FREQUENCY FOLLOWING RESPONSE WORKSHOP 2022 BARCELONA

FFR Workshop 2022

8-10 June, Barcelona, Catalonia, Spain

ABSTRACT BOOK

Welcome

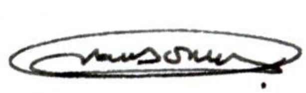
Welcome to the ***4th Frequency-Following Response Workshop*** (FFR2022). After a two-year restriction period due to the COVID-19 world-wide pandemic, we can think of no better location to celebrate this edition than in Barcelona, a warm, open and friendly city embellished by its unique architecture and exciting cultural life. It is a pleasure to host this meeting at the historic building of the University of Barcelona, the heart of the city's superior studies since 1450 A.D., to share our knowledge, learn from top level speakers, and ultimately enjoy the company, in person, of the members of this growing scientific community.

The Frequency-Following Response (FFR) is a sustained auditory evoked potential that has gained recent interest in auditory cognitive neuroscience over the past few years, as it captures, with great fidelity, the tracking accuracy of periodic sound features in the ascending auditory system. By analyzing the FFR it is possible to read neural traces from the scalp as sounds are transcribed in the neuronal aggregates and how these neural sound traces are shaped by different auditory experiences, contexts, and challenging conditions, such as listening in noise, with age and in speech and language disorders. Moreover, the number of developmental studies recording the FFR during the first years of life in healthy and clinical conditions are growing exponentially, as the FFR provides a neurophysiological correlate of language acquisition and processing.

Despite its popularity, a lot remains unknown about the FFR: what are the underlying processes involved in generating the response? What do the components making up the FFR reflect exactly? What kind of analyses are most appropriate to characterize the response? And what does inter-individual variability in the FFR signify? The aim of this workshop is to bring the FFR community together and to open up the discussion on the origins and interpretation of the response, explore new recording and analysis techniques, and discuss hot topics in this rapidly evolving field.

We would like to thank each of you for attending the FFR2022 meeting and bringing your expertise to our gathering. We look forward to seeing you in Barcelona for what promises to be a most stimulating and enjoyable event.

Sincerely,

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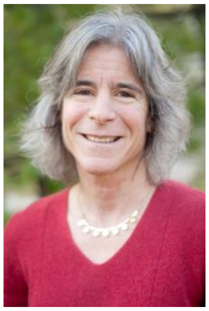

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Institutional Support

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The Institute of Neurosciences (UBneuro) was created under the premise to gather all research at the University of Barcelona that focused on a common goal: understanding the nervous system as a whole to give response to society challenges. It is a frontrunner in international neuroscience research, being one of the few institutes in the world that investigates the brain at every level. This includes research groups in neurobiology, neuropharmacology, pathophysiology, neurology, psychiatry, clinical psychology, neuropsychobiology and cognitive neurosciences. The Institute has been awarded with the María de Maeztu Excellence Unit accreditation, and gathers near to 450 researchers from the University of Barcelona.

ICREA

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ICREA, Catalan Institution for Research and Advanced Studies, is a foundation supported by the Catalan Government and guided by a Board of Trustees. ICREA was created in response to the need to seek new hiring formulas that would make it possible to compete with other research systems on a similar footing by focusing on hiring only the most talented and extraordinary scientists and academics.

Sociedad Española de Neurociencia

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The Spanish Society for Neuroscience promotes the development of knowledge and education in the field of neuroscience as well as the collaboration between worldwide homologous organizations.

Institut de Recerca Sant Joan de Déu

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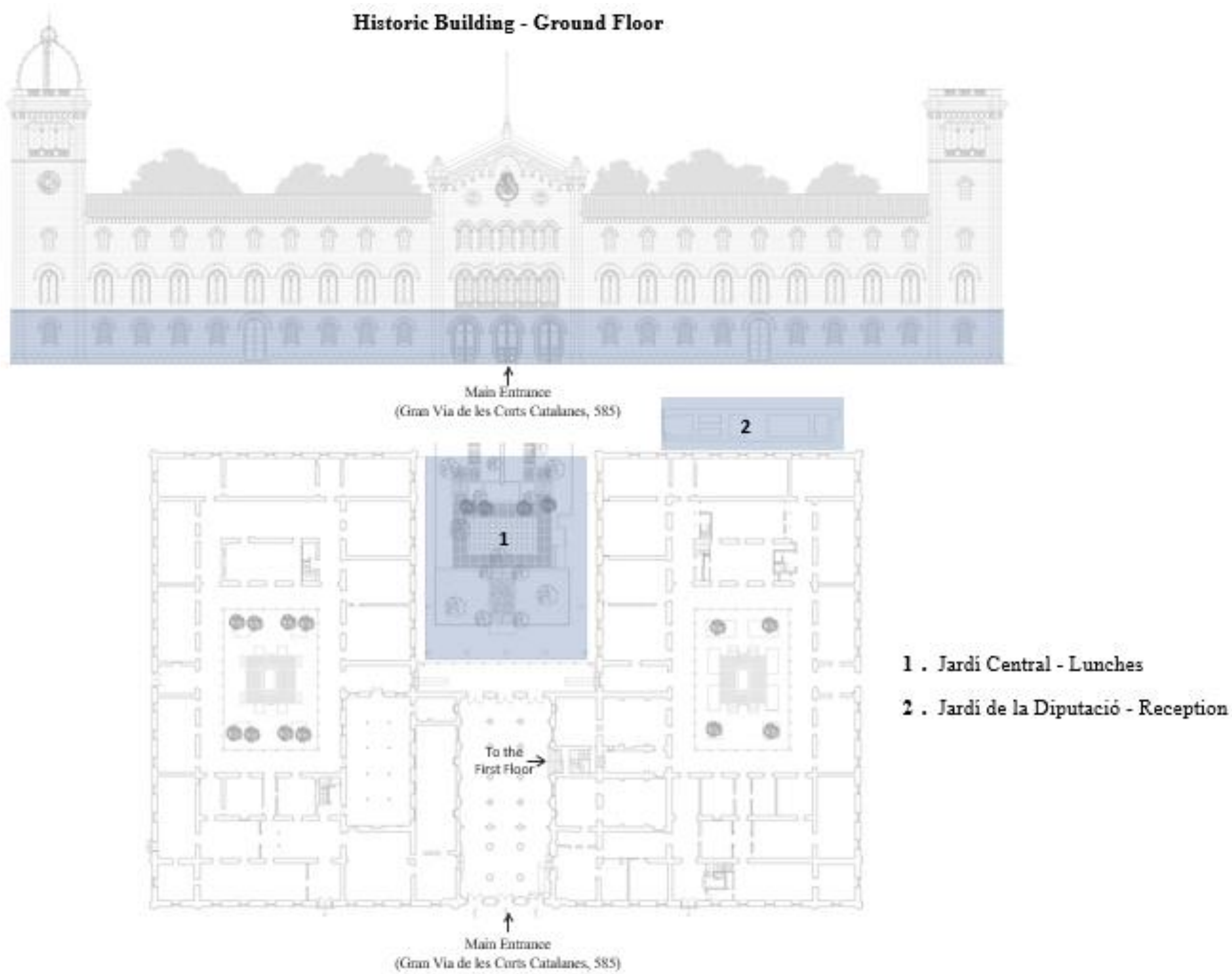
https://www.irsjd.org/en/

The Institut de Recerca Sant Joan de Déu (IRSJD) is a research and innovation center in biomedicine. The IRSJD was created in 2015 through a collaboration agreement between the SJD Barcelona Children's Hospital, the Universitat de Barcelona, the Universitat Politècnica de Catalunya, the Parc Sanitari Sant Joan de Déu and the Fundació de Recerca Sant Joan de Déu.

Practical information

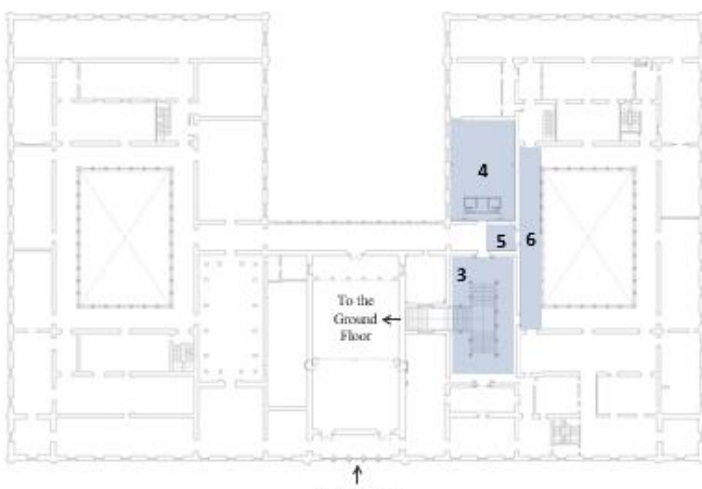
Locate yourself:

Spaces related to the workshop in the Historic Building of the University of Barcelona.



Historic Building - First Floor

Main Entrance
(Gran Via de les Corts Catalanes, 585)



Main Entrance
(Gran Via de les Corts Catalanes, 585)

3 . Escales d'Honor - Registration

4 . Aula Magna - Talks

5 . Corridor - Sponsors

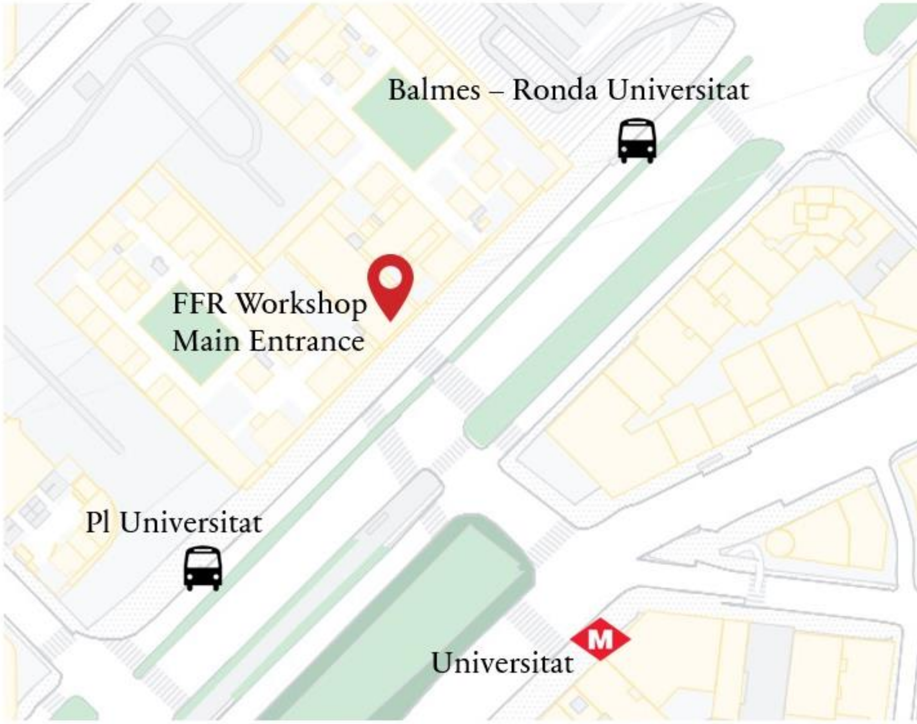
6 . Galeria del Claustre – Coffee breaks & Poster sessions

How to arrive:

Metro lines 1 and 2, stop: ***Universitat***

Bus lines **H12 “Gornal - Besòs / Verneda”** and **52 “Pl. Catalunya / Collblanc**, stop: ***Pl Universitat***

Bus line **63 “Pl. Universitat / Sant Joan Despí”**, stop: ***Balmes – Ronda Universitat***



Balmes – Ronda Universitat
FFR Workshop
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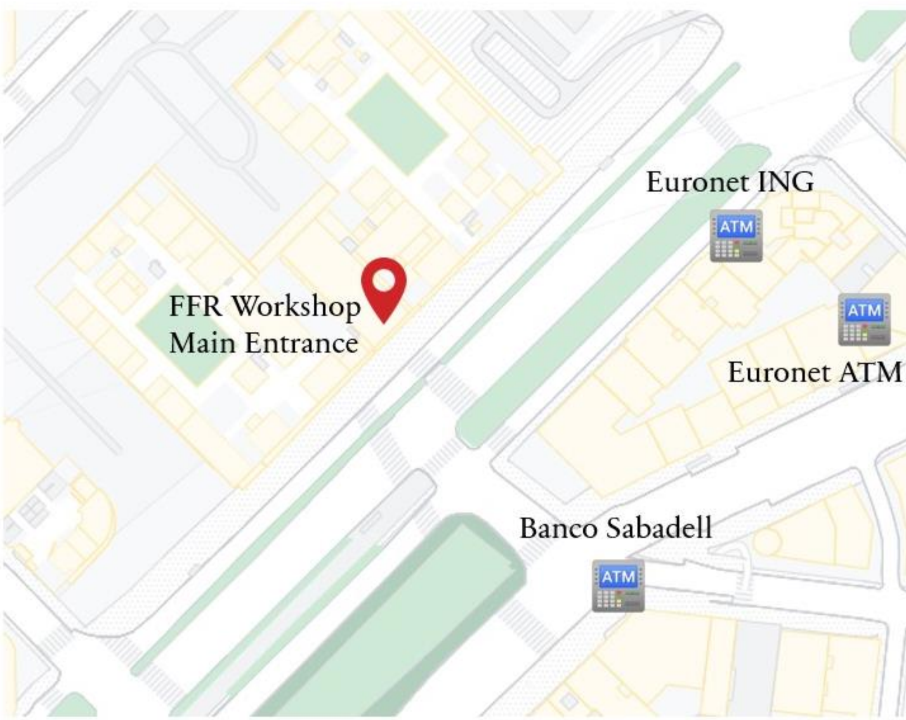
Pl Universitat
Universitat
M

Nearby ATMs:



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FFR Workshop
Main Entrance
ATM
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ATM

General information

Language

The official languages of Catalonia are Spanish and Catalan. However, Barcelona is a multicultural city where you can easily speak in English or French.

Currency

The official currency is the Euro (€). It is not common to accept other currencies in cash in Barcelona. However, you can pay easily with a credit card, and ATMs are easily found throughout the city centre, as well as at the Barcelona Airport. There is also a 'Change Money' service close to the University of Barcelona.

Shops and malls

The opening hours of shops and malls are typically 9.30 h – 21:00 h (with variations depending on the area). Although these are the regular opening hours, you can find restaurants and stores open all day in more touristy areas. Lunchtime in the city usually is between 13.30 pm and 15.30 pm and dinner between 20:00 h and 22.30 h. During the conference, lunchtime will be 13:00 to 14:00.

Useful emergency numbers

112 All emergencies

092 Local police

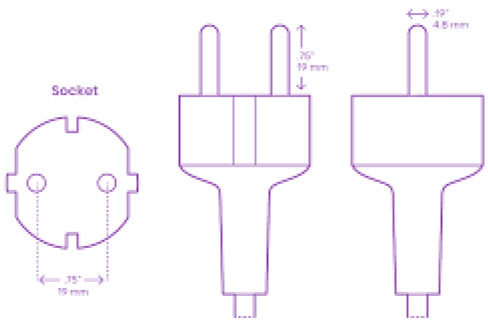
061 Medical emergencies

Security

Barcelona is no more dangerous in terms of theft than any other large European city. However, please keep an eye on your bags and wallets and never put your bag on the back of a chair, on the table in a bar, etc. Take special care in the Metro and bus.

Socket

In Spain, the standard voltage is 230 V, and the frequency is 50 Hz. The plugs and sockets are type F (see figure below). Be sure to bring a proper adaptor to plug in your electronic equipment as needed.



Health and safety

Check information about travelling to Spain to know more about requirements depending on your country of origin.

https://www.sanidad.gob.es/en/profesionales/saludPublica/ccayes/alertasActual/nCov/spth.htm

It is the responsibility of each participant to have insurance to cover expenses in case of accidents or illness. The organizers will in no case cover the cost of insurance or any costs associated with these eventualities. For medical services, Hospital Clínic is a public hospital close to the Historic Building of the University of Barcelona. Public hospitals in Barcelona are of high quality.

Getting from the airport to the city center

Participants of the FFR workshop will need to arrange their own transportation from the airport to the place they are staying in Barcelona. For all the information regarding how to reach and leave the airport, please visit: http://www.aena.es/en/barcelona-airport/public-transport.html

To get from Barcelona El Prat Airport to the city center there are basically three options: bus, metro and train or taxi.

Bus

Aerobús

AEROBÚS is the quickest option to reach Barcelona city centre, and the average trip is 30 minutes. The A1 stops outside Terminal 1 every 5–10 minutes and the A2 stops outside Terminal 2 every 10–20 minutes; they both run 5:30–00:30 and make stops at strategic points in the city like Plaça Espanya, Gran Vía, Plaça Catalunya and others. A one-way ticket costs €5.90, a round-trip ticket costs €10.20 and is valid for return within 15 days. Tickets can be bought on the bus or from vending machines in T2 and online. The AEROBÚS service is not integrated into the fare system; you will need to buy another ticket once in the city centre if you require another means of transportation to reach your final destination.

For further information, please visit: https://www.aerobusbcn.com/en

L46 and N17 Buses

These are regular bus lines. Bus 46 (Plaça Espanya – Airport) routes between the airport, both terminals T1 and T2, and Barcelona Plaça Espanya. The operating hours are from 4:50 h to 23:50 h, and the frequency varies throughout the day: they leave the airport every 15 or 30 minutes. Bus N17 (Plaça Catalunya – Airport T1) routs between terminal 1 of the airport and Barcelona Plaça Catalunya. It is a night bus that operates between 21:55 h to 4:45 h, leaving the airport every 15 minutes. You can transfer to the metro or city buses from both final stops.

They have less luggage space, make more stops along the way and don't run as frequently as the Aerobus, but unlike the Aerobus, they are integrated into the fare system and, therefore, you can use the a TMB travel card which can make the trip much less expensive. A single ride costs €2.40, but there are also integrated tickets for 10-trips (T-Casual) or the Hola Barcelona Travel Card. You can buy both single tickets and TMB travel card from ticket vending machines. Travel cards are integrated and can be used on the metro, buses, tram and short- distance train journeys.

For further information, please visit: https://www.tmb.cat/en/barcelona/buses/-/lineabus/46

Metro and train

Metro

Metro line L9 Sud connects the airport terminals T1 and T2 with the city of Barcelona every 7 minutes. The journey takes you 32 minutes and operates every day from Monday to Thursday (5:00 h to midnight), Fridays and eves of public holidays (5:00 am to 2:00 am), non-stop on Saturdays and from 5:00 h until midnight on Sunday. An airport ticket to Barcelona city centre costs 4,60 €. The Airport Metro station is not integrated into the fare system; you will need to buy another ticket once in the city centre if you require another means of transportation to reach your final destination.

For further information, please visit: https://www.barcelona-airport.com/eng/barcelona-airportmetro.php

Train

RENFE is the Spanish train company and the train station is located across the road from Terminal 2B (T2B); take the escalators towards departures then follow the Renfe signs. The station is located at the bottom of the escalators on the other side of the road. There are ticket vending machines before you get on the train. The train stops at Sants Estació and Passeig de Gràcia, from where you can transfer to the metro or city buses. Travel cards can be purchased at the vending machines in the station; a single ride costs €5.15. Travel cards are integrated and can be used on the metro, buses, tram and short- distance train journeys.

Taxi

Barcelona taxis are distinctively black and yellow and have a green light on the roof, which is lit when the taxi is available. There are various taxi stands at each of the terminals so waiting in line is minimized; there are usually many taxis and lines move quickly. Flagging down a taxi is not permitted at the airport. In addition to the regular fare, there is an airport surcharge as well as an extra charge for luggage. This information is posted inside the taxi on the back window. The total fare, surcharges included will show up on the meter. The price is around 35€, and it takes 20 minutes to reach Universitat de Barcelona in the city centre.

Getting around Barcelona

Walking: Barcelona is perfect and well prepared for walking, and it is the best way to visit the centre: The Old Town, streets in the Gothic Quarter, Barceloneta and the beach, the Palau de la Musica Catalana, La Sagrada Familia, Casa Batlló, La Pedrera, El Born district and La Ciutadella Parc.

Buses and Metro: the Metro is the best and fastest way to move around. You can buy a 24h unlimited ticket, T-DAY (ten trips for 10,50€) or a single ticket (2,40€) that you can buy on the bus or in the metro, with your credit card or cash. All metro tickets can be combined with the bus and train network. See Barcelona public transportation website for detailed information (https://www.tmb.cat/en/barcelona-transport).

Tour Bus: For more general sightseeing, we recommend the Tour Bus, which has two different routes and visits all the highlights of Barcelona.

Taxi: Otherwise, taxis are easy to find throughout the city. Other companies such as Cabify or Freenow are also available in the city through their telephone apps.

For detailed information about routes, visits, tickets, etc. visit the Consortium of Tourism website (https://www.barcelonaturisme.com/wv3/en/).

Best Poster Award

The MIT Press sponsors a Best Poster Award and $200 in their book will be awarded to the best poster presented at the Workshop by a MSc/PhD student or young postdoc (less than three years after the PhD degree). An individual message will be sent to all authors submitting a poster to confirm eligibility and willingness to participate.

A panel of FFR experts will evaluate those participants' posters that meet the requirements described and have expressed their desire to participate via email. During the Closing remarks section, the winner will be announced and awarded with the MIT press prize.

Abstracts

Keynote lectures

Keynote lecture 1

The multilayered FFR: Insights from studies of bilingual populations

Erika Skoe[1]

[1]University of Connecticut, Department of Speech, Language, and Hearing Sciences, Institute for the Brain and Cognitive Sciences

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Over the last 20 years, the frequency-following response (FFR) has provided a window into experience-dependent reorganization of the adult and developing brain, relating to human communication. The simplicity of the FFR recording paradigm – in particular the ability to record FFRs to stimulus trains with few electrodes and under passive listening conditions – has increased the popularity of the approach. Recent work, however, is moving away from recording FFRs to single sound trains, towards paradigms with more naturalistic elements and contextual richness. While videos are a common approach to distract and calm the participant during the recording of the FFR — especially for paradigms involving children or when the recording session is long — the video's influence has not been systematically investigated. This talk will take as its centerpiece my group's recent investigation into whether the language of the movie has as a modulatory effect on the FFR. FFRs were recorded to repeating speech syllables that played while monolingual English speakers and Spanish-English bilingual speakers watched cartoons in English and Spanish. Findings have increased our understanding of the real-time, top-down operations that act upon the FFR and the multifaceted influence of language experience on the FFR. This work will serve as a foundation for a more general discussion of the origins and modulatory influences of the FFR, what studies of bilinguals can reveal about the multi-task nature of auditory processing, and the untapped opportunities for using the FFR to studying the many layered archeology of the human listening experience.

Keynote lecture 2

Frequency-Following Responses to Speech: Neural Sources and Modulatory Influences

Bharath Chandrasekaran[1]

[1]*Department of Communication Sciences and Disorders, University of Pittsburgh, USA.*

The frequency-following responses (FFRs) are electrophysiological ‘neurophonic’ potentials that reflects phase-locked activity from neural ensembles across the auditory system. FFRs provide an objective, non-invasive, and easy-to-record snapshot of the integrity of supra-threshold speech processing. Despite the clear translational promise as a biomarker, FFRs are not a part of typical diagnostic batteries in clinics. Critical barriers to effective translation include a poor characterization of the underlying sources of the scalp-recorded FFRs as well as how these sources are modulated by context, attention, arousal, and experience-dependent plasticity.

In this presentation, I will discuss a cross-level, cross-species, systems neuroscience-focused research program that aims to overcome these critical barriers to effective translation. Using machine learning and novel analytic approaches, we demonstrate that the FFRs are continuously modulated by ongoing stimulus statistics and predictability, are sensitive to short-term sound-to-category auditory training, and are continuously modulated by attentional and arousal systems. To provide a mechanistic understanding of the sources and modulatory influence on the FFRs, we turn to intracranial recordings from humans, macaques, and guinea pigs. Our results suggest the need to revise theories and models of human subcortical auditory processing and plasticity with a more careful characterization of the underlying sources of the scalp-recorded FFR.

Keynote lecture 3

Teaching an old dog new tricks: New innovations in the frequency-following response (FFR) to characterize online changes in brainstem-cortical function necessary for robust speech perception

Gavin Bidelman[1,2]

[1]Department of Speech, Language and Hearing Sciences, Indiana University, USA .[2]University of Memphis, School of Communication Sciences and Disorders, USA.

Speech perception demands precise neural coding between brainstem and cortical levels of hearing. In animal models, brainstem-cortical interplay is achieved via descending corticofugal projections from cortex that shape midbrain responses to behaviorally-relevant sounds. Attentional engagement of corticofugal feedback may assist human speech perception but has never been confirmed and remains highly controversial in humans. In this talk, I will review our recent innovations to frequency-following response (FFR) paradigms which have allowed us to reinvigorate old controversies on attentional modulation of brainstem activity, subcortical-cortical communication, and the source origins of speech-evoked FFRs in humans. In a series of studies, we are probing these questions by recording source-resolved neural activity simultaneously from brainstem (BS) and primary auditory cortex (PAC) via high-density EEG during demanding speech-listening tasks and in various populations of listeners. The approach has enabled us to (i) track how normal and pathological hearing alter auditory processing and the transmission of speech information across the BS-PAC neuraxis, (ii) establish novel assays of corticofugal efferent system function in human audition, and (iii) unequivocally demonstrate attention actively modulates auditory brainstem processing during speech perception. Our findings underscore the importance of assessing connectivity (i.e., neural transmission) in understanding the brain basis of hearing and its deficits and pave the way for new avenues of assessing biological factors that govern real-world listening skills across the lifespan.

Oral Communications

Talk 1

A Multidisciplinary Review of Frequency Following Response Analysis with Machine Learning Decoding Models

Arseneau-Bruneau, I.[1,2,3,4,5], Core L.[1,2] , Chen, E.[1,2], Llanos F.[6], R. J. Zatorre[1,2,3,4,5]

[1]McGill University, Canada. [2]Montreal Neurological Institute, Canada. [3]Centre for Research on Brain, Language and Music (CRBLM). [4]Laboratory for Brain, Music and Sound Research (BRAMS). [5]Centre for Interdisciplinary Research in Music Media and Technology (CIRMMT). [6]University of Texas at Austin, USA.

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A decade has passed since the first demonstrations of machine learning (ML) analysis applied to the frequency following response (FFR), and nearly two dozen publications now exploit these data-driven approaches. Decoding models, such as when a classifier predicts a stimulus or a condition from an FFR input, are increasingly popular. However, optimizing ML parameters is not always straightforward and remains highly dependent on the research question and model choice. Further, important FFR mechanisms have recently been redefined (cortical contributions, entrainment) and highly impact the interpretation of previous and novel findings. Thus, technical expertise is required, while FFR applications are more diversified than ever; such multidisciplinary knowledge may not be accessible to all. Indeed, papers that provide a rationale that links algorithm parameters and research questions are rarer and may be limited by the space constraints of journals. Hence, we provide a scoping review across FFR fields that surveys the application of ML decoding models. Our aim was to identify the extent of the current applications, recommended ML practices, and interpretations considerations in light of recent FFR fundamentals. Overall, we examined FFR publications in relation to classifier guidelines for EEG (Lotte et al. 2007; 2018; Combrisson et al., 2015; Holdgraf et al. 2017) and highlighted key questions for young researchers considering the specificities of the FFR. Finally, we identify guiding principles and reunite resources that bridge technical and auditory neural fields. Such a multidisciplinary scoping review will help knowledge transmission across FFR disciplines and contribute to more reproducible practices.

Acknowledgements / Funding

IAB is supported by the Fonds Quebecois de Recherche en Santé, the Centre for Research on the Brain, Language and Music, the Center for Interdisciplinary Research in Music, Media, and technology. LC's work was supported by an undergraduate award from the Natural Science and Engineering Research Council of Canada (NSERC-CREATE : Complex Dynamics of Brain and Behaviors). RJZ is a fellow of the Canadian Institute for Advanced Research and is also supported by a grant from the Canadian Institute for Health Research.

Talk 2

Contribution of primary auditory cortex to scalp-recorded envelope following responses in the macaque monkey

Teichert, T.[1,2]

[1]Department of Psychiatry, University of Pittsburgh , Pittsburgh, USA. [2]Department of Bioengineering, University of Pittsburgh , Pittsburgh, USA.

The envelope-following response (FFR_{ENV}) is a scalp-recorded electrophysiological potential that closely follows the periodicity of complex sounds such as speech. The exact neural origin(s) of FFR_{ENV} is(are) still a matter of debate. Initially thought to reflect mostly activity from the cochlear nucleus and inferior colliculus, current thinking envisions multiple sources in brainstem, midbrain and cortex. In line with this assumption, we could recently show that the responses to individual F0 cycles of the stimulus (F0-responses) feature several spectro-temporally and topographically distinct components that likely reflect the sequential activation of brainstem (<5ms; 200-1000 Hz), midbrain (5-15 ms; 100-250 Hz) and cortex (15-35 ms; ~90 Hz). To confirm the cortical origin of the 90Hz component and to study more closely the properties of cortical FFR_{ENV}, we recorded local field potentials in primary auditory cortex (A1) of three macaque monkeys using either large arrays of individually movable semi-chronically implanted electrodes that covered the entire tonotopic map of A1 or laminar probes that covered the entire cortical depth of individual cortical columns. Our preliminary results clearly confirm the cortical origin of the 90Hz component. Furthermore, we were able to quantify to what degree the reduced contribution of cortex to scalp-recorded FFRs at higher frequencies (above ~100 Hz) are caused by i) an inability of cortical neurons to follow higher frequencies, ii) destructive temporal superposition of F0 responses from adjacent F0 cycles, or iii) destructive spatial superposition of F0 responses from different tonotopic parts of A1.

Talk 3

Individual differences in frequency-dependent fluctuations in the FFR amplitude

Tonelli, L.C.[1], Tichko, P.[2], Skoe E.[1]

[1]Department of Speech, Language, and Hearing Sciences, University of Connecticut, United States, Storrs, CT 06269-1085. [2]Department of Music, Northeastern University, Boston, MA 02115, USA.

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The auditory frequency-following response (FFR) is a scalp-recorded, evoked potential that reflects the spectrotemporal properties of tonal stimuli. The FFR's spectral amplitude fluctuates according to the stimulus frequency, a phenomenon thought to reflect multiple cortical and subcortical generators phase-locking to the stimulus with different response latencies. When these volume-conducted signals are recorded, interference patterns emerge in the FFR: The FFR is amplified when the volume-conducted signals are in phase and attenuated when out of phase. The phase-interference patterns are frequency-specific and produce "FFR fine-structure", the waxing and waning of FFR amplitude as a function of stimulus frequency. Here, our goal was to study individual differences in frequency-dependent fluctuations in the FFR amplitude. FFRs were recorded to 13 different tonal frequencies (29 Hz – 293 Hz) in 43 healthy young adults. As predicted, the magnitude of the FFR varied systematically in all participants, as a function of stimulus frequency. FFR maxima emerged at ~43, 51, 87, and 207 Hz, and valleys emerged at ~29, 61, 110, and 293 Hz. Individual variation was also observed: roughly half of the participants showed a global maximum at 43 Hz and the other half at 51 Hz. For a possible biological explanation, we employed a theoretical model of the FFR including six putative generators. Collectively, our findings reinforce that for any given stimulus frequency, the FFR represents neural activity from multiple generators, and highlight how individual differences at one generator could alter FFR fine-structure patterns. Currently, we are exploring how language experience can affect the FFR.

Acknowledgements / Funding

This research was funded by the National Science Foundation (NSF) and by research startup provided by the University of Connecticut.

Talk 4

Frequency-following response is altered by brain state but not by sleep events

Jourde, H.R.[1,2,3], Merlo, R.[1,6], Greenlaw, K.[1,2,3], Coffey, E.[1,2,3,4,5]

[1]Concordia University, Canada. [2]Centre for Research on Brain, Language and Music (CRBLM). [3]Laboratory for Brain, Music and Sound Research (BRAMS). [4]McGill University, Canada. [5]Montreal Neurological Institute, Canada. [6]Université de Montréal, Canada.
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The sleeping brain is less sensitive than the alert brain to external stimuli, and evoked auditory responses vary in amplitude across sleep and wake states (Colrain & Campbell, 2007). Recent work suggested that the frequency-following response (FFR) amplitude also differs according to alertness, as indexed by the number of oscillatory events called sleep spindles (11-16Hz) (Mai et al. 2019). Sleep spindle density correlates with individual resistance to arousal by stimuli (Schabus et al., 2012), and it has been proposed that either spindles themselves (Mai et al. 2019) or neural refractory periods following spindles protect sleep-dependent memory processes against interference (Antony et al. 2018). To explore the effect of sleep on the FFR, we obtained MEG/EEG recordings during a 3-hour nap from 15 subjects who received binaural auditory stimulation (i.e. /da/ syllable) at 55dB SPL, and analyzed FFR amplitudes form brainstem, thalamic, and cortical sources (Coffey et al, 2019). We observed differences in frequency encoding across sleep stage in cortical - but not subcortical - structures. Notably, neither sleep spindles nor their refractory periods seem to impact FFR amplitude, suggesting that brain state rather than specific sleep events influences fine sound processing. By exploring the FFRs along sleep stages and during sleep events, we add a characterization of the impact of brain states on early sound processing to existing knowledge about the impact of brain state on slower evoked responses.

Acknowledgements / Funding

We thank Marc Lalancette, Sylvain Baillet and Robert Zatorre for support, Meredith Rowe, and Zatorre Lab trainees for assistance with data collection. This work was supported by Awards to HRJ from the Center for Research on the Brain, Language and Music (CRBLM). EBJC is supported by grants from the Natural Sciences and Engineering Research Council of Canada (NSERC) and Fonds Quebecois de Recherche en Nature et Technologies (FRQNT).

Talk 5

Frequency following response deficits in infants with hyperbilirubinemia: A model for diagnostic utility of the FFR

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Early Detection of Hearing Impairment (EDHI) programs have been highly successful in diagnosing hearing loss in infants and young children, allowing thousands of children to receive treatment at earlier ages. Detection of hearing loss in neonates and children who cannot reliably respond behaviorally is widely accomplished through the use of the Auditory Brainstem Response (ABR). While the ABR provides excellent information about hearing acuity, it is far less sensitive to suprathreshold deficits in neural encoding than other electrophysiologic measures, such as the frequency-following response (FFR). The ability to identify such deficits is crucial because they have been purported to influence language development and understanding speech in noise. Consistent with this view, low-amplitude FFRs are associated with language impairment and other developmental delays, while high-amplitude FFRs are observed in groups with expert auditory experience such as professional musicians and tonal language speakers.

Emerging work from several laboratories suggests that the FFR can be used in infants to detect suprathreshold developmental differences beyond the click-evoked ABR. In this talk we will review the recent data in this area demonstrating the associations between the FFR and developmental differences. We will also describe our recent work demonstrating a reversible effect of bilirubin on the FFR in neonates held in the neonatal intensive care unit (NICU). These data raise the possibility that suprathreshold deficits associated with other neonatal risk factors such as prematurity, hypoxia and cytomegalovirus may also be detected with the FFR. We also present preliminary data on follow-up measures of behavior in children with low FFR amplitude at birth and validation of a signal called a ‘click plus’ which can allow both ABR and FFR responses to be recorded simultaneously. Such work provides an important step to increase the feasibility of clinical recording of FFR, thereby allowing diagnost utility of suprathreshold measures to be widely assessed in neonates and young children.

Talk 6

Detection of abnormal neural encoding of speech sounds at birth using the frequency-following response

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Neonates born with an unexpected birth weight are at high risk of short- and long-term complications. These newborns appear at each end of the birth weight Gaussian distribution and are known as neonates born small-for-gestational age (SGA) or affected by fetal growth restriction (FGR) and neonates born large-for-gestational age (LGA). Since the prevalence is approximately 9% for each group (SGA/FGR and LGA), international health organizations claim the need to improve objective tools to early detect those cases at greatest health risk. Therefore, to contribute to this goal, we explored whether essential language skills such as voice tracking at birth would be affected by altered fetal growth through with an auditory evoked potential called frequency-following response (FFR), which reproduces with great fidelity the spectro-temporal features of the complex auditory stimulus such as speech. Our findings revealed a lower SNR in FGR neonates compared to the AGA group in the absence of spectral amplitude differences. For this study, we suggested that underlying defective myelinization may have impacted their neural phase looking capabilities. However, in the LGA neonates we observed also a lower SNR but accompanied by attenuated spectral amplitude compared to the control group. Here we suggested the underlying pathophysiology may be related to the high adipose tissue in the LGA neonates which, via pro-inflammatory products, which could compromise the strength of the stimulus F0 encoding. We concluded that different clinical conditions, based on distinct underlying pathophysiology, could affect in a different manner the FFR and, consequently, yield differential results regarding the spectral amplitude and the SNR parameters.

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Talk 7

Selective brain response to voices at four months of age

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Several studies have demonstrated the existence of voice preferring regions in the adult human brain- the "temporal voice areas" (TVAs). Yet, how early in development a selective categorical response to voice is observed remains poorly understood. We investigate voice categorization in the 4-month-old infant brain relying on a Fast Periodic Auditory Stimulation (FPAS) paradigm combined with scalp electroencephalography (EEG). This approach provides an objective marker of the brain's automatic ability to categorize vocal information with a high signal-to-noise ratio within a short testing duration. Infants listened to a stream of heterogeneous sounds presented at 3.33 Hz to elicit a brain response at the same frequency in the EEG amplitude spectrum. Importantly, sequences were created so that voice stimuli appeared at 1.11 Hz. This voice presentation rate elicits an additional response in the EEG spectrum only if the brain discriminates voices from other sounds and generalizes them across heterogeneous exemplars. Results show a voice-selective neural response at 1.11 Hz over the temporal electrodes. Critically, the response is reduced when infants listened to a scrambled version of the stimuli with disrupted intelligibility but identical spectral content. These results suggest that the infant brain successfully discriminates vocal stimuli versus non-vocal stimuli and generalizes them across many exemplars, recognizing the voice excerpts as items of the same category. As the voice response is not explained by the spectral content of voice stimuli alone, this study provides evidence of high-level voice categorization as early as 4 months of age.

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Talk 8

Neural plasticity induced by music begins before birth: evidence from neonatal frequency-following responses

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It is known that fetal hearing experiences modify auditory, linguistic and musical preference of newborns from the very first moment of birth. Thus, neonates prefer their native language, recognize their mother's voice and show greater responsiveness to lullabies presented during pregnancy. Yet the neural underpinnings of this experience inducing plasticity have remained elusive. Here the frequency-following response (FFR), an auditory evoked potential elicited to complex sounds, was used to show that prenatal music exposure enhances the neural encoding of the stimulus pitch along the auditory hierarchy at birth. FFRs were recorded in a sample of 60 healthy term neonates during their first days of life, divided into two groups according to their musical exposure reported by their mothers through a questionnaire (29 high-musically exposed; 31 low-musically exposed). The FFR was recorded to either a /da/ or an /oa/ stimulus, analyzed in averaged polarities during a section in both stimuli identical in duration (113 ms) and fundamental frequency (F0 = 113 Hz), and quantified as the spectral amplitude to the stimulus F0. Data revealed that neonates exposed daily to music exhibited larger spectral amplitude at F0 as compared to the low-exposed group, observing this effect across stimuli. Results indicate that musical exposure during last trimester of pregnancy enhance the encoding of low-frequency components, such as those typical of the fundamental frequency of the human speech, suggesting that prenatal music exposure modulate the tuning to human speech in support of early language processing and acquisition.

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Talk 9

Musical and linguistic implications of the modulatory role of the SLC6A4 and DRD4 genes on subcortical pitch encoding

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The frequency-following response (FFR) has been systematically used to study neural encoding of sounds for its tracking properties of the incoming stimuli and because it is highly sensitive to environmental factors and interindividual experiences. It is also known from twin studies that pitch perception and auditory skills are genetically influenced, but the actual genes regulating neural encoding of sounds remain largely elusive, especially at subcortical stages. We previously showed that genetic variants in the serotonin transporter (SLC6A4) gene modulated the FFR response to speech stimuli, but the functional relevance of this association and potential interactions with other intervening genes are still unknown. Here we analyze the influence that genetic variants in the SLC6A4 and dopamine D4 receptor (DRD4) genes exert on FFR assessments of pitch extraction and explore the functional implications of the observed associations on audiological, phonological and musical skills.

To do so, we characterized EEG responses to an /oa/ syllable presented binaurally 3000 times in 130 young healthy participants. For the fundamental frequency of the stimulus, total amplitude, SNR, neural lag, cross-correlation, pitch strength and pitch error measurements were extracted. Performance of participants in different musical, linguistic and audiological domains was assessed through different behavioral tests. Genotypes for the VNTR polymorphisms in the SLC6A4 and DRD4 genes were obtained from DNA extracted from saliva samples.

Potential associations between these genes and electrophysiological and behavioral assessments of pitch extraction will provide us with relevant keys of the molecular and cellular pathways that shape the neural networks involved in sound processing.

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Talk 10

Auditory brainstem response evoked by speech sound as a predictor of behavioural performance in children with Auditory Processing Disorders, a pilot study

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Objectives: Auditory processing disorders (APD) are clinically identified using behavioral tests which require the individual to remain attentive and cooperative for relatively long periods of time. However, changes in attention and motivation can easily affect accurate identification. This study aimed to investigate if auditory brainstem response evoked by speech sound (speech evoked ABR) could be considered as a complementary measure to identify children with APD.

Methods: Both speech evoked ABR and behavioral tests were collected in ten APD school-aged children (8.06 years) and compared to ten age-matched typically developing (TD) children (9 years). Speech-evoked ABR was elicited using the five-formant syllable /da/. Central auditory processing capacities such as binaural integration, temporal resolution, sequential auditory organization, and signal/background separation were investigated using the behavioral tests.

Results: The preliminary analysis demonstrated that children with APD had lower behavioral tests performances compared to children without APD. Moreover, longer latency and/or smaller amplitude had observed in some children with APD compared to their normal peers. Some behavioral tests such as sequential auditory organization showed a significant correlation with the amplitude and/or the latency of speech evoked ABR waves.

Conclusion: Behavioural and electrophysiological evaluation would provide complementary information for the identification of APD in children. Some of speech evoked ABR waves could be considered as a predictor of behavioural test performance in children with APD. Findings could be an interest to the Audiologists and lead to earlier identification and intervention. However, the results should be interpreted with caution due to the low sample size.

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Talk 11

Pitch tracking measurements: Exploring the most informative predictor for musical, phonological and audiological skills

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Introduction. The Frequency-Following Response (FFR) is a neurophysiological response widely studied to assess the pitch tracking accuracy of the auditory system. The FFR has been proposed as a potential biomarker for literacy problems and alterations in FFR have been associated with problems in phonological awareness, reading difficulties and dyslexia. However, a systematic assessment of which FFR parameters are most informative of different cognitive abilities has not been conducted. **Methods**. One hundred and thirty young healthy adults were recruited. Neural responses were recorded in response to a novel two-vowel /oa/ syllable, with a rising pitch ending, in two different background conditions: In quiet and in noise. In addition, four behavioral tests were applied to assess musical, audiological and phonological skills. **Results**. Different pitch parameters were extracted and associated with the performance in our four behavioral tasks. Among them, Pitch strength and Pitch error were the most informative measurements and were significantly correlated with performance in speech-in- noise tasks, specifically in low predictability conditions, in phonological tasks (Word and PseudoWords reading skills) and in musical abilities, both globally and in the tuning, accent, tempo and pitch sub-areas. **Conclusion**. Among different FFR parameters, two pitch tracking measures were observed to be most informative since were consistently associated with performance in most of behavioral tests used. They can be considered good biomarkers of auditory processing, but also reliable predictors of performance in musical, audiological and phonological tasks.

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Talk 12

Peripheral frequency following responses in young and older participants using electrocochleography

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Previous studies showed that frequency following responses (FFR) to tonal stimuli decline with increasing age, even in listeners with clinically-normal audiometric thresholds. This has been attributed to an age-dependent reduction of neural synchrony in the central auditory system. However, our recent work suggested that an age-dependent degeneration of auditory nerve (AN) fibres could be the main cause of the reduced FFR with age. Here, we recorded simultaneously brainstem potentials (using a traditional vertex-to-ipsilateral mastoid setup) and electrocochleographic responses (using a tympanic membrane electrode). Fifteen young and fifteen older subjects participated in the study. All listeners had pure-tone thresholds better than 25 dB HL up to 6 kHz. FFRs to 10-ms long pure-tone bursts were recorded at frequencies of 516, 1032 and 3096 Hz, presented at 100 ppSPL. In addition, responses to 100-µs clicks presented at 115.5 ppSPL were recorded with the same electrode montages. The results show a trend of a reduced peripheral FFR amplitude in the older listeners. The click-evoked responses representing the AN compound action potential also indicate a reduced amplitude in the older listeners. The magnitude of the pre-synaptic cochlear microphonic was estimated from the results to the 3 kHz tone-burst, at which the AN responds minimally. Overall, the results indicate that the peripheral FFR may be a potential biomarker of AN degeneration.

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Talk 13

Rapid Responses to Auditory Frequency Change, Its Magnitude and Direction – from Brain Processing to Action

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Auditory frequency change [FC] may convey to perceivers potentially crucial environmental cues. Indeed, short-latency behavioral responses to FC have been documented in animals and humans. Our research-line explores swift effects of FC and its parameters on human motor action and seeks insight on where this auditory information may be relayed into motor commands. In the present study we employed an intensely demanding FC-detection RT task, monitoring simultaneously behavior (RT, kinematics, EMG) and brain activity (EEG, ABR-EEG; analyzing ERPs from brainstem up to N100, plus FFR). 32 musicians heard sequences of rapid single-frequency pure-tone beeps (beep-rate: 8 Hz, jittered). FCs, of manipulated magnitude and direction, were presented (FC rate: 1 Hz, jittered; seven frequencies). RTs were rapid (203 ms), muscle-work onset was detected already 70 ms post trial-onset. Both showed FC magnitude and direction effects: Bigger steps and melodic fall yielded earlier action. Brain activity decoded FC and its parameters already at brainstem and through the following components. FFR was analyzed (as pairwise phase-consistency) at mid-tone (530.5 Hz), comparing new-frequency beeps [NFb] vs 'filler' beeps [FLb]. At NFb, FFR peaked after Wave V, followed by a lesser plateau, whereas at FLb 1-2 robust FFR persisted through beep duration, lingering into an after-effect. FLb 3-5 exhibited adaptation. TF mapping showed 'honing in' into the frequency, and an after-effect following the tone. A major disadvantage of BioSemi's equipment was revealed. FC detection early up the auditory pathways – at A1 level, or even sub-cortically – was shown to be relayed into ultra-early action responses.

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To clarify affiliation of first/presenting author: Research was done as part of Boasson's doctoral studies at the Department of Musicology at the Hebrew University of Jerusalem [HUJI]. Boasson's last affiliation was at the Edmond and Lily Safra Center for Brain Sciences [ELSC] at HUJI, as Post-Doc at the Psychology lab of Prof. M. Ahissar. Presently Boasson is not affiliated.

Talk 14

The brain automatically categorizes discrete auditory emotion expressions

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Emotion expressions delivered through voices, in absence of verbal cues, are vital information for interpersonal communication. How the brain discriminates separate emotions delivered through voices however remains poorly understood. To fill this knowledge gap, we rely on electroencephalographic (EEG) recordings in humans combined with a frequency tagging approach to tag neural responses to certain emotion expressions. We selected five "primary" emotion categories (Anger, Fear, Disgust, Happiness, Sadness) vocalized by professional actors and actresses. We then implemented a fast periodic oddball auditory paradigm to investigate how the brain is able to automatically discriminate a target emotion category compared to other emotional categories (eg fear vs others; happy vs others), as well as generalize across different exemplars of the target emotion category i.e. fear or happy displayed by various actors in different styles and intensities. Participants were presented streams of non-verbal emotional sounds where the target emotion repeated periodically amongst other distractor emotional stimuli. To avoid evoking responses caused by differences in acoustic features, the stimuli were matched for harmonicity to noise, center of gravity, pitch and envelope. Additionally, we performed the "scrambling" of the stimuli which preserved the frequency content of the stimuli, but disrupted its intelligibility. Preliminary results suggest that the fast periodic oddball auditory paradigm is a promising indicator of the brain's ability to categorize non-verbal vocal emotion expressions objectively (behavior-free), rapidly (within few minutes of recording times) and robustly (high signal to noise ratio), making our technique particularly suited for testing infants or clinical populations with auditory deficits.

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Talwar, S- Cooperation Action Interantional (CAI).

Workshop / Quiz

Analyzing the FFR

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The frequency-following response, or FFR, is a neurophysiological response to sound that reflects processing of discrete sound features and ongoing neural dynamics. Because of its granularity, the FFR can be used to study the integrity and malleability of neural encoding of sound across the lifespan. It can index the adverse effects of linguistic deprivation, autism, concussion, and reading impairment, and can reflect the benefits of enrichment from short-term training, bilingualism, and musicianship. Given this vast potential, interest in the FFR has grown tremendously over the past decade. Yet, there remains a gap in the knowledge of its rich analytical potential. This talk explores the analysis strategies we have employed in studying the FFR, including ways to analyze FFR timing (peaks, autocorrelation, phase consistency, cross-phaseogram), magnitude (RMS, SNR, FFT), and fidelity (stimulus-response correlations, response-to-response correlations and response consistency)[1]. Using and refining FFR analysis techniques will further our understanding of how the brain reconstructs our sonic world.

[1]Krizman J, Kraus N (2019) Analyzing the FFR: A tutorial for decoding the richness of auditory function. *Hearing Research*. 382: 107779

Roundtable

Chair

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Poster Presentations

Authors sorted by alphabetical order

Poster 1

The Influence of Sensory-Motor and Predictability Mechanisms on the Frequency Following Response

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This study aims to better understand improvements in auditory perception related to music training by investigating mechanisms that may enhance the frequency following response (FFR). Since stronger associations between the auditory and motor systems of musicians could reinforce the neural representation of sounds when they result from an action such as playing an instrument (Zatorre et al. 2007), we aim to compare the FFR generated by sounds actively played on an instrument to FFRs to the same tones perceived passively. The FFRs were recorded on the scalp with electroencephalography [EEG] to provide a measure of the quality of the neural representation of the frequency encoding of musical tones. Our protocol compares the FFRs of highly trained pianists and non-musicians while they play on a digital organ, and while they hear the same sounds passively (2x2 Design), with the prediction that active conditions will result in enhancement of the neural encoding, and that the effects will be more enhanced in musicians due to top-down predictability mechanisms. The analysis involves traditional FFR procedures including amplitude and frequency tracking, as well as machine learning approaches indicated for EEG signals. The research will inform models of sensory-motor integration and predictive coding, revealing how the auditory system functions in an integrated manner with other systems rather than as a purely sensory modality.

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Poster 2

The FFR in Brazilian Portuguese Newborns, Toddlers and Adults: preliminary results of cross-sectional study

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Introduction: Frequency-following response (FFR) studies can guide understanding of auditory pathways' maturation. Objective: To compare the FFR to /da/ stimulus between newborns, toddlers and adults, recording both ears. **Method:** Ongoing cross-sectional study with 32 normal hearing and healthy subjects, without hearing risk factors, with Brazilian Portuguese as exclusively mother language: G1 (13 adults,26.6±4.27 years old), G2 (10 toddlers, 25.0±3.20 months) and G3 (9 newborns, 38.9±9.26 days of live). A 170 ms consonant-vowel stimulus /da/ was presented at an intensity of 80dBnHL in the right and after the left ear and 4,000 artifact-free neural responses in blocks of 1000 were collected. FFR analysis was performed in the temporal and spectral domains. **Results:** In comparison with adults, lower cross-correlation, pitch strength and error analysis were observed in newborns and toddlers in the right ear and lower spectral amplitude of the harmonics (transient and continuous in H2,3,4 and H5,6 in the right ear). Neuro lag in the right ear has been found to decrease among newborns and toddlers, with toddlers being similar to adults. On group comparison spectral amplitude of the harmonics (H 2,3,4) (transient) just were different between the ears. **Conclusion:** These preliminary results show that there may be an advantage of the right ear processing in the neural decoding of the speech stimulus during the auditory pathway maturation process among newborns, toddlers and adults. The patterns of response between the ears should be further studied given the clinical potentiality suggested to the FFR in the identification and monitoring of auditory disorders.

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Poster 3

Neonatal frequency-following responses in congenital syphilis

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Introduction: Syphilis can be transmitted from the pregnant woman to the baby by vertical transmission and constitutes risk indicator for hearing impairments and neurodevelopmental disorders. Objective: To study speech neural encoding in newborns with congenital syphilis during using the frequency-following response (FFR). **Method:** 97 infants were recruited at públic maternities of the city. A total of 71 babies were included in the sample, separated into two groups: congenital syphilis (41 newborns; 39.1 ±16.3 days) and control group (30 newborns, 36.4±13.3 days) without syphilis. All newborns were born at term and free of hearing risk indicators other than syphilis. A 170 ms consonant-vowel stimulus /da/ was presented at an intensity of 80dBnHL in the right ear and 4,000 artifact-free neural responses in blocks of 1000 were collected. Data were analyzed following the procedures in Ribas-Prats et al. (2019; Hear Res, 371, 28) to obtain a comprehensive picture of FFR in the time and frequency domains. **Results:** An enhanced spectral amplitude at the higher harmonics (average H5-6) was observed in the consonant transition and vowel regions of the stimulus in congenital syphilis group when compared with control group. No differences were observed at the F0 or any other FFR parameter. **Conclusions:** This study suggests that congenital syphilis influences the neural encoding of spectral characteristics of speech stimulus and, specifically, at the higher harmonics, showing no evidence of influence in the temporal domain.

Poster 4

Attention to sound features selectively modulates the ASSR and the FFR

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Endogenous attention shifting to different sounds within the auditory landscape can alter the neural encoding of acoustic features via top-down modulatory influence. How selective this influence is and the extent to which it affects the different hierarchical levels of auditory processing is a matter of debate. While task-dependent modulation of the Auditory Steady State Response (ASSR), a cortical response reflecting neural synchronization to periodic modulations of the sound envelope, is an established finding, evidence for attentional modulation of the Frequency Following Response (FFR), of cortico-subcortical origin, is controversial. Previous studies have implemented inter-modal and inter-stimulus designs and tracked ASSR and FFR separately, rendering impossible to distinguish attentional effects on the encoding of different sound features by different levels of the processing hierarchy. We recorded EEG from healthy participants actively listening to an ambiguous sequence of amplitude modulated (AM) sinusoidal tones arranged in mutually exclusive rhythmic patterns. We analyzed ASSR and FFR using a sound-brain activity cross-correlation procedure. Our results indicate higher correlation coefficients in ASSR (at a mean of 36ms lag) and FFR (at a mean of 7ms lag) when the participants attended to AM and pitch modulations respectively, suggesting that attention selectively enhances the representation of the target sound feature at the hierarchical level of the auditory pathway where that feature is best computed.

Poster 5

FFR- Index of Subconcussion Injury in Division I Collegiate Athletes

Cunningham, J., Krizman, J., Bonacina, S., Kraus, N.

Physical exercise through sports participation optimizes brain health. However, sports participation can increase the chances of injury to the brain, and this risk is inequivalent across sports. For instance, potential for head and body contact is much greater in American football and soccer than in tennis and golf. Post-mortem evidence suggests that a lifetime accrual of contacts leads to extensive brain deterioration – even in the absence of a frank head injury. Recent research has linked dementia in former athletes to long-term subconcussive damage, but no test exists to assess the impact of subconcussion while the athlete is still playing. We hypothesize that accrual of head impacts over time disrupts delicate auditory processing mechanisms captured in the frequency-following response (FFR) prior to manifestation of overt symptoms. Using the FFR to speech, we compared elite Division 1 collegiate-athletes divided according to their sport's contact level and Non-athletes on their encoding of the fundamental frequency (F0). We discovered that F0 magnitude varied with contact level, with the greatest decline in the highest contact sports. These findings suggest that despite the health benefits afforded by sports participation, athletes playing high contact sports may be at a greater risk of auditory processing difficulties even in the absence of a concussion. Thus, the FFR may be a sensitive test of subconcussive injury in purportedly healthy athletes. Furthermore, given that the F0 encoding decline parallels deficits seen in concussed individuals (Kraus, N. et al., 2016, Scientific Reports) this decline may similarly prognosticate future listening in noise (Thompson, E.C. et al., 2018, Brain Injury) and other cognitive difficulties in subconcussed athletes.

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Poster 6

TIOsync: an open Ahardware solution for high precision input/output trigger control suitable for FFR acquisition and other multisensory integration paradigms

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Our lab is developing an open-science multimodal behavioral and neuroimaging database characterizing healthy human auditory processing, including measurement of FFR. FFR measurements require high precision (<0.5ms) tagging of the EEG signal given an auditory stimulus. Tagging needs to be carried out by an external device that captures the output signals of the computer (audio, video) and sends low jitter and latency triggers to the EEG recording devices. Currently, there are commercial solutions but their cost is high and the hardware is proprietary. In order to solve this problem, we designed and built a circuit board costing under 200€, which can detect signals and send triggers with the required accuracy. "TIOSync" has 2 parts, one analogic and the other digital. The analogic part can detect different types of input signals (microphone, audio, photodiode, parallel port) amplitude levels and sends a trigger with sub-nanosecond precision. The digital part is compatible with different Arduino Due/Uno compatible boards and extends trigger implementation capabilities integrating new sensors or combining different inputs as trigger sources. TIOsync makes it possible to synchronize the presentation of other stimuli such as sound, vibrations, etc. The solution can also be used to test system latencies and jitters between output/input devices. FFR data collected with the TIOSync in a task that requires synchronization of motor and visual signals will be presented to illustrate its capabilities. TIOsync is an open-hardware solution that extends the FFR experimentation to a wider scientific community and that will improve testing methodology and results.

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Poster 7

Cross-Modal Approach to Studying FFRs in a Representational Similarity Analysis Framework

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The representational structure of sounds changes across the auditory pathway, but quantifying these representations non-invasively is challenging due to methodological tradeoffs between temporal resolution (scalp-recorded frequency-following responses [FFRs]) and spatial resolution (functional MRI). Here we leverage representational similarity analysis with FFRs, 7Teslafunctional MRI, and stimulus feature decomposition to put these different brain signals in the same space (common framework) and examine the dimensional characteristics of the underlying representation. We used 16 different tokens (4 speakers x 4 lexical tones) of a naturally spoken Mandarin syllable to obtain FFRs and functional MRI from the same native Mandarin speaking participant. We fit a multi-class support vector classifier to classify (mean accuracy >50%; chance = 6.25%) the FFRs to the 16 stimuli and constructed classification confusion matrices. Using multi voxel pattern decoding with the fMRI data, 16-stimulus classification was also above chance but was more accurate when stimuli were grouped into the four tones(mean accuracy> 50%; chance = 25%). We then computed distances between acoustic features of the stimuli (pitch height and slope and the first three principal components) and correlated the off-diagonal elements in the FFR and fMRI classification matrices to obtain representational similarity matrices. While auditory cortical fMRI patterns were more correlated with pitch height and pitch slope features of the stimuli, FFRs were more correlated with the acoustics-driven principal components. Our machine learning-driven and representational results suggest that FFRs encode acoustic representations across the auditory system, while fMRI is sensitive to higher-level categorical features, particularly in the auditory cortex.

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Poster 8

Influence of language exposure on neural sound encoding before birth: Effects of a bilingual fetal acoustic environment on the neonatal frequency-following response

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How determinant is the fetal acoustic environment for the newborns ability to encode and process sounds? Recent studies have demonstrated that fetal hearing experiences shape the infants' musical and linguistic preferences from the very first moment of life, as they respond differently to their native language and to their mother's voice just a few hours after birth. As bilingualism, relative to a monolingual environment, has been demonstrated to enhance evoked responses to speech in children and adults, the present study sought to determine whether a bilingual environment during pregnancy modulates the newborn's ability to process sounds. To do so, the frequency-following response (FFR), an auditory evoked potential elicited to complex sounds, was recorded in a sample of 90 healthy term neonates during their first days of life. Babies were divided into two groups according to their prenatal language exposure as reported by their mothers through a questionnaire (45 exposed to a bilingual fetal acoustic environment; 41 monolingual-exposed). The FFR was recorded to an /oa/ stimulus and quantified as the spectral amplitude and signal-to-noise ratio (SNR) at the stimulus F0. Results revealed that neonates exposed to a monolingual environment exhibited larger SNR of the F0 as compared to the bilingual group, whilst no differences where observed on the spectral amplitude of the F0. These results suggest that prenatal language exposure modulates the neural responses to human speech at birth, suggesting that a fetal monolingual environment provides a more stable background for newborns to encode and process sounds, which may eventually be beneficial for early language acquisition.

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Poster 9

Prestimulus amplitude reflects neural hyperexcitability in autism spectrum disorder

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Prestimulus amplitude, previously thought to reflect noise contamination in the FFR recording, may in fact reliably index baseline neural noise (Krizman et al. 2021). Baseline neural over-activity in autism spectrum disorder (ASD) has been reported in cortical EEG studies, and more recently utilizing the FFR (Patel et al. 2022). Such findings are consistent with the neural hyperexcitability theory, positing that neuronal inhibition has a cascading effect on a multitude of neural processes and associated phenotypes, in particular sensory processing in ASD (Yukatare & Sweeney 2017). Following methods modeled by Krizman et al. (2021), this project examined prestimulus amplitude in ASD, calculated by regressing out the variance introduced by non-neural noise sources, to generate a "purer" metric of neural noise. Findings replicated previously reported group differences in ASD from controls in the same sample, suggesting that prestimulus amplitude is a valid index of neural noise in ASD. Further, prestimulus amplitude significantly predicted autism symptom severity in the restricted and repetitive behavior domain (which encompasses atypical sensory processing), and in pragmatic speech-related behaviors (atypical use of intonation, volume, or rhythm in conversation), highlighting the impact that neural hyperexcitability may have on broader downstream ASD-related traits beyond sensory atypicalities alone. Taken together, results suggest that the FFR is a valuable tool for efficient and noninvasive measurement of neural hyperexcitability in ASD and provide evidence of specific contributions of neural noise on key clinical-behavioral phenotypes in ASD.

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Poster 10

Simultaneous cortical and sub-cortical brain responses to CV syllables in infants, a planned study

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This planned study aims to examine the contribution of cortical and sub-cortical structures for the encoding of syllables during early development. With this aim, we will record EEG activity during a single passive listening experiment that allows to gather both cortical and sub-cortical EEG responses (Bidelman et al., 2015) in the same infants. The experimental design thus includes two types of alternating blocks: blocks with high stimulation rate of a single syllable /da/, and “oddball” blocks with a lower stimulation rate and which includes three syllables (one standard /da/ and two deviants /ba/ and /ga). By longitudinally evaluating the same infants from 3 to 24 months of age we will decipher the the neurplasticity mechanisms supporting the maturation of the auditory system and the emergence of phonological categories representations during early development.

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Poster 11

Neural and Behavioural Predictors of Successful Second Language Perception

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Mastering a second language (L2) in adulthood is challenging, but it is unclear why some learners achieve better speech perception and production abilities than others. Behavioural tasks have revealed robust individual differences not only in L2 perception, but also in native language (L1) phonetic sensitivity (i.e., use of relevant acoustic cues to distinguish speech sounds) and perceptual gradiency (i.e., perception of gradual vs. sharp changes along a continuum of speech sounds). One hypothesis is that these differences in L1 perception relate to differences in how well speech sounds are encoded and could be related to early stages of L2 learning. The FFR also shows inter-individual differences among healthy adults, potentially reflecting the fidelity of sound encoding. We therefore examined individual differences in L1 perception, non-native perception, and the FFR, and explored the relationships among them. To measure L1 phonetic skills, English monolinguals responded to stimuli varying along a continuum (e.g., bet—bat) in two-alternative-forced-choice and visual-analog-scaling tasks. To measure non-native perception, participants discriminated unfamiliar German sounds in an oddity task. The FFR was elicited using the syllable /da/. We predicted that participants with greater L1 phonetic sensitivity and perceptual gradiency would show more consistent FFRs, and that this would also relate to better non-native perception. Preliminary behavioural results suggest that differences in L1 perception across tasks do relate to how consistently speech sounds are perceived, and may also relate to differences in non-native perception. This work advances our understanding of individual differences in how speech sounds are encoded and perceived.

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Poster 12

Rapid FFR- A new and faster technique to obtain the frequency following response

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The FFR has many possible clinical implications, which is why its use in clinical settings (as for the ABR) is likely to prove advantageous. However, obtaining the FFR is time-consuming, with recordings to a single sound requiring usually around 6 minutes. We propose a technique that can drastically decrease acquisition time while still detecting a robust response. To this end, we play a periodic steady-state sound continuously instead of interleaving shorter sounds with silent pauses. Additionally, rather than averaging across tens or hundreds of milliseconds of data as in the conventional FFR, we average across a single cycle of the stimulus. For example, a conventional FFR technique might average a 70ms stimulus 3000 times, with a 55ms break between each iteration, resulting in a 70ms ERP. In contrast, the rapid technique might present a steady-state vowel of 128Hz continuously for one minute, with the resulting ERP being only 8ms long. Possible neural adaption may require more repetitions for the new "rapid" technique than in the conventional one, but this would still result in an approximately 4x shorter recording time. In this experiment, we use different steady-state vowels to illustrate the feasibility of the new technique in measuring the neural response to variations in spectral shape. Implications for research and clinical practice will be discussed.

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Poster 13

Anatomical underpinning of the neonatal frequency-following response: a combined MRI-EEG study

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From the third trimester of pregnancy, the developing human brain follows a series of maturational patterns, including a myelination of white matter (WM) fibers, cortical gyrification, and increased gray matter (GM) volume. These can be decoded and related to functionality with techniques such as magnetic resonance imaging (MRI), magneto- and electro-encephalography (M/EEG). Volumetric anatomo-functional correlates of the frequency-following response (FFR) have never been assessed in neonatal population. Yet, several studies in adults have related volume of certain auditory brain regions such as the GM section of primary auditory cortex (PAC) and superior temporal gyrus (STG) to hearing abilities, IQ and language function, therefore motivating the present study. Here, we aim to explore the anatomo-functional relationship between auditory and language regions' volume (insula, corpus callosum, STG, medial and inferior temporal gyrus) and the FFR metrics (pitch measures, fundamental frequency, and temporal fine structure) at birth using EEG and MRI. To do so, structural MRI and FFR data were collected from a sample of 31 healthy term neonates, pre-processed and analyzed. Correlations of ROIs volume index with FFR parameters showed a greater contribution of WM regions than GM ROIs. Results also point out a significant role of STG's and medial and inferior temporal gyrus (MITG)'s volume on pitch measures, while corpus callosum (CC) volume stands out in temporal fine structure.

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Poster 14

Oscillatory entrainment of the frequency-following response across frequencies, species, and sleep stages

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The FFR has some surprising properties that may provide insight into how neural populations at and between different levels contribute to frequency representation (Coffey et al., 2021). Far from being merely a passive system in which each neural impulse from the cochlea is fed forward to downstream populations of neurons, the FFR appears to be generated or influenced by oscillatory processes (Coffey et al., 2021; Ross et al., 2020; Lerousseau et al., 2021). These oscillatory processes can be observed by a persistent post-stimulus "after-effect", and convergence to the input frequency upon sound onset and divergence upon offset (Coffey et al., 2021). While our long-term goal is to understand whether the FFR's oscillatory nature underlies a functional gain in the form of resistance to interference or degradation during perception, it is first necessary to explore its basic properties; i.e., the conditions under which oscillatory phenomena are observed. We posit that the oscillatory mechanism exists towards the higher-level end of the auditory system (meaning within the auditory cortex itself or between thalamus and cortex), yet is pre-attentive, conserved over species, and robust to changes in brain state. Borrowing data from existing datasets (EEG, MEG, intracranial), we characterize the after-effect and frequency tracking across frequency bands, sleep and wake stages, levels of the auditory system, and human and animal models.

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Poster 15

Efficient coding of frequency following responses to lexical tone covariation patterns

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Understanding the effects of statistical regularities on speech processing is a central issue in auditory neuroscience. Here, we introduce and validate a novel decomposition procedure, based on principal component analysis, to extract patterns of covariation between pitch contours. We used this decomposition procedure to investigate the sensory representation of lexical tone covariation patterns in native speakers of Mandarin Chinese and English learners of Mandarin tones. We assessed the sensory representation of lexical tone covariation patterns with the frequency-following response (FFR), which is scalp-recorded potential that reflects phase-locked activity from neural ensembles along the auditory pathways. Our results indicate that the sensory encoding of lexical tones, as reflected by the FFR, is strongly influenced by the underlying statistical structure of the auditory landscape. Specifically, we found a more efficient coding of the lexical tone covariation patterns that accounted for more distributional covariance across lexical tones. Notably, long-term language and short-term training experiences enhanced the sensory representation of these covariation patterns, which were also better predictors of perceptual categorization in learners. Combined, our results show that the sensory representation of pitch is strongly influenced by meaningful experience with the second-order statistical structure (i.e., distributional covariance) of the auditory input.

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Poster 16

Neonatal frequency-following response (FFR) to speech sounds presented in quiet and noise

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Background noise influence in speech perception has been studied across the age span and it has been linked to different language and developmental disorders. Nevertheless, to the best of our knowledge and despite its importance, speech-in-noise (SIN) has not been thoroughly investigated in newborns. Considering that the frequency-following response (FFR) has been used in SIN studies due to its sound mimicking characteristics, it could emerge as an effective tool to assess this phenomenon in newborns. The present study aims to compare how background noise could modify speech encoding in neonates and adults through the analysis of their FFRs. Participants were 16 healthy-term neonates (aged <48h afterbirth) without auditory risk factors, and 25 normal-hearing adults (aged 20-40 years). FFR were recorded to a 170 ms syllable /da/ of fundamental frequency (F_0) of 113 Hz presented at 65 dB. Noise condition was assessed by playing a Spanish six-talker babble noise at -10 dB signal-to-noise ratio. Several FFR parameters were retrieved from the recordings in time and frequency domains. Results showed that whereas adults exhibited larger spectral amplitude to the speech stimulus in quiet condition than in noise condition, newborns spectral amplitude did not differ significantly in the quiet condition or with background noise. This study constitutes the first step towards understanding the development of SIN encoding from the very first moment of life. Speech-in-noise encoding in newborns did not seem to be affected by auditory challenging environments, perhaps due to their perhaps due to their auditory system only being exposed to attenuated sounds during gestation.

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Poster 17

Development of the frequency-following response during the first 2 years of life: a preliminary study

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Several studies pursued the characterization of the development of speech sounds neural encoding through the recording of the frequency-following response (FFR), an auditory evoked potential that provides a non-invasive lens into sound processing in the brain. Knowledge of the maturity of speech encoding during the first two years of life may provide key information relevant for understanding the neural mechanisms of early language development. Here, FFRs were recorded longitudinally in a sample of 14 healthy term neonates tested at two moments: during their first days of life (newborns = 0 months) and at 21 months of age (infants = 21 months). FFRs were recorded to either a /da/ or an /oa/ stimulus, analyzed in averaged polarities in both stimuli during a section with equal duration (113 ms) and fundamental frequency (F0 = 113 Hz), and computed as the spectral amplitude and the signal-to-noise ratio (SNR) to the stimulus F0. Results revealed significant differences across groups, with larger spectral amplitudes ($t=-2.97$; $p=0.01$) and SNR values ($t=2.32$; $p=0.03$) at 21 months of age as compared with values obtained for the same infants at birth. These preliminary results suggest that the encoding of the low-frequencies increases significantly in amplitude during the first 21 months of life, in agreement with previous studies, to reach a more robust F0 encoding that seems to be adult-like already at an early age.

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Poster 18

Maturation of the neural encoding of speech sounds during the first six months of life: A longitudinal FFR study

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Language acquisition is a unique expertise that infants are able to master at very early stages of development. Speech perception and its developmental milestones are depicted across the literature for the first months of age in different populations and languages. However, the neural mechanisms underlying these maturational processes are still poorly understood. In the present study, we aim to unravel the developmental trajectory of the neural encoding of speech sounds during the first six months of life. For that purpose, we use the Frequency-Following Response (FFR) as a neural correlate to evaluate the tracking accuracy of complex sound features in the auditory system. For this study, the FFR was elicited to a tailored novel stimulus /oa/, which allows analyzing the neural encoding of both the stimulus envelope and its temporal fine structure (Arenillas-Alcón et al., 2021). Recordings were obtained in a sample of 54 healthy-term neonates at birth and retested at the age of six months. Results revealed a shortened neural lag and a maturation of the stimulus temporal fine structure neural encoding as a function of age, while no significant different stimulus envelope encoding was observed across the two time measurements. To our knowledge, this is the first study systematically describing the striking maturation of the fine structure encoding abilities since birth, already present at the early age of six months. The present study contributes to better characterize the neural developmental trajectory behind speech encoding abilities during the very early stages of life and supports its use to assess early abnormalities that could be associated to later language impairments.

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Poster 19

Developmental trajectory of the frequency-following response during the first six months of life

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Aim: To investigate the natural development of the neural encoding of different speech cues during the first six months of age, using the frequency-following response (FFR). **Methods:** The FFR to a /da/ stimulus was recorded in 80 healthy term neonates at birth in 35 neonates an at the age of one month in 45. Thirty-two returned for a second recording at the age of six months. The FFR was quantified as the spectral amplitude at the stimulus F0 and at the harmonics closest to the first formant of the syllable (HH5-6) to explore the envelope and the temporal fine structure neural encoding, respectively. **Results:** Enhanced temporal structure encoding observed at one month of age compared to birth, both at the stimulus' consonant transition ($W = 454.00$, $p = .001$) and its vowel ($W = 549.00$, $p = 0.02$). At six months of age, enhanced neural encoding of the stimulus F0 was observed at both regions compared to their early recordings (consonant transition: $F(1) = 7.24$, $p < .012$; vowel: $F(1) = 5.06$, $p < .032$). Also, significant improvements were observed for temporal fine structure encoding during the consonant transition ($F(1) = 5.15$, $p < .031$). **Conclusion:** These findings suggest that the encoding of the distinct accoustic cues follows a different maturational pattern. The enhanced fine structure encoding at the consonant transition at one and at six months are in line with previous studies in which more pronounced development of phase-locking capabilities were located at this region where the frequency contents of the formants rapidly change compared to the vowel.

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Poster 20

No effect of visual perceptual load on auditory 20-, 40-, and 80-Hz FFR_ENV

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In daily life, people need to be able to focus on task while ignoring task-irrelevant background noise. Theories of attention argue that processing of task-irrelevant auditory information should become attenuated when attentional capacity is exhausted by task-relevant stimuli, for example a visual task. According to the early-filter model, recurrent loops present through the entire auditory pathway should allow top-down modulation of earliest responses. The adaptative filtering model of selective attention suggests that such filtering occurs early when concurrent visual tasks are demanding (e.g., high load) and late when tasks are easy (e.g., low load). This research investigated whether auditory processing is attenuated during concurrent visual load manipulation, and at which stage of the auditory pathway. Recording FFR_ENV to different modulation frequencies during concurrent visual tasks with different load levels could show at which stages of processing the filtering happens when the task demands are high, low, or there is no tak at all.

Results showed moderate to strong evidence for no effects of visual load on 20-, 40- and 80-Hz FFR_ENV, but some comparisons were inconclusive. The convincing evidence points to the robustness of FFR_ENV against visual load manipulation, thus results support modality-specific attentional resources. Because it is possible that filtering occurs at one stage of auditory processing and does not change with visual task demands, results do not rule out the early-filter model. However, results are inconsistent with the adaptive filtering model because of task-irrelevant responses does not vary with the demands of the concurrent task.

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