Maastricht University

Music to the brain

Citation for published version (APA):

Disbergen, N. R. (2020). *Music to the brain: investigating auditory scene analysis with polyphonic music*. Ipskamp Printing BV. https://doi.org/10.26481/dis.20200401nd

Document status and date:
Published: 01/01/2020

DOI:
10.26481/dis.20200401nd

Document Version:
Publisher's PDF, also known as Version of record

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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Knowledge Valorisation

During everyday listening situations we are exposed to a multitude of simultaneous sounds. Our brain processes these sounds to allow us, among other actions, to have conversations with one another or enjoy listening to music. This task becomes especially impressive when observing the signal our auditory system has to analyze: a complex pattern of air pressure changes containing information from the sound mixture. The auditory system transforms these complex mixtures into segregated sound representations to allow for the extraction of behaviorally relevant information. This thesis provided insights as to how the human brain achieves such tasks, the potential social and economical implications of which are discussed here.

Within Domain Applications

This thesis investigated the neural basis of sound perception and organization, aiming to explain the auditory system's capacity to select and respond to relevant acoustic stimuli mixed with other competing sounds. Mechanisms for music listening as have been discussed here, are of further relevance for the study of how musical training may influence general auditory cognition. Disentangling the processes underlying the Auditory Scene Analysis (ASA) of music stimuli may be fundamental to understand the neural processes supporting music processing in general (Nelken, 2008). The experimental design introduced here could be combined with other tasks which are focused on the segregative or integrative mechanisms in audition to get a better understanding of the links which exist between music-specific and general auditory cognitive abilities.

Additionally, an improved understanding of the neuronal mechanisms supporting auditory perception is of interest to other cognitive neuroscience domains, such as language and vision. Language and music have been proposed to share common processing systems, while a comparisons to vision would allow for the investigation of analogies among the senses. Research into emotion could be furthered by the employment of music stimuli as well, since they tend to evoke emotional responses in most listeners. Questions related to (music) ASA are of importance not only to cognitive neuroscience, but also neuropsychology, cognitive psychology, and, especially in this case, music psychology. Methodological advancements for MRI acquisition and analysis are transferable to other neuroscientific areas of investigation and provide the wider scientific community with novel tools to investigate brain activity.

Hearing Dysfunction and Disease

To date, most of the treatments for conductive hearing loss have focused on trying to overcome perceptual losses by virtue of sound amplitude enhancement through hearing aids. The performance of these devices is notoriously bad in noisy environments, especially so regarding speech intelligibility and music perception. The simple intra ear-canal amplification of incoming sound mixtures results in a loss or distortion of acoustical information which is essential for the auditory system to perform source segregation or integration. As a consequence of this, auditory perception may be heavily distorted. The topic of this thesis is of additional relevance to the general study of aging, since aside from this type of hearing loss the capacity to track separate auditory streams diminishes with age.

Patients employing the current hearing aid technology are often unable to perform common and socially important tasks, such as having a coffee in one's favorite cafe with a friend. Due to the many competing sound sources present in such an environment, it becomes very challenging to filter out the voice of your conversation partner while wearing a hearing aid, even though they may only be one meter away from you. Results discussed here could be of relevance to develop and enhance the general design and algorithms of both classical hearing aids and cochlear implants. An improved understanding of how the brain performs sound segregation could inform novel algorithms employing similar approaches to be implemented in these artificial hearing devices. Currently, more sophisticated algorithms are offered in hearing aids which can selectively filter and enhance relevant frequencies, in this case of speech. Unfortunately, current algorithms do not allow to overcome most of the limitations because of, among others, the erroneous 'leaking' of frequencies from other competing sound sources or general background noise.

In general, resolving mentioned hearing-aid difficulties is highly complex and potentially requires a combination of amplification modulation, selective frequency enhancement, general noise reduction, and directionality selection. If it were possible for a user to optimize their hearing-aid filtering parameters to their preference, both in general and in a situation-specific manner, via an interactive application on, for example, their smartphone, this could potentially greatly enhance their lives. One of the possible implementations could be the employment of acoustic filters which are optimized for the selection of familiar voices, introducing hearing profiles for those we interact with most. Great advancements have been made in recent years with regard to active noise canceling headphones, algorithms employed in these devices to determine what is noise and how to accordingly cancel it out could be implemented in hearing aids for noise-detection and filter adjustments. The amount of ambient noise a hearing aid perpetuates could additionally be set by the user, or automatically detected, dependent on the environment they are in. For example, when walking around the city ambient noise is of great importance, while during a conversation it serves mostly as a distraction. Sound directionality estimations may additionally be employed to allow selection as to where the majority of sound sampling takes place, for instance on the frontal midline when having a one-on-one conversation. Considering all the possible parameter combinations which could be set on such hearing devices, it becomes of topical interest to automate them to a very large extend, preventing the need for users to spend excessive amounts of time switching between profiles or settings. Such a task requires learning a large amount of tuning parameters over time, introducing the need for learning algorithms which are capable of selecting optimal combinations of settings from a very large number of candidates, potentially in a context-dependent manner. Combining a multitude of learning architectures and algorithms, for example Bayesian reinforcement learning and data-fusion techniques, could permit the necessary combination and reduction of parameter space while continuing to allow for learning based on both algorithmic and user feedback.

Even though the research discussed here has been conducted in healthy volunteers, the advancements of its knowledge may be additionally employed to disentangle more general pathophysiological deficits of auditory cognition. For example, disorders of music cognition and perception are observed in listeners with amusia who are typically incapable of pitch perception and suffer from other deficits in both music processing and memory. Listeners with musical anhedonia show (strongly) reduced pleasure responses to music, despite having normal music perception and global functioning of the reward network. Our experimental approach may assist in developing a means to improve the characterization and diagnosis of such dysfunctions.

General Technological Applications

From a more technical perspective, general algorithm development related to stream segregation tasks, both in science and engineering, can profit from discussed advances. Both artificial speech and sound recognition relies on versions of stream segregation problems. Now that technology has become an integral part of most people's lives, there has been a great increase in efforts towards the improvement of algorithms capable of recognizing, separating, and analyzing sounds. Examples include speaker identification, speech recognition, music recognition, and most notably virtual assistants. Despite the recent phenomenal accuracy increase of these algorithms, which has been mostly driven by advancements in deep learning, these systems are far from perfect, especially in situations where there are many competing sound sources. Examples where these algorithms are heavily deployed is within the virtual assistant frameworks of Siri (Apple Inc.), Google Assistant (Google LLC), and Alexa (Amazon.com, Inc). Interaction with smart devices in both our homes and the wider environment are more and more driven through virtual assistant services, potentially becoming our main source of interaction with technology over time. These systems make use of highly advanced algorithms, often inspired by how the brain analyses its environment. Even though we have seen great improvements, the replication of human-level performance in sound segregation and analysis still appears to be far away. Results discussed in this work could be employed in the development of novel brain-based information representation systems, potentially aiding to equate or exceed human-level performance.

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