musikken, du skal undgå, når du arbejder
tv2.dk: Én sang synges igen og igen – udtryk for ”naiv optimisme”
Berlingske Tidende: Børns hjerner blev hurtigere ældre under coronakrisen, konkluderer nyt studie, som møder kritik
IFORM: Musik giver flyvende træning - og blødere landing
Kristeligt dagblad: Spotify har skærpet folks minder om året, der gik
Videnskab.dk: Fremmer alkohol det kreative geni?
Jyllandposten: Hvem gider høre fars musik? Hvem gider i det hele taget høre på far?
Musikeren: Musikalske A-og B-skoler