MIB 2020

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

MIB Annual Report 2020

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

Annual Report 2020

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

For Center for Music in the Brain - as for most other institutions - the year 2020 was to a great extent shaped by Covid-19. Luckily, the pandemic arrived in between the two funding periods of the center where most of our PhD students were in the later phase of their studies and had already collected their data. But with more than half the year away from the offices, we all had to adjust. We managed to move our lab meetings, research club, one-on-one meetings, and guest talks to online platforms. Getting used to such new ways of collaborating has in many ways been a positive learning experience which may help us towards more efficient working practices in the future. Most importantly, it has fertilized the ground for several new international collaborations and paved the way for future research stays for our PhD students and postdocs.

However, our core activity - carrying out research on human beings – was greatly challenged with the country in lock-down and the scanners closed. Therefore, we turned to other data sources, for instance our Spotify project that allows for correlating our music choices with daily behaviour. Another consequence of Covid-19 was that we sadly had to postpone the Music and Neurosciences Conference VII and the preceding summer school to June 2021 where they will take place as partly online events.

Overall, the productivity of MIB was not influenced by the pandemic, and we published many important experimental and theoretical papers in 2020 (see page 68 for an exhaustive publication list). Some of these papers concern musical interaction, which will be the focus of our second funding period, such as Assist. Prof. Ole A. Heggli's SCAN paper on brain networks involved in musical interaction and postdoc Jan Stupacher's paper in Scientific Reports about how our cultural upbringing and personal taste affect how we bond with each other when we move to music.

Other papers constitute novel theoretical developments and methods such as Prof. Morten Kringelbach's PNAS paper on dynamic coupling of whole-brain and neurotransmitter systems, postdoc David Quiroga's NeuroImage paper on the hierarchical brain processing of melodic surprise and Assist. Prof. Massimo Lumaca's Human Brain Mapping paper which uses a predictive coding-based analysis of the effective connectivity in a melodic oddball fMRI paradigm. The latter employs dynamic causal modelling to reveal that mismatch responses are best explained by a fully connected bilateral auditory network comprising the primary auditory cortices (A1) and the planum temporale (PT) and emphasizes the power of understanding brain responses to music in a predictive coding context.

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.

Many of the 2020 papers illustrate the extensive international network which MIB is nested in such as Finnish professor Petri Toiviainen's seminal NeuroImage paper on the brain networks underlying the musical beat—the result of a longtime collaboration with MIB professor Elvira Brattico— and the paper in NeuroImage on musical groove by Canadian PhD student Tomas Matthews and Senior Birmingham Fellow Maria Witek. Tomas will continue his career as postdoc at MIB starting in the autumn of 2021.

This year saw no less than five successful PhD defenses and in all cases the candidates have been given jobs at MIB, with other research groups or in the industry. Marianne Tiihonen defended her thesis before the pandemic reached Denmark, and it turned out to be the year's only in-real-life-defense. Marianne has continued her research career at Heinrich-Heine-Universität Düsseldorf. In the spring, Patricia da Mota and Leonardo Bonetti were the first to test the Zoom format for their PhD defenses. Even though it is less lively than a real defense, it turned out to be enlightening and festive experiences for both graduates and audiences. They were both subsequently employed as postdocs at Department of Food Science, AU and MIB, respectively. In the last part of the year, when we were all in the habit of everything happening on Zoom, Pauline Cantou and Stine Derdau defended their theses. Pauline is now working at CFIN, AU, and Stine has landed a job in The Health & Happiness Research Foundation.

As the result of a deliberate effort to upskill the MIB researchers' qualifications for applying for funding, the junior staff managed to attract generous funding in 2020. Postdoc Kira Vibe Jespersen received a DKK 350,000 grant from Helsefonden for her study on music listening as a means to improve sleep quality in adults with sleep-onset insomnia. Postdoc Leonardo Bonetti was awarded a DKK 700,000 Carlsberg Foundation Visiting Fellowship for the project "Using Music to Model the Brain's Realisation of Time" which enables him to spend two year at University of Oxford. Postdoc David Quiroga received DKK 1,310,000 from Independent Research Fund Denmark to go to University of California, Berkely for two years with his project "The neural basis of musical imagination". Finally, Assist. Professor Henrique Fernandes received EUR 45,000 from the Bial Foundation for the project "Brain routes to Creativity: uncovering creative flow in Jazz with neuromodulation."

MIB Assist. Prof. and AIAS-Cofund Fellow Niels Chr. Hansen was appointed a member of the Danish Young Academy, a network for talented young researchers under the Royal Danish Academy of Sciences and Letters. He is the first member ever who is a music researcher.

In 2020 MIB professor Morten Kringelbach finalized an extraordinary initiative. The Carlsberg Foundation and the American Pettit Foundation each donated £ 1 million for the creation of the "Erel Shalit Carlsberg Foundation Research Fellowship" in "Behavioural Neuroscience" at The Linacre College in Oxford. As the chair of this program Professor Kringelbach will lead the new interdisciplinary "Centre for Eudaimonia and Human Flourishing", which perfectly complements our research at MIB. Overall, this new angle on music and well-being fits well with the conclusions of a new international report 'Music on Our Minds: The Rich Potential of Music to Promote Brain Health and Mental Well-Being' from AARP: Global Council on Brain Health, which we helped shape and write at the start of the pandemic

With this annual report, we wish to highlight the scientific progress and key events in 2020 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

MIB lab meeting on Zoom in 2020.

PERCEPTION

Peter Vuust, Elvira Brattico, Morten L. Kringelbach

By Boris Kleber

The research into music perception has seen a number of exciting continuations and new developments. Despite the COVID-19 challenges, we were able to initiate, continue, or finalize most of our experiments.

A study initiated by former MIB postdoc Marina Kliuchko[1] compared brain responses between Danish and Chinese participants to tones with different degrees of expectedness in a melody in order to explore whether musical expectations may be culturally shaped. Postdoc David Quiroga, who analyzed the MEG data, modelled musical sound features to test two perceptual prediction models: one based on cultural learning of statistical regularities in music, as determined by a computational model of auditory expectations (IDyOM); the other one based on sound feature similarities between tones (e.g., pitch distance). Preliminary results favored the model of acoustic similarity over the one of cultural learning.

This does not mean that the listeners' cultural background and the listening conditions could not shape internal models of sound expectation. Rather, lower-level sensory expectations (i.e., "this sound feature may have a higher probability to appear next") may play a larger role in how our brain processes music than previously thought.

David Quiroga and colleagues also assessed how neural responses can be modulated by stimulus predictability (pitch dimension) and musical expertise[2]. While trained musicians and non-musicians watched a silent video, they listened to either predictable—a four-note repeated pitch pattern—or less predictable—non-repetitive complex melodies— musical stimuli played in the background. Dynamic causal modeling (DCM) of the MEG data demonstrated that increased uncertainty, either due to less predictable melodic patterns or due to a lack of musical expertise, can enhance neural gain in auditory areas through a reduction in the strength of intrinsic (inhibitory) connectivity in A1 and STG. These findings suggest that stimulus-driven and expertise-driven uncertainty reduction might rely on similar changes in effective connectivity, specifically in early processing auditory areas. Similarly, lower-level modulation of MMN responses have also been observed in participants with amusia[3], a disorder that is characterized by abnormal pitch processing. Reduced MMN amplitudes and longer peak latencies for all sound features with increasing levels of complexity were present in both amusic and control participants (Fig. 1), indicating that early pre-attentive mechanisms of auditory change detection remain sensitive to the degree of uncertainty of pitch sequences in the former group. High levels of uncertainty, however, revealed pitch-specific impairments in this population, thus supporting the hypothesis that higher-order fronto-temporal connections are impaired in amusia.

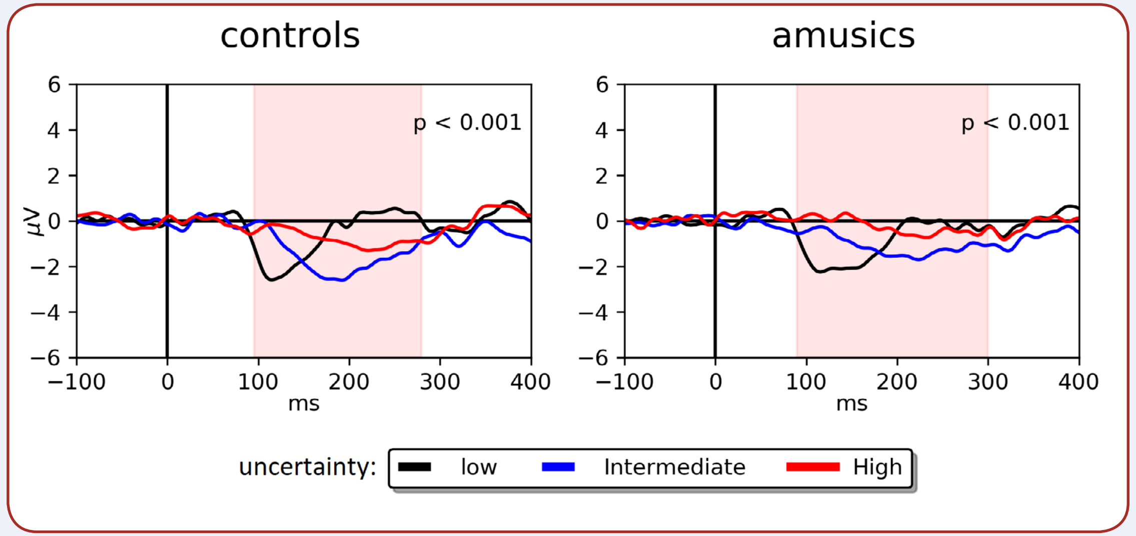

Figure 1. Mismatch responses (MMN) to pitch deviants, while amusic and control participants passively listened to melodies with different levels of uncertainty. Note how MMN responses become smaller and peak later as melodies get more complex and unpredictable. In the case of amusics, MMN amplitude in high-uncertainty melodies was very small and not statistically different from zero, thus suggesting an impairment in this population when predictability is very low.

Using the IDyOM model to simulate the culturally acquired expectancy dynamics of listeners, Assist. Prof. Niels Chr. Hansen demonstrated that musical phrase boundaries are perceived prospectively through having uncertain expectations about what comes next rather than just retrospectively through surprise once the next phrase has begun (as previously thought)[4]. This is consistent with a burgeoning view of the human brain as an eager, now-or-never processor of incoming sensory information. Together with Lindsey Reymore, Niels Chr. Hansen moreover investigated how some expert musicians show degrees of absolute pitch (AP) specifically for notes played on their instrument of training. Their theory on Instrument-Specific Absolute Pitch (ISAP) purports that articulatory motor planning as well as timbral and intonational idiosyncrasies acquired through years of daily practice equip some musicians with timbre-selective AP skills[5].

To make sense of music, our brain also extracts metrical structures by hierarchically grouping acoustic events into a stable periodic framework (beat) and corresponding temporal subdivisions. The mechanisms underlying beat perception can be probed using polyrhythms, which contain two different periodic metrical structures that compete against each other. In three online experiments, postdocs Jan Stupacher, Alexandre Celma-Miralles and Cecilie Møller asked participants to tap in time with the perceived beat of acoustic stimuli, and tapping consistency was registered. What they found was that a preference for synchronizing movement to rhythmic elements with lower pitch (i.e., the bass) is also evident in polyrhythms, perhaps due to physiological factors that also drive a bass-beat-movement effect, such as tactile and vestibular stimulation. The two other experiments focused on tempo and number of subdivisions as a modulator of beat perception, by experimentally controlling the number of subdivisions within polyrhythm cycles with increasing levels of complexity. They found (i) a tapping preference for pulse trains containing the simpler binary subdivision grouping and (ii) that beat perception in polyrhythms was not only constrained by the tempo of the beat itself but also by the tempo of the subdivisions underlying it.

The neural mechanisms underlying beat perception can be tested with the "frequency tagging" approach, which captures how neural oscillations are frequency-locked to the beat and meter by analyzing the frequency domain of EEG recordings. Postdoc Alexandre Celma-Miralles and Assist. Prof. Boris Kleber revealed that a preference of the brain to enhance the simplest binary subdivision grouping (duplets) may be an inherent property of neural oscillations, which can be enhanced by formal training in music[6]. In another study by Alexandre Celma Miralles, Cecilie Møller, and Jan Stupacher, 16 participants listened to a 3:4 polyrhythm, wherein the amplitudes of the 4-pulse train were increased by 8 dB in order to counteract the natural tendency to perceive the 3-pulse train as the underlying beat. To assess the effect of metrical context, experimental conditions were included in which the polyrhythm was preceded by an 8-second drum beat emphasizing either the 3- or the 4-pulse train. The results showed that neural entrainment to an ambiguous polyrhythm can be modulated by metrical context that structures the incoming events of the polyrhythm. This finding provides support for MIB's theory of the predictive coding of music.

The same group also collected EEG data that contributed to a pre-registered multi-lab study designed to replicate an influential frequency tagging study of Nozaradan and colleagues, showing that imagining metrical patterns (i.e., a march or a waltz) while listening to an unaccented, isochronous metronome can enhance neural responses at the strong beats of the imagined patterns. This brain activity likely reflects higher-level top-down processes. In addition to mental imagery, the new study also assessed the effects of conscious beat perception and musical expertise. We are currently expecting the results from our international collaboration partners.

New collaborations in 2020 involved a project initiated by postdoc Cecilie Møller with Prof. Preben Kidmose and colleagues at the Center for Ear-EEG, Dept. of Engineering, AU. The aim is to further extend the frequency tagging studies with combined scalp- and ear-EEG recordings. That is, polyrhythms are presented in different metrical contexts to assess neural and behavioral measures of both cognitively induced (Nozaradan paradigm) and perceptually induced (polyrhythm paradigm) beat perception. This will help to disentangle low-level sensory from higher-level perceptual processes in musical activities, and will assess the applicability of the innovative, discrete, and mobile Ear-EEG technology to measurements of brain activity associated with conscious perception in real-world situations, such as concerts. Furthermore, in a project initiated by Prof. Elvira Brattico, Niels Trusbak Haumann and colleagues succeeded in developing a novel method for measuring cortical brain responses to real music pieces with MEG/EEG[7]. The main research objectives of this project are to (i) determine the ecologically most important relevant findings in cognitive neuroscience and (ii) to unravel novel neural mechanisms that may only be discovered in the context of more realistic settings. In collaboration with Oticon Medical, Assist. Prof. Bjørn Petersen and colleagues are currently applying this new method to investigate whether cortical brain responses to real music are measurable in recently implanted and experienced cochlear implant (CI) users, and whether use-dependent brain changes can be observed in the cortical brain responses to real music.

The only project seriously challenged by the pandemic was OrkesterMester ("Orchestral musical training in schools"), which revealed robust perceptual mismatch responses (MMR) to unexpected musical features in children in a realistic school setting during pre-testing in 2019. Due to the COVID-19 related closing of Danish schools, however, the 7-8 years old school children could not finish their orchestral training for post-training measurements. Instead, we included adult non-musicians to compare their neural responses with the pre-training children results. EEG data collection (carried out by Alexandre Celma-Miralles, Silvia Bruzzone and Pætur Zachariasson) will continue once the current COVID-19 restrictions are lifted.

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PERCEPTION
Fingerprinting musical complexity in jazz improvisation – a neurobehavioral study

By Henrique M. Fernandes and Ana T. Queiroga

How the human brain defeats habit to generate unpredictable combinations of rooted knowledge and form original ideas is still unknown. Creating music is a dynamic process and a highly prized form of creativity[1]. Particularly in jazz, the ability to improvise sequences ‘on the fly’ results from a continuous fine tuning of predictability. This ability is sustained by the harmonious interaction between emotional, cognitive and motor processes to produce an aesthetically pleasing output[2]. However, how the brain of creative people, such as highly skilled jazz musicians, is able to maintain fluidity and balance between generated sequences of variable predictability remains a mystery.

To investigate the complexity of brain-behaviour synchrony occurring in musical improvisation, i.e., how the brain perceives, interprets and responds to past information and generates novel sequences with high aesthetic value, we developed a new interdisciplinary framework that combines music and neuroimaging data with statistical modelling and pattern recognition techniques. Shortly, we characterised the complexity of the metric dynamics underlying different modes of jazz playing and evaluated its potential as a predictor of music improvisation. Subsequently, we computed the degree of association between music metric and brain dynamics for different modes of jazz playing. Ultimately, this study aims at providing the first multimodal contribution to unravelling the neurobehavioral foundations of musical creativity.

In this study, we used the data of 16 experienced jazz musicians while (piano-) playing four different conditions under the chords of the jazz song “Days of wine and roses” (DWR). Participants were instructed to a) play the original melody of DWR by heart (*Memory*); b) play from a score sheet (*Read*); c) improvise on the melody (*iMelody*) and d) improvise freely on the chord scheme of DWR (*iFreely*). Further details can be found in[3]. The MRI-compatible keyboard[4] uses fiber-optic-based technology for detecting and converting sensor trigger data into a single-channel array of musical notes with precise temporal signature. We developed an open-source (Matlab/Python-based) framework (Fig. 1) – NeMuLink[5] – to perform extensive signal feature analysis from basic raw music data, with minimal user interaction required, divided into four fundamental steps:

1) Data normalisation and conversion: conversion of raw data into standard MIDI files according to pre-defined rules designed to ensure the robustness of this process across datasets.
2) Modelling pitch predictability: generation of a model of probabilistic predictions using IDyOM[6], trained with a large Jazz corpora (Weimar’s database; 431 music files). The generated model represents the estimated likelihood in a sequence,

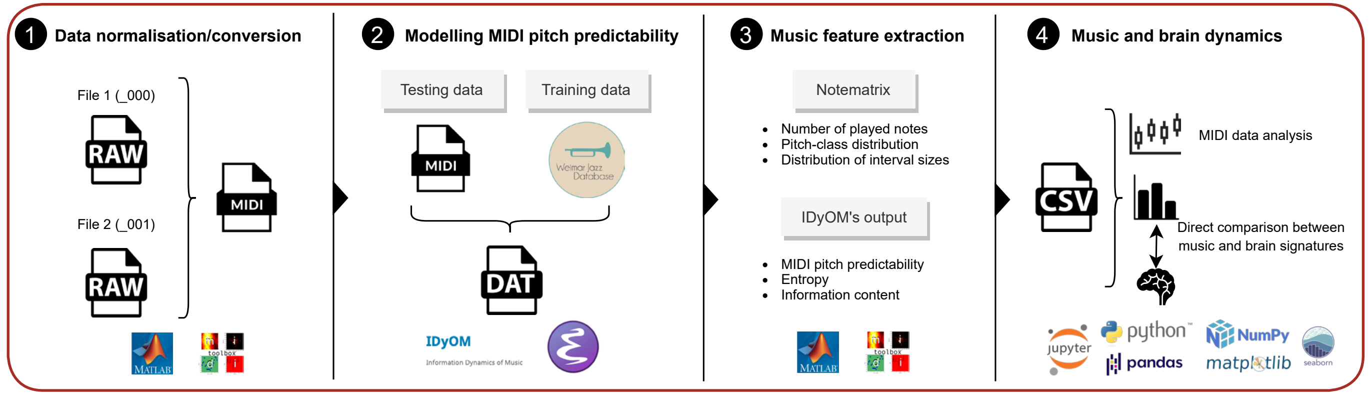

Figure 1. Overview of the NeMuLink’s workflow, divided in its four fundamental steps.

thus allowing the simulation of human perception experience to musical sequences in terms of predictability rating.
3) Music feature extraction: estimation of metric signatures (MIDI Toolbox[7]) for all played sequences across conditions.
4) Syncing brain dynamics and music metric signatures: measuring synchronicity between the generated musical patterns and the specific signatures of whole-brain connectivity supporting their production.

The metric signatures of all conditions were derived by computing the number of notes, pitch-class and interval size distribution. MIDI pitch predictability and entropy were also estimated to evaluate the expectedness of musical sequences.

Number of played notes: Our results show that music improvisation is characterised by a significantly higher number of played notes when compared to playing by heart (Fig. 2-i). Specifically, the average number of played notes per time-point (i.e., MR volume) is approximately 2 for the *Memory* condition, 2.5 for *iMelody* and 3.5 for *iFreely* (Fig. 3-iii), which suggests that this metric is directly proportional to the degree of dissociation from memory-based knowledge constraints (i.e., the original melody), and thus predict musical familiarity.

At the brain-level, our results indicate that, across all brain substates, *iFreely* is linked to a significantly higher number of played notes per MR volume than in the *Memory* and *iMelody* conditions. Furthermore, the occurrence of *Substate 3* - auditory-sensorimotor-salience network - is linked to a larger discrepancy in the number of played notes between the two modes of improvisation, with *Memory* surpassing *iMelody*.

Pitch-class distribution: Pitch-classes (PC) across conditions were predominantly associated with the F major scale, consistent with the original key of the DWR (Fig. 2-iv). Not surprisingly, this tendency is stronger in the *Memory* condition.

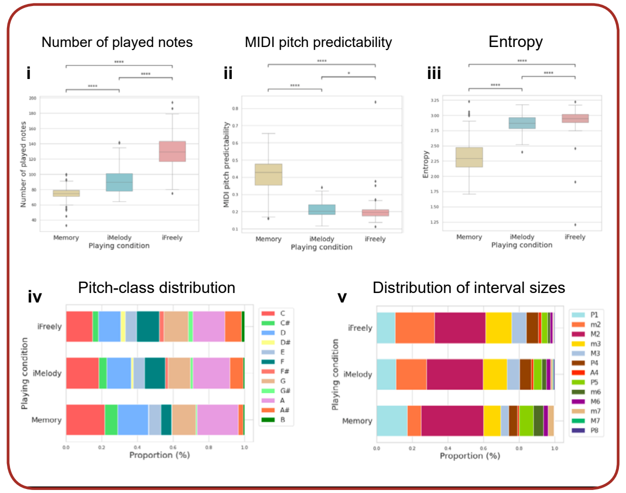

Figure 2. MIDI data analysis across playing conditions.

Our results suggest the existence of a gradient effect on PC distribution across conditions, with lower- and higher-range PC occurring more frequently in the improvisation modes (highest occurrence in *iFreely*), *iMelody* forms an intermediate layer of metric complexity. These results strengthen our hypothesis that the degree of metric complexity constitutes an important predictor of musical creativity.

Interval size distribution: We found that over 90% of the played intervals correspond to P4 or smaller intervals in *iFreely*, which confirms the expected trend for musicians to progressively play more notes in *iFreely* than in *iMelody* and *Memory*, with many of these using relatively small intervals (P4 and smaller) (Fig. 2-v). Interestingly, our results show that many of these chromatic notes are outside the diatonic scale, as indicated by the increases of D#, F#, and G#.

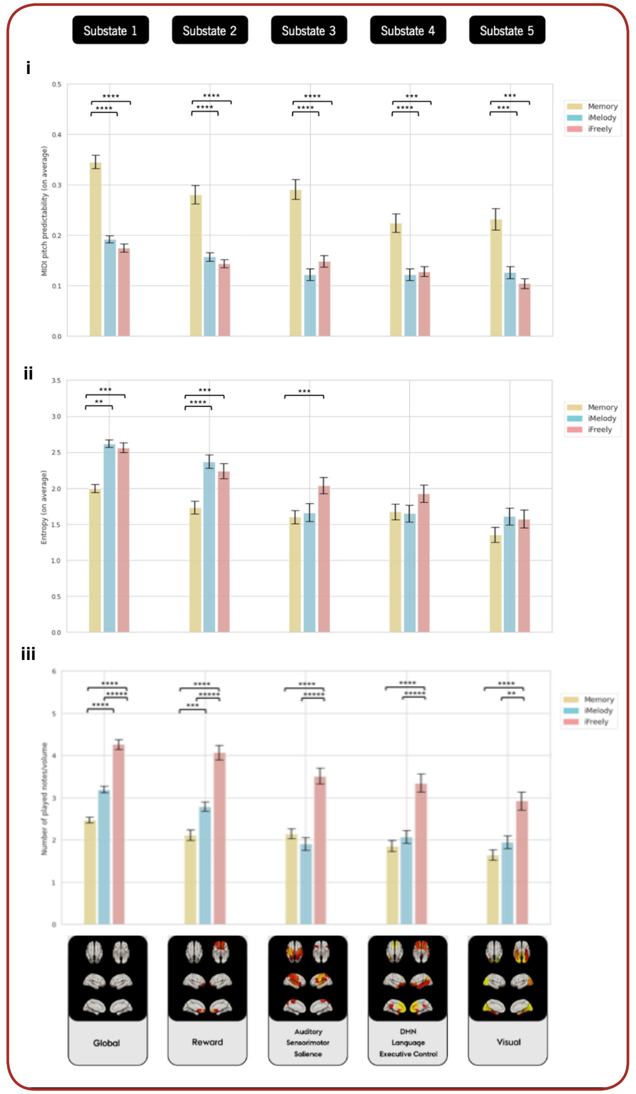

Figure 3. Synchrony between music features and brain dynamics.

Pitch Predictability: A key point of music improvisation relies on the balance of familiarity during music sequence generation. We found significant differences ($p < 0.05$, Bonferroni corrected) in MIDI pitch predictability between conditions (Fig. 2-ii). Specifically, improvisation modes are considerably less predictable and more entropic than *Memory*, with *iFreely* revealing the highest level of unpredictability.

At the brain level, a common trend across all substates is that pitch predictability increases significantly in the *Memory* condition compared to *iMelody* or *iFreely* conditions (Fig. 3-i). The occurrence of *Substate 1* – global network - and *Substate 2* - reward network – is associated with significantly larger entropy for both improvisation modes, which is exclusive to the *iFreely* condition in *Substate 3*. These results suggest that *Substates 1, 2* and *3* are linked to a more entropic music output, which may reflect a larger degree of music unpredictability and creativity. Furthermore, *Substate 3* is particularly linked to a substantial increase in entropy in the most creative/free mode of jazz playing - *iFreely*.

Taken together, our results suggest the existence of a metric-weighted gradient effect that predicts the level of improvisation or novelty value of a musical sequence. Particularly, across the three studied conditions, we found that improvising freely is associated with a higher number of played notes, frequency of low and high pitch-classes distribution, proportion of smaller intervals, pitch unpredictability and entropy. While playing by memory follows the opposite trajectory, improvising with melodic constrains forms an intermediate layer with significantly different levels of predictability and metric complexity than in *Memory* and *iFreely*.

When pairing these results with information on the brain dynamics generated during the production of these sequences, our findings suggest that the occurrence of *Substate 3*, an auditory-sensorimotor-salience network, is linked to a larger difference in entropy and predictability between the two modes of music improvisation. Moreover, its occurrence reflects a significantly higher degree of unpredictability and entropy between improvisation and *Memory*. As such, consistent with the previous findings[3] these results lend important support to the role of a wide auditory-sensorimotor-salience as a fundamental brain network for sustaining the production of sequences with high creative value. Hence, to regulate the assess to musical creativity in the human brain.

Additional information and figures can be accessed using this QR code.

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ACTION

Peter Vuust

The research topics in the Action strand are mainly focussed on musical rhythm[1], movement[2,3], interpersonal interaction[4], improvisation[5] and rehabilitation efforts[6-9]. They are based on the idea that the processes underlying perception and action are coupled such that perception minimizes prediction error by updating predictions, whilst action reduces prediction error by engaging motor systems to resample the environment, as has been formulated in the predictive coding of music (PCM) model. Musical interaction is then the continuous and reciprocal process between two or more individuals of harmonizing shared expectations leading to shared PCM[10].

In 2020, the Action strand published several theoretical and experimental studies on PCM[11-13], finalized data collection for other studies and saw Patricia da Mota successfully defend her thesis on musical improvisation (page 56) and Stine Derdau Sørensen her thesis on the nationwide mass experiment of musical competence and working memory in Danish school children (page 60). At the same time, we initiated promising new collaborations and study types partly prompted by the outbreak of the pandemic, which made it more difficult to perform studies on human participants.

In a particularly exciting new line of studies, we used big data made available to us from Spotify. From this data—over 2 billion samples—we found distinct diurnal cycles in musical listening habits. The music that people listen to cluster into five different time blocks corresponding to morning, afternoon, evening, night, and late night/early morning[14]. The music in these blocks has distinct profiles as revealed computationally through music information retrieval, reflecting what people typically do at different times of the day (Fig. 1). We found that these blocks follow the same order for every day in the week, but that they differ in length and starting time depending on the day of the week. The Friday and Saturday evening blocks for example—characterised by high tempo, danceability and large dynamical range— open earlier and end later than on other weeknights. In contrast, the morning block, characterized by low tempo, low danceability but high energy, is longer during the workdays than on the weekend. This study provides us with an extremely robust and detailed understanding of our daily listening habits and hints at how we live our lives. Furthermore, it illustrates how circadian rhythms and the way that modern life is organized into 7-day cycles influence the daily fluctuations in musical preferences on an individual as well as population level.

In a similar study, we analysed audio features from more than 220.000 tracks retrieved from almost 1000 Spotify playlists, containing the word "sleep" to determine the musical characteristics of sleep music. Surprisingly, even though sleep music in general is softer, slower, instrumental and more often played on acoustic instruments

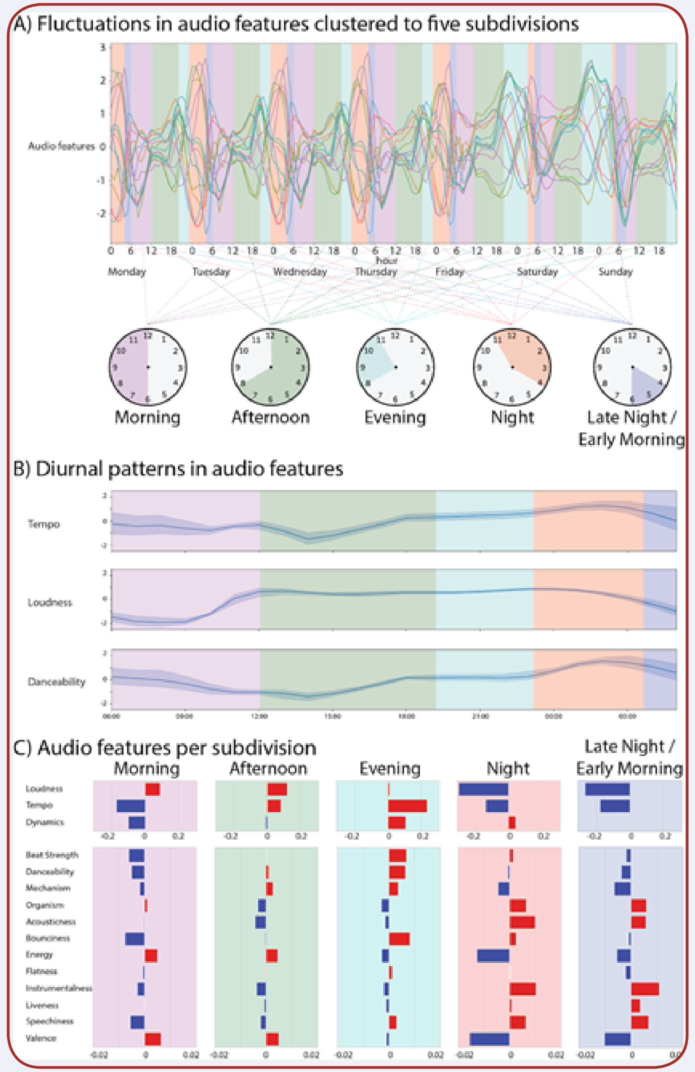


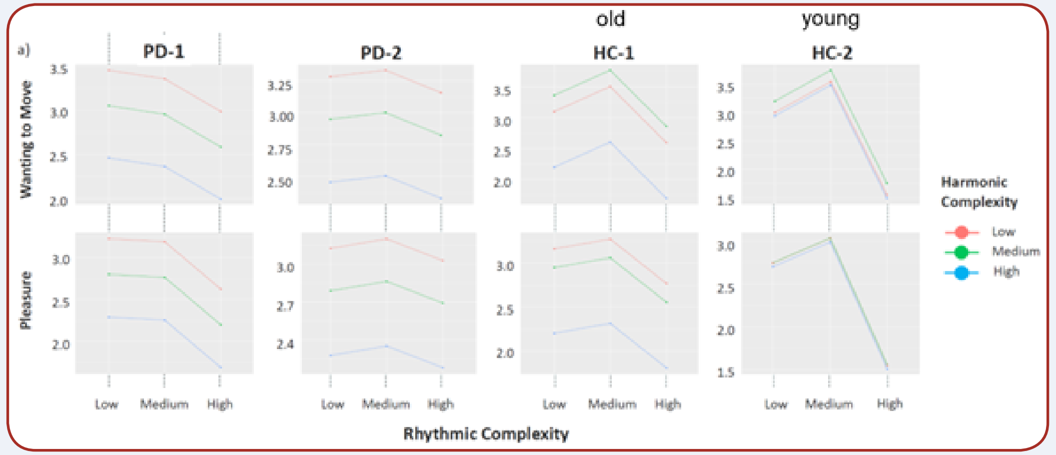
Figure 1. Diurnal patterns in audio features map to five subdivisions of the day. A: Normalised audio features plotted across the entire week. Using k-means clustering we found an optimal division into five distinct clusters, here shown as coloured overlays on the plot. We labelled the clusters' temporal occurrence by first calculating the mode onset and then using a descriptive term of the time of day. The clusters' temporal occurrences were always sequential and covered highly similar subdivisions of the day. We illustrate the mode onset and offset of each subdivision on the clock illustrations. B: To highlight the diurnal cycles in audio features we here show three audio features, Tempo, Loudness, and Danceability, across 24 hours starting at 06:00. The audio features are shown as the mean over all weekdays, and the shaded area indicate the 95% confidence interval. C: Here the cluster centroid values of the normalised audio features are shown, in relation to the grand average of the particular audio feature across the week.

than other music (Fig. 1), the music people use to sleep clusters into six subgroups with distinct profiles as revealed computationally through music information retrieval. In contrast to the general features of sleep music, three of these clusters are characterised by high energy and tempo as well as the presence of lyrics (read more on page 40).

Targeting more directly the performance of complex musical rhythms, we have developed a novel paradigm, to critically test a fundamental assumption in PCM—that the brain is hierarchically organized[15]. A core example of this relates to the executive control of movement, where distinct areas of the cortex such as PMC, SMA and primary motor cortices are specialized in different aspects of movement processes, and one hemisphere is supposed to be dominating the other. These ideas of more or less fixed brain hierarchies have serious shortcomings when trying to explain e.g., what is at the top in top-down control. We here used music as a model of motor execution and a simple task of keeping the beat with one limb and tapping a musical rhythm with another to show that the brain hierarchy is dynamically organized. It turns out that it is significantly easier to keep the beat in the right hand while simultaneously voicing the rhythm. In contrast—when pairing the hands—the right hand will more easily perform the rhythm. Using fMRI, we have shown increased activation in key areas related to beat perception such as the SMA, insula and cerebellum as well as the motor areas corresponding to the limb keeping the beat, when participants were asked to go against the limb hierarchy, regardless of combination of limbs. Furthermore, the results indicated that when experiencing the tension of working against the limb hierarchy, we activate a neural network related to keeping the beat (the inferred model) rather than performing the rhythm. The limb hierarchy fundamentally challenges the idea of a dominating hemisphere in hierarchical control and suggests that what is at the top in top-down control is dynamically changed by task requirements, context and individual expertise.

This study, based on the dichotomy between musical rhythms and the predictive brain model of the meter, extends longstanding Action strand studies of musical groove. In 2020, we showed that optimal levels of the pleasurable sensation of wanting to move is linked to neural activity in the brain's motor and pleasure networks[16] and can thus be seen as a result of precision-weighted prediction error arising from a discrepancy between the syncopation in the auditory input and the motor system's propensity towards isochronism. Importantly, optimal groove experience was associated with activity in nucleus accumbens and the OFC, which are key areas of the reward network that is particularly sensitive to the predictability of the consequences of action. The U-shaped relationship between syncopation and groove experience has been replicated independently of culture and rhythmic proficiency[17] and using physiological measurements such as pupillometry. It is influenced by musical expertise[17] and has a corollary in musical harmony[18].

Importantly, such studies involving core aspects of the motor system and auditory motor coupling have a clear potential for being translated into clinical applications. In 2020, we—despite the Corona restrictions—managed to finish a behavioral/



The U-shaped relationship between rhythmic/harmonic complexity in patients suffering from Parkinson's Disease (PD). PD1 = Parkinson's patients OFF medication (Dopamine Agonist (n=24)), PDA = Parkinson ON medication (Dopamine Agonist (n=23)), HC-1 = age-matched healthy controls (n=26), HC-2 = young healthy controls (n=27),

fMRI study (Fig. 2) showing that the U-shape curve is more pronounced in young than older participants age-matched to a group of Parkinson's (PD) patients. Importantly, the study showed that in contrast to healthy controls, the PD patients (on medication) are equally inclined to move to low and medium syncopated rhythms and prefer low syncopated rhythms if they are taken off medication. This shows how the fundamental understanding of the PCM mechanisms can inform our use of music in rehabilitation efforts for PD patients and our fundamental understanding of the relationship between groovy rhythms and dopamine release.

Other important clinical studies from the Action strand include collective singing training of patients suffering from Chronic Obstructive Pulmonary Disease (COPD). Here, we included 270 patients with COPD in a real life, randomized controlled trial and showed that singing training for 10 weeks was non-inferior to physical training and superior in St George's Respiratory Questionnaire (SGRQ) score ($p<0.01$)[19.20]. These studies provide the evidence and include training programmes which in principle are ready to be rolled out as a treatment for these patient groups.

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ACTION

Self-other integration in rhythmic synchronization

By Ole Adrian Heggli

Interacting with other humans often necessitates coordinated and cooperative behaviour. While the ongoing pandemic has stopped us from shaking hands, such a form of greeting is a complex feat of anticipating and adjusting movements. Yet, we perform it without thinking twice and without much conscious effort. One of the most fascinating aspects of human coordination is that it often leads to synchronized movements[1].

Synchronized movement may emerge spontaneously, such as when applauding after a performance where the applause starts chaotically before settling into a steady rhythm. It may be encouraged, as in nursery rhymes where songs are accompanied by dance-like movements such as in Itsy Bitsy Spider. Synchronization may also be intentional, as in the case of playing music together. When playing together, musicians must coordinate and synchronize their movements to facilitate the sounds that together makes what we perceive as music. A key observation here is that simply reacting to other musicians is insufficient[2]. The movement causing an instrument to produce sound needs to be initiated well before the actual sound is produced. Hence, prediction is a necessity for a music interaction to be successful.

Over the last decades, much progress has been made in understanding the predictive processes underlying rhythmic synchronization[3-4]. In laboratory settings, it has predominantly been studied using joint finger tapping paradigms wherein two people tap rhythms together. A particularly interesting discovery from this field is that rhythmic synchronization is more than just a transition from unsynchronized to synchronized actions. Instead, synchronized behaviour rests upon synchronization strategies[3, 5-7]. These are ways that interacting people adjust their behaviours towards reaching the shared goal of synchronizing with each other.

The most common synchronization strategy is mutual adaptation, wherein two interacting people continuously and reciprocally adjust their tapping[3]. In a leading-following strategy one person leads by being non-adaptive, forcing the follower to adapt in order to reach synchronization[5]. In previous work we uncovered a third synchronization strategy: leading-leading[6]. Here, interacting musicians were able to collectively synchronize yet exhibited little to no adaptation to each other, proving a puzzle for established theories of interpersonal synchronization. While these synchronization strategies are well documented within the field, multiple open questions regarding their nature remain[1, 3, 8]. For instance, what are the dynamical mechanisms underlying synchronization strategies? Or, how do they evolve over time, and what parameters contributes to the selection of a particular strategy?

Over the last years we have approached these questions through the approach of modelling, wherein the complex human behaviour observed in rhythmic interaction is approximated through mathematical and computational models which serve to develop, test, and extend theory. In 2019 we showed how the generative process of synchronization strategies could be modelled using a novel Kuramoto-based model[9]. Coupled oscillators, such as described in the Kuramoto model, have long been used to describe synchronization behaviour in a multitude of systems, ranging from flashing fireflies to nationwide power grid fluctuations[10, 11].

The key advance in our coupled oscillator model was implementing the fact that rhythmically interacting with other people is a two-pronged process: One needs to monitor and perform one own's actions, while at the same time monitoring and evaluating the actions of the interacting partner. In our model we integrated this as two separate, yet connected, oscillators, with one oscillator representing the motor processes involved in performing one own's actions and another oscillator representing the auditory processes monitoring the interacting partner. When we linked two such units the model provided a good fit with experimental data, showing that synchronization strategies can be reconstructed dependent on connections weights between within-unit and between-unit oscillators. This model illustrates a plausible biomechanical implementation of the bottom-up generative process of synchronization strategies and is already receiving attention not only within the field of rhythmic synchronization, but also in sensory-spatial integration of motor patterns in dance and in robot-to-human synchronization work[12, 13].

With a successful model for the bottom-up part of synchronization strategies, we turned our attention to the top-down influences on synchronization strategies, to determine how they may emerge, evolve over time, and to pinpoint parameters and mechanisms implicated in their temporal development. From previous work we know that synchronization strategies emerge spontaneously, that they may change throughout an interaction, and that they are dependent on individual differences such as musical expertise[5,6]. However, identifying exactly how these parameters influence the interaction has proven a challenge for the field.

In recent work we propose a new and novel model which proposes that the dynamics of synchronization strategies depends on simple predictive brain processes[14]. We propose that synchronization strategies, and rhythmic synchronization in general, crucially depend on self-other integration. This is the process of either integrating or segregating information from others (in this case the tapping partner) with actions performed by yourself. Previous works show how self-other integration, and the brain's tendency towards computational efficiency as formalized in predictive coding under the free energy principle, explains emergent synchronized behaviour[1]. Our model extends these observations to also account for intentional synchronization, yet retaining the ability to explain synchronization strategies.

In the metastable attractor model of self-other integration (MEAMSO), we model the brain as maintaining predictive cognitive models for the self (the actions one performs) and for the other (the actions performed by the interacting partner). These predictive cognitive models are continuously updated and refined dependent on calculations performed on incoming perceptual information. As a whole, MEAMSO approximates whether self-performed actions are likely to be integrated with the actions performed by the other, or if they are to be segregated (Fig. 1).

MEAMSO consists of three modules each performing calculations that are updated with each cycle of new information (Fig. 1). Its output is a state, indicating whether the integration or segregation between self and other is taking place. The first module performs instantaneous comparison between events occurring simultaneously or close in time. The second module performs correlational comparisons, and the third module calculates a model selection based on accumulated and weighted information from the first and second module. Together this creates a

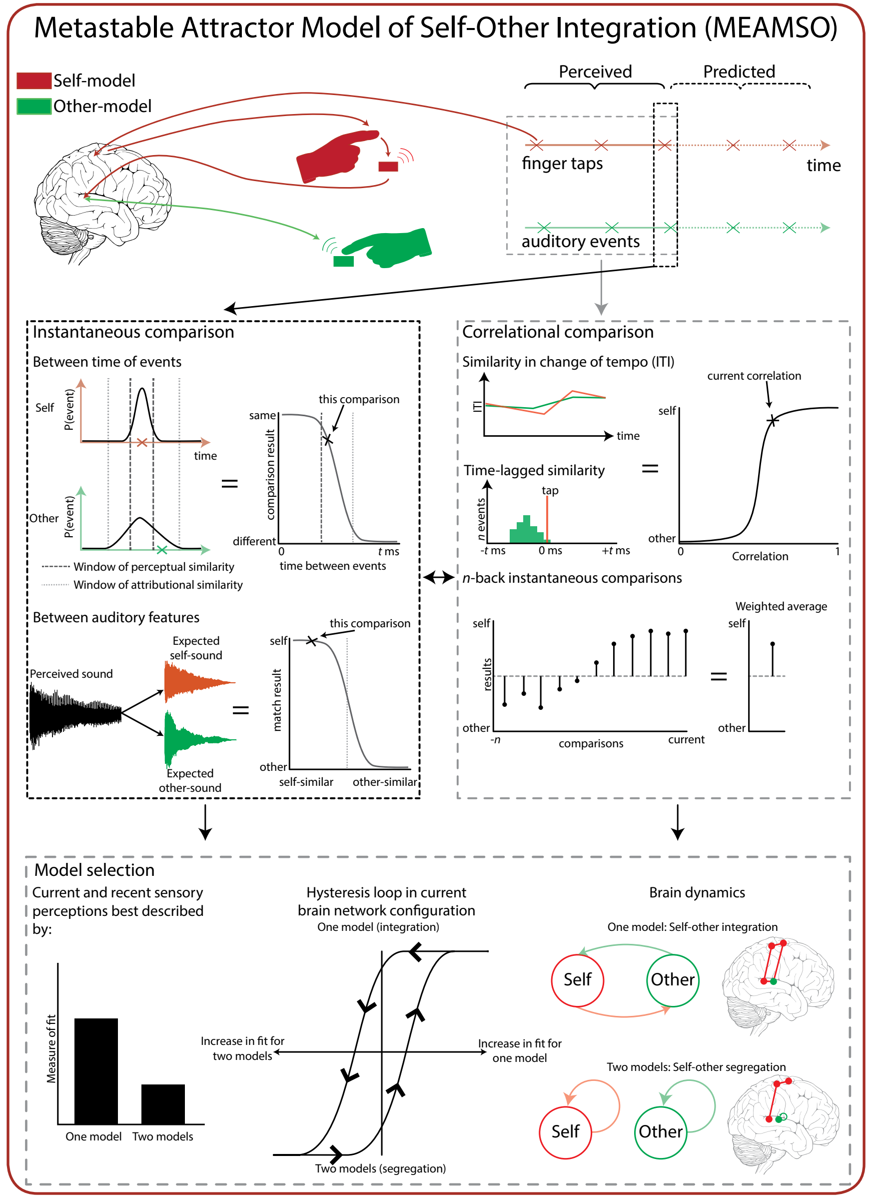

Figure 1 - An overview of the calculations performed by the MEAMSO. We show how finger taps and auditory events are passed through instantaneous and correlational comparisons which are accumulated as evidence for either one or two predictive models. This evidence is weighted using a Bayesian average, creating a hysteresis loop in the current brain network configuration of either self-other integration or segregation. Adapted with permission from Heggli et. al. 2021.

metastable dynamical system with two particular attractor states: self-other integration and self-other segregation. When considering a dyadic rhythmic interaction this results in three unique group combinations, which maps perfectly on to the three known synchronization strategies in dyadic interaction.

We tested the dynamical efficiency of our model on empirical data where we combined a stretch of mutual adaptation tapping with a transition to a stretch of leading-following tapping. By running MEAMSO from both dyad members' perspective we found that it successfully captured the hypothesised state, with the follower staying in a self-other integration state throughout the entire interaction, and with the leader switching from self-other integration to segregation as the interaction transitioned into leading-following.

Our models are able to explain dyadic rhythmic synchronization both from the generative and cognitive view and show how building biologically inspired models can advance our understanding of human musical behaviour. In particular, MEAMSO provides a rich and diverse set of predictions for rhythmic synchronization behaviour, such as formalizing the parameters nudging an interaction towards a particular synchronization strategy and explicitly modelling individual difference and instrument-specific expertise effects. We look forward to experimentally test these predictions in the coming years.

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EMOTION

Morten L. Kringelbach

Emotion is key to the successful navigation of the obstacles that life throws at us[1]. Pleasure is a key component to the multifaceted nature of emotion, and music is perhaps one of the most meaningful pleasures, arguably bringing more joy than other pleasures such as chocolate or coffee. As such music is a strong contributor to eudaimonia, the life well-lived[2].

The research in the Emotion strand continues to explore the strong links between music, emotion and eudaimonia[3,4]. This link has been strengthened with the founding of the new Centre for Eudaimonia and Human Flourishing at University of Oxford through generous donations from Carlsberg Foundation and Pettit Foundation.

This first-of-its-kind Centre will promote 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. As such the new Centre will be able to build a strong synergy with MIB research.

One early fruit of this new endeavour came about just before the start of the global pandemic, where I travelled to Washington DC to act as an expert for the Global Council on Brain Health. Based on our in-depth discussions, we produced the report "Music on Our Minds: The Rich Potential of Music to Promote Brain Health and Mental Well-Being". The report surveys how music is a powerful way to stimulate the brain across the lifespan - and how these effects can be used to promote health and well-being in across age and population.

One strong conclusion of the report is that music and emotion are intrinsically bound together, and that emotion is the glue that binds together perception, action and learning. This is clearly witnessed by the articles in the current Annual Report, where much of the research could be conceptualised in the general framework of emotion. Perhaps strongest, this is seen in postdoc Kira Vibe Jespersen's summary "Clinical application of music" (page 38), which draws together the emerging evidence for the clear benefits of music for well-being in health and disease.

But equally, take for example the research feature of postdoc Ole Adrian Heggli on "Self-other integration in rhythmic synchronization" (page 18) which is nominally listed under the Action strand but relies strongly on emotion. Similarly, emotion plays a key role in the PhD feature

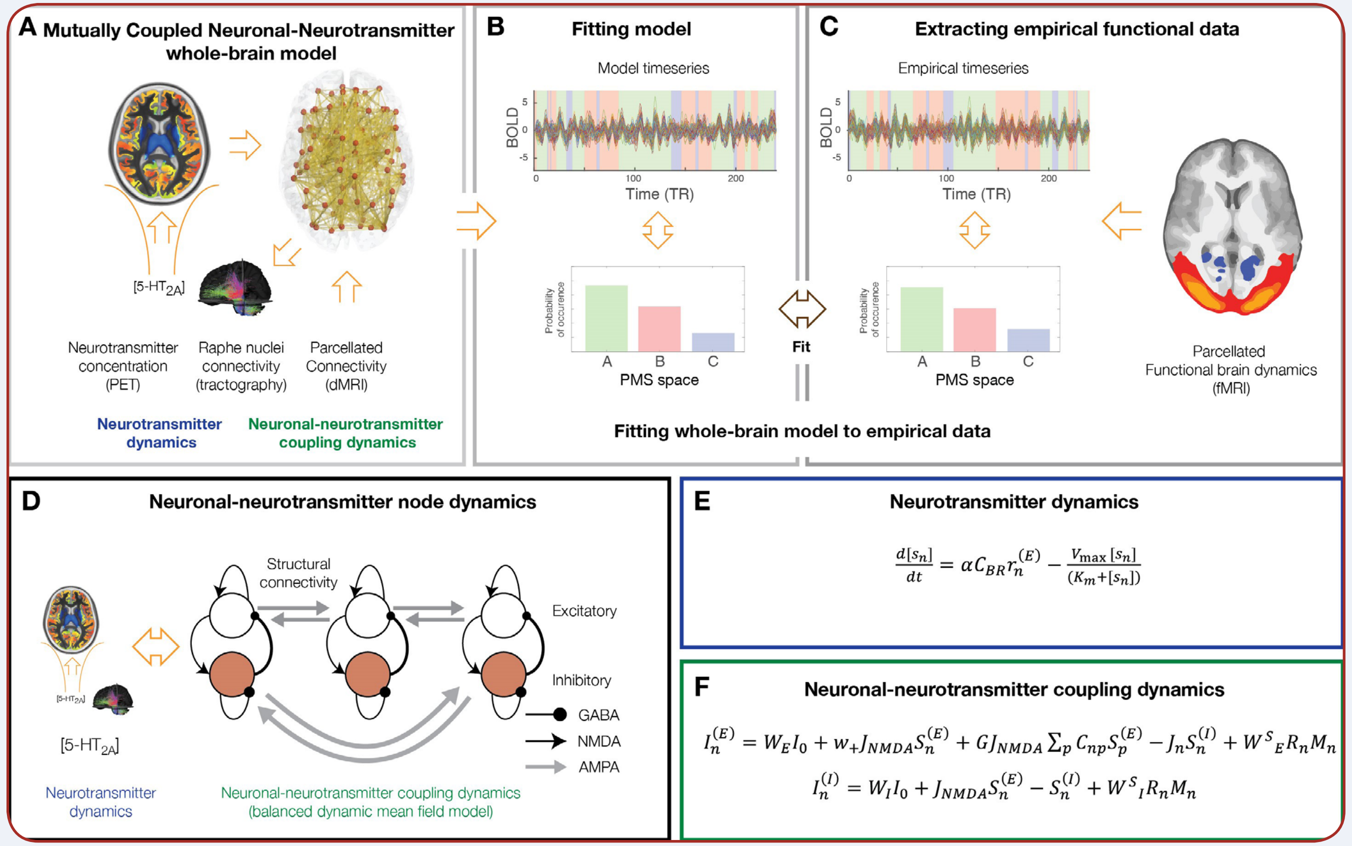
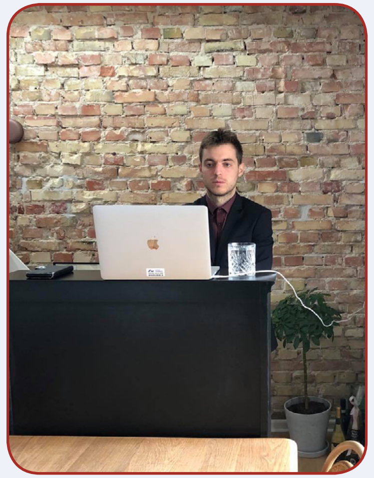


Figure 1. Overview of the Coupled Neuronal-neurotransmitter whole-brain model. A) We studied the mutual coupling of two different mutually coupled dynamical whole-brain systems (neuronal and neurotransmitter). B) This system is fitted to the empirical neuroimaging data, which is described by Probabilistic Metastable Substate (PMS) space, C) which is extracted from the empirical BOLD data. D) We achieve this by adding a coupled neurotransmitter system (blue) to modulate and interact with the neuronal system (green), which was modelled using a balanced dynamic mean field model that expresses consistently the time evolution of the ensemble activity of the different neural populations building up the spiking network[9,10]. E) The neurotransmitter system (blue) is modelled by a set of differential equations describing the dynamics of the neurotransmitter concentration level, which is given by the well-known Michaelis-Menten release-and-reuptake dynamics (see Methods)[11-13]. F) The neuronal coupling dynamics (green) is modelled by another set of differential equations describing the spontaneous activity of each single brain region consisting of two pools of excitatory and inhibitory neurons (see the Methods). We couple the neurotransmitter and neuronal dynamical systems through the anatomical connectivity between the raphe nucleus and the rest of the brain, estimated using dMRI from the Human Connectome Project (see Methods). The explicit coupling between the neurotransmitter and the neuronal system is given in the equations 16-17 (shown here and described in the Methods). As can be clearly seen, the neurotransmitter currents are applied to each region's excitatory and inhibitory pools of neurons using the effectivity/conductivity parameters (WE and WI, respectively). In each region, the neurotransmitter currents are also scaled by the each region's receptor density (measured in vivo using PET). The reverse coupling from the neuronal to the neurotransmitter system is given by inserting in the Michaelis-Menten release-and-reuptake equation the neuronal population firing rate of the source brain region of the neurotransmitter spread from the raphe nucleus.



Leonardo Bonetti defending his PhD thesis in his own apartment via Zoom.

by Leonardo Bonetti “Brain spatiotemporal dynamics of auditory patterns encoding and recognition” (page 52).

The link to emotion is also clear in the research feature by Assist. Prof. Henrique M. Fernandes and Ana Queiroga “Fingerprinting musical complexity in jazz improvisation – a neurobehavioral study” (page 10).This is listed as under the Perception strand, but jazz improvisation depends of course strongly on emotion. Similarly, this link is also demonstrated in the PhD feature by Patricia da Mota (page 56) describing her important research on the neural mechanisms underlying jazz improvisation.

Much of the research in the Emotion strand draws strongly on the new development of groundbreaking whole-brain models pioneered in collaboration with Prof. Gustavo Deco at Universitat Pompeu Fabra, Barcelona. This framework allows us to study 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. As described in details in the accompanying Emotion research feature, this has allowed us to finally determine the orchestration of brain function, i.e. the necessary brain networks allowing for its hierarchical organisation[5].

We are working on many other exciting new methods. As an example, in a technical tour-de-force, we have created a novel framework demonstrating the underlying fundamental principles of bidirectional coupling neuronal and neurotransmitter dynamical systems[6]. Specifically, in this study, we combined multimodal neuroimaging data to causally explain the functional effects of specific serotoninergic receptor (5-HT2AR) stimulation with psilocybin in healthy humans. 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

The dynamic effects of music on emotion are complex to untangle. As mentioned, for this purpose we have developed whole-brain computational modelling to reveal the underlying causal brain mechanisms[7]. 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[8].

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

The orchestration of brain function

By Morten L. Kringelbach

The celebrations in the 250th anniversary of the birth of Ludwig van Beethoven would not be the same without Herbert von Karajan's brilliant performances conducting Beethoven's memorable symphonies. The execution of any musical symphony is a hugely difficult task, demanding very significant skills on the part of each individual musician – but perhaps the most difficult task lies with the conductor who has to orchestrate the musicians into making the music cohesively come alive and speak to our deepest emotions.

In many ways the human brain is like an orchestra, where different regions perform very different types of processing, such as in the individual musician in the orchestra who needs to be able to read the music, play their instrument and listen to the music produced. Still, the role of the conductor is different, namely to coordinate and orchestrate the output of each musician into a cohesive whole. Without a conductor, the music invariably fails – as shown beautifully in Fellini's magisterial film "Prova d'orchestra" (eng. "Musical rehearsal").

It has been proposed that the human brain is similar to an orchestra in that it is hierarchically organised but that there is unlikely to be just a single conductor. Instead, in 1988 psychologist Bernard Baars proposed the concept of a 'global workspace', where information is integrated in a small group of 'conductors' before being broadcast to the whole brain[1]. This much celebrated theory proposes an elegant solution to how hierarchical organisation allows the brain to orchestrate function and behaviour by organising the flow of information and the underlying computations necessary for survival. As such, this is a theory of consciousness as pointed out by neuroscientists Stanislas Dehaene and Jean-Pierre Changeux, who proposed the 'global neuronal workspace' hypothesis where associative perceptual, motor, attention, memory, and value areas interconnect to form a higher-level unified space where information is broadly shared and broadcast back to lower-level processors[2]. Colloquially, the brain's global workspace is thus akin to a small core assembly of people in charge of an organisation; in other words like a group of many Von Karajans leading a musical orchestra.

Yet, until recently it had not been known where and how this orchestration takes place in the human brain. Using cutting-edge methods, we recently discovered the existence of a functional 'rich club' of brain regions incarnating this 'global workspace'[3]. This radical new discovery is based on a large dataset of over 1000 human participants with functional magnetic resonance imaging (fMRI) recordings, the findings have shed new light on the nature of consciousness.

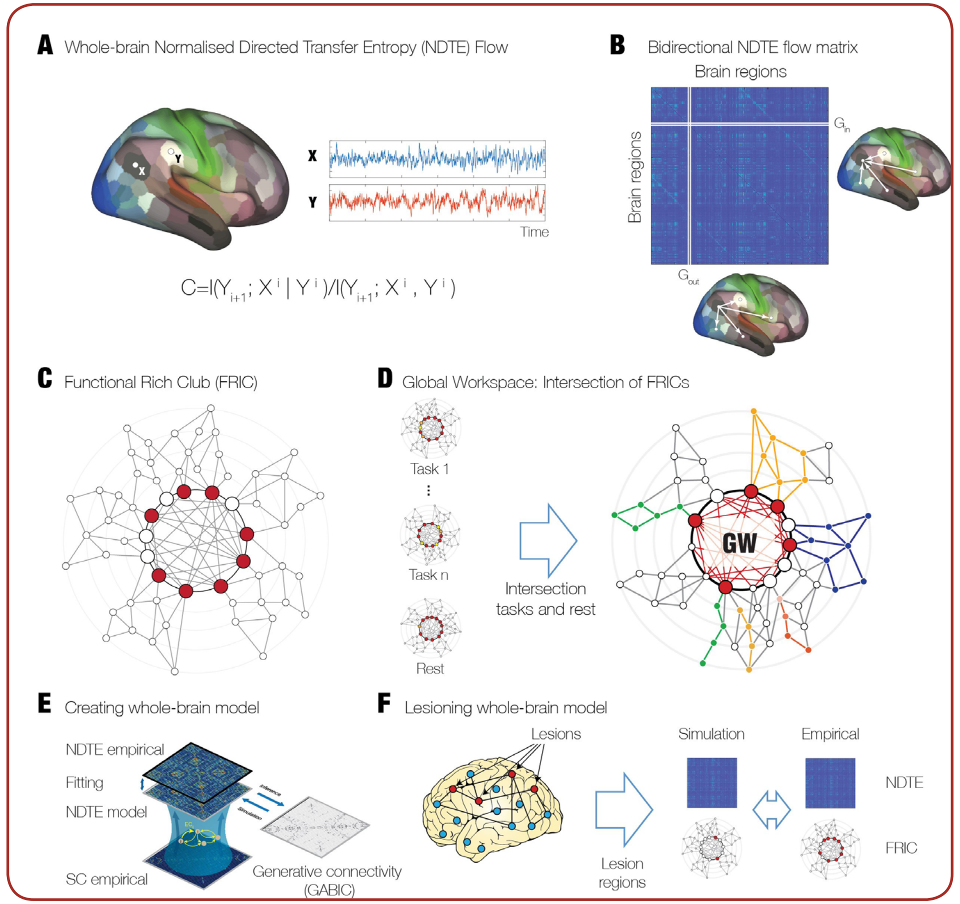

Figure 1. Overview of general theoretical framework. A) Causal bidirectional flow of information between any two brain regions is determined by computing the pairwise normalised directed transfer entropy (NDTE). The statistical significance is determined at the individual level by using the circular time shifted surrogates method[4] and at the group level by using P-level aggregation across individuals. B) The functional hierarchical organisation is given by the full NDTE matrix, where the rows contain the target regions and the columns contain the source regions. For each brain region, the total incoming flow of information, G_in, is simply the sum of all sources (ie the sum over the rows in the matrix). Similarly, the total outgoing flow of information, G_out), is the sum over all targets (ie the sum over the columns). C) The functional rich club (FRIC) is the smallest set of brain regions that integrate and orchestrate function in a given task. It can be identified as the most highly connected brain regions that 1) are more densely connected within themselves than to regions with lower connectivity, whilst 2) having the highest level of incoming directed flow (G_in) and 3) the lowest outgoing directed flow (G_out). D) The global neuronal workspace has to be relevant to all tasks and situation and must therefore be the common FRIC members across many different tasks, ie the intersection of FRICs from tasks and rest. E) In order to establish the causal importance of the FRIC, we fit a whole-brain model to the resting NDTE empirical data and extract the underlying effective connectivity (see Results and Methods). F) The whole-brain model is then systematically lesioned for regions belonging to the FRIC and compared to lesioning non-FRIC members. Overall, this confirms the causal importance of these regions in the orchestration of the functional hierarchical organisation of the human brain.

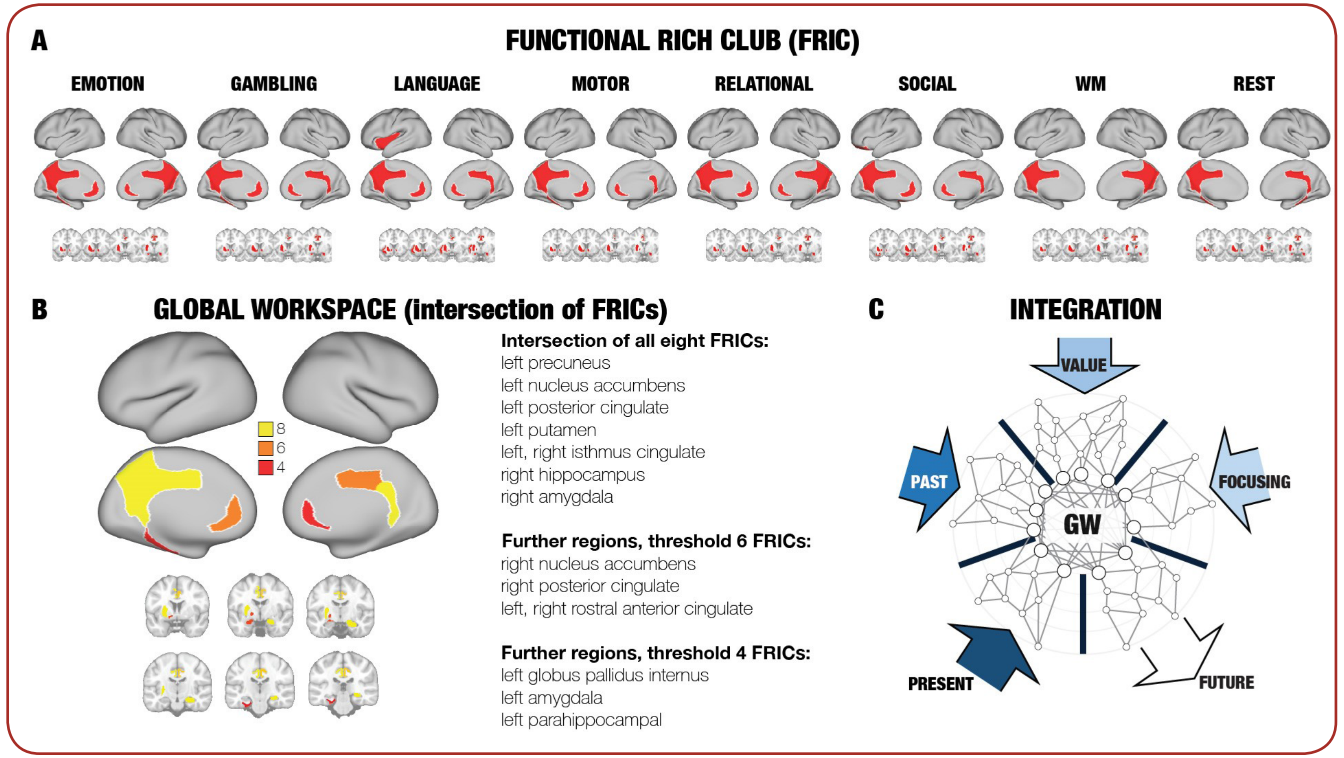

*Figure 2. **Identifying global workspace as the intersection of functional rich clubs for rest and seven tasks. A)** We computed the functional hierarchical organisation of all seven tasks (emotion, gambling, language, motor, relational, social, working memory) and rest for the HCP participants. This allows us to compute the 'Functional Rich Club' (FRIC) as the set of regions that define a 'club' of functional hubs characterized by a tendency to be more densely functionally connected among themselves than to other brain regions from where they receive integrative information (see Methods). As can be seen, these functional rich clubs are similar but not identical across tasks and rest. **B)** We compute the regions in the Global Workspace (GW) as the intersection of the FRIC members across all possible tasks and resting state. Here, we used the maximal amount of tasks available to provide a reliable estimate of the GW. At the bottom of the figure, we show a rendering of the cortical and subcortical regions in the GW. As can be seen, the FRIC regions for all seven tasks and rest defining the GW are the following eight brain regions: left precuneus, left nucleus accumbens, left putamen, left posterior cingulate cortex, right hippocampus, right amygdala and left and right isthmus cingulate. Lowering the threshold of participation in more than six FRICs adds two further regions: right nucleus accumbens and right posterior cingulate (in seven FRICs) and left and right rostral anterior cingulate (in six FRICs). Further lowering the threshold to four FRICs provides another three brain regions: left amygdala and left globus pallidus internus (in five FRICs) and left parahippocampal cortex (in four FRICs). **C)** These regions fit well with the idea suggested by Dehaene and Changeux that the Global Workspace is ideally placed for integrating information from perceptual (PRESENT), long-term memory (PAST), evaluative (VALUE) and attentional (FOCUSING) systems.*

To identify the global workspace, we determined the information flow between brain regions by means of a normalised directed transfer entropy framework applied to multimodal neuroimaging data a large group of healthy participants.
This revealed for the first time a set of unique brain regions orchestrating information from perceptual, long-term memory, evaluative and attentional systems across many different tasks. Furthermore, we confirmed the causal significance and robustness of our results by systematically lesioning a generative whole-brain model.

Our findings shed light on a major unsolved challenging problem in neuroscience. While the results presented here pertain to the global workspace of conscious task processing, future work could use our framework to investigate other states such as sleep and anaesthesia, allowing for a direct comparison with other theories of consciousness. Our framework could be used to investigate unbalanced brain states in neuropsychiatric disorders and be used to perturb and rebalance the model to identify novel optimal, causal paths to health.

Overall, our results demonstrate the general principles underlying brain processing which is highly relevant for the study of music in the brain. As such it will provide new insights into the fundamental role of emotion in music and in life more generally.

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LEARNING

Elvira Brattico

Music does really matter

When playing we use the somatomotor system of our central nervous system and hence our muscles to adjust our limbs and fingers or mouth (if we are brass or wood instrumentalists) to produce the expected actions and then sounds. Then, we activate our auditory, interoceptive and limbic systems to process the sounds we have produced, the emotions we are conveying and feeling, as well as the resulting changes in our internal organs (our respiration might increase if we are playing fast or our favorite song). All these outputs strictly depend, in a feedback loop, on the predictive models existing in each dedicated hierarchical brain system, and which are formed from our past musical activities. Finally, the somatomotor system provides a feedforward control to regulate the motor output to match the sensorimotor and emotional model of what we want to convey to the audience.

MIB activities in 2020 have continued to strive for adding details to the complex workings of the human brain when listening and playing a musical instrument, along with the continuous learning process of prediction, error, adjustment, correction, and back, that is intrinsic to the daily life of a musician, since childhood.

Can music learning really change anything?

All this learning comes with visible and measurable consequences in the brain and behavior across the lifespan. Hence, musicians have been named good "models" for neuroplasticity[1], namely for the typically human phenomenon of brain anatomically and physiological modifications occurring even in adulthood and even in sensorimotor (not just associative) cortices, as a consequence of adaptation to novel environmental demands. Even though most music neuroscientists, including those of us working within predictive coding theory of music, share consensus on music-induced neuroplasticity and have produced several related studies and reviews, some scholars have questioned this position on the grounds of its lack of experimental verification. The scarcity of studies on the specificity of the effects of music as compared with other training activities (e.g., sport) represent another limitation[2]. Similarly, when it comes to behavioral advantages consequent to music training, some scholars have raised a doubt on their solidity[2,3].

All this, combined with the fresh critical stance towards the entire field of psychology and cognitive neuroscience experimental findings, flawed by too many false positives, and failures in replicating the most "classical" findings, calls for action. And this is especially important when the behavioral consequences of music training and of incessant learning to refine predictions are under the eyes of us who are both musicians, parents and, ultimately, researchers.

Our approaches

To address all these doubts and criticisms, we adopted several strategies. The first consists in conducting systematic reviews and meta-analyses in order to organize the findings in the literature, and to obtain a final picture of the most reliable findings related to music listening and playing in the brain and behavior[4,5,6]. One of these reviews verified the significance of the transfer effects of instrumental music training on working memory abilities in school-age children[5] (see also PhD feature on page 60). Another review concentrated on neuroanatomical and neuroimaging findings from 79 experiments of gray and white matter differences (675 foci) between musicians' and nonmusicians' brains (N=2780), demonstrating increased volume/activity in musicians than non-musicians in auditory, sensorimotor and limbic areas, paired with decreased volume/activity in musicians' parietal lobule and cerebellum[6].

A second approach is to continue with the methodological advancements that allow us to refine our measures and obtain learning- and memory-related results that are increasingly more reliable and refractory to analysis and statistical errors (e.g., physiological noise and false positives, respectively) (see PhD feature by Bonetti on page 52). With this in mind, we have implemented a new statistical algorithm to extract evoked responses from the continuous MEG and EEG, which we validated for healthy adults[9], and are currently validating for cochlear implantees, and even for children recorded inside the school). Moreover, we have published our improved procedure to obtain evoked responses to sound onsets and acoustic feature changes from MEG/EEG recordings during continuous, realistic music listening[9], a method that will allow us to understand brain music processing in the most ecological and fast way, both in health and disease.

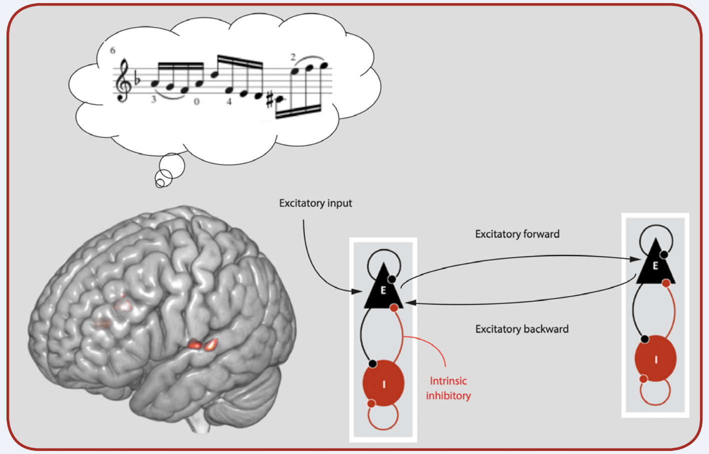
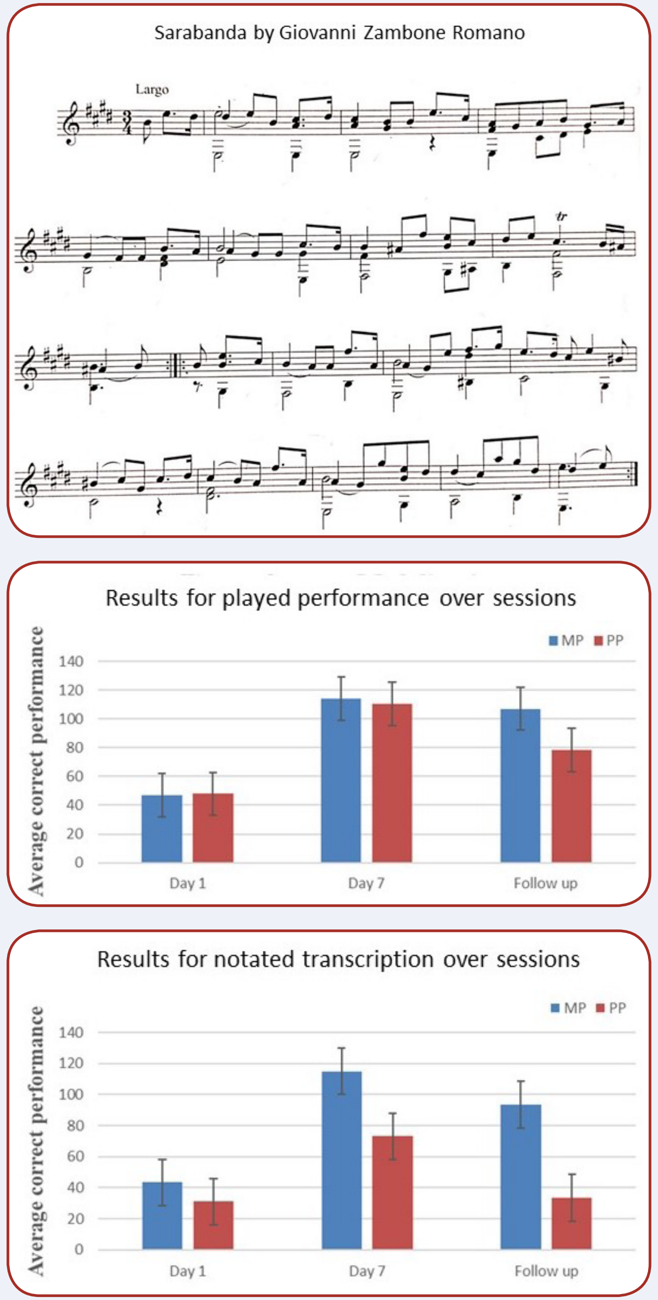


***Figure 1**. Results of dynamic causal model (DCM) analysis of MMN responses to pitch deviants in tone patterns [10].*

The third approach aims to not only measure and describe the brain changes following music learning but also to mathematically model them by means, for instance, of dynamic causal modelling (DCM), parametric empirical Bayes or machine learning techniques applied to fMRI or MEG data[11]. In a first fMRI study[10] we found a left-lateralized increase in feedforward connectivity from primary auditory cortex to non-primary planum temporale in the presence of a prediction error (an unexpected pitch) and an increase in excitation within the left primary auditory cortex. These findings point at the role of feedforward



and intrinsic connections within the left superior temporal gyrus for predictive processes related to pitch patterns. In modelling study by Quiroga-Martinez et al.[12], based on a previous MEG study[13], listening to a mistuned pitch was associated with lower intrinsic (inhibitory) connectivity in primary and non-primary auditory cortex, and lower backward (inhibitory) connectivity from non-primary to primary auditory cortex (Fig. 1). Musicians showed more disinhibition in the left primary auditory cortex and reduced backward connectivity, suggesting that musicianship and melodic predictability enhance neural gain in the auditory cortex during prediction error. Studies on tone predictive processing are also undergoing in relation with congenital amusia and with expertise for atonal music, in collaboration with INSERM, France[14] and Max Planck Institute in Frankfurt, Germany[15].

Finally, the MIB Learning strand strives to demonstrate that music training does matter also by understanding its diverse multi-modal and multi-domain faces (from the perceptual to cognitive to the emotional) (see PhD features on page 54 and 58) with the final goal of showing how each of those faces might impact on learning and the related predictive brain processes. For instance, 29 Danish and Italian classical guitarists were asked to practice a Sarabanda piece by G. Zambone Romano only physically or also mentally for 30 minutes over a period of one week, with better memory when performing or even transcribing the learned piece on a score (Fig. 2). These findings support the importance of systematically teaching mental practice in music academies. The study is in line with our efforts to bring the experiments into the music schools and conservatories, to follow music learning by experts in the real world rather than only in the lab[16].

***Figure 2**. Left: musical score of the Sarabanda by G. Zambone Romano learned by guitarist participants. Right: Results concerning the two types of learning strategies adopted over a week by guitarists[17].*

A predicting future

In conclusion, the multiple approaches adopted promise to ameliorate the sistematicity and robustness of our research. On top of those, longitudinal studies on music training are proliferating thanks to new collaborations with Danish and Italian educational institutions. Hence, this productive research year (despite the pandemic crisis) gathered multiple studies on how predictive processes do matter in changing the brain in many reliable and measurable ways.

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LEARNING

The impact of instrumental music training on children’s memory

By Ida Lorenzen & Elvira Brattico

Introduction

‘Music makes us smart’: this slogan has become popular since the times of the ‘Mozart effect’[1] and pushed mothers to play classical music to their kids even before they were born. While much of that phenomenon was due to journalistic sensationalism and to confounding factors in experimental design, some studies have shown that children become smarter after music training. However, the presence of non-musical, cognitive benefits of music training has been questioned due to contrasting findings[2-3]. Recent meta-analyses have tried to summarize these findings, but putting together in the same pot a broad range of music training programs[4], e.g., rhythm and pitch training[5], music theory, tapping tasks and rhythm games[6], moving activities to different kinds of music[7-8], kinesthetic movements and hand gestures[9-10], and, finally, learning to play a musical instrument[11-12]. Since some of the included music training activities were quite different from what is found in the real world and since each type of activities may target and train very diverse brain/behavioral functions, one can question the appropriateness of combining inherently different music training programs when investigating the potential cognitive effects (Fig. 1).

Hence, we wished to systematize and summarize the existing scientific findings on the effects of only real-world and community-based instrumental music training on short-term and working memory in school-age children. Our goal was to obtain a clear and definite picture of the impact of music training on the children’s mind.

Methods

A systematic literature search was performed in PsychINFO, ERIC, and Scopus. Longitudinal study designs including 5-13-year-old healthy children participating in first-time instrumental music training were included. Studies were subjected to meta-analyses using robust variance estimation which takes interdependency of effect sizes into account. Age, the extent of the intervention, the sensory domain, and subclassification were used as moderator variables.

Results

Based on a systematic review and meta-analysis of the resulting eligible studies, we found a small to moderate, statistically significant difference between children participating in instrumental music training vs. control children on a combined measure of short-term and working memory ability (Fig. 2). After adjusting the model for risk of bias, the effect was slightly reduced but remained statistically significant. Results of the exploratory meta-regression analyses showed no statistically significant moderators.

Discussion

With this systematic review and meta-analysis, we provided for the first time a complete and systematic overview of the effects of specific instrumental music training on working and short-term memory in children. This focus expanded earlier meta-analyses, which mainly focused on a broad range of heterogeneous music training programs and combined many different outcomes, e.g., academic and cognitive measures.

A strength of the study concerns the applied statistical method. While meta-analyses with dependent effect sizes were more likely to use simpler methods[13-14], the present meta-analysis was an attempt to alleviate previous statistical problems by adding a novel approach, which could take into account interdependency between variables in all of the analyses (RVE, moderation, subgroup and publication bias analyses). This is of importance in this line of research, since neuropsychological measures related to intelligence and memory functions tend to be highly correlated both across time and between short-term and working memory tasks[15]. With the chosen statistical methods, we were also able to use all the available effect sizes from each study in one combined model and could thus examine both continuous and categorical variables at once using meta-regression without the risk of artificially inflating significance.

Figure 1. *Examples of different types of music training with school-age children, ranging from the individual instrumental training with the violin teacher, to playing in chamber formation guided by the teacher, to orchestral rehearsal with a conductor up to choir singing with the school teacher for the traditional ”Morgensang” in a Danish public primary school (”folkeskole”). Photos by E. Brattico*

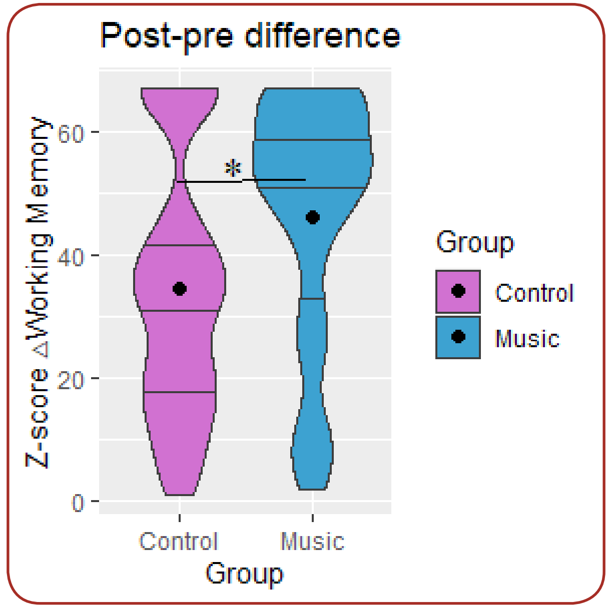

*Figure 2: Mean POST-PRE difference score divided by group (Blue = Music Group, Purple = Control Group). * p ≤ 0.05.*

Another strength is that the studies included provided both means and standard deviations for all groups at both before and after music training, which made it possible to take baseline differences into account, namely whether children who would start a music training program were already more or less skilled with memory already before starting the program itself as compared with children who would not start it. In addition, the assessment of all studies was carried out by two independent reviewers, which reduces the risk of bias in the selection and in the evaluation of the included studies[16]. Also, the low observed variance among the included studies' effect sizes suggest that the results are generalizable.

Despite these strengths, only 10 studies passed our selection criteria for inclusion in the review and meta-analysis. Hence, one outcome of this work is the call for more research in the field towards understanding all the possible implications of different types of music training on children's cognitive abilities.

Educational and scientific implications

This meta-analysis provides motive for offering instrumental music training to children apart from the intangible valuable benefits such as the social engagement, friendships and satisfaction that grow when making music with others and the confidence that develops when learning to play an instrument. Furthermore, results of this meta-analysis may have important implications for future research. A major emerging topic for future research concerns investigations of how individual differences such as genetic markers, personality traits and intelligence influence children's choices of what activities to engage in. Researching how different musical instruments and activities might impact on specific types of cognitive abilities might be important even for identifying what works best for children with learning difficulties and behavioral problems. Indeed, our previous and current studies with children demonstrate that collective orchestral music programs are effective on improving self-regulation of executive functions and decreasing impulsivity even in ADHD children[17]. Knowing in detail what are the effects of each type of musical activity and instrumental training would allow to identify the best strategies for rehabilitating

cognitive skills even in children with neurodevelopmental problems.

Conclusions

The current meta-analysis aimed at giving a synthesized estimate of the effect of music training on a combined measure of short-term- and working memory in children. Taken together, these abilities might be improved by music training. Our study points at the need for more randomized studies to fully allow causal conclusions to be made. Nevertheless, the robust findings obtained showing memory improvements after music training on school-age children provide motive for offering music training to advance cognitive abilities in the developmental age[18].

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CLINICAL APPLICATIONS OF MUSIC

Kira Vibe Jespersen

In 2020, the Global Council on Brain Health (GCBH) presented a new report showing that music can improve brain health and well-being. One of the experts behind the report was MIB professor Morten Kringelbach in collaboration with other top music researchers like Gottfried Schlaug and Daniel Levitin. The report concludes that music is a powerful way to stimulate the brain, and that these effects can be used to promote health and well-being in various populations. Music can be used for rehabilitation after stroke or in neurodegenerative disorders like Parkinson's disease and dementia. The fact that music engages multiple brain networks related to both attention, emotion, memory and movement also makes it an important tool for promoting healthy aging, and the report recommends everyone to incorporate music in their lives[1]

On a national level, we are happy to be knowledge partners with the new Danish Sound Cluster that recently received funding from the Ministry of Education and Research and the Danish Business Promotion Board. Their main activities include innovation projects and knowledge dissemination, and postdoc Kira Vibe Jespersen will be joining their workgroup "Sound Solutions for Healthcare and Welfare" as MIB representative. We look forward to the collaboration.

In 2020, MIB researchers have both finalized and initiated a number of clinical research projects. PhD student Mette Kaasgaard published a survey study investigating the practices of Danish lung choirs and the experiences of their singing leaders[2]. The study showed that lung choirs are heterogeneous concerning setting, duration, and content. The singing leaders are generally well educated musically, but lack skills in lung diseases, and the study indicates a need for the development of disease-specific methodological guidelines. In addition, Kaasgaard finished the large data collection for her clinical study including 270 participants with COPD[3].

In a different line of research, postdoc Kira Vibe Jespersen published a study evaluating the use of music as sleep aid for dementia-related sleep problems. This research project was conducted in collaboration with DTU, Struer – Lydens By - and a number of private actors as part of the "Sound and Health" project supported by the Danish Foundation of Innovation. Forty elderly persons with dementia and sleep problems were included, and the results showed that the majority of participants enjoyed the music intervention, and caregivers observed sleep improvement in almost half of the participants during the music intervention period compared to a baseline period (Fig. 1)[4]. Music interventions for dementia has received a growing interest in the recent years, and these results highlight the potential for using music for sleep improvement in this population.

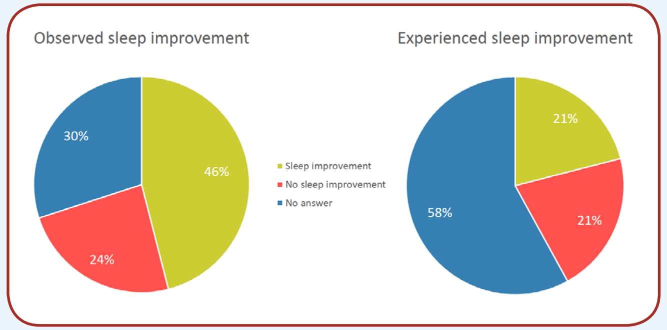

Figure 1 - Caregivers and participants reported observed and experienced sleep improvement during the 14 days intervention period. Sleep improvement was observed and reported in almost half of the responses. It is important to note that many participants were not able to provide a reliable verbal response due to their disease.

Another population who may benefit particularly well from using music as sleep aid are pregnant women with sleep problems. Sleep problems are highly prevalent during pregnancy, but the treatment options are limited, and music may constitute a safe and efficient intervention for pregnancy-related insomnia. This is the hypothesis that PhD student Nadia Flensted Høgholt is testing using a randomized controlled trial design comparing the effect of music to sleep hygiene. She is collaborating with midwifes in the Central Denmark Region to recruit pregnant women with insomnia, and data collection was initiated late 2020. The study uses an online setup in order not to expose the pregnant women to risk of infection with COVID-19.

Finding efficient interventions for insomnia is important since persistent insomnia is a risk factor for developing depression, anxiety, obesity and cardiovascular disorders[5,6]. In a recent study, MIB researchers also showed that insomnia disorder is related to reduced structural connectivity in a network related to emotion processing and interoception[7]. This highlights the relevance of testing new promising interventions for insomnia such as music.

One of the big questions related to the use of music as sleep aid is what characterizes sleep music. In a study conducted in the fall 2020, master student Rebecca Scarratt from Radboud University, the Netherlands investigated this question as part of her internship at MIB. She analyzed sleep playlists from the global music streaming platform Spotify to identify both universal and subgroup characteristics of sleep music. Please read the feature article at page 40 for more information.

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CLINICAL APPLICATIONS OF MUSIC

Rebecca Jane Scarratt and Kira Vibe Jespersen

The characteristics of sleep music

Music is capable of modulating emotions and states[1,2]. One way that music particularly changes our state of being is by either exciting or relaxing the listener. Arousing music such as “Dancing Queen” or “We Will Rock You” will most likely lead the listener to sing, dance along or at least tap their foot to the beat. Inversely, songs like “Falling in Love with You” or “Brahms’s Lullaby” are likely to make the listener sway slowly or feel sleepy. Many people use such effects of music in everyday life.

Before sleep many people turn to music either to distract them from their thoughts, to help relax them, as a habit, or as a comfort mechanism[3,4]. Previous clinical trials and reviews have found that music can improve sleep quality in both healthy and patient adult populations[5,6]. The effectiveness of music at inducing sleep may relate to the power of lullabies at relaxing infants[7,8]. Lullabies are composed of simple rhythms and melodies in every culture worldwide. They are also recognisable as lullabies between cultures, meaning that there must be something very distinct in their sounds[7,9]. In general, relaxing music is described as having simple repetitive rhythms and melodies, small changes in dynamics, slow tempos (around 60-80bpm), no percussive instrumentals, and minimal vocalisations[10,11]. However, little research has been done about the characteristics of the music that people use to sleep.

We conducted a study in autumn 2020 investigating the musical features characterising music used for sleep. In order to get a global sample of what tracks people listened to before sleep, we used the online streaming service Spotify. Spotify is a popular streaming service across the world as it is present in 101 markets on 6 continents. As of the 31st of December 2020, it has 345 million monthly users, covering all age ranges and making it a good platform to conduct worldwide studies of music listening behaviour such as bedtime music listening[12,13]. In this study, we retrieved all the playlists from Spotify that contained either “sleep” or “sleeping” in the title or the description that had more than 100 followers (Fig.1). By using the Spotify API, it is possible to retrieve musical features of tracks included in playlists. We retrieved the musical features for all the songs in all the 989 playlists and formed the Sleep Playlist Dataset with 225,927 tracks.

This dataset includes playlists that vary between 15 minutes and 365 hours, between 100 and 3,982,105 followers, between 2 and 9991 tracks per playlists, and the tracks vary between 1 minute and 971 minutes. 95,619 tracks appeared more than once, meaning that they were present in multiple playlists. Based on this, it is possible to

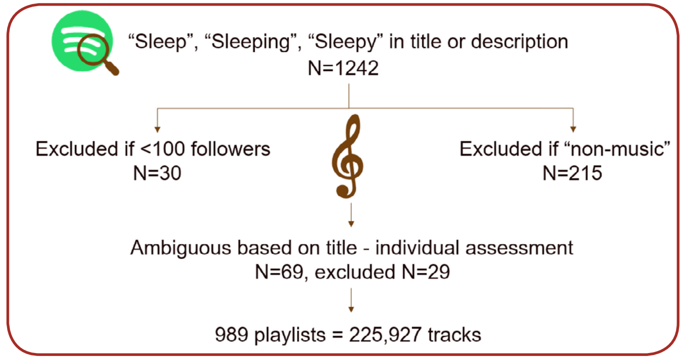

Figure 1: We acquired 1242 playlist by searching Spotify for sleep keywords. 30 playlist were excluded due to having less than 100 followers, and 215 playlists were excluded due to containing mainly non-musical audio such as speech. Sixty-nine playlists had ambiguous titles (such as “NO SLEEP”), and were qualitatively reviewed, leading to 29 exclusions. The final dataset included 989 playlists.

	Music Streaming Sessions (N=3,706,388)	Sleep (N=130,308)	R-Squared	*P*
Loudness	-9.60	-19.77	0.09	<0.001
Energy	0.59	0.23	0.06	<0.001
Acousticness	0.35	0.74	0.04	<0.001
Instrumentalness	0.21	0.62	0.04	<0.001
Danceability	0.56	0.42	0.02	<0.001
Valence	0.48	0.25	0.02	<0.001
Tempo	120.07	104.95	0.01	<0.001
Liveness	0.21	0.15	0.00	<0.001
Speechiness	0.10	0.07	0.00	<0.001

Table 1: We used linear discriminant analysis to compare the sleep music dataset to a dataset of general music listening (Music Streaming Sessions dataset). The results show that compared to general music, sleep music is more acoustic and instrumental, but with lower loudness, energy, and tempo.

determine the tracks that appeared the most times. The 5 most popular tracks are Dynamite by BTS, Jealous by Labrinth, lovely by Billie Eilish, Falling by Harry Styles and i love you by Billie Eilish. The most popular genres as defined by Spotify are “sleep”, “k-pop/k-pop boy group”, “lullaby”, “lo-fi beats”, “pop/uk pop”, “chillhop, lo-fi beats”, “electro pop/pop”, and “piano cover”[14].

We then compared this dataset to a dataset of general music listening in order to find the features that characterise sleep music the most. We found that sleep music has higher acousticness, instrumentalness and lower energy, loudness and tempo (Table 1). Therefore, we concluded that sleep music is generally soft, slow, calm, acoustic and instrumental. Despite these overall characteristics, there is a large variability within the dataset. To investigate this further, we did a clustering analysis based on the musical feature of the tracks. We found that the sleep playlists dataset could be divided into 6 distinct subgroups. Some of the subgroups have the same musical features as the overall dataset, whereas others showed the opposite pattern with low acousticness and instrumentalness and high energy, loudness and tempo. These subgroups were composed primarily of mainstream pop songs. Other groups were characterised by high liveness or speechiness.

Even though sleep music is generally slow, soft, calm, instrumental and acoustic, these subgroups illustrate how sleep music covers a broad range of music. This variety may be explained by the influence of familiarity, preference and individual differences. Listening to a song that is very well known by the listener decreases the cognitive load and increases predictability, thereby facilitating relaxation[15,16]. Furthermore, preferred genres are known to increase relaxation[11,17]. Because some of the subgroups had very different features than the Sleep Playlist Dataset in general, it suggests that familiarity and preference might be important when choosing music to use before sleep. The reasons why individuals listen to music before they go to sleep might also influence their music choice. A survey study reported that the respondents listened to music before sleep to distract themselves, to achieve a relaxation state or to provide comfort[3]. It is possible that different genres or tracks achieve the desired outcome better than others, thereby also influencing music choice. Using a large dataset of global music streaming, the present study demonstrates that sleep music has both universal and subgroup characteristics and thereby advance our knowledge on how music is used to regulate human behaviour in everyday life.

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MUSIC DURING COVID-19

Niels Chr. Hansen

The role of music during the COVID-19 pandemic

When the novel corona virus (SARS-CoV-2) swept across the globe in early 2020, music life relocated to the digital sphere where live-streamed concerts and humorous splitscreen videos quickly inhabited the social media landscape. With mixed success, instrument teaching[1], choir rehearsals[2], and group improvisation[3] switched to lockdown-compatible video-conferencing software, neighbours made music together from balconies, and healthy handwashing songs were commissioned—including a catchy tune featuring Music in the Brain researchers[4].

In Denmark—where lockdown measures were introduced on 12 March—the national song treasure was revived on primetime television, and a charming and competent choir nerd from Næstved—Phillip Faber—achieved celebrity status conducting the crowds from a seasoned grand piano in his manager's living room[5]. The Danish PM rode the musical wave posting videos of herself singing 1980's hits from the kitchen. Mette Frederiksen's Instagram account grew dramatically to nearly 400,000 followers, offering her a direct communication channel to >20% of young Danes[6]. Given the well-established social bonding effects of human music-making[7], it does not seem unreasonable to speculate whether communal lockdown singing contributed to the high levels of restriction compliance and trust in the government exhibited by the Danish population[8]. *But what were really the psychological dynamics underpinning the coronamusic phenomenon of 2020?*

Research convergence despite physical divergence

During the early days of the pandemic, I became part of a growing community of music scientists interested in tackling this pertinent research question. Informal Twitter chats developed into weekly Zoom meetings and shared Google drives. Eventually, I coined the #MUSICOVID hashtag and co-founded a global research network under that name. At the time of writing (March 2021), MUSICOVID comprises ~400 academics and industry partners representing nearly 250 universities, companies, and organizations in 45 countries from all six inhabited continents[9]. The network was inaugurated on 19 May 2020 during two virtual gatherings with 21 speakers and >250 worldwide attendees. Together with two German and Australian colleagues, I serve as guest-editor on the Frontiers Research Topic "Social Convergence in Times of Spatial Distancing: The Role of Music During the COVID-19 Pandemic."[10] This multidisciplinary initiative received more than 60 submissions and has by now accepted thought-provoking, high-quality articles from historical musicologists[11], ethnomusicologists[12], music educators[1], music therapists[13], performers[3], and music psychologists[14] —including several leading figures in our field. A fee waiver for COVID-19-related research enabled participation from regions of the Global South that are traditionally vastly underrepresented in music science. My engagement in coronamusic-themed research, moreover, led to an invitation to join a focus group on ”Cultural & creative sectors in post-COVID-19 Europe” initiated by the CULT Committee of the European Parliament. The final 150-page report provides a compelling analysis of challenges along with actionable policy recommendations to consolidate the professional resilience of musicians in their new digital diaspora[15].

Coping through crisis with music

A key goal of MUSICOVID was to prevent redundant efforts where funding and intellectual resources were wasted on investigating identical research questions through collecting small samples in parallel. By joining forces across institutional and national boundaries, we hoped the music science community could provide valid and timely answers, facilitating swift progress towards more specialized research problems. Two multi-national studies assessing musical habits and coping behaviours in a total of >10,000 participants attest to the fulfilment of this aim[14,16]. Generous seed funding from Interacting Minds Centre, AU, enabled me to take part in one of these collaborative efforts teaming up with like-minded colleagues from Boston, Dublin, Frankfurt, and Jyväskylä.

Our large-scale survey showed that more than half of our 5,113 demographically representative participants from France, Germany, India, Italy,

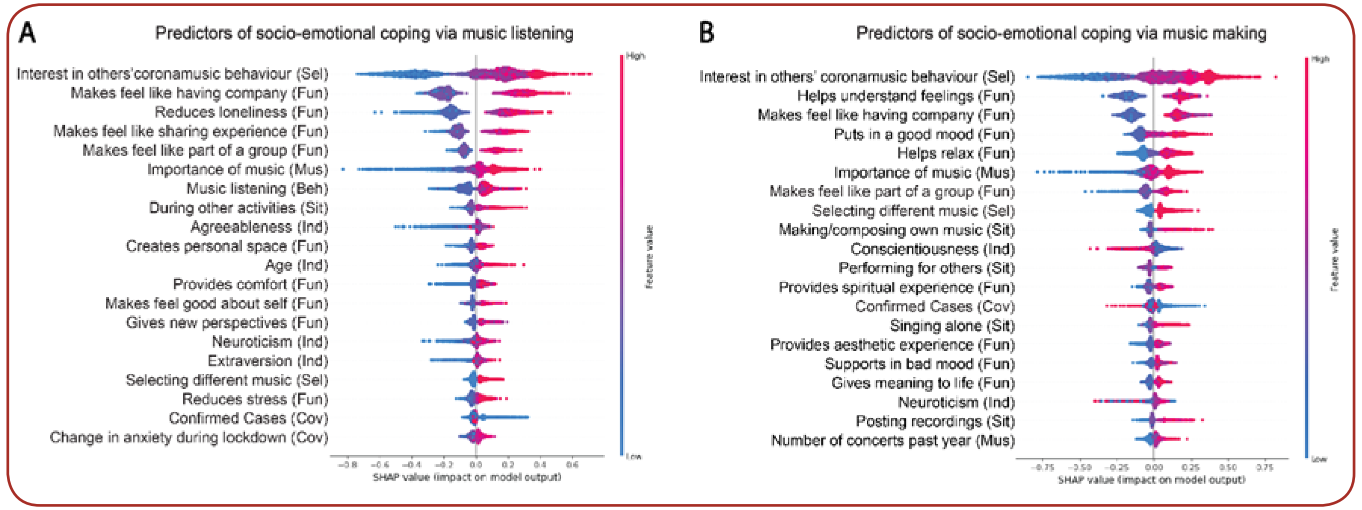

Fig. 1. Top-20 features predicting socio-emotional coping via (A) music listening and (B) music making. SHapley Additive exPlanations (SHAP) values depict the contribution of high (red) and low (blue) feature scores to overall prediction.

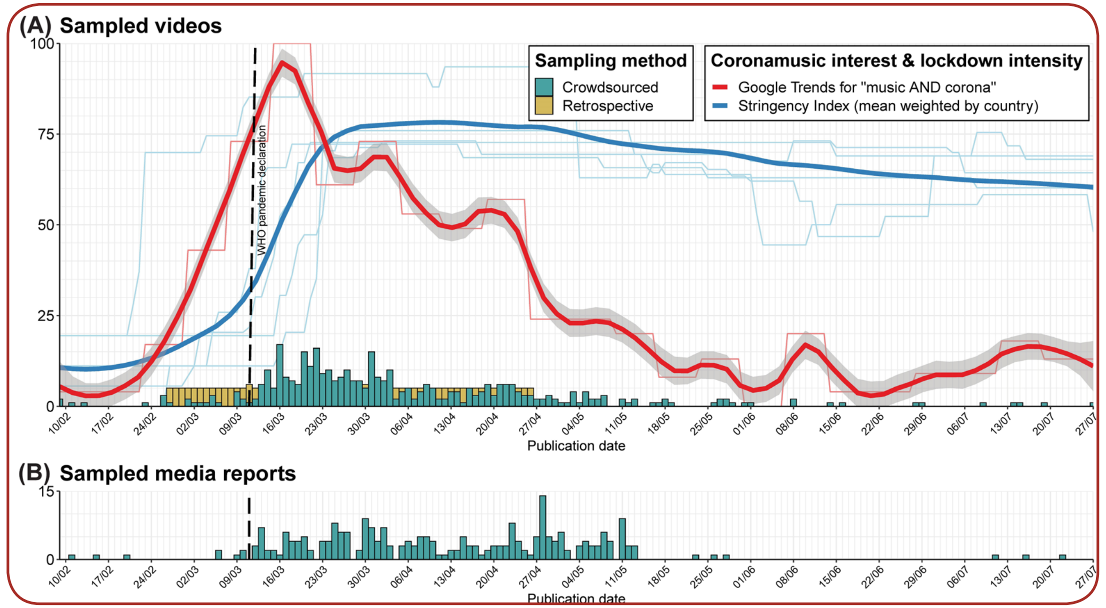

Fig. 2. Histogram of crowdsourced (turquoise) and retrospectively sampled (yellow) videos (A) and news reports (B) in the CORONAMUSIC DATABASE. The sampling period coincides with the pandemic declaration by the WHO on 11 March (dashed line), the peak in Google searches for “music AND corona” (red line), and the initial upsurge in lockdown measures (blue line). The last of these is represented by the average stringency index from the Oxford COVID-19 Government Response Tracker[19] weighted across all represented countries.

UK, and USA reported using music for coping during lockdown[16]. Whereas people experiencing increased negative emotions used music for solitary emotion regulation, people experiencing greater positive emotions used music as a proxy for social interaction. Light Gradient Boosting Machine regression, furthermore, identified interest in other people’s coronamusic as the strongest predictor of socio-emotional coping through music (Fig. 1). These findings suggest that contextually tailored musical innovations in terms of dedicated genres and new forms of expression may serve the achieving of essential wellbeing goals by boosting individual and collective morale when human societies face crisis. This, in turn, calls for expanding and deepening our knowledge of the coronamusic repertoire.

Documenting and understanding the coronamusic phenomenon

To create a resource for fellow researchers, starting from 26 March, I disseminated, first, a Google Sheet and, next, a SurveyXact submission site inviting the general public to crowdsource links to videos, hashtags, and news reports deemed to represent coronamusic[17]. Retrospective sampling of further videos was performed using systematic web-scraping from YouTube to ensure stable representation from 27 February to 26 April, when the popularity of coronamusic peaked during the introduction of stringent government measures (Fig. 2). Along with a dedicated team of music science colleagues from Jyväskylä, Oslo, and Oxford, we subsequently coded all items for country of origin, setting, SoMe platform, musical genre, emotions, and the presence of COVID-19-related lyrics, conflict,

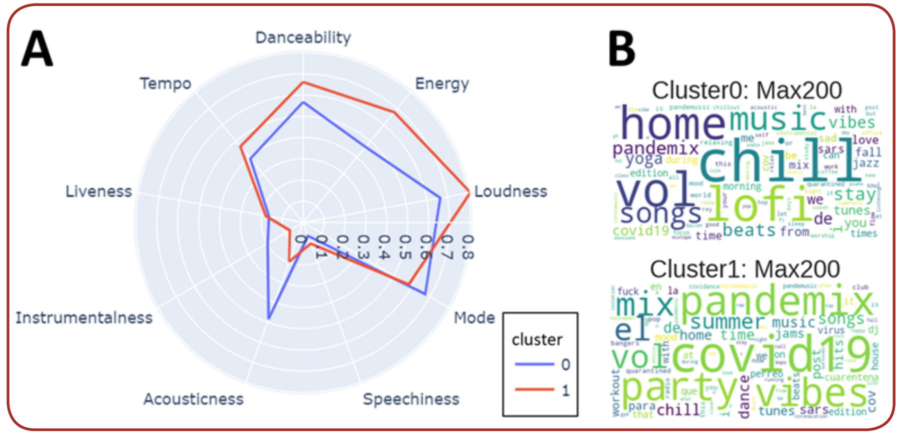

Fig. 3. (A) Average acoustic features and (B) title word clouds for two distinct sub-types of COVID-themed Spotify playlists, comprising low-energy, predominantly negatively valenced, “chill” music (“cluster 0”) and high-energy, predominantly positive, “party” music (“cluster 1”).

movement, health info, alongside other pertinent features. The full CORONAMUSIC DATABASE—comprising 465 video, 254 media, and 62 other items—is available via OSF, GitHub, and a Shiny App where users can explore the rich data material on their own[18].

Somewhat surprisingly—in light of the devastating consequences of a global pandemic—positive emotions (e.g., togetherness, happiness, gratitude, humour, and being moved) were much more prevalent in the CORONAMUSIC DATABASE than negatively valenced emotions (e.g., loneliness, longing, and grief/sadness). In an ongoing study, we employ natural language processing tools to determine whether a positive affective bias governed the making, sharing, and consumption of music during the pandemic. Specifically, using adequate control corpora from previous years, we will quantify the sentiment of (corona-)music-themed tweets on Twitter, subreddits on Reddit, user comments and lyrics on YouTube, playlists on Spotify, and major international news sources. Preliminary results show that 9,486 COVID-themed Spotify playlists with >0 followers (comprising 575,254 unique tracks) indeed exhibit significantly higher valence than a 3,706,388-track control corpus[20]. Additionally, K-means clustering on audio features suggest two distinct types of playlists: low-energy/low-valence, “chill” music (“cluster 0”) and high-energy/high-valence “party” music (“cluster 1”) (Fig. 3). Coronamusic practitioners may thus have capitalized on the short-term, mental-health benefits of positive affect[21] to regulate mood and stress in ways that facilitate subsequent problem-oriented, long-term coping[22].

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EDUCATIONAL ACTIVITIES

Bjørn Petersen and Elvira Brattico

Online knowledge sharing

In the light of the emerging Covid-19 pandemic, on March 12th the Danish government declared a nationwide lockdown, including all public institutions. This had the consequence that MIB staffers were encouraged to work from home, if at all possible. It also meant that the weekly lab meetings were moved online to Zoom, which after some adaptation has proven a well-suited platform for research presentations. A total of 32 in-house presentations have been shared in 2020, including some by visiting students, following a program organized by postdoc Cecilie Møller. A few of those presentations were presented 'physically' when MIB facilities were open in the two periods from May 25th – August 10th and from August 23rd – September 21st.

New supervision obligations

Following revisions of the Medicine education program, the Department of Clinical Medicine has asked MIB (together with 4 other departments/centers) to supervise medical students in their Bachelor's projects. MIB has agreed to offer supervision of up to four students per semester. The students will be teamed up with MIB postdocs and assistant professors to carry out empirical research, analyzing and interpreting data that they either collect themselves or that have been collected in the supervisors' project. The empirical Bachelor's projects carry 15 ECTS and have a duration of 15 weeks. MIB supervisors involved in the first term are postdoc Jan Stupacher (rhythm and predictive coding), postdoc Kira Vibe Jespersen (music for insomnia) and PhD student Victor Pando, MD, (music-induced analgesia). MIB has also agreed to supervise master's students of the Department of Clinical Medicine in their 3rd semester's "individual research trajectory" (8 weeks). One student has chosen to complete his course at MIB under the supervision of PhD student MD Nadia Høgholt, MD (the postnatal brain).

Besides these local obligations, the recent secondary affiliation of Prof. Elvira Brattico with the University of Bari in Italy has brought with it obligations to supervise Bachelor's and Master's students of psychology (4 completed in 2020) and educational sciences (2 completed). These additional resources represent an enrichment for MIB research, initiating new empirical projects having school children and university students as volunteer participants, such as one on musical competence (measured with the in-house MET and miniMET tests), empathy and musical reward sensitivity with both adults and school-age children. Moreover, these graduate students and two trainees (psychologists Fulvia Campo and Giulio Carraturo) have joined the team for a longitudinal study led by Prof. Brattico together with postdoc Maria Celeste Fasano (former MIB), investigating the beneficial effects of a collective music training program on autistic and ADHD children. These empirical studies have suffered some hindrances due to the pandemic, but nevertheless, data has been collected, with already 2 manuscripts now ready for submission and more to come.

Supervision and teaching activities

Continuing the good practices of previous years, MIB personnel, from professors to PhD students, has contributed to teaching and supervising local students both at RAMA and Aarhus University. At RAMA, Assist. Prof. Bjørn Petersen, as part of his responsibilities for the academy's R&D-activities, organized a research course titled "From project to knowledge base". The course was aimed at RAMA teachers, and former professor Søren Kjørup gave a presentation which provided an overview of the history of knowledge and how knowledge in the arts can be generated and documented. In addition to this, Petersen has given lectures on scientific and artistic research methods to RAMA students as part of their preparation for working on BA and MA projects.

In 2020, MIB has initiated a collaboration with Center for Ear-EEG, Dept. of Engineering, AU. Postdoc Cecilie Møller is co-supervising a master's project (biomedical engineering) which uses Ear-EEG, an innovative technology designed for measuring brain activity in real-world situations. The purpose of the project is to assess how Ear-EEG recordings compare with scalp EEG recordings in terms of measuring higher-level perceptual processes related to beat perception.

Supervision and teaching collaboration of MIB personnel (particularly, Prof. Brattico) with the Sino-Danish Center for Education and Research (SDC) was strengthened with the completion of a master's thesis in Neuroscience and Neuroimaging on a behavioral and EEG study of perceived cultural distance in music with 130 Chinese subjects, and the participation in thesis evaluation committees.

In Italy, Prof. Brattico taught two full online courses (Psychology of Personality and Individual Differences, and General Psychology) to local (plus some Erasmus) undergraduate students in psychology and in educational sciences at University of Bari. Similarly, postdoc Leonardo Bonetti ran a course in Environmental Psychology to psychology students at the University of Bologna. Teaching on topics closely related to MIB research, specifically Sound & Health, was also done by Prof. Brattico and Assist. Prof. Manon Grube for training meditator teachers in London.

Brainhygge

By November 2019 a new monthly seminar series, known as the 'BrainHygge' was initiated by MIB and CFIN. Planned to take place on the last Friday of every month, The BrainHygge has the format of a 45 minute lecture followed by 15 minutes of chaired Q&A. The concept of the meetings is such that primarily junior researchers (e.g., PhD and postdoc) employed at MIB and CFIN can present their work as an opportunity for all the different groups at MIB and CFIN to have a forum for group discussion and announcements. All MIB-and CFIN-employed researchers will be expected to give a BrainHygge talk at some point during their time at the centres.

Also, a few 'external' researchers in Denmark are expected to give talks (e.g., from the Translational Neuropsychiatry Unit, DANDRITE, or other local groups working on topics relevant to brain science). The selection and scheduling of speakers will be coordinated by a committee of junior researchers (MIB's own Victor Pando among them) divided evenly between each of the major topic areas of the centres. Committee membership will rotate each year, providing an opportunity for new members of the centres to become involved in the seminar. Two MIB researchers, postdoc Kira Vibe Jespersen and Assist. Prof. Henrique Fernandes, will be presenting their work in 2021.

Summer educational days in Aarhus and abroad

Unfortunately, by March 2020 the pandemic crisis forced us to postpone the planned Aarhus Summer School in Music Neurosciences to June 2021 and to rethink its format. In the light of the uncertainty caused by the world situation, the organizers are preparing an online course, with both live talks, recorded and live video materials, Q&A sessions with the teachers, poster presentations by students using virtual space navigation and plenty of pedagogical and technological tools for enhancing online interaction. Teachers at the Summer School are Robert Zatorre, David Huron, Virginia Penhune, Isabelle Peretz, Simone Dalla Bella, Maria Ruiz Herrojo, as well as MIB's own Morten Kringelbach and Boris Kleber. The Summer School is organized as a PhD course in collaboration with the Graduate School of Health at AU and planned in the week leading up to Neurosciences and Music VII conference.

International guest speakers

Since its launch in 2015, MIB has had a strong tradition of inviting international guest speakers to Denmark – ranging from upcoming researchers to renowned established experts in the field. However, due to the coronavirus situation, MIB had only few international visiting speakers in 2020.

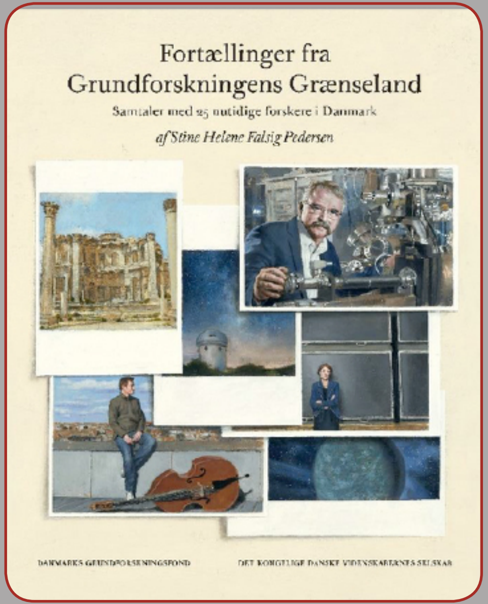
1. Sonja Kotz, Professor in Neuropsychology and Translational Cognitive Neuroscience at Maastricht University, gave a presentation about timing and auditory sensitivity as possible determinants of musicality.

2. Dr Philippe Albouy from School of Psychology, Université Laval, Canada gave a talk about non-invasive brain stimulation (NIBS).

3. Dr Anna Zamm, Marie Curie Postdoctoral Research Fellow at Department of Cognitive Science, Central European University, Vienna, Austria gave a talk on interpersonal synchrony.

Dr. Kotz' talk was presented at MIB in January before the lockdown, whereas Dr. Albouy and Dr. Zamm both gave their talk online via Zoom.

NEW BOOK ON BASIC RESEARCH BY DNRF



In 2020, Center Director Peter Vuust made it to the frontpage of a new book published by The Danish National Research Foundation and the Royal Danish Academy of Sciences and Letters.

The book is based on interviews made by Professor Stine Falsig Pedersen from University of Copenhagen. She has talked to several distinguished researchers – all current or former centre directors - and one of them was Peter Vuust. He talks about his untraditional way into research and the establishment of Center for Music in the Brain.

CleanHandsSaveLives

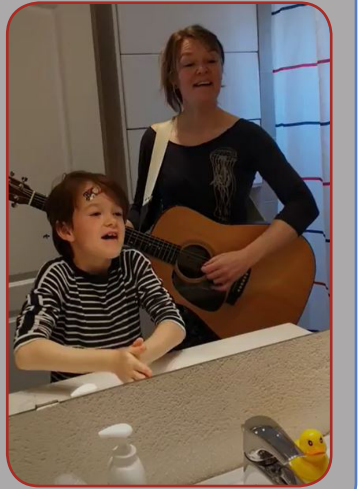
THE HAND WASHING SONG

May 5 2020 was WHO's Hand Hygiene Day. As part of an international initiative "The Hand Washing Song" was made available in 28 languages.

Professor Peter Vuust and Assistant Professor Bjørn Petersen contributed with the Danish version of the song:

Vaske hænder, mellem fingre
For og bag, gnub og skrub
Fingrene roteres, hænderne masseres
Tommeltot, gnides godt

MIB postdoc Cecilie Møller recorded the song for the international website: https://cleanhandssavelives.org/hand-washing-song/, and we even made a video (available on the MIB website) featuring Cecilie and her son Thor.



PHD FEATURE

Leonardo Bonetti

Brain spatiotemporal dynamics of auditory patterns encoding and recognition

Memory is one of the most important cognitive functions, plays a fundamental role for guiding individuals' behaviour and ultimately leads them to survival[1]. Several works proposed variegated perspectives and theories about memory[2]; in my PhD I mainly focused on two of the most important mechanisms underlying any complex memory process: encoding of new information (i) and recognition of information that was previously learned (ii). This topic is central in neuroscience and thus has been widely explored, providing relevant knowledge on processing, encoding, and recognition of single elements, especially within visual[3] and auditory domains[4,5]. Further studies investigated the recognition of spatial and visual patterns characterised by the synchronous combination of elementary items. Examples of such patterns are faces, visual objects and spatial paths. Although these works led to remarkable discoveries within neuroscience, the brain mechanisms underlying encoding and recognition of patterns extended over time remained obscure and thus unravelling such mechanisms became the main focus of my PhD.

To achieve these aims, in three studies, we combined the human universal non-verbal art that mainly acquires meaning over time, namely music, with state-of-the-art neuroscientific machines such as magnetoencephalography (MEG) and magnetic resonance imaging (MRI).

In the first study, we discovered the brain networks underlying encoding of sound information when listening to an entire musical piece. Results showed significant activations and centralities within the whole-brain network of a number of brain areas linked to auditory, attentional and memory processes such as primary auditory cortex, basal ganglia, frontal operculum, insula and hippocampus. Additionally, by using functional connectivity dynamics analysis, we unveiled the fast transition from primary auditory cortex to higher order brain areas occurring within the first 220ms from the onset of the sound to be encoded.

The second study of the PhD explored the neural substrate of auditory pattern recognition by contrasting the brain functioning underlying recognition of known versus unknown melodic sequences. The results showed two components of the event-related field (ERF) involved in the response to the stimulation. On the one hand, we observed N100 responses to each sound forming the auditory pattern. On the other hand, we discovered that the brain processing of the entire auditory pattern was associated to an additional component, which was a slow negativity (about 0.3Hz) arising after the onset of the second tone

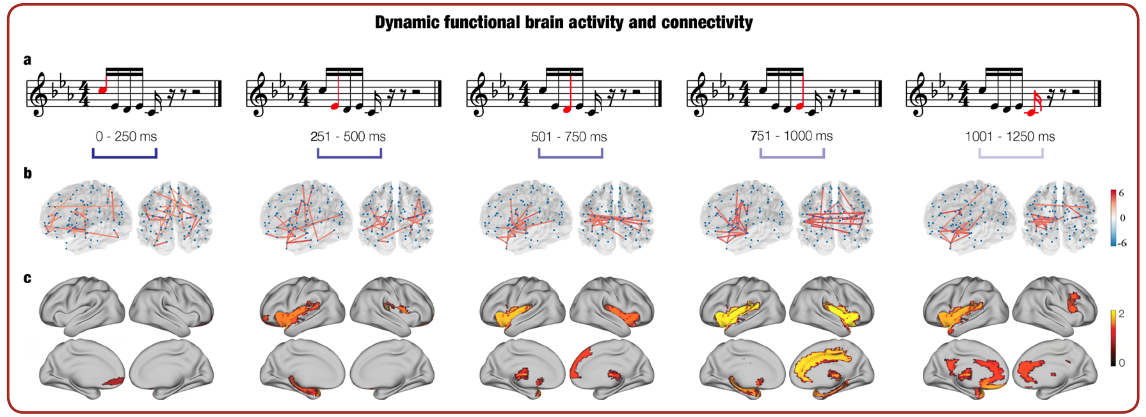


Figure 1. Brain activity and connectivity underlying recognition of the auditory pattern evolving over time.
***a** - Representation of the musical score of one of the melodic sequences used in the experimental task of the PhD. Red notes depict the progression of the sequence over time. **b** - Functional connectivity over time between brain areas underlying the recognition of the different tones forming the known auditory pattern. **c** - Brain activity over time underlying the recognition of the different tones forming the known auditory pattern.*

of the musical sequences, growing up to the end of the sequence and decreasing after the musical pattern ended. Notably, the known compared to unknown auditory patterns were associated to a larger amplitude of such slow negativity. As depicted in Figure 1a and 1c, source reconstruction algorithms located the neural sources of the ERF component within auditory cortex, cingulate gyrus, hippocampus, basal ganglia, insula and frontal operculum.

As illustrated in Figure 1a and 1b, the last study of the PhD focused on the dynamics of the brain functional connectivity underlying auditory pattern recognition. In this case, the recognition of the auditory patterns was accompanied by a significant centrality within the whole-brain network of several brain areas such as insula, hippocampus, cingulate gyrus, basal ganglia, frontal operculum, and subgenual and orbitofrontal cortices. Remarkably, the whole-brain connectivity was stronger for the last three tones of the musical sequences and, although very similar across conditions, it emerged more clearly for the known vs unknown auditory patterns.

To conclude, my PhD project shed new light on the dynamics of both brain activity and connectivity underlying encoding and recognition of auditory patterns that acquire meaning through their development over time.

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PHD FEATURE
Marianne Tiihonen

Multimodality of Affect - From Concept to Neurophysiology

The objective of this thesis is to further the understanding of the human affective system and its relationship to the visual and auditory sensory modalities, and to the levels of semantically representative and non-representative affective information.

Study I
An integrative literature review with a qualitative thematic analysis was chosen to understand how pleasure had been understood in the literature of music and visual-art[1]. It was found that music-induced pleasure is conceptualized around the elements of core affect and intrinsic reward, being biological, rather than culture and context specific in nature. Music was shown to be more involved in the homeostasis of the organism, having access to the parts of the nervous system beyond volitional control, such as autonomic nervous system and limbic structures of the brain. Visual-art derived pleasure was considered to emerge as a result of the conceptual act, and the experience seemed to depend on the perceiver´s active interpretation and attribution of meaning, referring to a more culture and context specific understanding of pleasure, thus being conceptualized more as an act of information processing consisting of feature encoding and interpretation.

Study II
The phenomenon of emotional ambiguity, liking something unpleasant, has been thematized as an emotion regulation mechanism[2]. Here it was tested whether the affective judgements of pleasantness and liking are separate phenomena already in the early behavioural responses, and whether they indicate sensory modality dependent differences when tested with a behavioural affective priming paradigm. The mixed effect analysis on the reaction times confirmed a bi-directional cross-modal affective priming, and a clear interaction effect between the sensory modality and task: While liking was rated fastest in both modalities, it was significantly faster in the visual modality. Regarding the task difference, it is speculated that providing the affective judgements are facilitated by different psychological mechanisms. Regarding the interaction effect, it is suggested that the visual modality is more susceptible to top-down influence.

Study III
In the third study applying combined EEG and MEG measures, it was investigated whether the sensory modalities indicate differences in their responsivity to modulation by valence[3]. Furthermore, it was investigated whether there are cross-modal neuronal modulatory effects based on the affective congruency from the semantically representative to non-representative affect. The results show that human ability to extract emotional information from auditory sources is fine-tuned to high-level affective nuances starting as early as 100ms. Furthermore, the congruency-based modulation of the visual modality shows that an affective transfer effect takes place cross-modally, from auditory to visual, and across affective information types, from semantically representative to non-representative.

It is concluded that affective dimension is an integral part of perception, and that affect should not only be understood as a higher order processing, in isolation from sensory modalities.

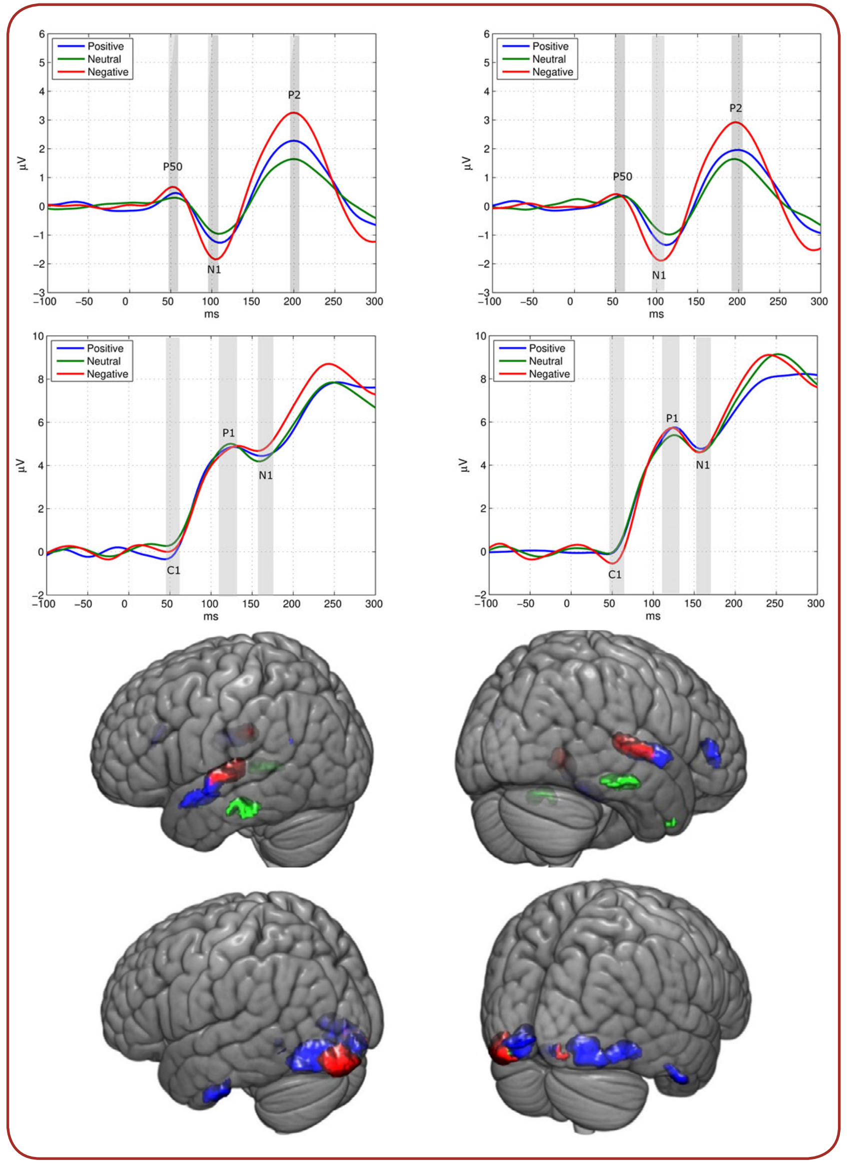

Figure 1: Multimodal ERP-responses and source localisation
(First row: Auditory responses, second row: Visual responses.) Left and right hemispheric evoked response potentials to the perceived valence types of positive, negative, and neutral emotions in three times points starting at 50ms after the stimulus on set.
(Third row: Auditory responses, Fourth row: Visual responses.) Left and right hemispheric source localisation of the primer responses to the positive, negative, and neutral valence types.
Colour legends: Red = 50 ms, Green = 100 ms, Blue = 100 ms after stimulus onset

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PHD FEATURE

Patricia Alves da Mota

Brain dynamics of predictability and improvisation: Evidence from jazz pianists and autistic listeners.

There is something unique about music that makes us all synchronise as one large unit. Regardless of cultural background, personal musical expertise, listening interests, context, mood or biological factors, we all share brain mechanisms with highly convergent architectures to make sense of and enjoy music; to receive, process, make inferences and predict[1]. Creating music is a remarkably dynamic process and a highly prized form of creativity. Jazz musicians are able to spontaneously generate novel pieces of music in a short time frame, creating musical pieces which are both aesthetically and emotionally rewarding. The neuroscience of jazz improvisation has shown promising results for understanding domain-specific and domain-general processes of creativity[2].

In this PhD project, I constructed a methodological framework to elucidate the brain mechanisms sustaining the complex relationship between creativity, predictability and pleasure. Firstly, we characterised the fingerprints of brain dynamics underlying the creative process in skilled jazz pianists (Fig. 1). For this, I used fMRI to derive the first comprehensive characterisation of the dynamic neural substrates underlying musical creativity in 16 skilled jazz pianists while they played by memory, improvised freely (*iFreely*) and by melody (*iMelody*), and during resting-state. I used the Leading Eigenvector Dynamics Analysis (LEiDA) to examine how different modes of improvisation (musical creativity) evolve over time, and which cognitive mechanisms are responsible for different stages of musical creation. The results reveal that a substate comprising auditory, sensorimotor and posterior salience networks had a significantly higher probability of occurrence (POc) in both modes of improvisation than in resting-state and play by memory. Another substate comprising the default mode (DMN), executive control (ECN) and language networks had significantly lower POc in

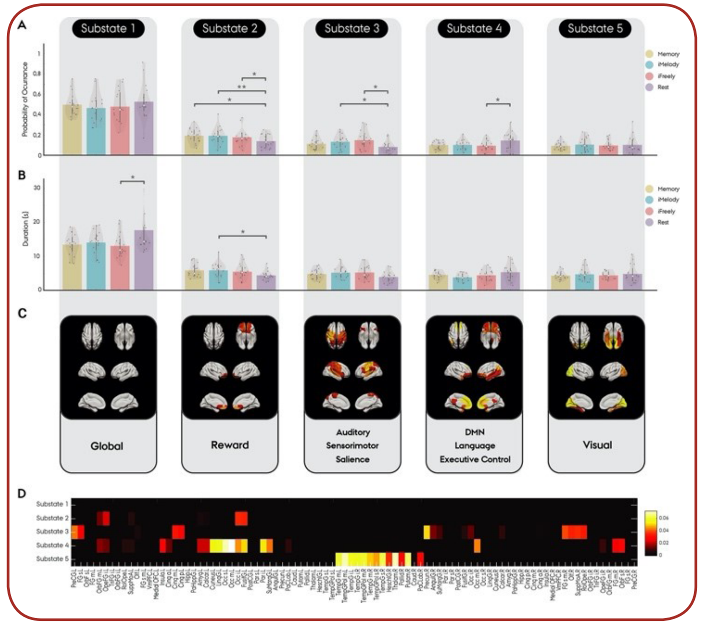

Figure 1. Signature of Musical Creativity.

iFreely than in resting-state, with *iMelody* having a higher POc than iFreely[3].

Secondly, we produced the first whole-brain computational models of music improvisation to discover the ensemble of brain regions and properties of the local dynamics that support efficient transitioning between familiar (memory) and creative states of musical production (Fig. 2). Our results from network model perturbations show that a transition from a memory-based to a creative states requires a higher dynamic richness obtained through increasing the level of noise of the BOLD signal of brain regions involved in vast range of cognitive processes important for creativity, such as the planning of complex behaviour, decision making, emotional/arousal regulation, semantic processing, memory, imagery and motor control. However, a transition of brain dynamics from a creative state to a memory state seems to occur upon decreasing the level of dynamic expansion of regions involved in memory retrieval, planning (imagery), motor, executive and emotion control.

Finally, we produced the first detailed description of which aspects of brain dynamics, namely which functional brain networks and differences in the patterns of metastable substate transitioning, underlie perceptual differences in the processing of familiar music in autism[4]. A group analysis using LEiDA revealed significantly higher probability of occurrence of a brain network in typically developing (TD) individuals compared to autistic individuals, during the listening to familiar music. This network includes limbic and paralimbic areas (amygdala, hippocampus, parahippocampal gyrus,

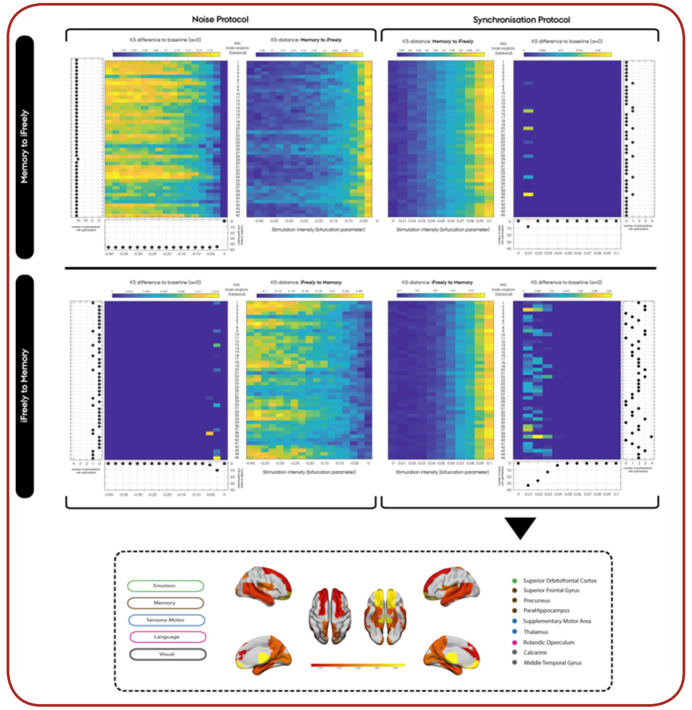

Figure 2. Perturbing the Memory and iFreely whole-brain Hopf Model (mean of 30 iterations).

and temporal pole). No significant differences were found between autistic and TD individuals while listening to a scrambled (unfamiliar; less predictable) version of the same music track.

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PHD FEATURE

Pauline Cantou

Self-regulation and musical training: Neural evidence from early adolescents and adults

Leaving childhood to enter adolescence is a significant milestone in life. This crucial step is associated with many emotional, social and cognitive challenges that early adolescents attempt to overcome by developing their own coping strategies[1]. This process can be influenced by individual traits and environmental factors that play a determinant role in the positive or negative behavioral outcomes. Moreover, this critical period is accompanied with major reorganization of cognitive and emotional brain systems leading to temporary "out of balance" self-regulation skills[2]. In consideration of these elements, out-of-school activities have been proposed to be possible mediators facilitating brain maturation and behavioral development during this tumultuous time. Notably, musical training has been shown to positively impact children's inhibitory control[3], 2018), a key component of self-regulation, although the neural substrates of this transfer remain unclear and poorly studied during the delicate period when children enter adolescence.

In my PhD, I addressed this gap in the literature by first examining individual differences and neural correlates of self-regulation in early adolescents (study 1), then exploring the impact of musical training on self-regulation and its associated resting-state network (study 2), and finally reviewing the effects of different types of training on resting-state functional brain architecture of adults, including musical practice (study 3). The latter contributes to a better understanding of our results obtained in study 2 from a developmental perspective.

In study 1, we tested whether self-regulation temperamental traits (effortful control and negative affect) can influence emotion regulation and its brain substrates measured during an fMRI color flanker task. We found that early adolescents with better self-regulation were faster to resolve conflict in a negative emotional situation and exhibited lower connectivity between cognitive-emotional areas (anterior insula and medial prefrontal cortex) when processing negative stimuli compared to neutral stimuli than those with poorer self-regulation.

In study 2, we carried out a longitudinal design to assess the effects of 5 months of musical training on musical and self-regulation abilities (inhibitory control), as well as on resting-state functional connectivity (rs-FC) in early adolescents. Our results showed improved rhythm synchronization skills in the music group relative to the passive group, associated with enhanced auditory-motor integration (between planum temporale and precentral gyrus) (Fig. 1). Moreover, musically-trained early adolescents exhibited reduced

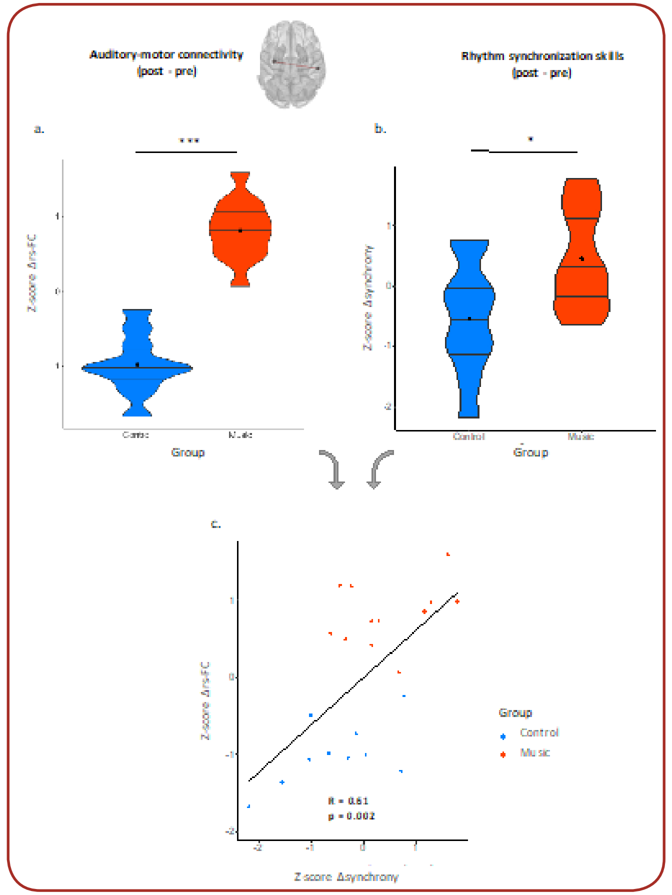

Figure 1. Group differences and correlations for the synchrony scores and rs-FC between the planum temporale right and precentral gyrus left. (a) Normalized rs-FC for the contrast post-pre (Z-score Δrs-FC) in each group, (b) Normalized synchrony score in the easy condition for the contrast post-pre (Z-score Δs-y2nchrony (easy-1)) in each grou0p, (c) correlatio1ns between no2rmalized synchrony and rs-FC for all participants (black), for the control group (blue) and for music group (red).

connectivity between cognitive-emotional areas (anterior cingulate cortex and medial prefrontal cortex) than their non-trained peers. This lower coupling was correlated with better inhibitory control in all early adolescents (Fig.2).

In study 3, we examined whether different types of intensive training can leave specific or general "silent neural traces". To do so, we reviewed the effects of expertise in the motor, cognitive and musical domains on functional brain plasticity at rest and discussed their domain- and training-related specificity as well as methodological issues[4]. In this review, we highlighted that musical expertise was consistently associated with both enhanced auditory- motor coupling at rest and increased rs-FC within the salience network.

Taken together, our results suggest that musical training accelerates the development of functional networks related to musical and self-regulation skills in early adolescents with increased auditory-motor integration and segregation between cognitive-emotional regions. This PhD dissertation provides a better understanding of the early adolescents' brain maturation and its modulation by musical training.

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PHD FEATURE
Stine Derdau Sørensen

A Mass Experiment: Musical competence and working memory in Danish children

Investigating the musicality and working memory capacity of thousands of children across the ages of 5 to 20 years in just one week is not trivial. However, this is exactly the challenge we faced in 2016 when MIB was invited to design and execute a mass experiment during the Danish Science Week. This annual event is arranged by Astra (the national Centre for Learning in Science, Technology and Health in Denmark) with the objective to introduce school children to scientific methods by providing an opportunity to get hands-on experience with a variety of topics. In six months, we designed an experiment, created background materials for the teachers to include in class, constructed a new musical ear test for children and made both questionnaires and behavioural tests available online. The project thus introduces a novel approach to collecting large scale behavioural data in music psychology by combining behavioural tests with online questionnaires in a school classroom setting together with the teachers as the experimenters. The project was successfully defended in October 2020.

Why is it interesting to map the musicality of the population, or more specifically, children? The study of individual differences in musical competence – defined as the ability to perceive, remember and discriminate melodies and rhythms[1] – is relevant in the light of the growing interest in understanding the effects of musical training in relation to other cognitive functions, such as sensory-motor skills, general cognitive ability, language processing and the deficits connected to them[2]. Furthermore, both formal music training and informal music activities have been shown to have a positive effect on children's auditory, cognitive and social development. Here, we aimed to examine the association between musical competence and working memory capacity in children which has been found previously in both children and adults[3,4].

Age group	Grade	Number of participants			Age
		Gender	*N*	%	*Mean*
First years of primary level	0^{th}-3^{rd} grade	M	1231	49.3%	8.3 years
		F	1267	50.7%	8.1 years
		Total	2498	100%	8.2 years
Intermediate level	4^{th}-6^{th} grade	M	4046	50.3%	11 years
		F	3994	49.7%	10.9 years
		Total	8040	100%	11 years
Final years of compulsory school	7^{th}-10^{th} grade	M	2950	50.7%	13.9 years
		F	2866	49.3%	13.8 years
		Total	5816	100%	13.8 years
Youth education	1^{st}-3^{rd} year	M	376	41%	16.8 years
		F	540	59%	16.7 years
		Total	916	100%	16.7 years
All		M	8603	49.8%	11.9 years
		F	8667	50.2%	11.8 years
		Total	17270	100%	11.8 years

Figure 1: Participants divided into four age groups based on school levels.

First, the project contributes with preliminary information on the development of a new musical ear test for children consisting of melodic and rhythmic discrimination tasks.

Second, we employed a Danish version of the Concurrent Musical Activities[5] inventory to obtain a score of musical activities for each participant. The project thus provides a quantitative overview of age and gender differences in children's musical activities which may represent a unique point of reference for future research and cross-cultural comparison.

Finally, we administered a forward digit span test to assess working memory capacity to investigate the relationship with musical competence. However, interpretation of results must be viewed in the light of the large sample size fallacy. Consequently, we investigated how much of the variance on the working memory test was explained by musical competence by employing structural equation modelling. In line with previous research, age was found to be a clear predictor of working memory, and the best fitting model was found to include working memory, degree of musical activities and age as the significant predictors for the performance on the musical ear subtests. However, musical competence did not predict performance on the working memory task and neither did degree of musical activities. Instead, the results indicated that working memory may predict the degree of engagement in musical activities.

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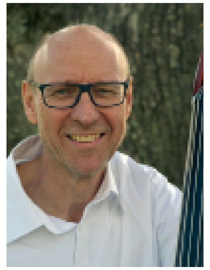

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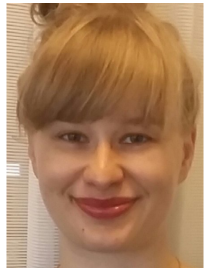

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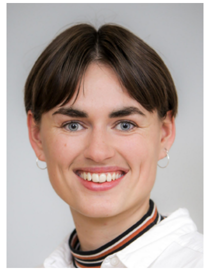

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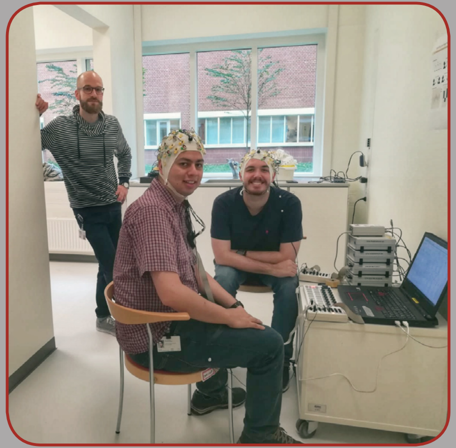


Fullbright student Andrew Moore from Oklahoma University, US testing an EEG paradigm with MIB postdocs Jan Stupacher and David Quiroga.

FUNDING FOR NEW PROJECT ON ONLINE MUSIC EDUCATION

MIB/RAMA Associate Professor Bjørn Petersen has been a driving force in the development of a new project which aims at systematically exploring different forms of online music education, within a wide range of skill levels.

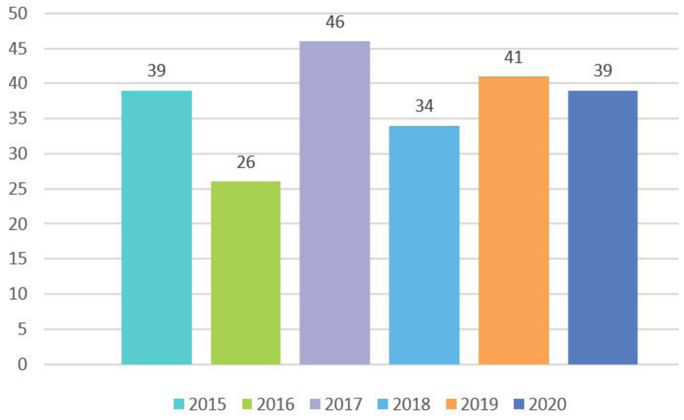
The project develops, initiates and evaluates online learning methods and is primarily aimed at music teachers and students, but may be relevant in online learning in general.

The project is a cooperation between RAMA, Aalborg University and Aalborg public school of culture and has received 1.8 million DKK from Den Obelske Familiefond, 1 million DKK from Augustinusfonden and 100,000 DKK from William Demant Foundation.

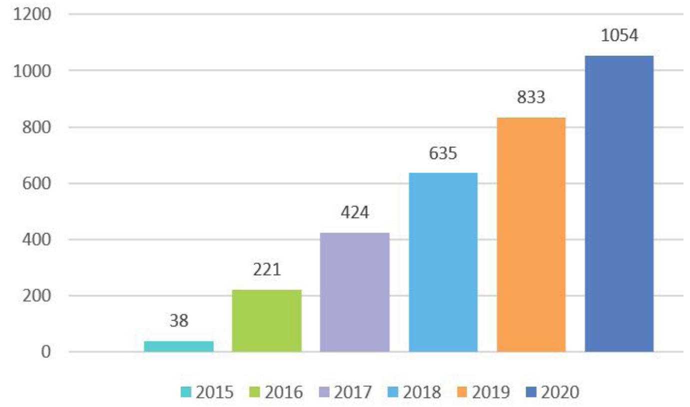
The project is scheduled to take off in October 2021 and run for 2.5 years.

PUBLICATIONS 2020

Number of peer-reviewed articles



Number of citations



Peer-reviewed articles

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PhD theses

Leonoardo Bonetti
Brain spatiotemporal dynamics of auditory patterns encoding and recognition

Marianne Tiihonen
Multimodality of Affect - From Concept to Neurophysiology

Patricia da Mota
Brain dynamics of predictability and improvisation: Evidence from jazz pianists and autistic listeners.

Pauline Cantou
Self-regulation and musical training: Neural evidence from early adolescents and adults

Stine Derdau Sørensen
A Mass Experiment: Musical competence and working memory in Danish children

Book chapters (selected)

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Dahlstrøm M, Stewart L, Shoemark H. The Potential of The Human Voice for Early Parent–infant Interactions in at-risk Populations. In The Routledge Companion to Interdisciplinary Studies in Singing. Vol. III: Wellbeing. Ed. Heydon R, Fancourt D, Cohen AJ. Routledge. 2020.

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Conference abstracts in proceedings (selected)

Kaasgaard M, Rasmussen DB, Ottesen AL, Vuust P, Hilberg O, Bødtger U. Sing-a-Lung: Group singing as training modality in pulmonary rehabilitation for patients with Chronic Obstructive Pulmonary Disease (COPD): A multicenter, cluster-randomised, non-inferiority, controlled trial. European Respiratory Journal. 2020 Sep 9;56(Suppl 64):4663.

Moorthigari V, Carlson E, Toiviainen P, Brattico E, Alluri V. Differential Effects of Trait Empathy on Functional Network Centrality. In Mahmud M, Vassanelli S, Kaiser MS, Zhong N, editors, Brain informatics. Cham: Springer. 2020. p. 107-117. (Lecture Notes in Computer Science, Vol. 12241).

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Other

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Reybrouck M, Vuust P, Brattico E (2020). Connettività cerebrale ed esperienza estetica della musica. Nodes – Journal of Art and Neuroscience. Translation into Italian of an original article published in Brain Sciences (2018).

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OUTREACH 2020

Talks at international conferences

David Quiroga
Neuromatch conferences 3.0, USA

Elvira Brattico
Keynote, XXVI Congresso AIP Sperimentale, Italy
Center for Science and Society, Columbia University, New York, NY, USA

Henrique Fernandes
Conference of Society for the Neuroscience of Creativity, Boston, USA

Jan Stupacher
SysMus - The International Conference of Students of Systematic Musicology, York, England

Mette Kaasgaard
Nordic respiratory Science Forum, AstraZeneca Nordic-Baltic, Denmark

Morten Kringelbach
Keynote, Birch lecture, International Neuropsychological Society conference, Vienna, Austria
BIOGEN, Portugal
College du France, France
British Neuropsychiatry Association, London, UK

Niels Chr Hansen
BCEM (Brain. Cognition. Emotion. Music) Conference, Leeds, United Kingdom
SEMPRE Conference (The Society for Education, Music and Psychology Research), Leeds, United Kingdom

Peter Vuust
Research seminar at Hochschüle für Musik, Theater und Medien Hannover, Germany

Other talks (selected)

Bjørn Petersen
Aarhus Music School, Denmark

Elvira Brattico
University of Bari Aldo Moro, Italy

Leonardo Bonetti
University of Bologna, Bologna, Italy.
University of Bari Aldo Moro, Bari, Italy
The Italian section of Mensa: The International High IQ Society, Italy

Massimo Lumaca
Weekly Research Seminar Program, Graz, Austria
Cognitive Brain Research Unit, University of Helsinki, Finland

Morten Kringelbach
Edinburgh University, UK
Orchestra of The Age of Enlightenment, London, UK
Mount Sinai Hospital, New York, USA
GCBH (Greater Columbia Behavioral Health), Washington DC, USA
Tel Aviv University, Israel

Nadia Flensted Høgholt
Bedre Barsel, Denmark

Niels Christian Hansen
MUSICOVID network event, Aarhus, Denmark

Peter Vuust
Lægeforeningen, Denmark
Det Jyske Musikkonservatorium, Aarhus/Aalborg, Denmark
Ishøj Kulturskole, Denmark
Sjællands Kirkemusikskole, Denmark
Hospice Limfjord, Denmark
Aarhus Teater, Denmark
Parkinsonforeningen Midtnordjyllands kreds, Denmark
Synscenter Refsnæs, Denmark
Innovation Horsens, Denmark
ATV Jord og Grundvandskonference, Denmark
Ballerup Kommune, Denmark
Holstebro Kommune, Denmark
Egmont Højskole, Denmark
Emmaus Højskolekursus, Denmark
Korstævne i Sønderborg, Denmark
FOF, Denmark

Alexandre Celma-Miralles
Barcelona Linguistics Hub Workshop, Universitat Autonoma de Barcelona, Spain

Victor Pando-Naude
The Interdisciplinary Summer School on Cognitive Neuroscience, Department of Nuclear Medicine and PET center. AU, Denmark

Participation in TV, radio and podcasts (selected)

Elvira Brattico
Vetenskapspodden, Sverige Radio P1

Kira Vibe Jespersen
Formiddag på P4
Glorias radio

Morten Kringelbach
BBC TV Documentary 'Cats tales'
NOVA-PBS TV Documentary 'Cats tales'

Niels Christian Hansen
P4 Østjylland
P2 Klassisk Formiddag
P2 Udsigten
YLE Radio
TV2 News
Dagens Nyheter
SVT
NRC

Peter Vuust
Go' Morgen Danmark, TV2
DR Tv-Avisen
DR2 Her er dit hit
TV2 Lorry
DR Musiksommer
Danmarks Underholdningsorkesters podcast om Beethovens symfonier
P1 Morgen
P2 Stines Søndag
P3
P6 Beat
videnskab.dk-podcast
Radio 4 Dagen i dag + Kraniebrud + Kræs
Radio Loud
Østjysk Radio
Danmarks Radio Østjylland

Alexandre Celma-Miralles
Podcast Laboratory News

Interviews in printed media/web (selected)

Elvira Brattico
Wall Street International
Italian main newspaper La Repubblica

Massimo Lumaca
www.videnskab.dk

Morten Kringelbach
Finnish main newspaper Ilta Sanomat
Spanish newspaper La Vanguardia
Turkish newspaper UneDio
Politiken
Jyllands-Posten
Altinget.dk
Daily Mail
Mind Matter News
Bustle.com
Medical Xpress.com
Psychology Today.com
nplusone.ru
Inverse.com
Weekendavisen
New York Times

Niels Christian Hansen
Information
Politiken
www.nrk.no
www.altinget.dk
www.yle.fi
Science Report

Peter Vuust
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www.videnskab.dk
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Seniorbladet
Aarhus Stiftstidende
Gaffa
Elbobladet
www.altinget.dk
Science Report

Alexandre Celma-Miralles
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