WORDS FROM THE DIRECTOR

The year of 2021 became the most productive year in terms of publications in MIB's existence, evidenced by 62 published papers compared to an average of 37 over the first six years of MIB. This was partly caused by Covid-19 and the consequent national lock-downs both in 2020 and in the first half of 2021, which gave us the possibility to focus on analyzing already collected data and writing up papers. The rise in quantity was coupled with an equally enhanced quality of the papers, where 27 of the papers were published in journals with an impact factor higher than five.

These publications strike an excellent balance between theoretical and experimental papers: Some papers lay out the theoretical fundament for the research into music and brain and contribute with new analytical tools and methods which are then used and tested experimentally. This is true for Professors Morten Kringelbach, Peter Vuust and colleagues. They used mathematical modeling to describe the hierarchical organization of the brain and brain connectivity resulting in insights and analyses tools which were then the basis for studying brain connectivity in relation to musical memory and are currently used in the study of musical improvisation. Other theoretical work was devoted to describing how music is shared between people, such as Assistant Professor Ole Adrian Heggli's MEAMSO model which describes musical interaction as guided by mutual reduction of prediction errors; in effect rendering themselves mutually predictable. These models inform our understanding of how competence, social context, and dyadic interactions rest on predictive brain processing in general and are at the core of MIB's future research plan as an extension of the PCM model to communication of musical meaning between individuals. The ideas are currently being tested in studies where laypersons and musicians tap together, learn musical excerpts from each other and improvise together. Of special interest to music learning is Professor Elvira Brattico, Professor Peter Vuust and colleagues' paper on the neural correlates of music listening in which it is proposed that music listening, even when conceptualized in an aesthetic and eudaimonic framework, remains a learnable skill that changes the way brain structures respond to sounds and how they interact with each other.

At MIB, we take particular pride in the efforts to translate our basic understanding of brain processing of music into experiments with relevance for patients as well as for music learners. Over the years, we have expanded our interests into clinical populations such as patients with cochlear implants, with autism, with sleep problems, with noise sensitivity, with chronic pain, and lately with Parkinson's disease, and we are part of a large-scale rehabilitation effort for patients with chronic lung disease. In relation to

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.

musicians and musical students we published two papers in 2021 co-authored with professors at the Royal Academy of Music which showed that mental imagery may be a way to improve the efficiency of musical practice, while at the same time reducing the probability of injuries from overtraining.

There is, however, no doubt that for most of us, hosting the Neuroscience and Music VII conference will remain the strongest memory from 2021. This event is the most important conference on music and neuroscience worldwide - held only every third year and always with the most prominent researchers within the field of music and brain as speakers. It had been postponed from 2020 because of Covid-19 but finally took place in 2021 at the Aarhus Concert Hall and online. Pioneering this event for the first time as a hybrid conference took its toll, but everyone at MIB and the Mariani Foundation made a massive effort, and the conference was a huge success with 100 onsite participants and more than 400 online participants. A full account of the conference can be found on pp. 66-73, where also Vice President of the Mariani Foundation Maria Majno with Luisa Lopez and this year's recipient of the Neuromusic Lifetime Achievement Award Professor Eckart Altenmüller have given their impressions of the conference.

Leading up to the conference our Summer School, led by Professor Elvira Brattico, debuted in an online version with 27 participants featuring prominent speakers such as Professors Robert Zatorre and David Huron. The summer school will be a biennial event from now on (see p. 63) and has been approved as a part of 'Summer University' at Aarhus University.

Later in the year we hosted the 14th International Conference of Students of Systematic Musicology (SysMus), this year arranged by MIB students and postdocs (see p. 62). SysMus was fully funded by Lundbeck and Carlsbergfondet, meaning that the 55 onsite participants and 119 online participants were able to attend for free. The SysMus conference is directed at young researchers in particular and gave us the opportunity to highlight the MIB research for this international crowd and thereby possibly to attract potential new PhDs.

In July, Christine Ahrends defended her PhD thesis investigating the role of predictability and uncertainty in human brain dynamics, and she has continued her career as a postdoc at CFIN, AU. Victor Pando defended his PhD thesis in September on musical groove in Parkinson's patients and was subsequently employed as postdoc at MIB. We said goodbye to long-term employees David Quiroga and Leonardo Bonetti. David went to University of California, Berkeley to study music processing with intracranial recordings in patients with epilepsy with funding from the Independent Research Fund Denmark, and Leonardo won a Carlsberg Foundation Visiting Fellowships at University of Oxford. We remain in close collaboration with both and see this as a great opportunity to expand our international collaborations and gain access to new methods and analysis tools.

The beginning of our 2nd period as a Center of Excellence coincided with returning to the offices after another national lock-down due to Covid-19. Soon the offices were buzzing with activity with the arrival of nothing less than 5 new PhD students: Gemma Fernandez Rubio, Alberte Seeberg, Mathias Klarlund, Olivia Foster Vander Elst and Rebecca Scarratt. We also welcomed a new postdoc, Tomas Matthews, who has been our long-term collaborator on the prominent studies on musical groove.

In November, we were extremely happy and proud to be joined by our new professor, Peter Keller. Peter has been a good friend and collaborator for years, and he is a perfect fit for MIB with his expertise. His main interest into musical interaction, of which he is a world-leading expert, coincides exactly with the goal of our second period which focuses on the role of music in establishing, maintaining and fine-tuning meaningful human relationships and interactions.

Again in 2021, MIB received generous external funding. William Demant Foundation granted Professor Peter Vuust, Associate Professor Bjørn Petersen and collaborators at Southampton University DKK 3,740,000 for a project investigating rhythm and groove perception in cochlear implant (CI) users and how this perception can be enhanced by use of an electro-haptic device (a wristband transmitting sound frequencies to the skin of the arm). Professor Elvira Brattico received DKK 1,1 mill from Sino-Danish Center (SDC) for a PhD project on the neuroscience of the cross-cultural impact on synchronization, with a particular focus on Chinese culture, and MIB was grateful to receive grants from SEMPRE and BIAL Foundation.

With this annual report, we wish to highlight the scientific progress and key events in 2021 and 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 MIB
Peter Vuust

PERCEPTION

Peter Vuust, Elvira Brattico, Morten L. Kringelbach

By Boris Kleber

In the Perception strand, several projects were successfully completed in spite of pandemic challenges. Specifically, the Orkestermester project (Prof. Brattico) was brought to a fruitful end[1]. Aimed to unravel developmental brain differences underlying auditory perceptual processes, the non-standard musical multifeature (MuMuFe) paradigm was used in non-musically trained children and adults to trigger auditory mismatch responses (MMRs) in the brain. This paradigm evoked acoustic prediction errors by introducing unexpected changes to timbre, pitch, and intensity in a tone sequence, as well as slides and omitted tones. By comparing children with adults, Postdoc Alexandre Celma-Miralles demonstrated, for the first time, robust MMRs in the EEG of both groups. The MMR polarity was negative in adults and positive in children, except for tone omissions (Fig. 1), suggesting developmental modifications. Children also showed greater absolute mean amplitudes and longer latencies across all acoustic manipulations. Moreover, musical sophistication tests (i.e., Musical Ear Test and the miniMET) revealed that children yielded lower scores in the melody than in the rhythm sub-test, whereas adults obtained similar scores, suggesting that rhythmic discrimination skills may develop before melodic skills, although these scores were not directly linked to the brain responses. In summary, the Orkestermester project demonstrated that the MuMuFe paradigm is a novel and useful tool for tracking developmental changes in neural responses to music in children, making it suitable for determining the age at which children's MMRs become more adult-like.

Assist. Prof. Niels Chr. Hansen's work on predictive processing and highly specialized types of musical expertise also progressed well during the past year. His collaborative study with Haley Kragness and leading colleagues in Canada and the UK demonstrated a role for predictive entropy as a prospective cue to the perception of musical phrase structure - a finding that may very well have implications beyond music such as in the domains of linguistic sentence structure, gestural coordination, and other types of non-verbal communication[2]. The first empirical tests of Niels Chr. Hansen and Lindsey Reymore's novel theory of Instrument-Specific Absolute Pitch (ISAP) in the general musician population also took off in 2021. Echoing MIB's goal to increase scientific rigor and reproducibility, key hypotheses and statistical analyses were all openly declared in a Registered Report[3]. Results from 40 expert oboists collected internationally during pandemic lockdown via digital conference software are currently prepared for publication.

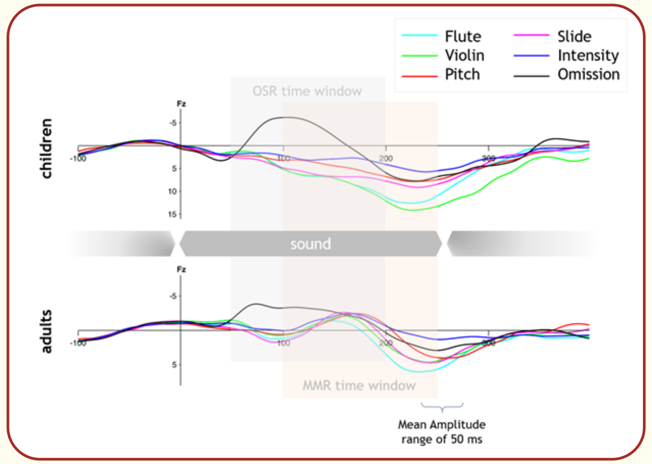

Figure 1: *Results from the Orkestermester project. Robust responses to unexpected acoustic features were found in both children and adults. Differences involved the polarity of EEG responses, which were negative in adults but positive in children.*

A study by Dr. Niels Trusbak Haumann and collegues addressed brain changes underlying age-related hearing loss, which has gained increasing scientific interest in recent years. Standard interventions for peripheral hearing loss involve fitting patients with electronic hearing devices to physically amplify the affected sound frequency bands. However, this approach neglects the accompanying brain changes, which may aggravate the consequences of age-related hearing loss. In fact, one of the most challenging problems in the elderly is the deterioration of speech and music perception in noisy environments. Prior studies using simplified auditory stimuli to trigger acoustically evoked potentials in the EEG reported larger amplitudes (i.e., less inhibition) of the P1 and N1 brain response components and smaller amplitudes of the P2, mismatch negativity (MMN), and P3a components in age-related hearing loss. On contrast, this study with older (55-77 years) and younger (21-31 years) participants used musical stimuli that differed with respect to their ecological validity: high = actual music recording; medium = synthesized melodies. Age-related response differences were expected to consist of either larger amplitudes—representing age-related fronto-temporal atrophy that may impair the processing of complex naturalistic auditory stimuli—or smaller amplitudes, which might indicate optimized neural responses for auditory stimuli that match one's actual hearing experience. The P1 and N1 components showed similar amplitudes across groups, whereas age-related effects yielded smaller amplitudes for the P2 components in recorded versus synthesized melodies, demonstrating that brain responses in older participants are differently modulated by ecologically valid sound samples. This suggests that our brain is more optimized for processing realistic auditory stimuli, emphasizing their importance for investigating neural mechanisms underlying age-related hearing impairments[4].

A new collaboration was established in 2021 between Postdoc Cecilie Møller and Prof. Preben Kidmose's group at the Center for Ear-EEG, Dept. of Engineering, AU. This resulted in the successful defense of Heidi Bliddal's master's thesis, which investigated the neural correlates of beat perception using the novel ear-EEG technology. By combining scalp and ear-EEG recordings in 20 participants, they found that (i) neural response peaks at beat-related frequencies were greater as what could have been expected based on scalp EEG data, indicating that (ii) neural correlates of beat perception can be reliably measured with this innovative, discrete and mobile technology. Postdoc Alexandre Celma-Miralles has joined the project as an expert in beat perception EEG paradigms in order to optimize the data processing pipelines.

In the multisensory domain, Postdoc Cecilie Møller published a DTI/MR paper, investigating audio-visual structural connectivity in musicians and non-musicians, analyzed by former MIB PhD student and current head of PsiLANTRO Lab at Universidad Nacional Autónoma de México Eduardo A. Garza-Villarreal. In a nutshell, the structural analyses showed that non-musicians relied more on visual cues for pitch discrimination. However, these results correlated positively with fractional anisotropy values in the inferior fronto-occipital fasciculus, which connects auditory and visual brain areas. These findings are an important contribution to the field of auditory neuroscience, as they show that the development of auditory skills associated with long-term musical training may not only alter the layout of unisensory auditory regions in the brain but also those supporting the simultaneous processing of multimodal sensory inputs.[5]

Indeed, real-world experiences are rarely limited to processing unisensory signals but rather require the parallel segregation and integration of different sensory modalities. Multisensory processes have therefore seen intense investigations

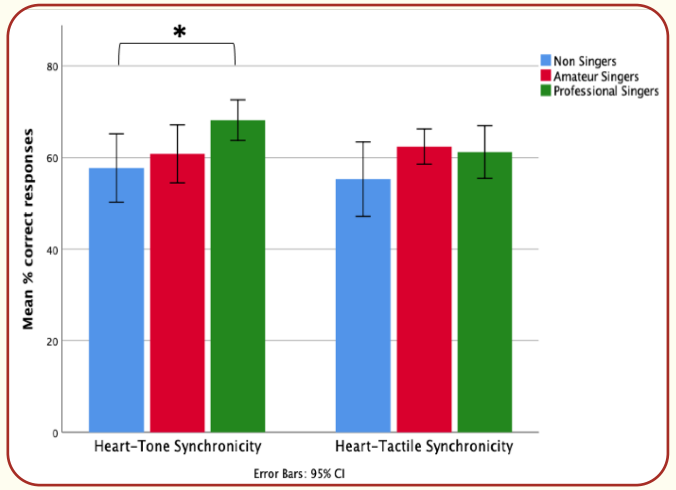

Figure 2: *(A) Differences in interoceptive accuracy as a function of singing experience using a heartbeat discrimination task. (B) Differences in singing accuracy, defined as the mean deviation from target pitch in cent (100 cent = 1 semitone). (C) Correlations between music sophistication tests and interoceptive accuracy, revealing a strong link between musical skills and the ability to perceive inner bodily signals.*

in recent years, revealing that cross-modal sensory experience can alter neural activation patterns and coordinate activity across different brain areas, which in turn enhances perceptual (e.g., seeing, hearing, touching) and motor performance. This notion has recently been extended to the processing of interoceptive information about the body state. That is, multisensory integration of coherent endogenous (i.e., interoceptive) and self-relevant exogeneous (visual, auditory, tactile) cues may inform perceptual representations and action selection, such as externally directed (e.g., skeletomotor) actions, which provide a robust mechanism for enhancing the detection of internal bodily sensations. Previous studies found a strong link between long-term musical training and enhanced cardiac interoceptive accuracy, which have been attributed to the effects of accumulated multisensory experience. In fact, musicians constantly integrate acoustic, visual, and tactile cues with interoceptive information about muscle tension, cardiovascular, and respiratory activity to orchestrate precisely timed and highly complex motor sequences. However, the question remains whether enhanced interoception also supports specific music skills. To address this question, Assoc. Prof. Boris Kleber assessed a large group of participants with different levels of singing experience (none, amateur, professional), using a battery of musical performance and perception task in addition to cardiac interoceptive accuracy tasks. Results confirmed the effect of musicianship on interoceptive accuracy by revealing enhanced interoception in professionals relative to non-singers (Fig. 2A). Ceiling effects on musical tasks among trained singers (Fig. 2B) perpetuated correlations with individual differences in interoceptive accuracy. However, enhanced cardiac interoception both across groups and within non-musicians was correlated with enhanced pitch accuracy during singing, as well as with enhanced musical beat discrimination (Fig. 2C). Together, these results provide the first direct link between interoceptive ability and musical skills, supporting not only the multisensory experience theory but also the increasingly popular view that one's ability to detect perceptual inputs and attribute meaning to them is strongly linked to one's own actions.

Self-related perceptual processes also play a substantial role in the emergence of feeling states, mood regulation, and psychopathology. Specifically, current neurobiological models of non-verbal emotional vocalizations have modelled the underlying neural dynamics from the limited perspective of either production or perception—but, critically, never combined. Thus, Assoc. Prof. Boris Kleber has initiated as series of behavioral and neuroimaging studies to assess the interaction between voice perception, production, and the self by using a novel paradigm to construct ecologically meaningful situations in the fMRI scanner. By inducing well-characterized, self-relevant emotion states, the aim is to disambiguate the parallel neural processes associated with acoustic self-perception from those associated with their conscious appraisal in order to determine whether the self-evaluation of our own voice influences the way we feel, which in itself may reinforce our production, thus creating an emotional acoustic feedback loop that modulates brain dynamics and consequently our mood.

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PERCEPTION

Perceptual learning of music patterns produces changes in the effective connectivity of auditory regions

By Massimo Lumaca

Natural sounds such as music and language are rich in structured patterns. In music, sound patterns like riffs and ornamentations, or chord progressions, form the bricks of melody, rhythm, and harmony. Accumulating evidence in auditory research suggests that humans are particularly sensitive to sound patterns: we learn them fast and flexibly so as to optimize their memory traces over repeated presentations[1]. Over the past two decades, with the progress of neuroscientific analysis techniques, scientists started to ask questions about how sound patterns are encoded and updated in the brain. What brain dynamics do support the optimization of memory traces during music learning?

In a recent study from MIB[2], we have tried to address this question by adopting two elements: i) predictive coding (PC) as a theoretical framework to address mechanistic questions about (perceptual) learning; ii) dynamic causal modeling of neural data as a computational tool to examine the network-level mechanisms that support the optimization of memory traces for auditory patterns. In PC, music learning can be thought of as a process whereby error signals, elicited by unexpected sounds, are passed on from lower- to higher-level regions of the auditory hierarchy to optimize predictive models of music regularities.

While classical neuroimaging analyses can be useful in localizing brain regions involved in this process[3,4], they cannot provide a mechanistic account of how those regions causally interact to allow the passing of prediction error signals.

The recent development of computational models in neuroscience, such as dynamic causal modeling (DCM), allows us to test mechanistic hypotheses directly from brain signals. DCM embodies a generative model —a biologically-inspired simulator of brain activity— that allows us to examine how brain responses change by adding or removing connections within (intrinsic connections) and among (extrinsic connections) the nodes of a network. Using an approach named 'Bayesian model selection', we can assess which network configuration (dynamic model) produces the best match between the simulated and observed data. More recent developments of second-level DCMs, the Parametric Empirical Bayes (PEB), further allow us to examine whether the observed signal is better explained by changes (increases or decreases) in the effective connections within the "winning" network.

In our study, 52 healthy volunteers underwent functional MRI (fMRI) scanning while presented with standard and deviant five-tone auditory patterns (Fig. 1A). First, we identified a bilateral network of auditory regions (A1, primary auditory

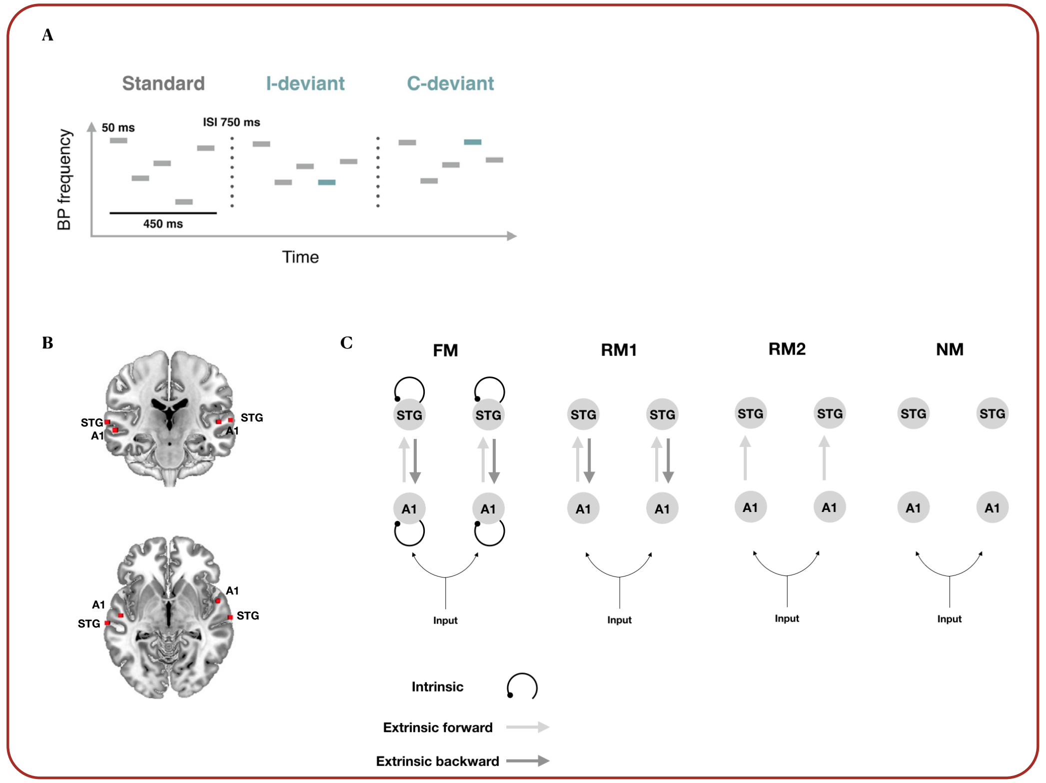

*Figure 1. Schematic illustration of the paradigm and brief description of the dynamic causal models. **A)** Five-tone auditory patterns (standard and deviant) presented to participants during fMRI scanning. Deviants were constructed such that the fourth tone violated the melodic contour ('C-deviant') or the interval ('I-deviant') of the standard sequence. **B)** Anatomical network of four auditory regions where deviants elicited larger BOLD response than standards. **C)** Four competing models built on the network of interest: full model (FM), reduced model 1 (RM1), reduced model 2 (RM2), and null model (NM). These models differ for the presence (or absence) of intrinsic and extrinsic connections.*

cortex; STG, superior temporal gyrus) whose activity was larger for deviant than for standard sounds (Fig. 1B). Then, we constructed four competing configurations of the same network, having the same anatomy but differing in the way they were connected (Fig. 1C). A Bayesian model selection revealed that the network with all connections (full model) outperformed the others in explaining brain activity to deviant responses (Fig. 2A). Within that network, we found the same responses being accurately predicted by left-hemispheric changes in effective connectivity: a decrease in the intrinsic connectivity of the left A1 and a concomitant increase in extrinsic connectivity among left HG and PT (Fig. 2B,C).

These results can be interpreted within the PC at a neurobiological level[5] (Fig. 2B). Following an unexpected sound in the melodic pattern, the participants briefly orient their attention to the auditory stimulation. Attention-related mechanisms affect the activity of two neural populations in the primary auditory cortex: inhibitory interneurons and pyramidal neurons encoding the prediction errors (PEs). Specifically, the reorienting of attention towards oddball sounds reduces the influence of interneurons on the pyramidal neurons, which are de facto disinhibited and

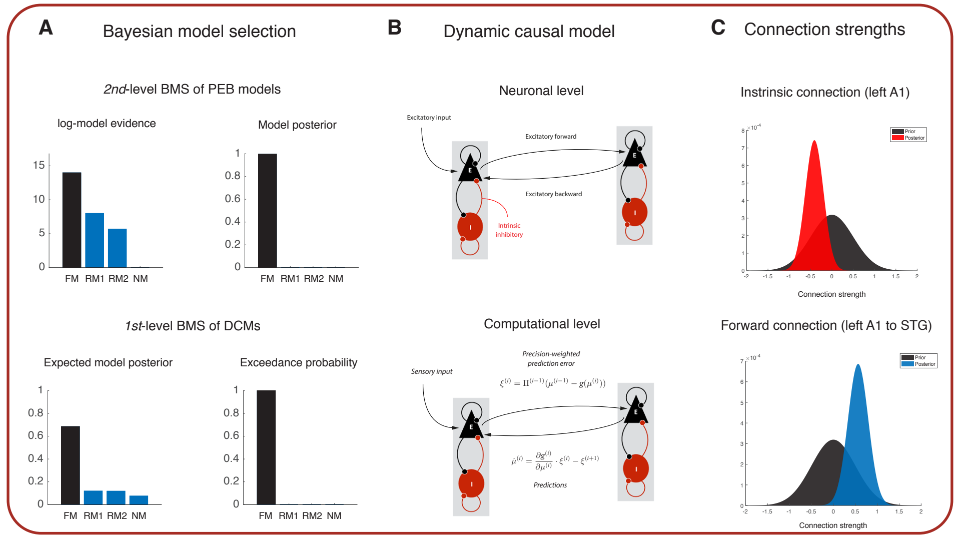

Figure 2. Results of the DCM analyses. *A)* A Bayesian model selection reveals that the full model (FM) is the best at explaining the data. *B)* Neural and computational representations of the winning model. Interneurons (red spheres) inhibit the pyramidal neurons (black triangles) through intrinsic connections. A1 and STG communicate through extrinsic connections. *C)* Increase of effective connectivity from A1 to STG, and decrease of intrinsic connectivity within A1, are represented as movements of posterior distributions from the prior

more responsive. Pyramidal neurons are then free to pass the PEs to secondary auditory cortices, optimizing the internal predictive model of the pattern.

Our result supports the widely-accepted view in PC that attention operates as a gain controller, increasing (or decreasing) the responsiveness of PE neurons according to the salience of the stimulation[6]. We support this idea in the auditory domain using, for the first time, DCM on a brain network identified with the millimetric resolution of fMRI. Our work suggests that the superior temporal gyrus alone can establish mental models of simple sound patterns, generate predictions, and update these models when predictions are not fulfilled. Future studies need to address the role of frontal circuits for more complex auditory stimulation.

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WHEN MUSIC NEUROSCIENCE MEETS A DIGITAL ART FESTIVAL

Aarhus Futura: imagining the world 5 years from now is a festival that aims to stimulate creativity in Digital Culture Dissemination, Art, Technology, Science and Speculative Design. It was founded in 2021 with the intention to offer a platform to promote digital culture, produce digital art installations and digital live performances, bringing together a global community of artists, scientists, developers, designers, entrepreneurs, activists and audiences.

In this first edition (October 9th, 2021), MIB postdoc Alexandre Celma-Miralles collaborated with Mathieu Durand (Dystopian Creatives) to create the event "Your Noisy Brain", a short neuroscientific "experiment" about the mysterious world of our minds. Over 6 hours, more than 22 volunteers participated in this experience at Kulbroen in Aarhus, Denmark and received an IRIS image showing their "neural states" during the listening of six musical genres (i.e. Indie Pop, Hard Rock, Classical, Techno, Funk-reggae, and Reggaeton). Our idea was to track and depict changes in mental states related to the perception of different music styles.

We used portable electroencephalographic technology (Emotive Insight 2) to record participants' brain responses to six musical genres in real time. The Emotiv Brain-Computer-Interface software provided us with values for stress, relaxation, interest, engagement, excitement and focus. Using a custom-made program (TouchDesigner 2021.15240), we presented 30-second musical excerpts while digitally printing the values from the wearable EEG device into a colorful IRIS image. During the experience, participants could watch as the IRIS image changed in real time along with their "neural states". After the experience, the final IRIS image was sent to the participants by email along with the list of the presented songs.

Collaborations with intersectional festivals like AarhusFutura attract the general public to neuroscientific research, and at the same time researchers are offered a perfect window to develop naturalistic out-of-lab studies.

Postdoc Alexandre Celma-Miralles recording the IRIS image of Tomas Matthews. Examples of other IRIS images appear here in the background. More intensity in color means higher values in each recorded mental state. The list of the presented songs (in clockwise order) was 1. "Hitzeman" - Zetak & Oques grasses; 2."Painkiller" - Judas Priest; 3. "Cold" - Jorge Méndez; 4."Everytime we touch" - Cascada; 5."Outta road" - Naâman; and 6. "Con altura" - Rosalia.

ACTION

Peter Vuust

The Action strand focuses primarily on musical rhythm[1], and how it relates to movement[2], interpersonal interaction[3,4], musical expertise[5,6], improvisation and rehabilitation efforts[7-8]. Action and perception are linked in the predictive coding of music (PCM) model, so that perception minimizes prediction error by updating predictions, while action minimizes prediction error by engaging motor systems to resample the environment.

In 2021, we published experimental papers, meta-analyses[9], analyses of big data[10,11], contributed substantially to the theoretical development of PCM[12-14] and attracted substantial external funding for continuous clinical studies of the perception of rhythm in patients with cochlear implants.

Many of these results were presented at the Neuromusic VII conference, where we also presented our new theoretical model of how PCM may be extended from describing music in the single brain to musical interaction, which is featured in our review paper in Nature Reviews Neuroscience[15] (Fig. 1). According to this model, musical communication is shaped by the interacting individuals' predictive models through reciprocal predictive coding mechanisms. The interaction leads to shared predictive models, a process which is mediated by action-perception coupling of both individuals.

The PCM model for musical interaction resonates well with other theoretical work on musical interaction from the Action Strand[16,17] and a series of experiments carried out in collaboration with the Institute for Psychoacoustics and Electronic Music (IPEM) in Gent. IPEM PhD student Mattia Rosso conducted studies in Aarhus and Gent in which he had pairs of participants tapping to metronomes which were running at slightly different tempi. The participants were either coupled, i.e., could see each other or hear each other, or uncoupled, i.e., had no contact at all. In the coupled conditions but not in the uncoupled conditions, the participants' tapping were affected by their partners' tapping when the phase between the metronomes was small, but less so when the metronomes and thereby the tapping of the dyads had drifted towards being in antiphase. Accordingly, EEG recorded during the experiment showed beta-band bursts synchronized to both one's own tapping and to the partners tapping, indicating that there may be a common brain mechanism which is responsible for tracking both one's own tapping and for predicting a partner's taps.

These tapping studies shed light on the moment-to-moment communication and coordination of actions which is an important part of musical performance. Another aspect of musical interaction is studied by Assist. Prof. Massimo Lumaca, who uses signaling games to investigate how music is transmitted from one person to another and the underlying neural mechanisms of generational learning. Using diffusion tensor imaging (DTI) as well as a more advanced dMRI technique: fixel-based analysis (FBA), Lumaca showed that interindividual differences in the human capacities for encoding and recalling auditory patterns are associated with variation in the organization of cross-callosal white matter pathways[18]. In subsequent experiments, he discovered a temporoparietal network in which the length of connections was related to the degree of compositionality introduced by each player, and that compositional behavior was linked to integration measurements in the left posterior cingulate cortex and left angular gyrus[19]. Individual differences in how we communicate musical material over generations are thus linked to differences in the structure and wiring of the brain underlying individual differences in PCM.

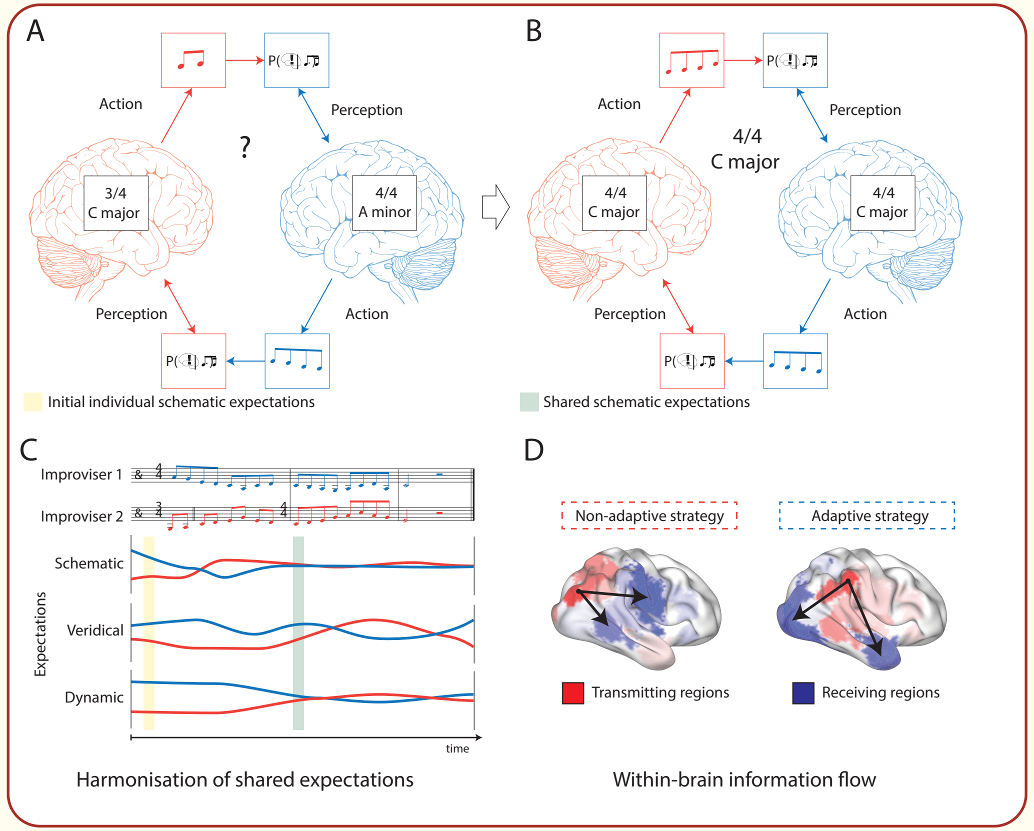

Figure 1. *The figure presents a model of musical communication inspired by predictive coding showing the continuous and reciprocal process of harmonizing expectations.* ***A)*** *Two improvisers (red and blue brain) may initially have different schematic expectations— i.e., they could experience different meters (a 3/4 and 4/4 meter) and tonalities (C-major and A-minor) while playing together.* ***B)*** *Over the course of the interaction these models may become harmonized into a shared experience of a 4/4 meter and C-major through reciprocal predictive coding mechanisms.* ***C)*** *The panel shows how a simulated interaction between two improvisers may evolve over time with three different types of simultaneously occurring and interacting musical expectations: schematic, veridical, and dynamic expectations. Initially (marked with yellow, corresponding to part a), the schematic expectations (based on experience of meter and tonality) are quite different as illustrated in the music examples. After a while (marked with green, corresponding to part b), when a shared predictive meter and tonality model has been established, the schematic expectations of the two improvisers converge. The middle and bottom panels illustrate that veridical expectations (of familiar musical material), and dynamic (short term) expectations will be more but not fully harmonized after the shared schematic expectations are established.* ***D)*** *A data-based example of synchronization of dynamic metric expectations, when two individuals from the same musical background tap a simple rhythm together (Vuust et al.2022).*

The power of the PCM is illustrated by the continuous line of studies in which the Action strand have investigated the inverted U-shape of groove – the link between degree of syncopation in a musical rhythm and how much we feel pleasure and urge to move. It is now a well-established fact that humans prefer to move to rhythms with intermediate amount of syncopation compared with high levels of syncopation, which we find too complex, and low levels, which we find to boring. In 2021, we showed how the inverted U-shape can be replicated with a minimal stimulus set[20] and that it can be accounted for by PCM as a product between amount of prediction error and precision of the metrical model. Currently, we are investigating the inverted U-shape in relation to musical rehabilitation in Parkinson's disease and for Cochlear Implantees.

Studying the sensation of groove in patients suffering from Parkinson's disease, Victor Pando-Naude showed in his PhD dissertation (see p. 76), which was defended in 2021, that the peak of the inverted U-shape is skewed towards rhythms with less syncopations for these patients, an effect which is more pronounced when they are off their usual medication. Furthermore, connectivity analyses on fMRI data shows enhanced functional connectivity between auditory areas and premotor cortex, for simple and medium complex rhythms, in contrast to isochronous and highly complex rhythms which do not engage the motor system. This is consistent with the claim of PCM that syncopated rhythms reaching the auditory cortices feed forward prediction error to the motor system which in turn provides updated predictions in the form of enhanced meter perception, supposedly by trying to move the body to support the meter (resampling of the environment).

In prolongation of this study, we have recently initiated a study in collaboration with University of Southampton investigating the inverted U-shape in patients with cochlear implants, based on generous funding from William Demant's foundation. These patients typically have substantially impaired music perception as well as impaired sound localization and speech recognition in background noise even though they do have close to normal perception of single streams of rhythm. What we do not know is how they cope with rhythm which is more complex and not in a single-stream as would be the case for most music. To facilitate the experience of musical rhythm and groove in such a more challenging musical setting, we provide them with a specific wearable electro-haptic stimulation, developed by Southampton University, to study their ability to move to the music and their experience of groove and the neural enhancement of feeling the beat, as measured by "frequency tagging" of the EEG. We will then use machine-learning techniques to convert audio to haptic stimulation to maximize benefit while ensuring real-world validity. The final goal is to be able to provide the CI users close-to-normal rhythm and groove perception when listening to real music, contributing to enhanced quality of life and enhanced social skills.

The social aspects of music is also the focus of the research of Postdoc Jan Stupacher who is interested in the questions how cultural familiarity with music and personal musical taste affect social bonding when moving to music in synchrony or asynchrony with another person. In an online video paradigm with participants from all over the world he showed that the influence of movement synchrony and social bonding is less affected by what music we are familiar with but more affected by what music we enjoy[21]. When the context-providing music was more enjoyed, social closeness increased strongly with a synchronized partner, but only weakly with an asynchronized partner. This interaction effect did not occur for musical familiarity: When the music was more familiar, social closeness was higher independently of movement synchrony.

In sum, the studies in the Action strand shows that the reason why music connects us may be that it combines bodily synchronization with positive emotions and indicates that if there is an evolutionary advantage of music, it is probably due to its ability to synchronize our movements, emotions and brains. This research has in turn strong implications for how we train musicians[22] and for the use of music in rehabilitation efforts.

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ACTION

Using polyrhythms to study beat perception online

By Cecilie Møller, Jan Stupacher & Alexandre Celma-Miralles

Studying the hierarchical organization of temporal patterns is an interdisciplinary effort. In our everyday life, we subdivide and structure time for example in speech and music. In a series of three behavioral online experiments with 300 participants, we investigated temporal processing from a music perception and cognition perspective[1]. Our results demonstrate a yet neglected influence of beat subdivisions on beat perception: Individuals most often synchronized with beats that contain binary as opposed to ternary or irregular groups of subdivisions. Such binary grouping of subdivisions reflects a propensity towards simplicity, which is also evident in a wide range of human behaviors, in cognition, in early stages of development, and across musical cultures.

The capacity for beat perception in music is often described as the ability to extract a regular pulse from a complex metrical structure. The extraction of a regular pulse also entails the perception and grouping of faster metrical units, i.e., beat subdivisions[2]. In polyrhythms, two metrical structures coexist, rendering several possible beats with which we can synchronize our movements (Fig. 1). In the present study, we used polyrhythms to focus on the yet neglected influence of beat subdivisions, i.e., the least common denominator of a polyrhythm ratio. In three online finger-tapping experiments, participants tapped in time with the perceived beat of 1) 2:3 and 3:4 polyrhythms in a wide range of tempi (n = 100), 2) polyrhythms with increasing levels of complexity, i.e., 2:3, 2:5, 3:4, 3:5, 4:5, 5:6 (n = 120), and 3) 2:3 and 3:4 polyrhythms with two octaves pitch differences between pulse trains (n = 80). Based on previous work[3], we hypothesized that participants would prefer to tap to a beat with binary rather than ternary or irregular subdivision grouping, and ternary rather than irregular subdivision grouping, suggesting a perceptual ranking of subdivision grouping.

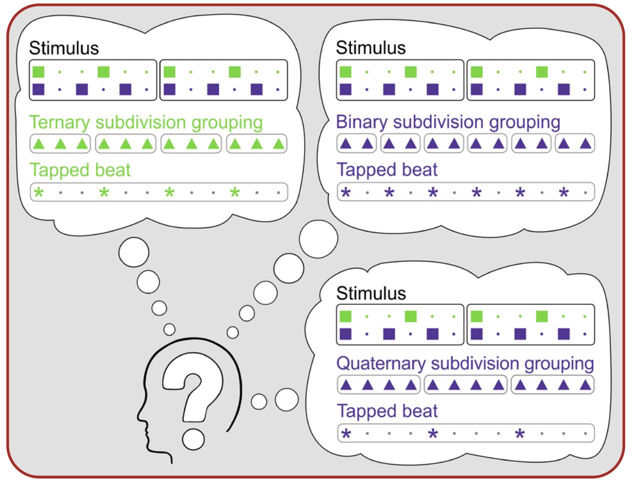

Figure 1: *Three different examples of interpretations of a 2:3 polyrhythm that lead to three different behavioral outcomes when synchronizing body movements, such as finger tapping, to the stimulus. The subjective experience of the rhythm's 'feeling' depends on the perceived beat, which in turn depends on the grouping of subdivisions.*

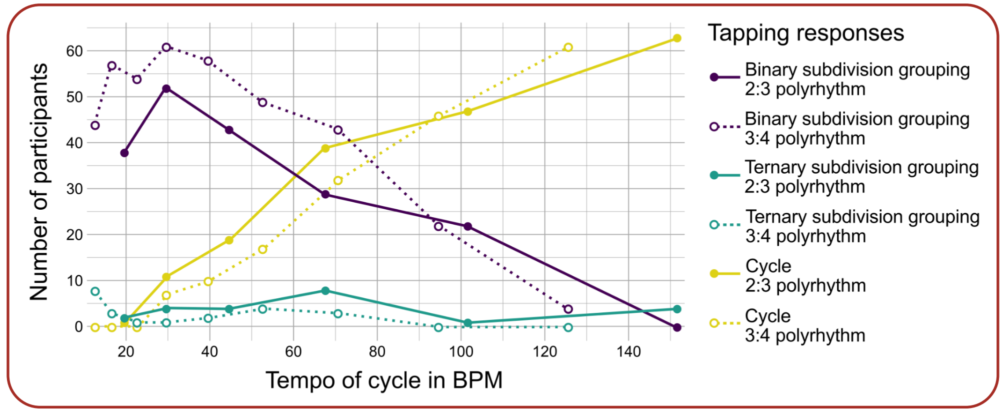

Figure 2: *Participants' preference for subdivision grouping in the tempo experiment. The different lines in the plot represent responses with binary (dark purple) or ternary (green) subdivision grouping. At slow and moderate tempi, most participants tapped in time with one of the response categories that admitted a binary subdivision. At faster tempi, participants switched to tap in time with the cycle (bright yellow). Only a few participants' tapping behavior corresponded to ternary subdivision grouping.*

In the Tempo experiment, participants most commonly chose to tap in time with pulse trains admitting a binary subdivision, i.e., the fast and slow pulse trains in the 2:3 and the 3:4 polyrhythms, respectively (Fig. 2). When tapping rates were too fast to synchronize with the pulse train admitting binary subdivision, an often used strategy was to tap in time with the cycle. This means that the vast majority of participants consistently avoided tapping in time with pulse trains admitting ternary subdivision.

In the Ratio experiment, we used more complex polyrhythms (e.g. 3:5 or 5:6) and found similar metrical preferences. In polyrhythms that combined binary and ternary or uneven subdivisions, participants preferred to tap in time with the pulse train admitting binary subdivision. In polyrhythms that combined ternary and uneven subdivisions, they preferred to tap with the pulse train admitting ternary subdivision.

In the Pitch experiment, we investigated how beat perception in polyrhythms is influenced by low frequencies. High energy in bass frequencies are important for inducing movements, such as tapping in time with the beat and dancing[4,5]. Consistent with these findings, in the current experiment, lower pitch modulated the tendency to tap to pulse trains admitting a binary subdivision. In sum, the findings of all three experiments support our idea of perceptual ranking of subdivision groupings for beat perception in polyrhythms.

Advantages and challenges of online studies

Collecting behavioral data during a pandemic is challenging because of the limited possibilities for face-to-face interactions with research participants. An obvious and increasingly popular solution to this problem is to use online data collection. In the case of questionnaire studies, this has been a common approach for a long time. Behavioral studies, however, are typically performed in a highly controlled lab setting and are harder to convert into an online format. This

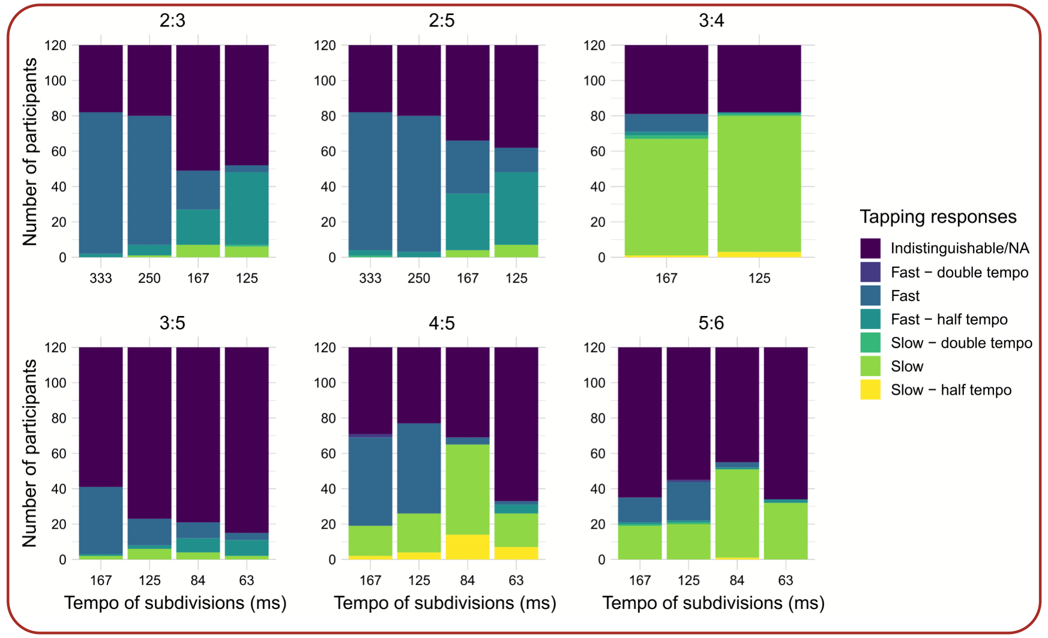

***Figure 3**: Tapping responses of the experiment presenting polyrhythms of different ratios. Metrical categories of the tapping responses for the individual tempi in each of the polyrhythm ratios. The category "Indistinguishable /NA" includes consistent tapping to the cycle and subdivision levels and to the polyrhythm itself, as well as inconsistent and no tapping responses.*

is especially true for experiments like the current one that depends on precise time measures such as tapping data. When collected online, this data is inherently noisy because participants use different operating systems, sound cards, browsers and input devices (mouse, touch pad, keyboard), which can influence tapping responses in indefinite ways. We met these challenges by focusing our analysis on inter-tap intervals and converting the linear tapping data into circular data. This means that we placed each tap on a circle in relation to an expected metrical periodicity. If the taps were constant, they should all have a similar angular phase and fall in a particular region of the circle, regardless of the sound-tap delay or missing taps. We used this property of circular statistics to categorize which metrical periodicity participants tapped. That is, for each possible metrical option (e.g. all subdivisions, fast or slow meter, cycle), we placed the taps on a circle whose period represented the corresponding metrical periodicity and afterwards selected the metrical category in which taps were most consistent. This method allowed us to discard inconsistent tapping responses that did not follow a regular beat (see the Indistinguishable/ NA category in Fig. 3). These include for example participants tapping the rhythm and not the beat, or switching back and forth between metrical categories, and responses with browser- and device-induced noise.

Future perspectives

Our findings suggest that we structure subdivisions in musical rhythms in the simplest possible way, i.e., binary over ternary over irregular. The knowledge about the universality and limits of the human propensity towards simple subdivision grouping in temporal processing still has to be refined. Two main questions for expanding the current research are: How does the interpretation of polyrhythms depend on our cultural background on the one hand and on individual differences on the other hand? Investigating these questions will help us to better understand whether the preference for binary subdivision grouping is a universal phenomenon.

Simple binary rhythms are dominating the Western musical culture whereas more multifaceted rhythmic patterns are prevalent in non-Western musical cultures, e.g., in the Balkans, Africa and Latin America. Although a recent cross-cultural study shows that perceptual priors representing small-integer ratio rhythm categories are universal[6], a remaining key question is whether there are cultural differences in metrical flexibility. In other words, the simplest grouping patterns are present even in musical cultures with rich, multifaceted rhythmic patterns, and members of these cultures are likely more rhythmically adept.

Greater metrical flexibility is also associated with musical training, as indicated by studies showing that trained musicians demonstrate more complete hierarchical representations of the rhythmic structure of music[7]. There might be other individual differences in beat perception, such as an individual's preferred motor tempo, age, or the instrument that a musician plays. A bassist, for example, may be more affected by lower pitched tones in a polyrhythm than a violinist. We are currently investigating these potential influences.

To sum up, the findings of the present online finger-tapping study suggest that subdivisions, not beats, are the basic unit of beat perception. The principle underlying the binary grouping of subdivisions reflects a propensity towards simplicity, which is widely applicable to human perception and cognition of time. Pandemic or not, online research studies are likely here to stay, and we will continue our efforts to develop recording and analysis techniques that allow us to take advantage of their worldwide reach.

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EMOTION

Morten L. Kringelbach

Emotion and pleasure are key to our survival as individuals and as a species[1]. There are many pleasures such as chocolate or coffee, but music is one of the most meaningful pleasures, perhaps uniquely available to humans[2,3] and as such a strong contributor to eudaimonia, the life well-lived.

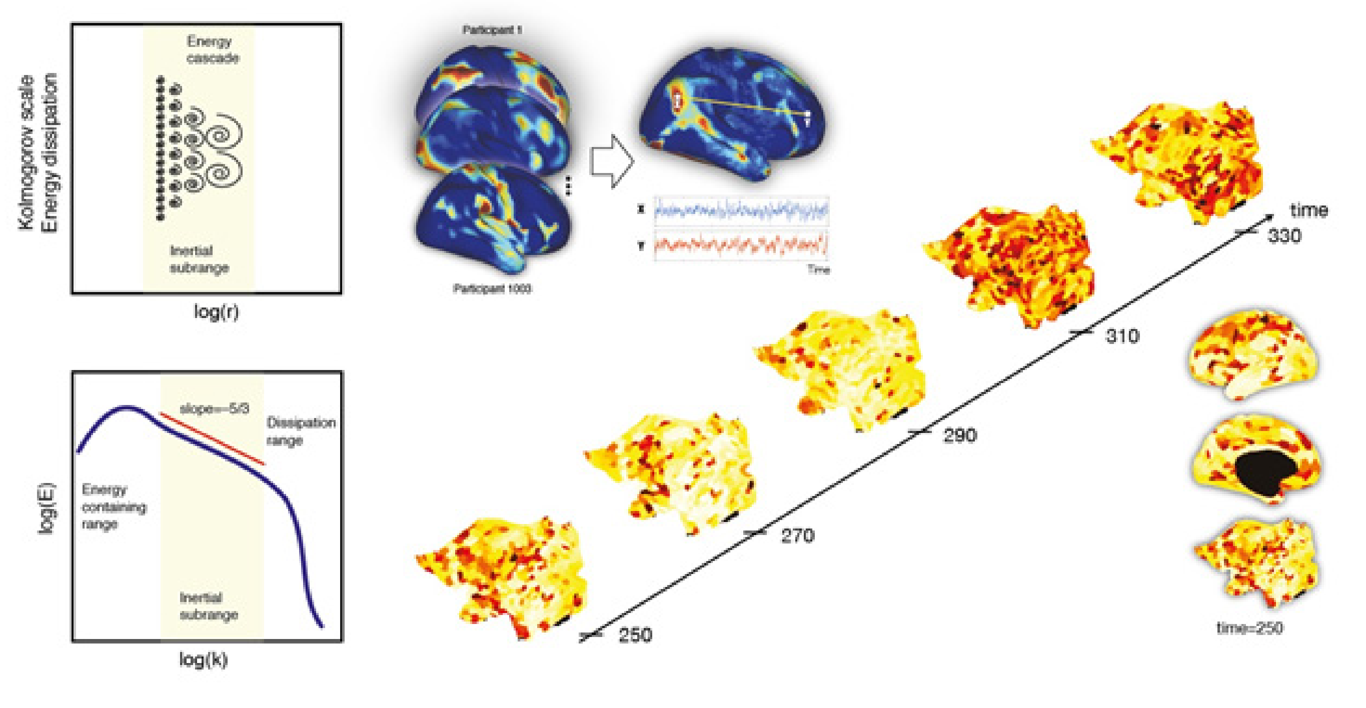
The research in the Emotion strand explores the strong links between music, emotion and eudaimonia[4,5] and strongly synergises with the other MIB strands of Perception, Action and Learning.

As such, dance is an excellent example of such cross-strand synergy, as shown in the research feature by new doctoral student Olivia Foster Vander Elst (see p. 25). In general, across human cultures, music is an important source of emotion, including positive emotions and pleasurable experiences. Our brains and bodies are moved by music as part of an active process in which our brains are constantly generating predictions of what is likely to happen next. The constituent elements of music (melody, harmony, and rhythm) are processed in an active, sustained musical pleasure cycle that gives rise to action, emotion, and learning, led by activity in specific brain networks. The 'sweet anticipation' stage of this pleasure cycle is both highly motivating, and pleasurable.

Music, groove and dance can generate positive emotion, and especially in the case of dance, an important element of this collective positive emotion arises from engagement with other people. Yet, most neuroscientific research on music to date has focused on an individual processing music passively, rather than interacting, and until now very little neuroscientific research has been undertaken on dance. In her planned research, Olivia will focus on the dynamics and underlying brain mechanisms of the collective experience of music making and dance, with a special focus on salsa.

Another doctoral student in the Emotion strand, Christine Ahrends, successfully defended her thesis this year. Her PhD project investigated the role of predictability and uncertainty in human brain dynamics, using examples from the brain at rest, during auditory processing and under LSD (see p. 74).

In 2021, the Emotion strand has been strengthened by establishing of the Centre for Eudaimonia and Human Flourishing at Linacre College, University of Oxford, made possible through generous donations from the Carlsberg and Pettit Foundations. This new centre focuses on promoting research into human flourishing through convening and fostering interdisciplinary teams of neuroscientists, musicians, philosophers, psychologists, social scientists, physicists, biologists and anthropologists. The collaborative goal is to clarify psychological, cultural and philosophical issues pertinent to human flourishing and to connect these insights to contemporary investigation of the neural correlates of emotional and cognitive states.



Turbulence in the brain. *The left part of the figure shows the Richardson and Kolmogorov's energy cascade in fluid dynamics and the underlying fundamental statistical rule of turbulence. The right part shows how the brain activity of over 1000 healthy participants exhibit similar underlying turbulence principles. To graphically show the evolving turbulence and the different levels of synchronisation across space and time, this is plotted on a scale from yellow to red rendered on a flat brain hemisphere (similar to how a round globe can be shown on flat map). The vortical structure of the turbulent fluctuations can be seen even better on this video: http://www.kringelbach.org/turbulence/FigS1_empirical_small.mp4. Images from Deco and Kringelbach[11].*

Whole-brain perspectives

The complexity of Emotion requires the development of groundbreaking whole-brain models pioneered in collaboration with Professor Gustavo Deco at Universitat Pompeu Fabra, Barcelona. This framework allows us to draw causal mechanistic inferences about neuroimaging data, not only for music but for all kinds of data. We continue to develop new methods to allow for a better causal understanding of the links between music and the brain. One of the most exciting fruits of this labour is our new methods understanding the brain dynamics in non-equilibrium, where we are proposing a new theory of thermodynamics of mind[6] (see p. 28) based on our finding of non-reversibility and turbulence in the brain[7, 8].

Longer term, this could provide a better understanding of why psilocybin is showing considerable promise as a therapeutic intervention for neuropsychiatric disorders including depression, anxiety and addiction, ideally combined with music.

Conclusion

We have developed whole-brain computational modelling to reveal the underlying causal brain mechanisms[9] designed to untangle the dynamic effects of music on emotion. These developments will help us identify how music evokes emotion and how music can best help emotion regulation. Taken together, such findings provide the necessary novel tools that could be used to reveal the underlying mechanisms by which music can elicit emotion, change lives and contribute to a flourishing life[10].

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

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EMOTION

Emotions in Music, Groove, and Dance

By Olivia Foster Vander Elst

Music elicits a wide range of responses in audiences, ranging from simple to nuanced, positive to negative, and can be emotional and/or physical. Physical responses to music can be small motions such as tapping a foot, all the way through to complex full-body movements recognisable as dance.

Dance music such as Salsa music is particularly good at eliciting both positive emotion and movement in listeners. The corresponding dance form is also called Salsa, a partner dance where, traditionally, the man leads and the woman follows. The leader directs the dance, planning it spontaneously. He communicates cues to the follower such that she is able to respond quickly and easily with the correct moves[1]. Synchronisation to the music, interpersonal coordination, and synchronisation are therefore all crucial for a successful, and pleasurable, dance.

The footwork in Salsa dancing is based on 8 beat phrases. The dancers step on beats 1, 2, and 3, then on 5, 6, and 7, resulting in a "quick quick slow quick quick slow" pattern of movement. Partners face each other, and their footwork is mirrored. The leader always starts on the left foot, the follower on the right. Figure 1 shows

Photo by Oliver Robinson

this in musical notation, including the leader and follower stepping patterns.

This pleasurable urge to move to music is often called groove[2–5]. It has been proposed that optimal musical pleasure is associated with: high prediction precision combined with high surprise; and low prediction precision combined with low surprise[6].

This is exemplified in the case of groove and syncopation. When there is too little

***Figure 1**: The dance rhythm, quick quick slow, as part of an 8 beat phrase, and the difference stepping patterns employed by leaders and followers[1].*

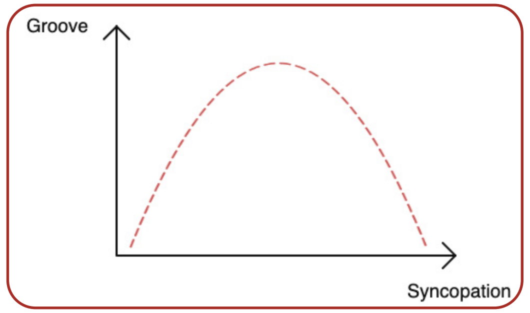

Figure 2: *Inverted-U shape relationship between degree of syncopation and amount of groove experienced.*

syncopation in a rhythm, it is perceived as boring. If there is too much syncopation, no meaningful predictions can be made. An intermediate amount of syncopation provides an optimal ‘sweet spot’[7,8,10–12] where meaningful predictions can be made, but there is also some violation of expectations, keeping a listener’s interest. The tension between the predictability and surprise induces strong feelings of groove[8,13]. The result is an ‘inverted-U’ relationship between syncopation and groove, shown in Figure 2.

A combination of motor and reward networks in the brain appears to drive the sensation of groove[10], and the nervous system is more engaged when listening to high-groove music/rhythms than when listening to either low-groove music/rhythms or noise[4].

In the sweet spot of medium syncopation, the brain is constantly evaluating the prediction error between its model of the music and the music itself. Embodiment is of clear importance in this context, as moving one’s body to the music helps a listener to make sense of it. Movement can be used to ‘fill in’ the strong beats missing from the rhythm, making it easier to predict where the beats should fall[14]. This is particularly pertinent in Salsa, where strong beats are often omitted from the music, and weak beats emphasised, resulting in differences between expected and actual onsets of sound. This is illustrated in Figure 3 for the ‘clave’ rhythm, an important and recurring rhythm in Salsa music.

Dancing to the music is therefore a useful activity as it can help us to understand the music. However, it is also intrinsically a pleasurable activity. Indeed, people will often choose to continue dancing long after they would feel exhausted by other activities, for example going to the gym or running. It is postulated that this arises from a much longer time spent in the pleasurable ‘liking’ phase of the pleasure cycle, combined with a weaker satiation phase[15].

Emotional reactions to dance appear to be linked to activity in the posterior parietal cortex[16], and the occipitotemporal and parietal regions of the action observation network are the most strongly activated by observation of dance movements that are rated as both difficult to reproduce and emotionally pleasing[17]. When people observe dance sequences that they are more familiar with, they find the experience more enjoyable, and regions of the brain associated with this aesthetic response shift from subcortical regions to posterior temporal regions, involved in processing multisensory integration, emotion, and biological motion[18].

Music, groove, and dance are closely intertwined and important sources of emotion. The three

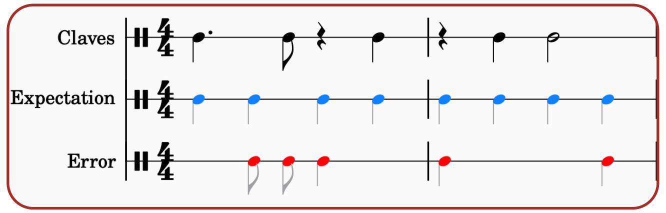

Figure 3: *Top: the clave rhythm, which is performed using two wooden blocks also called claves. Middle: metric expectation of rhythms occurring on every beat. Bottom: The beats on which there is a difference between expected rhythms and those that occur.*

phenomena provide useful avenues for researching emotion and embodiment, as people use movement to music to aid in making sense of it. However, the neuroscience of dance, especially aspects relating to pleasure, is an area of research still in its infancy. More research is needed, with well-controlled studies, and more portable brain scanning technology. Developments in neuroimaging technology such as wearable MEG[19] will hopefully make it possible to research the neuroscience of music, groove, and dance in more naturalistic contexts and on a larger scale in future.

Furthermore, of the research that has been carried out, most has focused solely on individuals. Given the importance of interaction and collective positive emotion in dance, the dynamics and brain mechanisms responsible for the collective experience of music-making and dancing is an area ripe for future research.

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EMOTION / FLOURISHING

Morten L Kringelbach and Gustavo Deco

The turbulent brain: The thermodynamic arrow of time in the mind

According to thermodynamics, any living organism is constantly exchanging a flux of matter and energy with its environment. As such, the system is in non-equilibrium and in his book "What is life" from 1944, the Austrian physicist and Nobel Laurate Ernst Schrödinger proposed that sustaining life is exactly predicated on avoiding equilibrium: "How does the living organism avoid decay? ... By eating, drinking, breathing and ... assimilating. The technical term is metabolism". According to this view, the ultimate equilibrium is death, and thus survival depends on staying as far as possible from equilibrium.

Schrödinger was foremost a physicist, primarily known for his work in quantum physics, where many will know his famous thought experiment concerning 'Schrödinger's cat' who, paradoxically, may be considered simultaneously both alive and dead. This arose from discussions with Albert Einstein in 1935 about the problems of the Copenhagen interpretation of quantum mechanics.

Later in life, however, he turned to the big important questions of discovering the essential forces of life and how the field of thermodynamics could help. In those days, the scientific study of the human brain was still in its infancy, and as such not part of Schrödinger's focus. But since then, neuroscience has made great strides and it has become abundantly clear the brain must be the main driver of how organisms can avoid equilibrium and death. In fact, very recent discoveries have started to cast new light on how brain may even thrive on non-equilibrium; and how turbulent, non-linear brain dynamics help find order in largely disordered environments in order to enhance the chances of survival.

Thermodynamics of mind and the brain's dark energy

Over the last decades, brain scientists have focused on how the brain seems to be primarily reflexively driven by momentary stimulation from the environment when we engage in specific tasks. Yet, as shown by the pioneering research by the American neurologist Marcus Raichle, it has become increasingly clear that the brain is not solely extrinsically driven but instead mostly shaped by intrinsic resting state activity, switching between brain states whilst interpreting, responding to, and even predicting environmental demands.

This view is supported by the fact that the metabolic energy consumption maintaining the intrinsic resting brain activity is much larger than that used by extrinsic task-driven demands. Given that by some estimates over 20% of the total energy consumption is taken up by the brain which only represents 2% of body weight, Raichle has poetically spoken of the brain's "dark energy".

Here, we propose to fuse the ideas of Schrödinger and Raichle to suggest the idea that the flow of energy between the brain and environment is driving the non-equilibrium needed to sustain life. This leads to a novel theory of the thermodynamics of mind, using the ideas from physics precisely able to quantify and characterise the brain processing leading to non-equilibrium.

The arrow of time and entropy

According to the second law of thermodynamics, proposed by Rudolph Clausius and Sadi Carnot, over time a system tends to go from order to disorder. In the language of thermodynamics, this increase in the level of disorder can be expressed as 'entropy'. As such, the law states that when entropy production is larger than zero, this corresponds to a system which is in non-equilibrium and irreversible in time. This is true for all living systems. In contrast, if there is no entropy production in the system, this is a system in equilibrium and reversible in time. This establishes a firm link between entropy production, non-equilibrium and irreversibility, famously expressed as 'the arrow of time' by the English physicist Arthur Eddington.

An excellent example of a non-equilibrium system with associated entropy and the arrow of time can be illustrated when watching a film of a glass being shattered. The entropy increases as the system goes from order to disorder, and the causal sequences of events, and thus arrow of time, are very clear. In contrast, when watching the same

***Figure 1**. Leonardo da Vinci: experimental studies of turbulence in water. Leonardo da Vinci, Studies of Turbulence: rectangular obstacles in flowing water; and water pouring from an aperture into his experimental tank. Windsor Castle, Royal Library, 12660v8. Image from Royal Collection Trust © Her Majesty Queen Elizabeth II 2021.*

film sequence in reverse, we immediately recognise that it is not possible for the glass to come back together, going from disorder to order. The impossibility of the events is abundantly clear, and the arrow of time must be reversed.

Intriguingly, in his most recent film 'Tenet', Christopher Nolan combines such visual segments which are both running forward and backwards in time. This initially creates confusion, but we quickly learn to discern between the different visual elements, like cars on a motorway strangely flipping back from destruction, and to immediately recognise such violations of the expected forward arrow of time.

The beauty of thermodynamics is that the arrow of time can be elegantly mathematically described in terms of entropy production, which increases when a system goes from order to disorder, such as when a glass shatters. The total entropy production can be computed, and if this is larger than zero, a system is said to be non-reversible and in non-equilibrium. In other words, a glass being shattered is a clear example of a non-equilibrium and non-reversible system.

In contrast, as an example of a system in equilibrium, imagine watching a film of colliding billiards balls. When watching this film both forward and backward, you would be hard pressed to distinguish the arrow of time for each film. In thermodynamical terms, this is because the process is not producing entropy and creates a reversible process.

These thermodynamic concepts are powerful tools that could in principles be applied to anything. We and other researchers have therefore started applying them to brain signals. This allows us to measure how the environment is driving the brain by simply measuring the level of non-reversibility in brain signals. In ongoing research we are studying how these tools can capture the arrow of time and entropy production in the brain, allowing for a precise assessment of how both the external world and our body drives the brain to non-equilibrium in different situations. Potentially, this could even be used to characterise changes in equilibrium in the diseased brain before any overt symptoms have started showing.

Deep learning the arrow of time in the brain

Recently, we have combined thermodynamics with the power of a machine learning technique called deep learning to characterise the arrow of time in brain signals[1]. The deep learning approach has been very successful in creating useful tools such as automatic machine translation from one language to another. The key idea is for the deep learning algorithm to learn patterns in large datasets and then generalise this learning to new examples. As an example, take language learning, where deep learning would be fed with a text in two or more languages and then learn to generalise when a word occurs in a certain context. This allows the algorithm to generate machine translations that are much better than previous technology, as can be seen when using for example Google Translate.

We used deep learning as a tool for learning to distinguish between forward and backward versions of brain signals. Initially, in the learning phase, each brain signal is labelled with either

Figure 2. Leonardo da Vinci: studies of turbulence in water compared to curling hair. Leonardo da Vinci, Studies of Turbulence: water flowing around vertical posts; and a comparison of turbulent water with curling hair. Windsor Castle, Royal Library, 1257910. Image from Royal Collection Trust © Her Majesty Queen Elizabeth II 2021.

forward or the artificially generated backward version, and the deep learning algorithm learns to distinguish them with high accuracy. In the test phase, new brain signals are fed to this deep learning algorithm and classified according to the rules.

As a homage to Christopher Nolan, we called this algorithm TENET (Temporal Evolution NET). The beauty of this algorithm is that the level of accuracy of using TENET on brain signals directly provides the level of irreversibility and non-equilibrium for a given brain state. In this way, we can assess the level by which the environment is driving the human brain under different condition, whether resting or performing tasks.

Our results confirmed that in general the brain is being driven by the environment, and, importantly, the human brain is closer to non-equilibrium and more irreversible when performing different tasks than when resting. In contrast, when using TENET to characterise the resting state brain activity in neuropsychiatric patients with bipolar disorders, ADHD and schizophrenia, we found that the brains of these patients are closer to equilibrium than healthy participants. This shows that their brains are more isolated from the environment and more likely to be intrinsically driven. This fits with how, for example, rumination in depressed patients can lead to the malignant isolation from the external world that can drive depression.

Overall, using thermodynamic methods to characterise brain activity could potentially be highly useful in providing novel biomarkers that can help identify those at risk of disease much in advance of the first serious symptoms occurring. In fact, taking a step further to build whole-brain models of brain activity in disease might help identify strategies for interventions that could lessen the risk of the brain becoming closer to equilibrium and therefore less able to engage in the world.

These findings are promising but there are still challenges to overcome. One of the main criticisms of deep learning has centred on the largely black box nature of advances, which may have had considerable practical utility for solving complex problems but have produced little in way of new insight into how this is achieved mechanistically. This black box criticism does not apply to our use of deep learning for learning the arrow of time in brain signals, since we used it merely as a highly efficient tool for discovering the level of the reversibility in brain signals. In fact, we have since used other, unrelated techniques for estimating the entropy production and reversibility of brain signals, which have helped us gain a deeper understanding of the thermodynamics of mind.

Turbulence

Complementing these thermodynamics findings, and in order to really understand the non-linear generation of non-equilibrium brain states, we have also used the principles of turbulence. This research has allowed us to move beyond merely establishing the arrow of time in non-equilibrium systems.

Turbulence is something most people primarily associate with whirlpools of water or with often frightening experiences aboard airplanes. But turbulence is first and foremost a fundamental and highly useful principle in nature that provides optimal mixing properties, allowing for the efficient transfer of energy/information over space and time.

In fact, research over the last century has shown that turbulence is the optimal way of cascading energy across spacetime over many scales, which is a fundamental organising principle of physical systems. On a very practical level, this has been shown to have many important and relevant applications; from turbulent stirring whilst cooking which helps mixing ingredients to finding more energy efficient ways of improving chemical plants, airplanes and windmills.

Historically, turbulence was coined by Leonardo da Vinci who was faced with one of his most difficult challenges when trying to capture the underlying order in the seemingly randomness of water creating whirlpools. Nevertheless, he did not shy away from trying to understand and depict the underlying generating principles of such crowded dynamics. He came up with the phrase “turbulenza” in vernacular Italian, derived from “turba”, the Latin word for crowds[2].

This characterisation of eddies at varied scales remarkably predates the seminal observations by the English polymath Lewis Fry Richardson (1881–1953), pioneer of the mathematical weather forecasting, who described the important turbulent energy cascade principle. This built on Leonardo’s observation that there are differently sized vortices or eddies in a fluid, where each eddy corresponds to a rotational movement. The interactions between large and smaller eddies interchange energy, in the form of velocity or kinetic energy; this is called the energy cascade and transfers energy across scales, which roughly correspond to the size of different eddies.

This energy cascade was described in a humorous verse by Richardson: “Big whirls have little whirls / That feed on their velocity, / And little whirls have lesser whirls / And so on to viscosity ...”, a play on Siphonaptera, the taxonomic order of fleas, used in a brief poem by Augustus De Morgan, paraphrasing Jonathan Swift: “Great fleas have little fleas upon their backs to bite ‘em; And little fleas have lesser fleas, and so ad infinitum”.

These poetic observations were formalised by the great Russian mathematician Andrey Kolmogorov in his ground-breaking phenomenological theory of turbulence. This highly influential theory demonstrates a fundamental power scaling law, revealing the key underlying mechanisms of fluid dynamics, namely the energy cascades that balance kinetics and viscous dissipation. The spatial power-scaling law is a hallmark of turbulence and provides a mathematical description of Richardson’s earlier concept of cascaded eddies. This correlates remarkably with Leonardo’s observation that the constriction of circumference towards the centre of the vortex is more rapid than the diminution of the water’s impetus, which is why the water revolves faster near the centre.

A thriving turbulent brain

The thermodynamics of mind dictates that the brain must ensure our survival by moving us as far as possible from equilibrium. Unfortunately, the brain is rather slow, with the signals taking on the scale of tens of milliseconds to travel between neurons which does not leave much time to react to dangerous things in the environment. For many years, it has therefore been a conundrum how the brain is still able to process so much information so quickly. Turbulence turns out to be a key answer to this deep question, given that it is the guiding principle for energy/information exchange across all levels in nature.

Recently, we demonstrated that necessary fast information-sharing across the whole brain is made possible by turbulent information cascades[3,4]. Furthermore, we were able to show that the orchestration needed for survival in a complex environment is made possible by turbulent information cascades using rare long-range anatomical connections. This provides the necessary speed of information transfer for a small global workspace of regions to act as the conductors for the orchestration of consciousness[5].

Overall, Schrödinger’s question of what makes us survive could equally well be posed in terms of how the brain allows the optimal degree of mixing between intrinsic and extrinsic information. As it turns out, turbulence is Nature's optimal method for mixing and transmitting energy/information across time and space in the most efficient way. The novel results presented here shows that the brain clearly employs turbulence in its quest to stay far from equilibrium in order to survive.

As such, turbulence and thermodynamic non-equilibrium are two sides of the same coin of how the brain is driven by and navigates the environment. These principles allow us not only to survive but also, from time to time, to thrive. One of our main current goals is therefore on using this framework to discover the underlying brain mechanisms by studying brain states such as meditation, music and psychedelics that are known to evoke states of eudaimonia and flourishing.

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NEW FACE AT MIB: PETER KELLER

Photo: Wissenschaftskolleg

Professor Peter Keller joined MIB and the Department of Clinical Medicine in November 2021. Prior to that, he was Director of Research and leader of the 'Music Cognition and Action' research program in the MARCS Institute for Brain, Behaviour and Development at Western Sydney University in Australia.

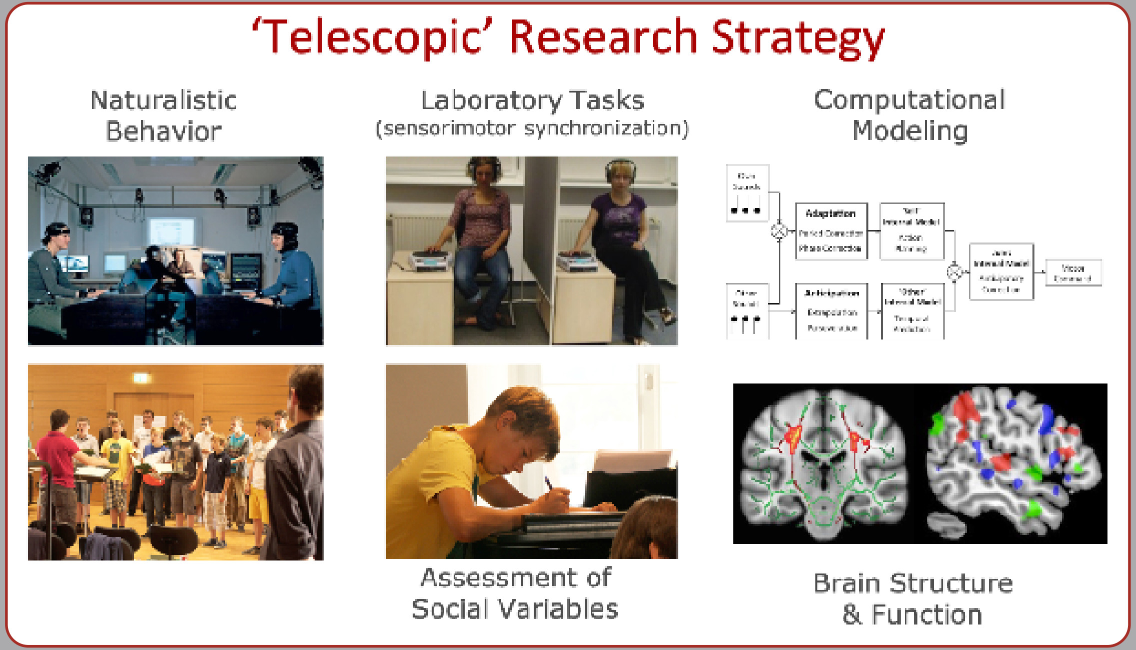
After initial training in music performance, as an orchestral trombonist, Peter obtained degrees in musicology and composition (Bachelor of Music) and Psychology (Bachelor of Arts), and a PhD in Psychology from the University of New South Wales in Australia. Past appointments include research positions at Haskins Laboratories and Yale University (New Haven, USA), the Max Planck Institute for Psychological Research (Munich, Germany), and the Max Planck Institute for Human Cognitive and Brain Sciences (Leipzig, Germany), where he led the Max Planck Research Group for Music Cognition and Action.

His service to the field includes being former editor of the interdisciplinary journal Empirical Musicology Review, past editorial board member at Advances in Cognitive Psychology, Royal Society Open Science, and Psychological Research, and current membership on editorial boards at Music Perception and Psychomusicology: Music, Mind, and Brain.

Peter's research addresses the psychological processes and brain mechanisms that allow people to interact and communicate through music. His work is guided by the overarching assumption that music making in groups is a 'microcosm' of human interaction. The central idea behind this assumption is that participation in collective musical activities draws on sensory, perceptual, cognitive, motor, and emotional processes that support other forms of social behaviour in everyday life. Conceptualising music as a readily controlled microcosm has the practical benefit of highlighting its potential as a domain for studying social cognition and collective behaviour more generally. The implications of his research program therefore extend beyond music science to the broad disciplines of cognitive neuroscience and psychology.

Peter is particularly interested in how skilled musicians are able to achieve high levels of precise yet flexible interpersonal coordination when playing in ensembles, and why individuals differ in their ability to do so. His research aims to understand what this individual variation can tell us about brain structure and function, and how this knowledge can be applied in domains ranging from health to the arts.

Together with many talented students and collaborators, he has made theoretical, methodological, and empirical contributions to this topic. A major theoretical contribution is the 'ensemble skills' framework, which describes how a set of core sensory-motor and cognitive processes facilitate rhythmic interpersonal coordination by allowing co-acting individuals to anticipate, attend, and adapt to each other's action timing. Methodological advances include the development of techniques for assessing capacities relevant to sensorimotor synchronization and interpersonal coordination. For example, the ensemble skills framework has been instantiated as a computational model—the adaptation and anticipation model (ADAM)—that can be used to estimate the degree to which an individual engages in each ensemble skill and how the skills interact.



These theoretical and methodological advances provide the foundation for an empirical approach that uses a telescopic research strategy. At a macroscopic level, the approach considers the relationship between naturalistic ensemble performance, behaviour in the context of laboratory tasks designed to probe specific psychological processes under controlled conditions, and assessments of personality obtained through psychometric tests. At the next, intermediate level, computational modeling and computer simulations are used to gain a deeper understanding of the relationships that are observed. Finally, at a microscopic level, the neurophysiological mechanisms underpinning the processes that are identified are investigated by using a range of neuroscientific tools to examine brain structure and function, including magnetic resonance imaging (MRI), noninvasive brain stimulation techniques, and electrophysiological methods.

Knowledge gained along this route translates into practical benefits through applications in pedagogy, technology, and health. With regard to pedagogy, his research has informed music educational practices aimed at fostering excellence as a performer in musical groups. Future pedagogical work will focus on training ensemble skills in children and conservatory students, as well as 'fine-tuning' ensemble skills in expert performers. On the technological front, his approach has been applied in the context of human-machine interaction, specifically in optimizing the fluency of human-robot teaming. Finally, health-related applications have targeted the assessment and treatment of clinical conditions that impair movement timing and social functioning. Future work will address a range of neurological, psychiatric, and neurodevelopmental conditions, with the chief benefit being the use of a unified conceptual framework to characterise different clinical phenomena.

Joining MIB gives Peter the opportunity to conduct research on musical behaviour and brain function with a world-leading interdisciplinary team. Being situated at the Department of Clinical Medicine will facilitate collaboration on projects with applications related to health, while links with The Royal Academy of Music enable pedagogical and cultural implications to be explored. Ultimately this will lead to new applications based on better understanding of the mechanisms by which music promotes social, emotional, and physical wellbeing.

LEARNING

Elvira Brattico

From learning to flourishing

During the past six years of MIB research, the Learning strand have accumulated behavioural and neuroimaging findings leading to a closer understanding of the neural mechanisms governing music learning, across contexts (in and outside the lab), across the lifespan (in childhood, adulthood and ageing), across generations (in lab models of cultural transmission) and even across cultures (Western and Asian). We also made progress in our understanding of the impact of music learning on, among others, general cognitive abilities, executive functions, memory skills, motivation and emotional self-regulation (see recent reviews[1–3]).

The last two years of pandemia pushed us to move forward by encouraging us to rethink about mental health and wellbeing and to closely examine the role of music in them. Mental health is not simply identified with the absence of disease but with the presence of individual self-realisation, stress management abilities and active contribution to one's own community[4,5]. In positive psychology, the concept of "flourishing" well represents subjective and psycho-social well-being connoting virtue, growth and resilience[6]. In a forthcoming Routledge book, we propose how music, mindfulness and the arts could represent a resource for the society to bring flourishing in all educational settings and across the lifespan[7].

A very recent model, originally conceived to illustrate active music interventions in stroke patients[8], can be borrowed here to describe the process of learning to play a musical instrument across the lifespan. This peculiar type of learning requires massive motor repetition, audio-motor integration, self-monitoring, as well as reward and intrinsic motivation to learn, which, in turn, contribute to audio-motor learning by boosting synaptic plasticity (similarly to motor exercise[9]) and to increase the self-efficacy and autonomy of the learner. All this might result in an improved quality of life and, we here propose, even in the flourishing of the individual and the whole community.

The challenges and pleasures of learning music

MIB research has proved that music learning follows predictive coding theory principles[10] in how ascending prediction errors are minimised by posterior expectations during repeated experience and learning over the lifespan. This leads to accumulating posteriors and increased precision of predictions for sounds and actions. How such learning modulates the local precision gains within the bilateral auditory cortex or the prefrontal-hippocampal circuitry, and how it might be exploited to preserve those neural mechanisms in ageing have been under our close scrutiny, in a series of functional and effective connectivity studies using MEG combined with MRI[11–17].

MIB research further discovered that during music listening and playing, these learning processes provide a reward when the sounds and actions fulfil predictions that are neither too little nor too precise[18–20]. This rewarding minimisation of errors drives us to repeat the musical experience in the pleasure cycle of wanting, liking and learning, and can be measured in the reward circuits of the brain, specifically in the ventral striatum and in the orbitofrontal cortex, both in adults[19] and pre-adolescent children (Fasano et al., resubmitted).

These emotions and rewards accompanying music learning are experienced not only in solitude but also socially. At the core of social emotions and a supposed mechanism of music-emotion induction is empathy, i.e., the ability to infer and share emotional experiences and to feel another's emotions through, for instance, vocal or facial synchronisation with them. We found that the pleasure and reward from musical activities, and the related neural circuitry, closely depend on individual trait empathy[21-22]. This close relation between social emotions and music might be at the core of the success of collective music training programmes that are becoming popular among kids around the world[23].

Music learning for flourishing in childhood

Young humans show hypersensitivity to social reward, and this might make music learning more engaging when done in groups, leading even to the non-musical transfer of motivation towards all school activities. This hypothesis was confirmed in a behavioural study conducted in Italy with over 100 normotypical and ADHD children following an El Sistema-inspired collective music training programme (Fasano et al. in preparation). Providing self-control and freedom of selection in children's training could strengthen their feelings of self-efficacy, competence and autonomy and lead to better long-term learning outcomes[24].

The promotion of self-regulation has been very important in increasing the efficacy of educational programmes[25]. This is precisely what we aim to investigate in a just launched longitudinal behavioural study by Lippolis et al. with over 300 pre-adolescents (10-14 years old) from 3 different Italian middle schools, in collaboration with Prof. Daniel Muellensiefen from the University of London. In two experimental sessions in the IT labs at their schools, our participants perform fun game-like adaptive music aptitude tests, behavioural tests for non-verbal intelligence and visuo-spatial working memory (for an example, see Fig. 1). In the same session, they also answer psychological questionnaires assessing self-efficacy, relational difficulties, quality of life and empathy skills.

Music learning and beauty for living in harmony in adulthood

In a behavioural study by PhD student Mathias Klarlund with 100 Chinese adults, we further aimed to understand how the cultural and ethnic biases that we implicitly possess might play a role in perceiving melodies. While our participants replicated the typical implicit bias for their own ethnic group affecting the performance in classification tasks for words and faces, they did not show such bias (but only a musical bias related

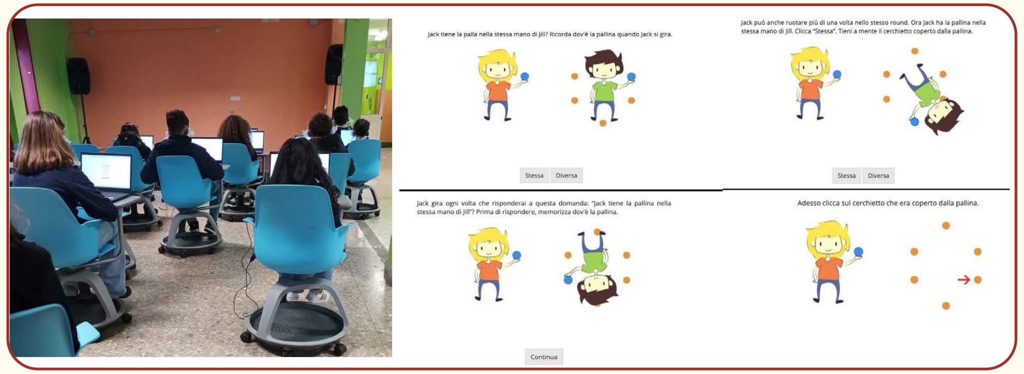


Figure 1. Example of screenshots of the online behavioural test called Jack&Jill utilised for a longitudinal study with pre-adolescent children (Lippolis et al., in preparation).

to individual perceptual abilities) when classifying Chinese or German melodies, reinforcing the conception of music as a universal language. Moreover, in a collaborative neurophysiological study with the Max Planck Institute of Empirical Aesthetics in Germany[14], we systematically explored the emotional, physiological and aesthetic aspects of a music listening experience in all its phenomenological complexity by means of interviews and qualitative analysis. We demonstrated the even existential relevance and transformational value of music[26]. With other two ongoing neuroimaging collaborative studies by Prof. Brattico and colleagues from the newly appointed Finish Centre of Excellence in Music, Mind, Body and Brain and from German and Italian universities, we further discovered that specific patterns of brain connectivity unfolding over time during music listening accompany the experience of musical beauty, with richer connections between cognitive, emotional and reward brain areas (particularly the orbitofrontal cortex) during listening to beautiful musical passages and mainly between sensory areas during listening to ugly musical passages (Fig. 2). All together, these studies represent further demonstrations of the power of music learning and culture which transcends national borders and cultures, and which effectively connects the brain.

The most recent study initiated by MIB Learning researchers (Brattico, Matarrelli et al.) tests the bold hypothesis that music learning even in adulthood can improve emotional abilities as a whole, even outside the musical practice. Two hundred participants from music therapy schools and conservatories in Italy as well as control participants from non-musical universities are taking part in a longitudinal study evaluating whether learning to play a musical instrument or to become a music therapist would enhance emotional intelligence, defined as the set of skills needed to identify, manage and express emotions[27]. Importantly, having good emotional intelligence is linked to well-being, success and personal flourishing as it allows people to use emotions as a compass orienting choices towards reaching personal satisfaction and happiness.

In sum, much still remains to be determined about whether and how music learning can lead to flourishing or on the psychological and neural mechanisms facilitating this path. What is certain is that in these times of crisis, music and MIB research on it can certainly bestow a beam of hope.

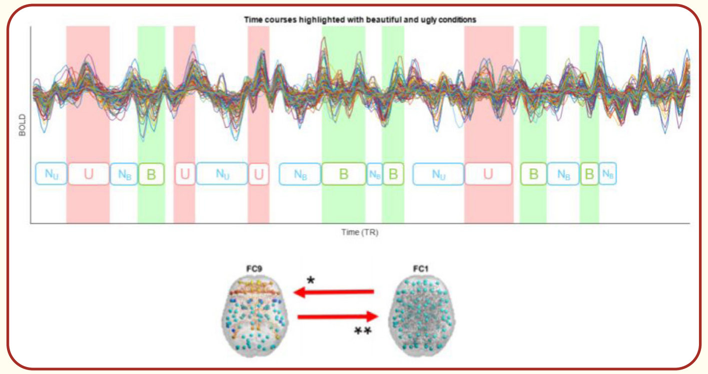


Figure 2. Example of dynamic connectivity findings obtained by Dai et al. in an ongoing study concerning the temporal evolution of brain fMRI signal during listening to a musical piece that includes passages consistently rated as beautiful or ugly (top image) and that produce functional connectivity states that alternate global connections with communication between orbitofrontal reward and associative brain areas.

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LEARNING

The role of individual differences in musical reward sensitivity: Behavioural evidence from children and adults

By Giulio Carraturo

Music is universally considered one of the most pleasurable human experiences, although, like other aesthetic stimuli, it is abstract and does not directly imply any obvious natural advantage. In this perspective, it is essential to explore the individual differences that underlie how people experience reward associated with music listening and music-related activities.

As empathy trait, musical abilities and age have been identified as central factors in influencing physiological and emotional responses to music[1-2-3], we conducted a study to investigate their contribution to musical pleasure in a developmental comparison of 48 children and 42 adults[4]. Trait empathy, musical abilities and musical reward sensitivity were assessed with Interpersonal Reactivity Index[5], Musical Ear Test/Mini Musical Ear Test[6-7] and Barcelona Musical Reward Questionnaire (BMRQ)[8], respectively.

Our first finding suggests that musical reward sensitivity is positively correlated with empathy in both children and adults, in line with a recent neuroimaging study reporting that highly empathic people show a significantly higher overall brain activation, specifically, in prefrontal and mesolimbic areas, which are part of the reward circuitry[9]. Our study confirms and extends these results also on a behavioural level.

Secondly, we found that musical abilities are not predictive of musical reward sensitivity, neither in adults nor in children. However, musical abilities, when inserted in a regression model including empathy, significantly contribute to predict musical reward sensitivity, but only among adults. This suggests that during childhood musical pleasure might mainly depend on intrapersonal factors (such as empathy), whereas among adults, other factors such as musical abilities become prominent in affecting music reward experience.

A further relevant result is that adult and children scores in BMRQ sensory-motor scale (assessing the capacity of music to intuitively induce body movements synchronized to a rhythm's beat) were nearly equal, whereas the largest difference arose in the BMRQ emotional evocation scale, related to the emotional impact of music on individuals, with adults scoring significantly higher than children. This suggests that in childhood and adulthood distinct types of musical pleasure are experienced. Thus, also in light of our findings, music perception research would greatly benefit from a psychometric measure of musical reward in children, appropriate to the unique characteristics of this age group.

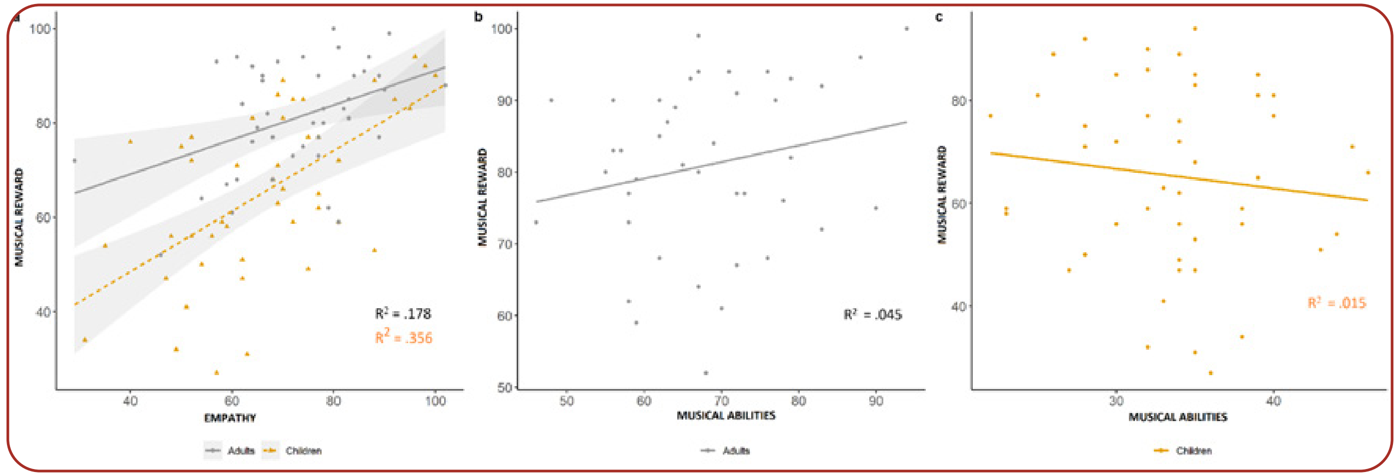

***Figure 1**: Graphical Depiction of Correlation Coefficients. **A)** Scatterplot Showing the Significant Correlation between BMRQ and IRI Scores in Both Adults (Dots, Solid Line) and Children (Yellow Triangles, Dashed Line); **B)** Scatterplot Showing the Non-significant Correlation between BMRQ and MET Scores in Adults; **C)** Scatterplot Showing the Non-significant Correlation between BMRQ and MiniMET Scores in Children.*

In conclusion, empathy plays a crucial role in determining individual sensitivity to musical reward, whereas musical abilities are less influential, especially in childhood. That is, more empathic people find music listening and music-related activities more pleasant than people with lower empathy levels. Music, on the other hand, does not require specific knowledge and competence in order to appreciate and derive pleasure from it. This may underlie the great value that people attribute to music, which persists over generations and cultures.

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LEARNING

Fast-scale neural encoding and predicting processes for sounds

By Francesco Carlomagno & Leonardo Bonetti

The fast-scale brain processing of sounds and auditory sequences is a key topic in neuroscience. Indeed, investigating such processing allows us to shed new light on how the brain elaborates the present sound and makes prediction for the upcoming ones forming an entire musical sequence. Astonishingly, traces of this prediction are observable already in the first 250ms after the presentation of the sound[1]. As a matter of fact, previous research in music neuroscience has shown that several brain responses occurred already in the first 250ms after the sound onset. For example, it has been widely established that as a response to sound stimulations, the brain generates several components of the event-related field/potential (ERF/P) such as P50, N100, P200[2]. Additionally, when presented with deviant sounds inserted in sequences of coherent ones, the brain generates the mismatch negativity (MMN), an automatic signal peaking after 150-250ms from the onset of the deviant[3].

Here, we describe two studies that we conducted at Center for Music in the Brain benefitting from the combination of the excellent temporal resolution of the magnetoencephalography (MEG) with the spatial resolution of the magnetic resonance imaging (MRI).

In the first study, we investigated the differential automatic brain mechanisms underlying processing of sensorial and cognitive sound deviants. Conversely, in the second study we focused on the early brain connectivity patterns associated with conscious encoding of the sounds of a structured musical piece.

Specifically, in the first study we analyzed MEG data collected during a listening task from 104 participants. The task was composed of several sensorial deviants (pitch mistuning, rhythm mistake and timbre) and cognitive deviants (pitch modulation, rhythmic modulation and transposition). The results showed that the brain regions involved in the analysis of low-level sensorial deviants and high-level cognitive deviants differed. In detail, for the sensorial deviants

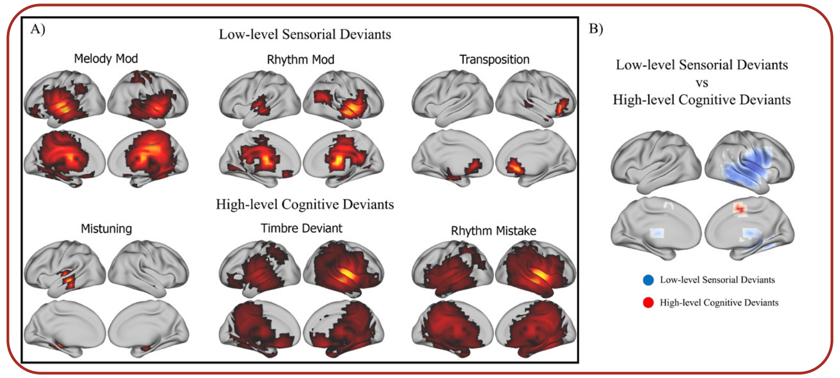

***Figure 1**. **A)** Localization of the brain areas involved in the responses of low-level sensorial deviants and high-level cognitive deviants. **B)** Significant comparison analysis between low-level sensorial and high-level cognitive deviants.*

we discovered a greater activation in sensory cortices, in particular primary and secondary auditory cortex and insula (Fig. 1A). Conversely, we found a major activation of areas such as cingulate cortex and hippocampal regions in response to cognitive deviants (Fig. 1B). Those results provide additional evidence on the different brain mechanisms involved in the discrimination of complex musical stimuli and the detection between sensorial and cognitive auditory deviants. Moreover, they refine our understanding of the automatic predictive processes operated by the brain in response to qualitatively different categories of deviants.

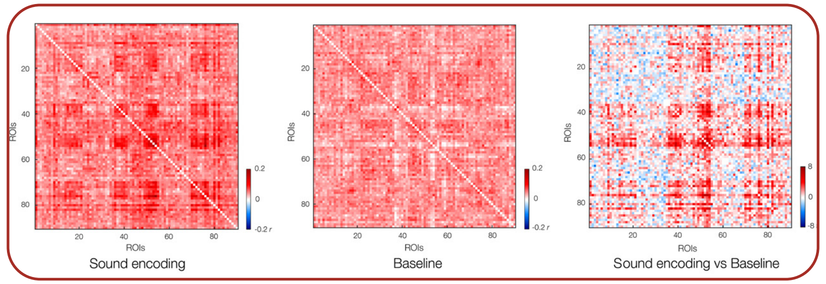

***Figure 2**. Functional connectivity underlying conscious encoding of musical sounds. Brain connectivity patterns computed in the first 220ms from the onset of the sounds (left) versus connectivity in resting state, used as baseline (central). The right matrix shows the contrast between the functional connectivity underlying sound encoding versus resting state (baseline).*

In the second study, we investigated the fast-scale brain mechanisms for conscious encoding of sounds forming a complex temporal sequence[4]. Here, we recorded MEG brain activity of 68 participants while they listened to a highly structured musical prelude. The results showed a strong activity recorded in the auditory cortex, especially Heschl's and superior temporal gyri, and insula in the first 220ms from the onset of the sounds. Notably, while the activity was mainly localized in those areas, connectivity analyses at the same time window highlighted that sound processing recruited a vast network of brain areas recruited during the sound encoding, with a principal activation of primary and secondary auditory cortices, frontal operculum, insula, hippocampus and basal ganglia (Fig. 2). Importantly, the strength of the centrality of these areas within the whole brain network was equal among them all. These results suggest that brain activity and functional connectivity involved the same network of brain areas differently.

In conclusion, our studies revealed how the qualitative nature of deviant sounds was reflected in the automatic predictive processes of the brain. Moreover, we have revealed a dissociation between the functional connectivity and the brain activity occurring in the first 220ms from sound onset when participants consciously encoded musical sequences.

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CLINICAL APPLICATIONS OF MUSIC

Kira Vibe Jespersen

The year 2021 has been marked by the restrictions caused by the Covid-19 pandemic. We have all been limited in our daily activities, and clinical research projects have been particularly vulnerable to these restrictions. Nevertheless, MIB researchers have still been productive, and several new initiatives have seen the light of day.

At the Royal Academy of Music, a new initiative is facilitated by Assoc. Prof. Margrethe Langer Bro, who did her PhD on live music in cancer treatment. She is now teaching a course on music and health at the Royal Academy of Music, Aarhus/Aalborg. This very popular course gives the students the relevant prerequisites for doing concerts in health care setting such as hospitals or nursing homes.

Another initiative comes from Prof. Elvira Brattico. In collaboration with the neurology department at the hospital Fondazione S. Maugeri, Bari, Italy, she is setting up a study to evaluate the impact of music listening in combination with non-invasive brain stimulation in patients with disorders of consciousness. In addition to assessing the impact on clinical and neurophysiological outcomes in the patients, they will evaluate the influence of the intervention on caregiver's burden and psychological distress. The project has great potential for both diagnostic assessment of states of consciousness and for developing music interventions in neurology.

A third initiative was taken by Assist. Prof. Kira Vibe Jespersen who extended her previous line of research on music and sleep by initiating a randomized controlled trial on music as an early intervention for sleep-onset insomnia. In addition to evaluating the effect of the music intervention, this project also aims to unravel the psychological and neurophysiological mechanisms that may be driving the effect.

A fourth initiative comes from Postdoc Victor Pando-Naude who finished his PhD in 2021 (see p. 76). In prolongation of his previous research on music perception in Parkinson's disease[1] (Pando-Naude et al., in preparation), he has initiated a project to investigate how music can be used as a supporting therapy for motor rehabilitation in patients with Parkinson's disease. Using stimuli with varying degrees of rhythmic complexity, the study seeks to answer the question of what is the optimal level of musical rhythmic complexity that can positively affect the gait of patients with Parkinsons disease?

MIB has a long-standing tradition for doing research in Cochlear Implants (CI), and in 2021, Assoc. Prof. Bjørn Petersen and colleagues finished a project on music perception in recently implanted CI users. In this project, they used an adapted version of the musical multifeature MMN paradigm[2] including four deviants (intensity,

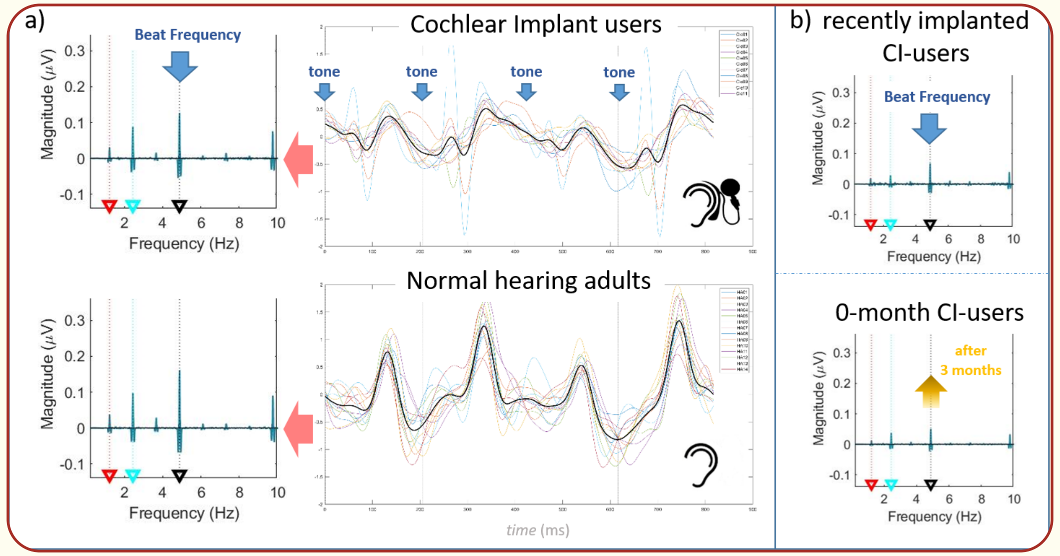

Figure 1. Frequency spectra of the EEG of Cochlear Implant users and Normal Hearing participants. The peak at the beat frequency ***a)*** *does not differ between experienced CI-users and elderly normal hearing participants. However, these peaks* ***b)*** *are smaller in recently implanted users. Interestingly, after 3 months of getting the cochlear implant, this peak increases in amplitude at the beat frequency.*

pitch, timbre and rhythm). The results showed a significant improvement in neural discrimination of pitch and timbre in the first three months after CI switch on as reflected in MMN amplitude[3].

In prolongation of this project, Postdoc Alexandre Celma-Miralles took an EEG frequency-tagging approach to examine beat perception and neural synchronization in CI users. The results showed that the response to the beat in experienced CI users was similar to matched participants with normal hearing, whereas the neural response in recently implanted CI users was smaller (Fig. 1). This suggests that beat perception improves over time, when the brain of the CI users becomes tuned to the information provided by the cochlear implant.

Importantly, the research on music and CI has been strengthened substantially in 2021 through a 3,740,000 DKK grant from the William Demant foundation for the "Feeling the beat" project by Assoc. Prof. Bjørn Petersen and Prof. Peter Vuust. In this project, Alberte Baggesgaard Seeberg who started her PhD in 2021 will be investigating groove perception in CI users in collaboration with Oticon Medical and researchers at Southampton University.

Another grant in 2021 came from the Danish Sound Cluster to support the update of the 2014 whitepaper on "Music interventions in health care" with 175.000 DKK. The project is done by Assist. Prof. Kira Vibe Jespersen and Prof. Peter Vuust in collaboration with Oticon Medical, WS Audiology and SoundFocus. The 2014 version of the whitepaper has been extremely popular, and since the research in this field is growing rapidly (Fig. 2), an update is much anticipated. The updated version will integrate the most recent

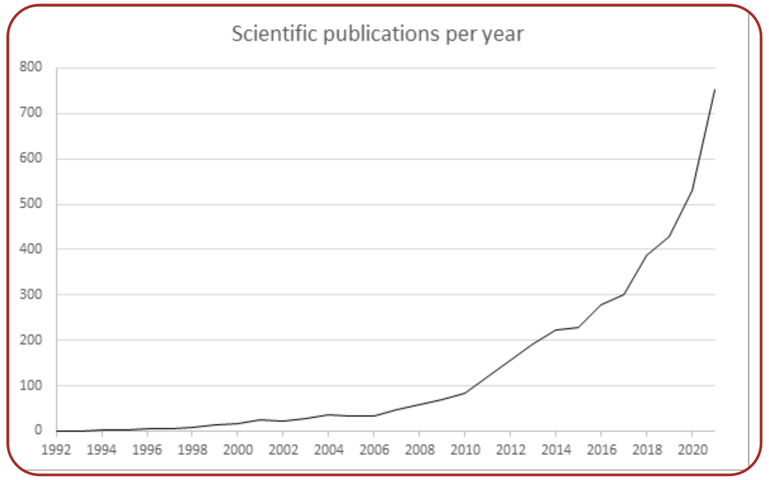

Figure 2: *Scientific publications on "music intervention" for each of the years 2009-2021. Publication statistics extracted from the scientific database Scopus.com. A total of 4,140 publications were identified in the search conducted on February 4, 2022.*

evidence covering a wide range of topics within both somatic and psychiatric disorders as well as general well-being. In addition to updating the existing topics, substantial research has emerged in new fields that have therefore been added. The new topics include music interventions for COPD (see p. 49), multiple sclerosis, dental procedures, pain management, ADHD, pregnancy and birth[4]. The new whitepaper will be published in 2022.

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CLINICAL APPLICATIONS OF MUSIC

Might singing be a potentially relevant training modality for people with Chronic Obstructive Pulmonary Disease (COPD)?

By Mette Kaasgaard

Background

Chronic Obstructive Pulmonary Disease (COPD) is a common disease characterised by chronic inflammation and airflow limitation. Predominant symptoms comprise dyspnoea, cough, and sputum. Furthermore, COPD is associated with decreased physical activity, social isolation, psychological distress, and impaired quality of life (QoL)[1,2].

Pulmonary rehabilitation (PR) is a key component in COPD care and improves e.g. physical capacity and QoL and is based on evidence-based activities[1,2]. Physical Exercise Training (PExT) is the gold standard activity in PR. However, challenges in PR are ability to perform PExT, high drop-out rates, and lack of maintenance. Therefore, alternative evidence-based activities have been requested to supplement an increasingly personalised PR offer[1-3]. Several novel activities and approaches have been suggested, but evidence remains scarce.

Singing has been suggested as a novel approach, potentially relevant for people with COPD. Singing has become increasingly popular as a leisure time activity in COPD and may be relevant as a novel PR intervention as singing is both a physiologically-oriented activity, focusing on e.g. respiratory muscles, and a social activity associated with joy and cohesion. However, impact of singing on key outcomes in PR such as walking distance is still not known, and high-quality studies are requested[4–6].

Study design

In order to address current requests, we conducted a multicentre, randomised controlled trial (RCT) to investigate whether singing (intervention) was non-inferior to conventional PExT (comparator) within a 10-week PR programme. Primary study outcome was change in exercise capacity, measured by the Six-Minute Walking Test Distance (6MWD) with a minimal important difference (MID) of 30 metres. Further, we included selected secondary outcomes, e.g. within lung function, dyspnoea, quality of life, anxiety and depression, and adherence.

The trial was conducted between August 2017 and May 2019. Eleven municipalities and their community PR services participated, and a total of 270 COPD patients were included from municipalities distributed all across Denmark: Lolland, Vordingborg, Faxe, Slagelse, Rudersdal, Helsingør, Hedensted, Silkeborg, Ikast-Brande, Vesthimmerland og Lemvig.

Intervention

For the intervention, we used the best-practice, most well-described disease-specific methodological approach, Singing for Lung Health (SLH)[5–7]. As there exists no common available approach to singing in COPD and no disease-specific training in Denmark[8], all of the Danish singing leaders assigned for the trial participated in a mandatory, special training workshop facilitated by the British team of experts before trial initiation. The training included introduction to pathophysiology in COPD, knowledge about challenges in COPD (including breathing patterns), methodological approach in SLH, suitable exercises and musical repertoire, ideas for implementation of movement/dancing during singing, and approaches to building safe group dynamics.

Study participants assigned to either SLH or PExT underwent a 10-week PR course twice weekly at the local community PR service (healthcare centre), that is 20 sessions in total, each of 90 minutes' duration. Sessions were delivered as group-based activities, with inclusion of individual supervision and tailoring of content. Besides the training, both study groups participated in

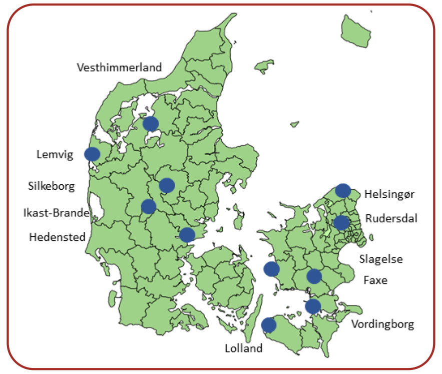

***Figure 1:** Map of Denmark divided into 98 municipalities. 11 participated in the RCT. Municipalities in the RCT are marked by red dots and names. Source (map): Wikipedia.*

additional patient education as part of standard PR, e.g. including education on lifestyle change and on management of disease and everyday life.

The PExT intervention was delivered by locally-based physiotherapists, experienced in COPD and PR. The training was based on the Danish national clinical PR guideline, as delivered at usual care, with some tailoring to local preferences and individual participant needs[3]. Prior to the intervention, each healthcare centre provided a description of its usual care delivery of PR.

Content and delivery of SLH and PExT are described in the Supplementary files of the RCT article[9].

Results

In total, 270 eligible COPD (SLH group: n=145; PExT group: n=125) patients were included in the study. Drop-out rate was higher than

***Figure 2:** The Danish singing leaders underwent disease-specific training with Singing for Lung Health founder Phoene Cave (mid front). Private photo*

expected (28%; n=75), due to which participants were continuously included until the reaching of sufficient study sample, and a total of 195 participants (SLH: n=108; PExT: n=87) completed both baseline and follow-up assessments.

At baseline, the two study groups were comparable, except that the SLH group had lower lung function. Females accounted for 62.2%, mean age was 69.5 ±8.4 years. Mean BMI 27.8 ± 6.0, mean pack years 40.5 ± 21.3, mean FEV1% predicted 51.4% ± 16.8%, and mean 6MWD 382.3 ± 102.4 metres.

SLH was non-inferior compared to PExT in improving 6MWD and in the proportion of participants achieving MID in 6MWD (30 m) (p=0.81 [95%CI -7.28;9.30]), see Table 1 and Figure 5.

Non-inferiority related to 6MWD remained after adjustments for sex, age, BMI, GOLD class, and expectations. In both groups, adherence was correlated to chances of achieving MID in 6MWD.

We found no between-group difference regarding lung function, dyspnoea, quality of life, anxiety and depression, and adherence.

Conclusion

The study demonstrated that singing/SLH provided meaningful changes in key PR outcomes and was non-inferior to PexT regarding change in 6-Minute-Walk Test Distance (6MWD) and achieving MID in 6MWD measured after 10

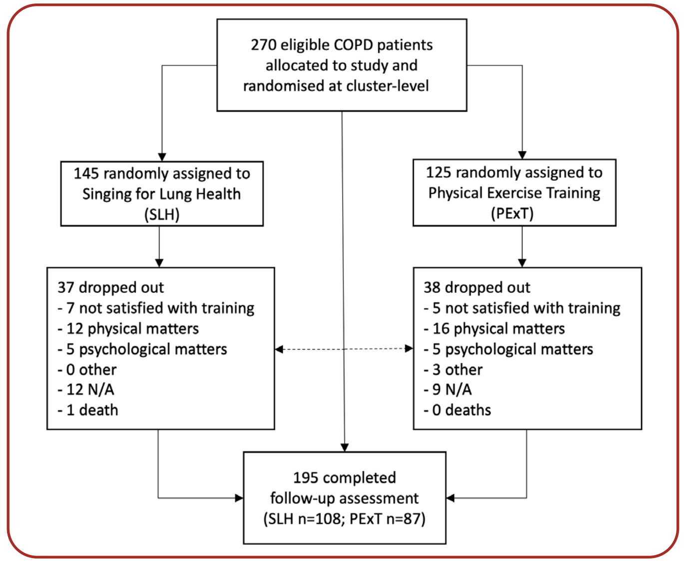

***Figure 4:** Study 2: Consort Flow Diagram*

***Figure 3:** A) Participants singing while dancing, instructed by singing leader Mette Abraham. B) Singing leader Inger Kold instructing participants in singing a Danish folk song.*

Private photos.

	Singing for Lung Health (SLH) (n=145)		Physical Exercise Training (PExT) (n=125)		Between group difference (p-value)	95% CI
PRIMARY OUTCOME						
6MWT distance, meters						
Baseline	374.1	±105.0	391.6	±99.0	0.17	
Follow-up	387.2	±100.5	405.7	±104.5	0.14	
Change from baseline	13.1	±36.3***	14.1	±32.3***	0.81	[-7.28;9.30]
MID (30 m) achieved	31	(21.8%)	31	(25.0%)	0.57	
SECONDARY OUTCOMES						
St. George's Respiratory Questionnaire (SGRQ)						
Total score						
Baseline	46.1	±17.1	44.0	±17.0	0.32	
Follow-up	43.0	±16.6	42.5	±18.9	0.81	
Change from baseline	-3.0	±8.8***	-1.5	±9.2	0.16	[-0.62;3.73]
MID (-4 units) achieved	51	(35.2%)	35	(28.0%)	0.21	
Adherence to intervention						
Participation rate, n (%)	16.55	±3.0	16.3	±3.1	0.41	[-0.02;0.35]
0-24%	22	(15.2%)	21	(16.8%)	0.90	
25-49%	11	(7.6%)	12	(4.4%)		
50-74%	24	(16.6%)	21	(16.8%)		
75-100%	88	(60.7%)	71	(56.8%)		
Drop-out rate, n (%)	37	(25.5%)	38	(30.4%)	0.42	

Table 1: *Changes in 6MWD and SGRQ. Adherence to intervention. Data are presented as mean ±SD unless otherwise stated. 6MWD: 6-minutes walking test; MID: minimal important difference (MID): 30 m; SGRQ; MID: -4 units.*

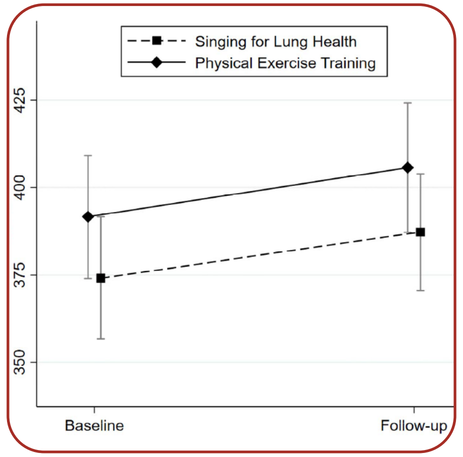

Figure 5: *Changes in 6MWD from baseline to follow-up in both SLH and PExT study groups.*

weeks' training in community-based PR. In both study groups, effect was positively related to adherence.

To conclude, singing - delivered as SLH - appears to be relevant and beneficial in COPD in both objective and subjective parameters. Thus, delivered as a disease-specific, structured intervention, singing may represent a health-promoting activity that is more than a pleasant leisure time activity. Singing/SLH may be relevant to include as part of a diverse, personalised offer to supplement PExT in future PR. Furthermore, singing - delivered as SLH - is a safe, cheap, and easily implementable activity.

Our study is the largest study by far within this area, represents an important contribution to the current body-of-evidence, and will be suitable for inclusion in future systematic reviews and meta-analyses in order to further evaluate the effectiveness and efficacy of singing for COPD.

Further studies are needed to define and develop preferred, standardised, homogenous delivery of singing in COPD. Moreover, further high-quality studies are needed to confirm effects in both objective and subjective parameters, to assess long-term effects and maintenance, and to evaluate health-economic aspects.

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RAMA COLLABORATION

Imagine, Sing & Play – a study on the effect of vocal and mental practice on musical performance

By Kristian Steenstrup, Boris Kleber, Niels Trusbak Haumann, Peter Vuust & Bjørn Petersen

Behind the scenes

Within the classical music world there is a strong competition for few orchestral positions, and professional musicians in symphony orchestras meet a demand for high-level technical and flawless performance. Even this is not regarded sufficient as music performance at this level is considered meaningless without highly expressive and interpretative elements. For students at music academies, this has led to a vastly intensified practice activity to meet this demand. Such intensive and time-consuming activity challenges the physical apparatus and the mental wellbeing of the performer[1], potentially causing negative effects in the form of physical injuries, focal dystonia and overuse syndrome.

Concurrently, studies on use-dependent neural plasticity using musical learning and performance as a model have generated important insights into human brain physiology, including higher cognitive processes implicated in controlling sensory, motor and emotional systems. In addition, strategies that aim to improve the effects of deliberate musical practice on instrumental and vocal performance have gained increasing scientific interest, providing novel insights into the cognitive basis of sensorimotor learning and corresponding benefits on learning efficacy, e.g., mental practice[2,3], varied practice[4], interleaved practice[5] and use of solfege[6].

All this leads to the hypothetical question: Can physical practice be substituted or at least supplemented by alternative methods, such as mental practice (auditory and motor imagery) and overt singing, without compromising the overall performance quality?

Cast & plot

In the present study, researchers from Center for Music in the Brain and the Royal Academy of Music Aarhus/Aalborg set out to try to answer that question. The study involved 50 participants, all of whom played trumpet, studying at leading institutions in Germany, Denmark and Switzerland.

In line with both previous research[7] and pedagogical traditions, we hypothesized that a strategy in which physical practice is combined with motor and auditory imagery and overt singing will be equally effective in improving musical reproduction and quality as mere physical practice and more effective than strategies relying solely on either motor and auditory imagery or overt singing alone.

Furthermore, we hypothesized that prior solfege training and application of interleaved/varied practice regimes as well as the nature of focus of attention, individual sleep habits and use of meditation would impact the general performance level as well as the ability to improve during acquisition.

Action

The participants' tasks during the testing involved playing a total of five unfamiliar short etudes before and after applying one of four different practice strategies, including physical practice (PP), auditory/motor imagery (MP), singing (SOL), and a combination of the above (COM). A fifth no-practice "strategy" (NP) was also applied as a control condition. The trials were organized in five different sessions, such that all participants played all 5 etudes and applied all 5 strategies in randomized order and combinations. In all sessions, the participants' performances were recorded both before and after applying the respective practice strategy.

Build-up

All recorded performances were independently assessed by three expert raters. The raters were required to assess the recorded performances on five different parameters: (1) pitch errors, (2) rhythm errors, (3) sound quality, (4) intonation and (5) musical expression. Pitch and rhythm errors were measured by counting the number of bars in which pitch and rhythm differed from the musical score.

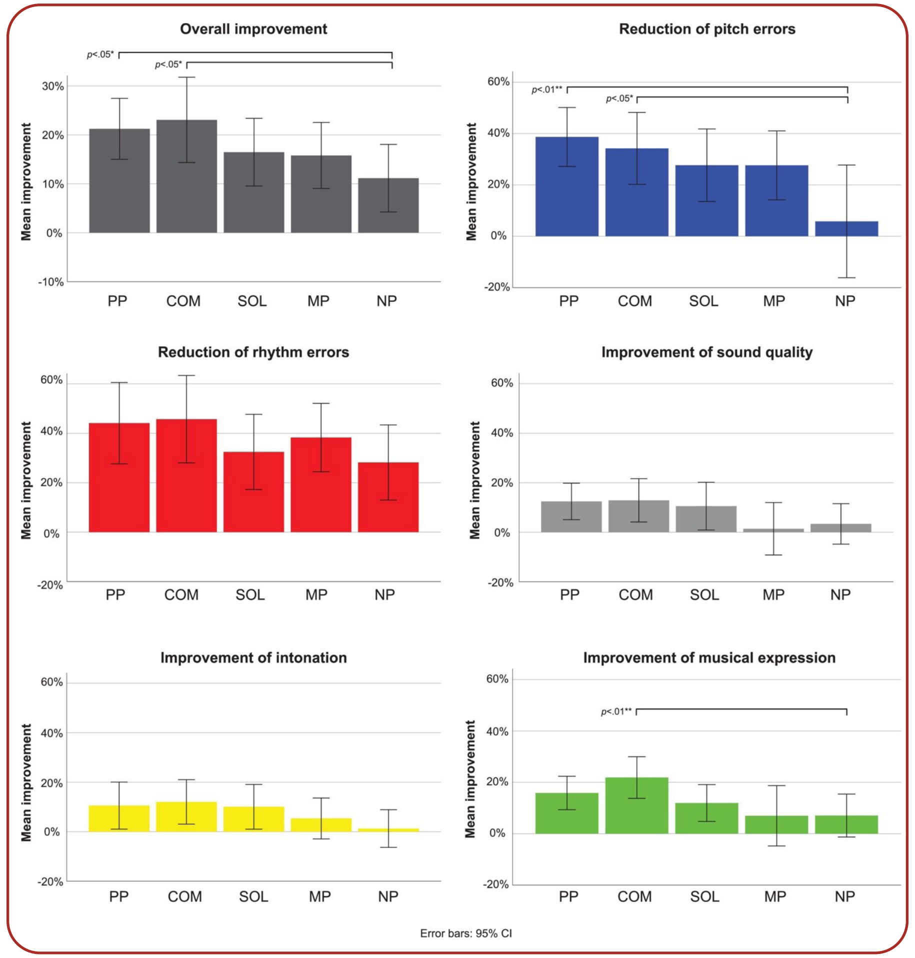

Figure 1. *Mean overall improvement and improvement in pitch, rhythm, sound quality, intonation and musical expression for the five different practice strategies. *p < 0.05; **p < 0.01. PP = physical practice, COM = combined strategy, SOL = overt singing, MP = mental practice, NP = no practice.*

To verify that the expert ratings of numbers of bars with pitch and rhythm errors were a true reflection of the actual number of notes with errors, we also performed a semi-automatic pitch and rhythm error detection procedure that provides pitch and onset times of each played note, as implemented in the CUEX software[8].

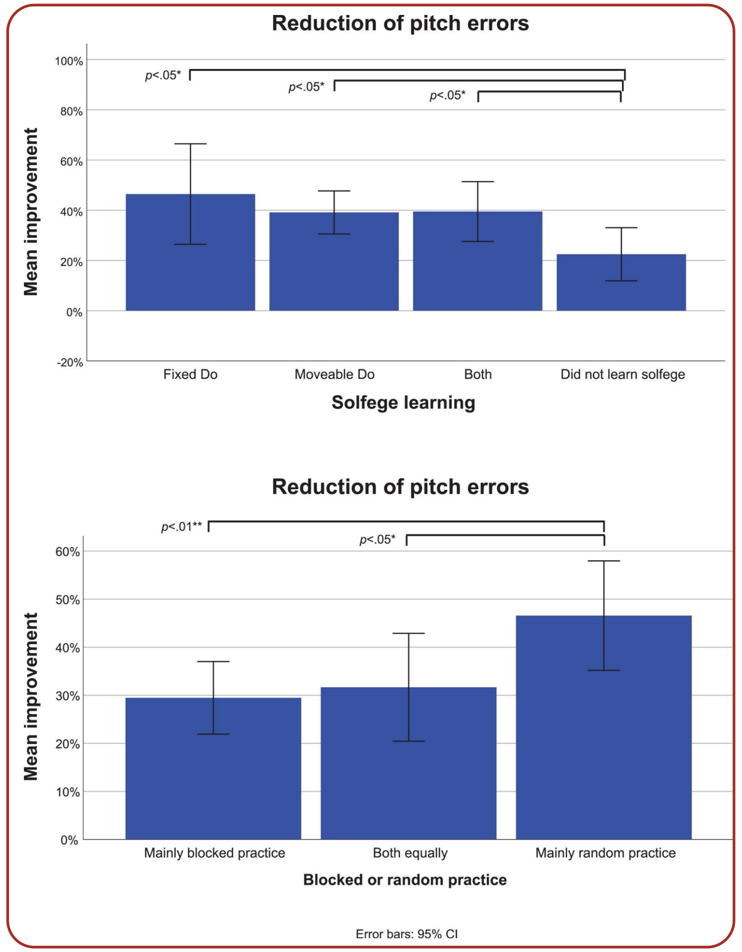

Figure 2. *Effects of reported learning of different solfege and blocked vs. random practice methods on pitch accuracy improvement.*
**p < 0.05; **p < 0.01.*

Resolution
The results confirm and extend previous findings, indicating that compared to no practice, a strategy which combines physical practice, imagery and singing is as efficient as extensive and repetitive physical practice in improving both the overall performance and the pitch accuracy. Furthermore, the combined strategy is more efficient than practice strategies that rely on motor/auditory imagery or overt singing/solfege alone (Fig. 1).

Moreover, the combined practice strategy produced a significantly higher level of musical expression as compared to all of the other four practice strategies. The findings suggest that application of mental imagery and singing may have a strong potential as complementary practice strategies, providing a less physically taxing alternative to physical practice and a more musical outcome.

Interestingly, among the trumpet students who reported to have learned solfege, there was an improvement in pitch accuracy which was higher than among students who did not learn solfege. A similar result was found in students who reported to mainly apply random practice, compared to students reporting applying mainly blocked practice or both (Fig. 2). Remarkably, neither duration, onset nor extent of music training showed any significant correlation with performance improvement or the general level of performance.

End of story
In conclusion, the findings suggest that applying practice strategies that complement conventional physical practice can reduce physical practice quantity while maintaining the same performance quality. Furthermore, solfege training and use of random practice strategies seem to beneficially influence the pitch-related performance accuracy. The study adds valuable insight into brass instrument performance, which may generalize to musical practice and, in a wider perspective, to many other forms of learning, in which cognitive processes and motor skills are involved.

For the full story, read Steenstrup et al., 2021[9].

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NEW FACES AT MIB

ONE POSTDOC AND FIVE PHD STUDENTS

TOMAS MATTHEWS is a new postdoc at MIB. He recently completed his PhD in Psychology at Concordia University in Montreal under the supervision of Prof. Virginia Penhune and in collaboration with Dr. Maria Witek and Prof. Peter Vuust.

Tomas' research is focused on how the rhythmic, and thus predictable, nature of music (and speech) can facilitate communication, drive us to move, and bring us pleasure.

During his postdoc, Tomas hopes to expand on his work investigating the pleasurable urge to move to music, known as groove, while also gaining experience with the use of computational methods, EEG, and MEG.

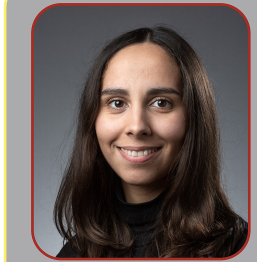
ALBERTE SEEBERG is a new PhD student at MIB. She has a background in Cognitive Science and has obtained both her bachelor's and master's degree from Aarhus University.

Previously, Alberte has been working at MIB as a research assistant as part of a project on cochlear implant users and their perception and enjoyment of music.

During her PhD, Alberte will continue to be working on music perception in cochlear implantees. More specifically, focus will be on rhythm and groove perception in cochlear implant users and the potential for perceptual enhancement through haptic stimulation.

OLIVIA FOSTER VANDER ELST is a new PhD student at MIB researching the neuroscience of music and dance. She is an accomplished violist, having studied at Wells Cathedral School. Subsequently, she read Chemistry at the University of Oxford on a 4-year Master's programme, where she researched magnetic field effects in both liquids and crystals.

Olivia is delighted to pursue her interests in science, music, and dance at MIB. Her particular research interests in neuroscience are groove (the aspect of music which makes one want to move), interpersonal interaction (particularly in partner dancing), and the effects of dance & musical training.



GEMMA FERNANDEZ RUBIO is a new PhD student at MIB. She is a Psychology graduate from Complutense University in Madrid incl. a one year Erasmus exchange at Edinburgh University. At the same time, she earned a degree in Music Composition from the Royal Superior Conservatory of Music in Madrid.

Gemma joined MIB for a research stay in November 2020 and worked on the analysis and collection of MEG and MRI data She recently completed her master's thesis titled "Brain mechanisms underlying the recognition of complex auditory patterns" and finished the Research Master in Cognitive and Clinical Neuroscience at Maastricht University.

During her PhD, she plans to investigate the encoding of complex musical sequences and how previously acquired information influences this process.

MATHIAS KLARLUND is a new PhD student at MIB researching the neuro-science of the cross-cultural impact on synchronization, with a particular focus on Chinese culture. He is partly funded by the Sino Danish-Center, from where he received his double master's degree in 'Neuroscience and Neuroimaging'. Subsequently, he read Biochemistry at the University of Copenhagen, where he conducted research on the autonomous oscillatory activity of the PreBötz complex in the mammalian brainstem. He also has a bachelor's and master's degree in classical guitar from the Royal Danish Academy of Music in Copenhagen.

His particular research interests are in the cross-cultural aspects of musical cognition and how interpersonal interaction is effected by the cultural constellation of interactors, as well as the cultural specificity of music and musical expertise.

REBECCA SCARRATT is a new PhD student at MIB. After having completed her internship at MIB in the fall of 2020 resulting in her master's thesis 'Alpha activation, relaxation and variation of dynamic complexity in music' from Radboud University, the Netherlands, Rebecca is delighted to continue her research. During her PhD, she will investigate the predictive coding aspect of singing as well as the neural networks of emotional singing and the singing of lullabies.

While at MIB in 2020, Rebecca also worked on an explorative study using Spotify to identify the music that people listen to while trying to go to sleep. She will continue this research and expand it to look into the music that people use to study in a collaboration with Makiko Sadakata from the Amsterdam Music Lab.

EDUCATIONAL ACTIVITIES

Bjørn Petersen and Elvira Brattico

Hybrid knowledge sharing

In the winter and spring of 2021, Covid-19 restrictions still meant that MIB's weekly lab meetings were held online on Zoom. However, after the summer break, all staffers were allowed to stop working from home and return to their workplaces. Thus, from August to December, MIB lab meetings could again be held physically. Taking advantage of experiences earned from both the NMVII conference and the Summer School of Music Neuroscience, the lab meetings were held in a hybrid format, making it possible for both attendees and speakers to attend and present remotely via Zoom. A total of 29 in-house presentations were shared in 2021 following a programme organized by Postdoc Cecilie Møller. The presentations are a core activity at MIB, providing young researchers with the opportunity to get feedback from colleagues on issues such as experimental design, test paradigms, statistical approaches etc. In other cases, senior researchers share results from recent publications, thus conveying valuable inspiration and ideas to fellow researchers.

Supervision of medical BA students

As in 2020, 2021 also saw huge interest from medical students in completing their BA projects at MIB under supervision by a MIB researcher. A total of 10 matches were made between medical students and MIB supervisors equally distributed by five in the spring and five in the autumn. Eight of the projects were empirical, and two were theoretical. In all projects, the students showed great commitment in their engagement and efforts to interact both with supervisors and administration. Feedback from external reviewers indicate that the submitted BA theses both are of high quality and cover topics and methods that are highly relevant to the students' profession.

In one project supervised by Postdoc Jan Stupacher, a medical student took part in data collection and data analysis and successfully wrote up his thesis in the form of a brief article. The data has been used in a manuscript currently under review in PLOS ONE. A short preprint version can be found at https://psyarxiv.com/n3yhq.

In another project supervised by Assist. Prof. Ole Adrian Heggli, a BA student took part in the exploration of links between depression and music listening. The student used tools developed at MIB to build a large dataset of music linked to depression and acquired audio features metadata from Spotify's public database. Following the construction of the dataset, the student manually coded music playlists to different categories, to better understand how various aspects of depression may be mirrored in our listening habits.

Assist. Prof. Kira Vibe Jespersen supervised three medical students in 2021. In the spring, two students conducted a systematic review entitled "Music as an intervention to improve sleep" as their bachelor project. In the fall, one medical student also chose to do a systematic review for the bachelor thesis. This project was entitled "The effect of music on sleep quality in hospitalized patients", and it is currently being prepared for submission to an international sleep journal.

Taken together, the cooperation with the Department of Clinical Medicine represents a win-win opportunity in which students earn long-lasting, important, and relevant insight and experience with research methods and reporting and in which MIB researchers achieve teaching experience and much needed assistance with their experiments.

Supervision and teaching abroad

During her stay at the University of Bari Aldo Moro, Prof. Brattico had the opportunity to teach three courses for undergraduate students of psychology and educational sciences and for graduate students of philosophy, respectively, on general psychology, personality psychology and psychology of learning and memory. She also taught a brief, advanced course of general psychology with practical sessions for psychologists at a psychotherapy school and short courses on music neuroscience aimed at musicians from a music therapy school in Milan and from the Conservatory of Bari. Similarly, this year Postdoc Leonardo Bonetti also taught a course on environmental psychology at the University of Bologna in Italy.

Other teaching activities at the Department of Clinical Medicine, AU

In 2021 MIB staffers have significantly contributed to graduate teaching of neuroscience at the Department of Clinical Medicine, AU. Prof. Brattico lectured at the Neuroscience Graduate Course at the Graduate School of Health. Moreover, in July she co-organized, together with Dr. Janice Wang from CiFOOD, the session Perception for the Interdisciplinary Summer School on Cognitive Neuroscience (4/7/2021-22/7/2021), which was part of AU Summer University (5 ECTS).

PhD student outreach activities

In the spring, PhD student Signe Hagner was responsible for half of the bachelor's course "Subject studies" at the Department of Dramaturgy and Musicology, Aarhus University. The course was entitled "Introduction to Music in the Brain" and aimed to present the students with an overview of the different strands within the research field as well as to introduce them to different scientific methods used in neuroscience. While cooperation with the Department of Dramaturgy and Musicology has been a long-sought ambition at MIB, it has so far not fully materialized. It is therefore a great achievement that Signe, herself a musicologist, has managed to spur an interest and arrange this course.

SysMus21

In November, MIB was the host of SysMus21 (International Conference of Students of Systematic Musicology) in collaboration with Aarhus Institute of Advanced Studies (AIAS). SysMus conferences are annual, student-run conferences designed to allow advanced students in the fields of systematic musicology and music science – particularly those studying for PhDs or completing Master's degrees – to meet and discuss their research, each year in a new location.

The 2021 organizing committee consisted of PhD student Signe Hagner (chair), Postdocs Christine Ahrends and Jan Stupacher and Assist. Prof. Niels Chr. Hansen. Due to the pandemic, the conference was held in a hybrid format with 55 onsite participants and more than 100 attendees who followed the conference on Zoom and in Gather.town. Dr. Nori Jacoby from Max Planck Institute in Frankfurt and Dr. Jonna Vuoskoski from RITMO in Oslo were invited as keynote speakers.

SysMus participants in the Aarhus University Park

The day before the conference, all onsite participants were invited to a half-day satellite event, where researchers at MIB introduced our research center and the research area "music in the brain" through talks, assignments and a tour of the scanning facilities at Aarhus University Hospital, Skejby.

SysMus21 was a great success with 76% of the respondents in the evaluation reporting that their conference experience had been "excellent". It provided an exellent opportunity to present MIB and Aarhus University to a wide range of young, aspiring researchers, while contributing to the development of talent within the field of systematic musicology.

RAMA Research

The MIB/RAMA cooperation intensified in 2021, as Postdoc Cecilie Møller and Assist. Prof. Kira Vibe Jespersen became engaged in the planning of RAMA's annual research course. Together with Assoc. Prof. Bjørn Petersen, who is responsible for the academy's R&D activities, they organized a course titled "Systematics in developmental research: idea - operationalization – interpretation". Due to Covid restrictions, the course was held exclusively online. Acknowledging the fact that online learning draws much stronger on attention than does physical, the course leaders adjusted the programme, incorporating shorter presentations and several shorter intermissions.

In both their planning and execution of the course, Møller and Jespersen demonstrated their unique expertise within both dissemination and research methods. As implied in the title, the focus was on applying systematic approaches in developmental research, the most prominent type of knowledge production conducted at RAMA. In an interchanging schedule of presentations and group work, the two course leaders covered important topics such as experimental designs, interview guides, questionnaire methods, online data collection and more – all in one day.

Aarhus Summer School in Music Neuroscience

The postponed Summer School in Music Neuroscience (director Prof. Elvira Brattico) was held from June 14 to June 17 with a comprehensive programme, organized by Prof. Elvira Brattico and Assoc. Profs. Boris Kleber and Bjørn Petersen and coordinated by Centre Administrator Tina Bach Aaen. The programme featured a line-up of internationally acclaimed speakers. Although the original plan was to present the course in a hybrid format, the uncertainty regarding Covid-19 travel restrictions forced the organizers to revise and hold the course online on Zoom and with poster presentations in Gather.town. At the end of the day, this may have been for the better for all, as hybrid formats are notoriously challenging and often tend to disfavour the online participants.

The course was offered as a PhD course in cooperation with Graduate School of Health, Aarhus University, carrying 3.2 ECTS credits. Students were stimulated in a multitude of ways. First, teachers provided students with reading material before the start of the course. Prerecorded videos were provided both asynchronously and during the afternoon sessions conducted by MIB tutors (more about this in the following). Moreover, each day students were offered the opportunity to show a poster on their research interests or findings to the teachers. At the end of each day, students also prepared learning diaries which then served as a final evaluation for obtaining the ECTS credits.

A total of 27 students signed up for the course, representing a multitude of nationalities, professional backgrounds and relations with music. The success of the course was picked up by Aarhus University who accepted the course as part of the fixed offering of the Summer University.

Thus, we can proudly announce that the next edition of the Summer School will be held in July 2023.

The course was organized in an interchanging schedule of talks, methodological demonstrations, and poster sessions. Talks covered a broad range of topics within the neuroscience of music and were given by eight international experts including Prof. Morten Kringelbach and Assoc. Prof. Boris Kleber from MIB. After the talks, the participants had the opportunity to interact with the speakers in Q&A sessions asking questions either inspired by the presentations or originating from the provided pre-course reading materials.

The speakers presenting at the Aarhus Summer School of Music Neuroscience were professors
1. Robert Zatorre (McGill University, Canada): Musical pleasure emerges from the interaction between reward and auditory systems.
2. David Huron (Ohio State University): Is a Scientific Approach to the Study of Music Unethical?
3. Simone Dalla Bella (McGill University): Moving to the musical beat: Bridging individual differences and motor rehabilitation.
4. Maria Herrojo Ruiz (Goldsmiths, University of London): Learning and body-brain interaction in music performance.
5. Virginia Penhune (Concordia University, Canada): The effects of early musical training and the concept of sensitive periods.
6. Isabelle Peretz (University of Montreal, Canada): How neurosciences of music can inform education.
7. Morten Kringelbach (MIB, AU): Whole-brain models for revealing the pleasure of music and improvisation.
8. Boris Kleber (MIB, AU): Brain mechanisms underlying singing.

For the methodological demonstrations, a team of MIB researchers took on them to change from what should have been hands-on demos to online sessions – and did a fantastic job. One of the approaches was the application of 'flipped classroom', allowing students to pick up the basics of the different neuroimaging techniques and experimental paradigms from prerecorded videos. In the actual teaching sessions, the instructors gave oral presentations and walked the participants through preprocessing tools and the different data analysis methods and options, using Zoom's screen sharing function.

The MIB researchers involved in the teaching sessions were:
1. EEG and behavioral experiments: Kira Vibe Jespersen, Cecilie Møller, Ole Adrian Heggli, Jan Stupacher and Alexandre Celma-Miralles
2. fMRI: Henrique Fernandes, Massimo Lumaca and Boris Kleber
3. MEG: Leonardo Bonetti, David Quiroga and Niels Trusbak Haumann

For the poster sessions, a dedicated space was set up in the web-conferencing software Gather.town. Gather.town provides participants with the ability to move around as avatars and interact with other participants based on their locations in the room, almost like real life. As part of the course,

Talks by Nori Jacoby and Jonna Vuoskoski

students were given the opportunity to present their research on virtual poster boards and convey it to other students, teachers and organizers. Also, speakers would attend the poster sessions giving valuable feedback.

The Gather.town platform was set up by PhD student Signe Hagner and her team of hardworking co-workers who all deserve plenty of credits for planning and executing this complex task to a very high standard. Importantly, the course immediately preceded the NMVII conference, hence, serving as a precious opportunity to test Gather.town with real participants securing a sheer success at the conference.

International guest speakers in 2021

Since its launch in 2015, MIB has had a strong tradition of inviting international guest speakers to Denmark – ranging from upcoming researchers to renowned established experts in the field. In addition to the list of talks presented at the NMVII conference and the Summer School in Music Neuroscience, MIB had talks from the following researchers:

1. Sylvie Nozaradan from MARCS Institute, Western Sydney University, Australia & Institute of Neuroscience, UCLouvain, Belgium (online).
2. Jonna Vuoskoski from RITMO, University of Oslo, Norway.
3. Nori Jacoby from Max Planck Institute for Empirical Aesthetics in Frankfurt, Germany.
4. Mark Fletcher and Sam Perry from Institute of Sound and Vibration Research, University of Southampton, United Kingdom & University of Southampton Auditory Implant Service, United Kingdom.
5. Jonathan Cannon from Department of Brain and Cognitive Science, Massachusetts Institute of Technology, Boston, USA (online).
6. Francesca Ciardo from University of Modena and Reggio Emilia, Italy.
7. Neil Todd from Prince of Wales Hospital Clinical School, UNSW, NSW, Australia & Department of Psychology, University of Exeter, United Kingdom (online).

THE NEUROCIENCES AND MUSIC VII

By Bjørn Petersen

In the days June 18-21, MIB hosted the international conference The Neurosciences and Music VII (NMVII) in the Aarhus Concert Hall. The conference is the most prominent conference in the field of neuroscience and music worldwide and was arranged in partnership with the Italian Mariani Foundation (FM) and co-hosted by the Royal Academy of Music, Aarhus/Aalborg (RAMA). The Lundbeck Foundation generously funded the conference with 300.000 DKK which significantly contributed to cover the expenses.

Postponement
The conference was originally planned to take place in June 2020, but as the realities of the Covid-19 pandemic emerged, it was decided to cancel and postpone to June 2021. As it became clear in the early months of 2021 that the pandemic would still restrict traveling for many potential participants, particularly from overseas, it was decided to hold the conference in a hybrid format in which the audience could attend and the speakers present either physically or online.

Professional A/V-management
In order to realize this plan, MIB hired the Danish company Getvisual (GV), which offers audio-visual expertise in virtual and physical management and production of conferences. GV provided an optimal solution for a complex issue, and thanks to a professional and well-planned execution, the conference was run smoothly and timely. In addition, the Concert Hall management showed a significant level of flexibility along the way while also the technical staff was instrumental in the successful implementation of the programme.

The NMVII in numbers
The NMVII attracted 89 physical and 417 online participants coming or attending from all over the world. Of the 506 participants, 59 were speakers and 294 presented a poster.

Opening ceremony
By courtesy of the Municipality of Aarhus and the Mayor's office, the organizers were granted the privilege to host the conference's opening ceremony in the scenic ballroom of the Aarhus Town Hall. Here, in addition to exclusive tastings from the local kitchen, the physical attendees enjoyed welcome speeches by FM vice president Maria Majno, director of MIB Professor Peter Vuust and representative from the Aarhus city council Counsellor Kristian Würtz. To kick off and highlight the interactive musical component of the conference, the evening also offered participants the chance to join in on parts of a Song, Dance and Playing performance led by RAMA Assoc. Prof. Lena Gregersen.

Opening talk in the Town Hall by Vuust

Würtz, Lopez, Majno and Vuust

Gregersen from RAMA with her group

Scientific programme
The conference included a keynote by Karl Friston, 11 symposia and 2 workshops, covering research within a broad field of music and neuroscience, presented by some of the most respected researchers within the field such as Robert Zatorre, Isabelle Peretz and Stefan Koelsch.

Workshop 1: Research on music interventions in community settings - towards learning and wellbeing across the life span.
Organizers: Assal Habibi and Mari Tervaniemi

Workshop 2: Putting music to trail: Design and progress of ongoing clinical trials on music-based interventions in neurological rehabilitation.
Organizers: Teppo Särkämö, Jennifer Grau-Sanchez, Antoni Rodriguez-Fornells

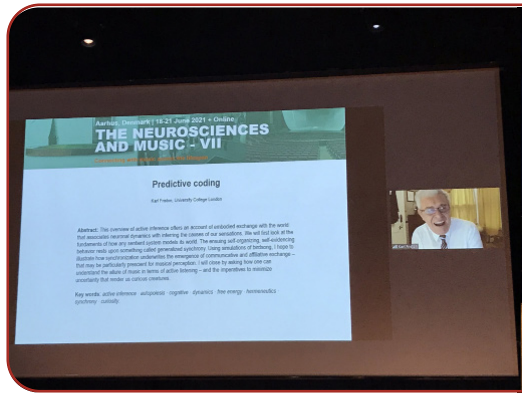
Symposium 1: Sensorimotor integration in music production across the life span. Chair: Maria Herrojo Ruiz. Speakers: Maria Herrojo Ruiz, Peter Pfordresher, Giacomo Novembre, Shinichi Furuya

Symposium 2: Towards a genomics of musicality. Chair: Henkjan Honing. Speakers: Isabelle Peretz, Sarah Wilson, Fredrik Ullén, Reyna L. Gordon

Symposium 3: Universality and variability of music across the lifespan and across culture. Chair: Samuel Mehr. Speakers: Samuel Mehr, Laurel Trainor, Nori Jacoby, Josh McDermott

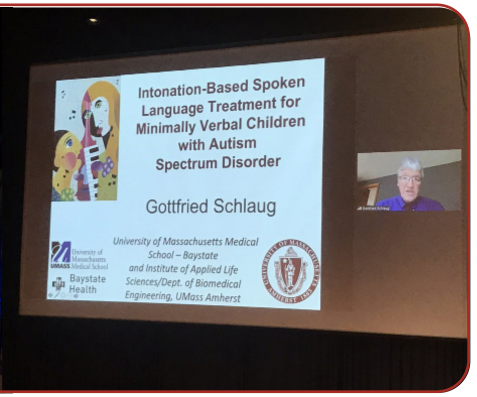
Symposium 4: The impact of long-term music interventions on behavior and brain plasticity over the lifespan in healthy individuals and in individuals with ADHD or autism spectrum disorder. Chair: Gottfried Schlaug. Speakers: Peter Schneider, Anne Marie Seither–Preisler, Eckart Altenmüller/Clara James, Christian Gold/Karsten Specht, Gottfried Schlaug

Symposium 5: Examine the development and neurodynamics of complex mental processing: What can (and can't) we learn from engagment with full-length pieces of music. Chair: Matthew



Keynote by Friston

The local Symposium 6 chaired by Penhune with Vuust, Kleber, Kringelbach and Bratttico



Symposium 4 chaired by Schlaug

Sachs & Petri Toiviainen. Speakers: Petri Toiviainen, Alluri Vinoo, Matthew Sachs, Mor Regev

Symposium 6: Brain mechanisms underlying musical interaction and improvisation across the lifespan. Chair: Virginia Penhune. Speakers: Peter Vuust, Boris Kleber, Morten Kringelbach, Elvira Brattico

Symposium 7: Towards music-based auditory rehabilitation for older adults. Chair: Benjamin Zendel. Speakers: Claude Alain, Frank A. Russo, Benjamin Zendel, Gavin M. Bidelman

Symposium 8: The role of music training on executive functions in child and adolescent development. Chair: Jennifer Bugos. Speakers: Minna Huotilainen, Jennifer Bugos, Franziska Degé, Daniel Müllensiefen

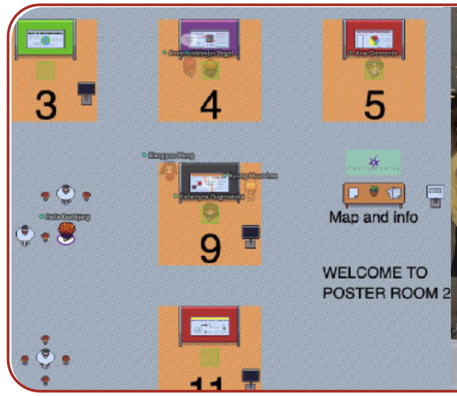
Symposium 9: Music interventions for neurological and neurodegenerative disorders. Chair: Stefan Koelsch. Speakers: Noelia Martínez-Molina, Simone Dalla Bella, Séverine Samson, Stefan Koelsch

Symposium 10: Musical pleasure as a tool to improve memory and affect. Chair: Robert Zatorre. Speakers: Ernest Mas-Herrero, Laura Ferreri, Pablo Ripollés, Neomi Singer

Symposium 11: Emerging approaches to large-scale and longitudinal studies of impact of music on human development in children and asolescents. Chair: John Iversen. Speakers: Dan Gustavson, John Iversen, Miriam Lense

Poster sessions

Similar to the symposiums, the poster sessions also needed to be accessible online. This challenge was solved by a hard-working and inventive group of MIB students and postdocs by creating a dedicated



Poster sessions in Gather.town....

.......and in the Concert Hall

RAMA Big band

NMVII virtual space on the platform Gather. town. Here, the conference participants, using their laptops, were able to study the posters and discuss the content with the presenters and fellow conference delegates.

Musical interactions

Taking advantage of the close partnership with The Royal Academy of Music, MIB was able to add six ‘interacting with music’ sessions to the programme, which presented different live performances by RAMA teachers and students. Among these were the RAMA Big Band conducted by Prof. Jens Christian Jensen, Prof. Jim Daus in a vocal interaction with the audience, and sisters Rebecca and Gabriella Fuglsig in front of their El Sistema-inspired children’s orchestra Musik-Sak. These musical sessions significantly contributed to the programme, reflecting the important artistic aspect of the conference theme.

Social programme

The physical attendees had the opportunity to meet and network at three social events: a conference dinner at The Railway Repair Shop, a musical jam session at the Royal Academy of Music and a Music, Exhibitions and Light Supper event at The Old City Museum of Aarhus. These events added a great opportunity for socializing and networking to the program as well as a chance to experience some of the local atmosphere.

Summary

Hosting NMVII has been a unique opportunity for furthering the field of neuromusicology and has significantly increased the awareness of the high quality of research carried out at MIB and in Denmark in general. As expected, the conference held a very high level with large impact on the scientific field and with potential to influence Danish society and health care in years to come. Within MIB, the hosting of the conference yielded a significant contribution to the general knowledge both scientifically, practically and logistically, knowledge that will be of high value in future projects.

Photos pp 66-73: Mariani Foundation and MIB

THE NEUROCIENCES AND MUSIC VII

Impressions - A memorable edition, beyond all odds

By Maria Majno and Luisa Lopez

18 June 2021, striding across the City Hall Park, bright sunshine in one of the year's longest days: no time to look around or even upward, there will be time to admire the Clock Tower by Arne Jacobsen and Erik Møller … Must make it in time for the inauguration, surely the official Municipality protocol will not allow for significant delays… Enter the bright sunny space of the atrium, and gone is all anxiety: a sudden sense of successful landing, relaxation, friendly conversations ongoing among the "Happy Hundred" able to attend in person. Immediate connection with the city council representative, and quick coordination of messages, a heartening solution to lingering disbelief, which had prevented rejoicing until the actual moment: we are tangibly "there" as representatives of the worldwide Neuromusic Community, who will be connecting globally despite time differences, overcoming nostalgic qualms and dismissing all temptations of envy.

Keywords: cooperation and courage. The former, as spirit of collaboration, has been in the DNA of the Neuromusic series from the start, with the defining intention to highlight in turn each partner's particular strengths. This time, MIB presented an original constellation: the impetus of a youthful institution combined with the status of established researchers, the Scandinavian cohesiveness yet the eclectic international reach, the scientific concentration and the extraordinary care for high-level musical representation: all aspects which a protracted preparation phase, as silver lining of the pandemic-related delay, offered even more opportunities to reveal and appreciate. The second – an invitation to be daring as well as attentive – was actually enhanced by the exceptional circumstances: during the first Covid-19 wave, postponing for a year seemed almost too prudent an option, whereas the successive "waves" made the endeavour suspenseful until shortly before: for months, enrolled participants had been fibrillating about whether international regulations would not allow entry into Denmark and under which conditions. Would there be an in-person gathering at all, and should we rather opt for the safe bet of an all-virtual edition?

We are still happy and grateful that the pendulum, during the intensified organizational meetings, finally halted on the shared choice to go for the less anodyne solution: a more demanding but promising "hybrid", with a leap of faith enabled by the guarantee of a fool-proof streaming service: in fact, entrusting all technical responsibilities to the "Get Visual" team, firmly in the wings, was the strongest prerequisite in order to concentrate on other aspects. The first challenge appeared between the known and the unforeseeable: how would the ascertained motivation of a cohesive

community react to a sudden mix between on-site attendees and a four-fold majority of long-distance connections? Would the precious interaction of poster sessions adapt to the virtual environment and do justice to the kaleidoscopic presentations by researchers from all over?

Admittedly, the work-in-progress hothouse on Gather.town was an experiment which we would not have successfully pulled off without the imaginative assistance from the local team of youngsters shepherded by Signe Hagner (is the notion of "avatars" unsettling only for those above a certain age?). On another hand, the chemistry of Symposia was all along surprisingly lively, with overtones of solidarity from those present supporting the remote effort of communicating through (neuro)music across the space and time span: much admired was the good temper of speakers having to present at ungodly hours and making no fuss about it.

In fact, if the best organization is said to be the invisible one, guardian angels Hella Kastbjerg and Tina Bach Aaen were the living proof of this maxim, save for the fact that one could always find them when needed, with the certainty that all queries would be solved. This also reflected on the ability to rescue the social programme in spite of covid restrictions, and the evenings at the fascinating Railway Repair Center and the Old Town Museum were as smooth as could be, providing the opportunities to discover new voices in the Neuromusic counterpoint.

Prof. Eckart Altenmüller receiving the Neuromusic Lifetime Achievement Award.

There was fun at the roaring Jam Session and amusing moments at the Awards Ceremony, where a carefully orchestrated surprise was put in jeopardy by the reasonable but – by local standards – undisciplined request to move this moment forward. Thank you again, Peter Vuust and Elvira Brattico: Scandinavian and Mediterranean styles were reconciled in the delight to honour Eckart Altenmüller and in the impulse to transform a touching personal acknowledgment in the "Mariani Young Investigator Award", to be continued.

So here goes the 7th edition of the conference… without the seventh-year itch: on the contrary, memories linger in balance: excitement and focus, discipline and informality, precision and warmth. All qualities that can be applied to the outstanding series of musical interludes coordinated by Bjørn Petersen with his colleagues at RAMA: among many intense performances, the crowning moment was in retrieving the joy of live voices, and we still feel the shiver of when the emotion of the singers became one with that of the audience. A spark after a long silence, a release guiding new steps, with commitment and control, unforgettable.

THE NEUROCIENCE AND MUSIC VII

Impressions - Midsummer-(Night)-Dream in Aarhus

By Eckart Altenmüller

After 18 months of Corona pandemic, finally the seventh "Neuroscience and Music Conference" took place in Aarhus. During the most beautiful time of the year with Scandinavian bright blue skies we enjoyed unique hospitality of our Danish friends. Some hundred enthusiasts for music and (neuro-) science gathered from June 18 to 21, 2021. All was made possible by the wonderful hosting committee at the MIB, led by congress president Peter Vuust and by the generous sponsoring and organization of the Mariani Foundation, presided by Maria Majno and scientifically coordinated by Luisa Lopez.

We were all after a long time of forced retraction craving for personal gatherings, for meeting friends and re-connecting again. Still, the conference had to be organized in a hybrid manner, since many of the international colleagues were unable to leave their countries. However, the Aarhus team and location in the Concert Hall was perfectly fit for a hybrid meeting enabling closeness to our distant colleagues. Using the Gather.town software during the poster sessions and pauses was fun, Marauders Map connected with friends and participants all over the world.

The central theme of the conference indeed was: Connecting with music across the lifespan. This refers not only to the societal consequences of making music in groups or to music induced changes in brain connectivity but also to the developmental aspects, to live-long neuroplasticity and to the urgent need for more inclusivity in music making and music education, allowing everyone to participate and explore his or her creative potentials.

"Connecting with music" entailed also a very practical approach: The six musical interludes activated the audience with singing, clapping, moving but also listening to short concerts of excellent musicians from Aarhus. And connecting with music was also the motto of the "After-Conference" programme, e.g., in form of a hilarious Jam session of the participants or when listening to the wonderful Vuust Trio at "Den Gamle By" with Peter and his sons Frederik and Mikkel.

The overall scientific level of the conference was outstanding, and speakers included the world-leading peers in neuroscience and neuropsychology of music. It is here not the space for a thorough review on key-note-speech, workshops, symposia, or poster-sessions and I will only highlight new trends and some of my favorites. Topics included sensorimotor-auditory integration in music making, genomics of musicality, universality of music across cultures, long-term effects of music on brain development and brain aging, musical learning, and brain processes during musical improvisation. A very high quality was reached in the symposia on the beneficial effects of music in neurorehabilitation, be it in developmental disorders such as dyslexia, ADHD, autism, or in depressive disorders, stroke, neurodegenerative disorders like different types of dementia.

In terms of scientific paradigms, neo-phrenological localization approaches and dualistic concepts of the brain as a complex array of autonomous modules were abandoned. Compared to previous Neuromusic conferences, the designs of experiments were much more oriented towards ecological, behaviorally relevant stimuli. Researchers frequently applied "real" music and considered predictive coding, adaptive anticipation, short and long-term learning processes and all kinds of functional and dysfunctional developmental processes.

Methodology included cutting edge brain imaging and data analysis, network and graph-theory, up-to-date neuropsychological testing, genetic analyses and novel statistical methods. The topics and populations under investigation were well defined and much more homogeneous as compared to presentations in previous conferences. Understanding emotional and motivational aspects of music processing was directly or indirectly involved in almost all topics.

I personally found the Keynote of Karl Friston most illuminating, enlightening principals of predictive coding and its impact on brain action, on human nature, and more generally of our vision of the world. It was a captivating synthesis of Neuroscience, Neuropsychology and Neurophilosophy.

With respect to the conference as a whole, it was most satisfying to see how far science in the field of neuroscience of music has advanced since the inception of the Neuromusic Conferences almost 20 years ago in Venice. And it was emotionally touching to meet all the many young researchers, master's and doctoral students, contributing to advance knowledge in the field and at the same time being so cheerful, creative, and easy going. Maybe, this joy of research results from the overall object of research, music, precious to all our hearts.

It remains for me to thank the team at MIB in Aarhus and the Mariani Foundation for this wonderful event. I am looking forward to Neuromusic VIII.

The a-cappella choir Vocal Line

PHD FEATURE

Christine Ahrends

Uncertainty and predictability of human brain dynamics at rest, during auditory processing, and under LSD.

The brain is not a static object, but it changes over multiple time scales, from (sub-) millisecond molecular activity and neuronal firing to second to minute whole-brain functional fluctuations. These different temporal and spatial levels are interdependent, and their interaction enables the brain to carry out complex functions[1]. Dynamics at the level of the whole brain arising from thousands of interconnected neurons are complex, but we can describe the trajectory by which the brain evolves temporally as transitions between functional networks, e.g. in resting-state fMRI recordings. Specifically, we can model whole-brain dynamics as a sequence of brain "states", each one a distinct pattern of functional activation or connectivity. Using these models, it may then be possible to predict a future state of the brain, but there is also uncertainty associated with the patterns in which the brain transitions between states. In my PhD project, I aimed at investigating the role of predictability and uncertainty in human brain dynamics by studying three main questions: 1) Can we predict individual functional activation during a future paradigm based on current resting-state functional connectivity (rsFC)?, 2) What are the data and model requirements to be able to estimate temporal changes in rsFC from fMRI recordings?, and 3) Is uncertainty of brain dynamics itself an indicator of the state of the brain?.

Functional connectivity during rest (rsFC) and while the brain is engaged in a task form a stable functional architecture that is unique to an individual, like a fingerprint. It has been suggested that this makes it possible to predict an individual's brain response to a task from their rsFC[2]. In Study 1, we used fMRI recordings of participants during rest as well as while listening to a melodic contour paradigm. We then used a regression model to predict inter-individual differences in functional activation in the paradigm from time-averaged rsFC. We demonstrated that this prediction, using time-averaged information, only succeeds in sensory association cortices. In Studies 2 and 3, we therefore focused on a dynamic model of slow fluctuations in FC and amplitude.

Since there is no definite way of measuring brain dynamics, they have to be estimated by a model and their outcome, namely the estimation of how dynamic the brain is may vary. In other words, even if the brain (data) was always the same, a model may estimate its dynamics in different ways each time it is run if it is non-deterministic or biased by other parameters. In Study 2[3], we used a large resting-state fMRI dataset and simulated fMRI recordings with different parameters. We then showed which aspects of the data and the model influence the ability to detect temporal

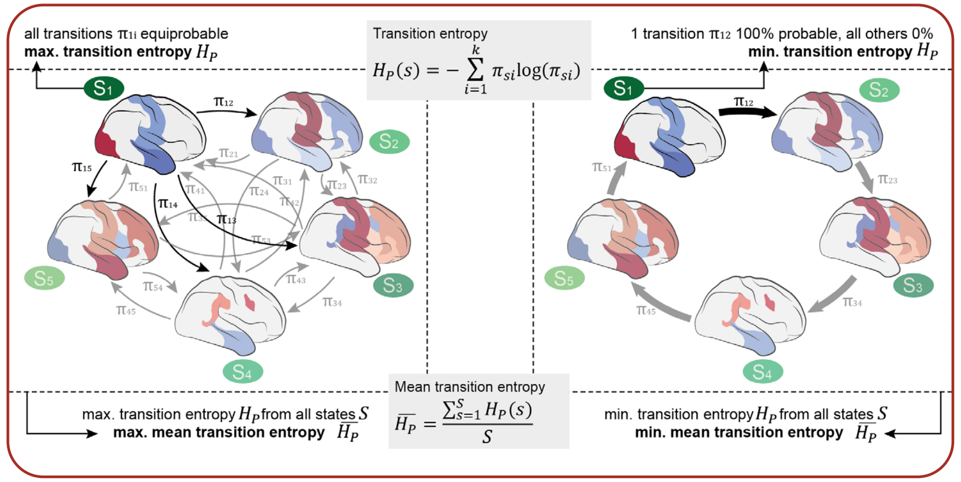


Figure 1. *Transition entropy describes uncertainty of brain state transitions.* ***A)*** *If transitions between brain states were all equally probably, transition entropy would be high. In this case, it would be difficult to predict the next state of the brain from any point.* ***B)*** *If, on the other hand, transitions between brain states always occur in the same pattern where there is always one state transition with 100% probability, transition entropy would be low. It would be possible to predict exactly which will be the next state in this case. Figure adapted from Ahrends et al. (in prep.).*

changes in FC using a Hidden Markov Model (HMM)[4], and we suggested recommendations for this estimation. Following these findings can improve the reliability of time-varying FC models.

Using this type of model on fMRI recordings allows estimating whether the brain tends to transition in stereotypic patterns that follow a strict order (low entropy), or whether it switches randomly between all possible configurations (high entropy), as illustrated in Fig. 2. Entropy (uncertainty) has been suggested to underlie changes in altered states of consciousness, such as the psychedelic state[5]. In Study 3, we used fMRI recordings of participants under LSD and placebo, and we described their brain dynamics using a HMM. We then demonstrated that the entropy of brain state transitions is higher in sessions with LSD than with placebo.

In this PhD project, I studied the role of predictability and uncertainty as important principles of brain dynamics. Brain dynamics are inherently uncertain, making a perfect prediction of the brain's functional temporal evolution impossible. The degree of uncertainty in brain dynamics can explain spatiotemporal functional patterns in the normal waking brain and the brain in an altered state of consciousness. Without uncertainty, the brain would be unable to adjust to its environment and instead only follow a predetermined path. Uncertainty is thus a condition for the brain's flexible dynamic configuration.

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PHD FEATURE

Victor Pando-Naude

Musical groove and Parkinson's disease

Music modulates the activity of brain areas involved in auditory, motor, timing, and emotional processing, and it is evident when we start to tap our foot to the rhythm of a groovy song. This experience relies on the brain's ability to integrate external stimuli with internal representations, expectations, and/or predictions[1]. The continuous flow of information requires specialized neural mechanisms such as audio-motor coupling, a phenomenon driven by temporal predictions and associated with cognitive and emotional mechanisms. Thus, music represents an ideal framework to study such complex and interesting brain mechanisms and has important implications for the use of music in the treatment of psychiatric and neurological conditions. Creating a bridge between basic and applied research became the focus of my PhD.

In study 1, we conducted a systematic review and activation likelihood estimation (ALE) meta-analysis of neuroimaging studies investigating music perception, production, and imagery. The aim was to identify patterns of brain activity that could reflect the top-down/bottom-up nature of the brain[2]. We found that music perception relies on auditory, (pre)motor, and limbic areas, music production on audio-motor areas, while imagery relies on motor areas of the cortex and thalamus, and distinct parietal regions related to theory-of-mind (Fig. 1). Taken together, our findings provide robust evidence that the brain requires different structures to process similar information which is made available either by the interaction with the environment (bottom-up) or by internally generated content (top-down).

In studies 2 and 3, we tested the hypothesis that the experience of groove relies on the adequate interaction between audio-motor coupling and the reward processing in the brain, with the basal ganglia playing a central role[3,4]. Auditory

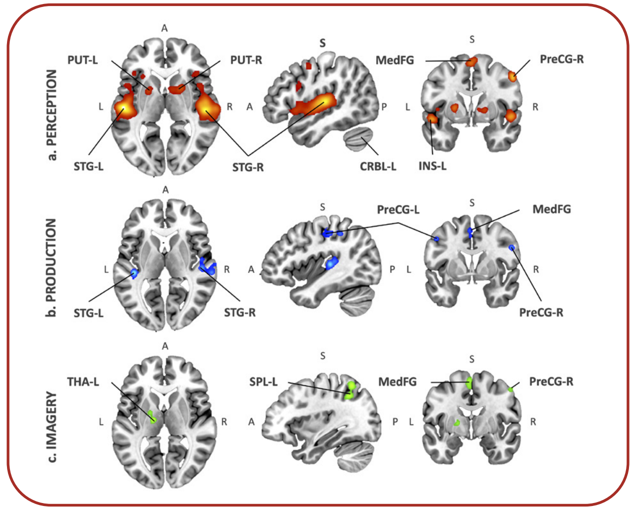

***Figure 1.** ALE meta-analytic review of music perception, production, and imagery. CRBL cerebellum, INS insula, MedFG medial frontal gyrus, PreCG precentral gyrus (primary motor cortex or M1), PUT putamen, SPL superior parietal lobule, STG superior temporal gyrus (primary auditory cortex), THA thalamus, R right, L left, A anterior, P posterior. Adapted from[2]*

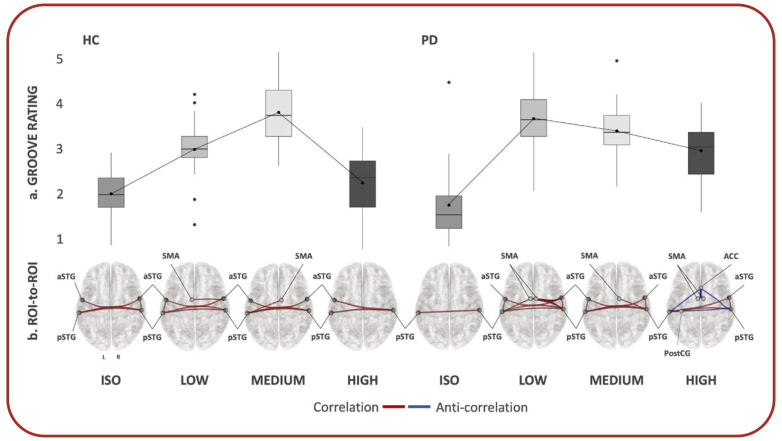

***Figure 2.** Neural correlates of groove in Parkinson's disease. ACC anterior cingulate cortex, PostCG somatosensory cortex, SMA supplementary motor area, STG superior temporal gyrus, R right, L left, a anterior, p posterior.*

stimuli were presented to Parkinson's disease (PD) patients and healthy, age-matched controls (HC) consisting of musical sequences with varying rhythmic complexity (isochronous, low, medium, high). Participants were scanned with fMRI and were asked to rate their experienced pleasurable desire to move to the rhythms. As previously reported, healthy adults showed an inverted U-shape with preference for medium complex rhythms, supporting the idea that auditory, motor, timing, and reward areas are interacting when perceiving violations and fulfilments of musical expectations that elicit pleasure. Distinctively, PD patients shifted this relationship towards less complex rhythms reflecting a preference for more congruence between predictions and uncertainty, possibly due to dysfunctions of the basal ganglia (Fig 2a).

Then, we analysed brain functional connectivity correlates as a function of each rhythmic condition (Fig 2b). Regions-of-interest (ROIs) included auditory, sensorimotor, and reward areas. We found that, in HC, isochronous and high complex rhythms showed significant correlations exclusively between auditory areas. In low and medium complexities, we found additional correlations between auditory cortices and supplementary motor areas, stronger with medium syncopated rhythms. In PD patients, isochronous rhythms only showed significant correlation between posterior auditory cortices, while low and medium complexities also showed additional correlations between auditory cortices and supplementary motor area, stronger with low syncopated rhythms. High complexity in PD showed anticorrelated functional connectivity between auditory and sensorimotor cortices.

Taken together, our findings contribute to the overall aim of building a bridge between basic science and clinical applications of music. By studying the underlying mechanisms in health and disease, we contribute to current models trying to explain such mechanisms (groove in the brain). In turn, better understanding of these mechanisms may guide future approaches for treatment (groove for PD).

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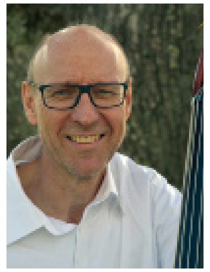

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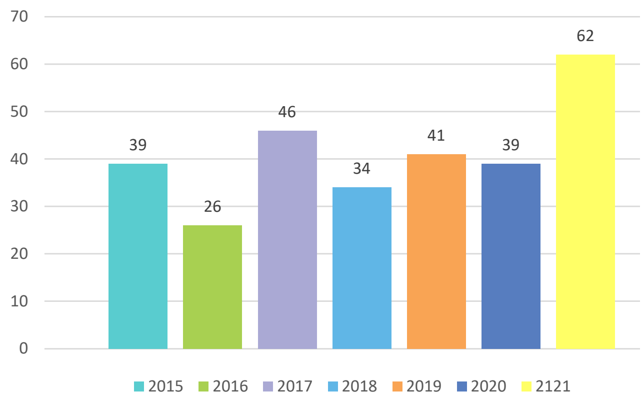
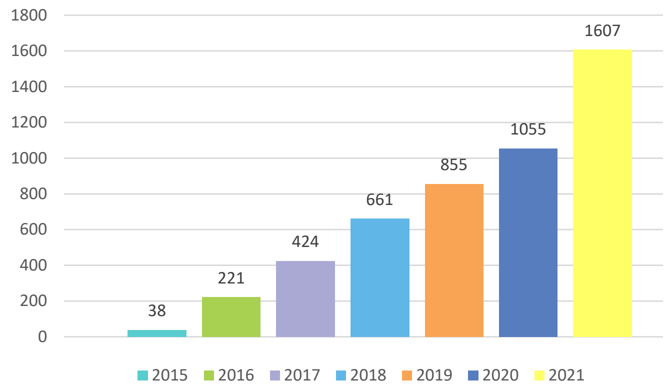
PUBLICATIONS 2021

Number of peer-reviewed articles



Number of citations



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PhD theses

Ahrends, C. Uncertainty and predictability of human brain dynamics at rest, during auditory processing, and under LSD.

Pando-Naude, V. Musical groove and Parkinson's disease

Book

Vuust, P, Fra solo til samspil. Forlaget Grønningen.

OUTREACH 2021

Talks at international conferences

Alexandre Celma-Miralles
FENS Regional Meeting - Satellite Event: "Music and the Brain"

Boris Kleber
The Neurosciences and Music VII, Aarhus, Denmark
European Voice Teachers Association, Belgium

Elvira Brattico
International Music Therapy Day, Bari, Italy
11th Italian Information Retrieval Workshop (IIR 2021), Polytechnics of Bari, Italy
MEG Nord, Moscow
Workshop on Power of music, University of Bari Aldo Moro, Italy
Workshop on Music as a therapy to the brain, Manfredonia, Italy
The Neurosciences and Music VII, Aarhus, Denmark

Jan Stupacher
37th Annual Meeting of the German Society for Music Psychology, Hamburg, Germany
International Symposium Art in Motion 2021 – Rhythm, Munich, Germany

Kira Vibe Jespersen
Danish Sleep Research Day, Copenhagen, Denmark
14th Nordic Meeting in Neuropsychology, Copenhagen, Denmark
Forskningens Døgn, Denmark

Mette Kaasgaard
European Respiratory Society International Congres, Denmark

Morten Kringelbach
The Neurosciences and Music VII, Aarhus, Denmark
Symposium on Making the Cultural Brain of the Child, Nobel Forum, Sweden
Symposium on The Neurobiology of Hatred, Nobel Forum, Sweden
CNS Workshop on Dynamic properties of brain states and their transitions, Paris, France
7th Congress of the German Society for Eating Disorders e.V. (DGESS), Germany

Niels Chr. Hansen
Seminar on Creativity and Resilience in Times of Covid-19, Aarhus University, Denmark
16th International Conference on Music Perception and Cognition (ICMPC), Sheffield, UK
Sixth International Conference on Analytical Approaches to World Music (AAWM), Paris, France
Rhythm Production and Perception Workshop, RITMO, Oslo, Norway

Peter Keller
17th Annual Neuromusic vConference: Rhythm and Interpersonal Coordination, Hamilton, Canada

Peter Vuust
SysMus21 - International Conference Series of Students of Systematic Musicology, Aarhus, Denmark
The Neurosciences and Music VII, Aarhus, Denmark
Music and CI Symposium, Cambridge, UK
Art and Affect in the Predictive Mind Conference, UK

Other talks (selected)

Alexandre Celma-Miralles
Timing Research Forum

Bjørn Petersen
VIA University College, Denmark

Boris Kleber
Dagmar Gustafsons Elever, Sweden

Elvira Brattico
CBRU seminar, University of Helsinki, Finland
Research day at the Center for Neurodegenerative Diseases, Panico Hospital, Tricase, Italy
Event "Art and Science Across Italy", Istituto di Fisica Nucleare (IFN), Italy and CERN, Geneva, Switzerland
"The International Year of Sound", Polytechnics of Bari, Italy

Kira Vibe Jespersen
Køge Bibliotek, Denmark

Morten Kringelbach
Christian Margot Symposium, Geneva, Switzerland
Oxford Psychedelics Society, UK
Royal Society Copenhagen, Denmark
CN Seminars, Paris, France
Guardian Masterclass, UK
Oxford Uehiro Centre, UK
Imperial College, London, UK

Niels Chr. Hansen
Queen Mary, University of London, UK
Interacting Minds Centre, Aarhus University, Denmark

Peter Keller
Department of Physical Therapy, Tel Aviv University, Israel

Peter Vuust
Lundbeck, Denmark
The Royal Academy of Music, Aarhus/Aalborg, Denmark
Dansk Musiker Forbund, Denmark
Sundhedsstyrelsen og Sund By Netværket, Denmark
Roskilde Oplysningsforbund, Denmark
UC Syd, Denmark
Demensfællesskabet, Fredericia, Denmark
Holbergskolen, Denmark
Lægeforeningen Sjælland, Denmark
Horsens Teaterfestival, Denmark
Friskoleledere Helgenæs, Denmark
LMS Festival, Aarhus, Denmark
Department of Political Science and Government, Aarhus University, DK
Generator, Ringkøbing, Denmark
FOF, Aarhus, Aarhus, Denmark
Department of Mathematics, Aarhus University, Denmark
Sundhed og Omsorg, Aarhus Kommune, Denmark
Statens Naturhistoriske Museum, University of Copenhagen, Denmark
Dansk Audio, Copenhagen, Denmark
Danish Cardiovascular Academy, Aarhus, Denmark

Participation in TV, radio and podcasts (selected)

Elvira Brattico
BBC Radio 4, radio, UK

Kira Vibe Jespersen
Zeit Wissen, podcast, Germany
P2 Foyeren, radio, Denmark
P4 Klar vikar, radio, Denmark

Niels Chr. Hansen
P2 Puls, radio, Denmark
P3, radio, Denmark
Radio 4, radio, Denmark

Ole Adrian Heggli
NPR, radio, USA
RNZ, TV, New Zealand

Peter Vuust
TV2 Go'morgen Danmark, TV, Denmark

Brainstorm, videnskab.dk, podcast, Denmark
Heads Up! podcast, Denmark
Nova Radio aftenklubben, radio, Denmark
P1 Kulturen, radio, Denmark
P4 Formiddag, radio, Denmark.
P1 Supertanker, radio, Denmark
Radio 4 Kraniebrud, podcast, Denmark
Radio 4 Kræs, radio, Denmark,
RadioLoud Gravergruppen, podcast, Denmark
Radio Nova Aftenklubben, radio, Denmark
TV2 Lorry, TV, Denmark
Stetoskopet, podcast, Denmark
Stir Fried Fascination, podcast, Sweden

Interviews in printed media/web (selected)

Alexandre Celma-Miralles
www.newscientist.com: Haunting lemur songs have a rhythm similar to human music

Cecilie Møller
Vid & Sans, Denmark: Hvorfor oplever vi musik som støj?

Massimo Lumaca
MIND, Le Scienze, Italy: Il cervello predittivo

Mette Kaasgaard
Kristeligt Dagblad, Denmark: Forskere søger svar: Kan lungesyge synge sig til bedre trivsel?
Fysioterapeuten, Denmark: KOL Sangtræning øger gangdistance
Lungeforeningen www.lunge.dk, Denmark: Tips og øvelser: Få mere luft i hverdagen

Morten Kringelbach
Politiken, Denmark: Efter årtiers frygt og forbud: Trippet er tilbage
Information, Denmark: Forudsigelsesmaskinen
Popular Science, USA: The last sip
Infobae, South America: Por qué no siempre el placer produce felicidad, según el neurocientífico que estudia el hedonism.
Psychology Today, USA: The new neuroscience of pleasure
Politiken, Denmark: Kæmpe gennembrud: Lammet mand kan skrive ved tankens kraft
Wired, UK: Sex toys are switching from hedonism to health
Science Focus, USA: This is your brain on puppies: The adorable neuroscience of cuteness

Niels Chr. Hansen
Kristeligt Dagblad, Denmark: Hjernen forudser fremtiden, når man lytter til musik
Videnskab.dk, Denmark: Er hjernen blot en 'forudsigelses-maskine'?
Videnskab.dk, Denmark: Fra Rihanna til Robbie Williams: Spotifys data hjælper musik-forskning
Videnskab.dk, Denmark: Hjerneforskere er tossede med at bruge musik til at undersøge hjernen
Jyllands-Posten, Denmark: Musik er et vidunderværktøj, når forskerne skal undersøge hjernen
Weekendavisen, Denmark: Da musikken blev født
NRC, Netherlands: Muziek helpt om de eenzaamheid tijdens corona te bestrijden, blijkt uit onderzoek

Peter Vuust
Videnskab.dk, Denmark: Vidunderbørn: Hvordan bliver de så vilde?
Videnskab.dk, Denmark: Hvorfor får musik os til at græde?
Videnskab.dk, Denmark: Hvorfor motiveres vi af musik, når vi træner?
Kristeligt Dagblad, Denmark: Portræt
Jyllands-Posten: Peter Vuust: Bassisten har utrolig meget magt
Diverse dagblade: Hvis det swinger for lederen, swinger det typisk også for medarbejderen
Aarhus Stiftstidende: Rytmehans - kan du høre noget?
Dr.dk: Mulan, AC/DC og Suspekt: Her er de danske sportsstjerners musik, før de skal i ilden

Ole Adrian Heggli
www.videnskab.dk: Fra Rihanna til Robbie Williams: Spotifys data hjælper musik-forskning
The Telegraph, UK: Be it Morning Has Broken or Night Fever, there's a perfect song for every time of the day.
Daily Mail, UK: Music to suit our moods all day and all of the night.