Use-Inspired Music Cognition: Designing Cognitively Informed Musical Interventions for the Brain

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Abstract

As the field of music cognition is rapidly burgeoning, researchers are beginning to consider how the unique amalgam of scientific and humanistic study of music may translate towards large-scale interventions that may improve cognition for many, including but not limited to people from neurodiverse populations. Here I examine novel ways in which music cognition research may help improve cognition, in ways that move away from overused tropes (e.g. the Mozart Effect) towards future directions of use-inspired music cognition research. As use cases, I will describe some recent studies in my lab that capitalize on new musical technology, developed from first principles from music cognition research, to help those with attention deficits, dementia and memory disorders, and Parkinson's Disease. Our results show how music cognition can help refine and target music-based interventions for multiple special populations, by pinpointing ways in which music capitalizes on fundamental operating characteristics of the brain.

KEYWORDS: *interventions, cognitive, neuroscience, entrainment, Alzheimer's Disease*

Introduction

In considering future directions in the field of music cognition, perhaps it is helpful to start with the early days of our field. In doing so I begin by acknowledging that technology has always informed music cognition. Figures such as Max Matthews and John Chowning, who were some of the founders of electronic music and sound synthesis, changed how we think about how the mind can perceive and produce music. Innovations in sound design gave rise to sounds like the Shepard tone, which helped shed light on the difference between pitch direction and pitch height. The work by Bregman on scene analysis (Bregman, 1990) was informed by sound design technology, and has since then informed sound design technology as well.

On the other hand, music cognition has always been inspired by subjective experience. The work by Diana Deutsch, for example, on the speech to song illusion and the tritone paradox, informed our study of individual differences. The work by Carol Krumhansl and colleagues on probe tone profiles (Krumhansl, 1990) was really a subjective rating of fit within a musical context that gave us some understanding into our mental representation of music. And that was coupled with the use of multidimensional scaling to define musical spaces, such as the work of David Wessel on timbre spaces (Wessel, 1979) and by Carol Krumhansl and colleagues on pitch spaces and tonal spaces (Krumhansl & Kessler, 1982). These examples were relatively objective ways to look at something that felt subjective at first. I was initially drawn to this field because I felt that it was a way to use somewhat objective methods to look at subjective experiences. The more I do research, however, the more I learn that these seemingly objective tools are certainly still implemented by humans. And of course, humans can be quite subjective at times. Thus, we have to be careful and responsible in how we think about data and why we acquire data, as well as how we use and reuse data.

Lessons from History of Music Cognition

It bears mention that there were some relatively dark pages in the history of music perception and cognition. One of these dark pages, perhaps, is the Mozart effect in 1993, when it was discovered that if you listen to Mozart Two-Piano Sonata K. 448 for 10 minutes or so, afterwards there was a boost in IQ scores, more specifically in mental rotation scores, that was related to IQ (Rauscher, Shaw, & Ky, 1993). It turns out there were lots of problems with that claim. First of all, we learned a lot about the importance of control conditions, or the ruling out of possible confounds and covariates that might contribute to this effect. Secondly, most of that effect is attributable to affective arousal. So the controversial question remains, and that is: Can music listening affect cognition? There is ample evidence for long-term musical training affecting brain and cognition (Habibi, Ilari, Heine, & Damasio, 2020), but can short term music listening also affect cognition? I think that is still an open question. As extraordinary claims require extraordinary evidence (Sagan, 1980), we need some extraordinary evidence to be able to make these extraordinary claims about music improving cognition.

So what are some ways in which we can go about finding these extraordinary pieces of evidence? And so to that, I turn to Pasteur's quadrants for scientific research (Stokes, 2011), a way to think systematically about how different kinds of research directions or research programs can really inform different goals.

One such goal is the quest for fundamental understanding. Basic research is focused on the quest for advancing fundamental understanding. Discoveries such as the electron or the structure of the atom are research that changed how we know how the world works. On the other hand, it's hard to think immediately about how that's going to apply to your life, even though it obviously has fundamental and important implications for many fields afterwards.

On the other hand, another goal is societal need. To meet this goal we should think about something that's useful: applied research. For example, the invention of the light bulb, a patentable invention that improved many lives, is built upon fundamental understanding, but it did not necessarily change fundamental understanding. I hope that music cognition research could turn towards something that's use-inspired, in that it can both be improvement in consideration of use, but also a quest for fundamental understanding.

		Considerations of use?	
		No	Yes
Quest for fundamental understanding?	Yes	Basic research	Use-inspired research
	No	–	Applied research

Figure 1: Pasteur's quadrants for classification of scientific research.

My claim is that music cognition can help refine and target music-based interventions for multiple populations. Trained as a cognitive neuroscientist, I think about ways in which music cognition can help reveal the fundamental operating characteristics of the brain. In this regard, there could be a use-inspired cycle between purely thinking about music and the mind, and applications for how this can be used to help people.

Here I will review a few different use cases from work in my lab. Our work on music and the reward system (Sachs, Ellis, Schlaug, & Loui, 2016) has inspired some ongoing projects in my lab on music-based intervention for older adults (Loui et al., 2017; Quinci et al., 2021). We are also interested in music and the auditory-motor system, and for that, we have some work that's ongoing on dance for Parkinson's disease (Krotinger & Loui, 2021). Thirdly, I will discuss music and neural entrainment, as more and more research is showing that music is a very effective way of entraining or tuning the neural activity or populations of neurons in the brain (Tichko, Kim, Large, & Loui, 2020). Can we capitalize on this knowledge towards making some music that might be useful for cognition?

Music and the Reward System

Let us begin by talking about music and the reward system. As we know, different individuals have different aesthetic responses to art (Harrison & Loui, 2014). When I listen to Rachmaninoff's second piano concerto, I often get the chills. I often feel like my hair is standing on end. But maybe that is not your experience at all. Maybe you find that when you listen to punk rock, you suddenly feel like your heart is racing and you get very excited and you feel very strong emotions. Several years ago, Matt Sachs and I surveyed two hundred undergraduate students on how frequently they experienced these strong aesthetic responses (Sachs et al., 2016). We then used multidimensional scaling to give a two-dimensional space of how closely related these different, strong aesthetic responses were. In this two-dimensional space, the points that are closer together mean that they're more frequently co-reported by multiple individuals. From this you can see that heart racing, heart skip a beat, hair stand on end, pit in stomach, lump in throat…. Items that actually pertain to part of the body show up on one side of the plot, whereas items that are more abstract and cognitive and maybe even transcendental (feeling like you're somewhere else, or losing sense of time, or feeling in awe, or feeling touched) show up on the other side of the plot. Chills shows up in the middle, which means that it is a fairly commonly reported strong emotional or aesthetic response to music that people get when they experience music. We can also do the same multidimensional scaling on people's ratings for how much they like certain musical genres. And then you can make certain predictions with this space. For example, if you enjoy listening to blues, you probably also enjoy listening to folk and reggae and bluegrass. If you enjoy listening to pop you probably also like rock and oldies and classical. Again, no one size fits all, but there's a variety of musical genres that are all equally good parts of the experience. We then looked into brain connectivity differences between groups of people who either got chills all the time and people who did not get chills, controlling for many different variables, including the

amount of musical training people had and personality differences, and also gender and age. What we found was that controlling for all these differences, people who get chills when they listen to music, tend to have a larger volume of white matter connectivity that was identified using diffusion tensor imaging, between the superior temporal gyrus, which is important for auditory perception, and the insula and the medial prefrontal cortex, which are important for emotion and for social reward processing. In other words, there are structural differences between the brains of people who get chills all the time and people who do not particularly feel emotional or feel chills when they listen to music.

After we published these results, we were approached by BW who is a musical anhedonic. He scored more than five standard deviations below the mean on all the variables within the Barcelona music reward questionnaire (Mas-Herrero, Marco-Pallares, Lorenzo-Seva, Zatorre, & Rodriguez-Fornells, 2013), and he reported a socially-debilitating lack of emotional responses to music. When we looked at his brain, we saw that there was a difference in structural connectivity in the white matter between areas that are important for auditory perception, specifically the superior temporal gyrus, and the areas that are important for reward, specifically the nucleus accumbens (Loui et al., 2017).

Amy Belfi and I defined, based on a review of the literature, a neuroanatomical model that's important for music and reward (Belfi & Loui, 2020). On one hand the auditory system is useful for making predictions about specific musical features as they come in. On the other hand, the reward system is important for learning and motivating the shaping and testing of predictions. Musical emotions and music reward probably hinge upon the successful interaction between these two networks within the brain.

From Model to Music-Based Intervention

This neuroanatomical model was implemented by Diana Wang, who was an undergraduate in my lab (Wang, Belden, Hanser, Geddes, & Loui, 2020). She looked at the regions of interest that were in the auditory network and in the reward and valuation network, and she quantified the functional connectivity of these reward and auditory regions in a large group of individuals. This is using an open source dataset called ADNI (Alzheimer's Disease Neuroimaging Initiative) (Jack et al., 2008). ADNI enabled us to look at 108 brains without having scanned any of those brains ourselves. Among healthy older adults, there was significant functional connectivity from both the auditory and the reward systems. There was also an overlap between these two systems, centering around the anterior insula, but really spanning many different areas of the brain. This functional connectivity was generally decreased in people with Alzheimer's disease, but there was still some preserved functional connectivity in the anterior insula. Thirdly, when looking at functional connectivity in those with mild cognitive impairment, we saw functional connectivity patterns that was closer to the healthy controls, again with the overlap between auditory and reward connectivity centering around the anterior insula.

This correspondence between the functional connectivity data and our anatomical model provides an actual therapeutic target for how the auditory system and the reward system might be talking to each other, as we design music-based interventions for healthy aging. Working with music therapists in the Berkelee college of music, especially Dr. Suzanne Hanser, we designed an eight-week-long intervention where a therapist comes in and works with older adults. We are starting with healthy, older adults, but we are moving towards people with mild cognitive impairment and hopefully eventually people with Alzheimer's disease as well. For our intervention, we are testing how much mindful listening every day, for an hour a day, can change your brain's activity, connectivity, and performance on a variety of neuropsychological tests. While we are doing this music-based intervention right now, I will specifically present some preliminary results from a functional magnetic resonance imaging task. In this task, participants listened to 24 different twenty-second long clips of musical stimuli, and made ratings of how much they liked the music and how familiar that music was to them. The musical stimuli included some songs that we used from previous studies, but also some songs importantly that were self-selected by the listeners. Listeners brought in what they thought they most enjoyed listening, and then we cropped them to the length that fits into the time they spent in the scanner. When listening to self-selected music, we saw activation unsurprisingly in the auditory areas. There was also significant activation in the medial prefrontal cortex, which is part of the reward system. Co-activated with the medial prefrontal cortex we also saw the posterior cingulate cortex, and these two regions together are part of the default mode network. Interestingly, there was also deactivation in some other areas. This deactivation was stronger when listening to other-selected music. A contrast between self-selected music listening and other-selected music listening revealed a strong effect

where there was massively higher activity throughout the brain of self-selected music compared to other-selected music. Music that you choose to listen to is much better at engaging your brain than music that someone else chooses for you.

While these results are still new and data collection is still ongoing, what's maybe not so new is the idea that music is important for social bonding, across many cultures. People across many cultures play music together, they sing together, they dance together. People in different musical cultures have love songs for example, and also lullabies, and people across many different cultures move together in response to music. And this is not something that we are taught to do, but it is just something that we do. There is something about music that compels movement together. Pat Savage and other colleagues and I mapped out how we thought this might be implemented in the brain (Savage et al., 2020). Musical features engage perception, action systems of multiple people, and that might be linked to, on one hand, the dopaminergic reward system, and on the other hand, the oxytocin and endogenous opioid systems. These systems together might be important for social bonding. Underlying areas in the brain that might be important for perception and action include superior temporal areas and motor areas which work together to enable perception-action coupling, but also in conjunction with the basal ganglia and the ventromedial prefrontal cortex. There are many other areas that are important that are involved in music listening, but this was one way to simplify it at this point.

Perception-Action Coupling and Parkinson's Disease

Perception and action coupling is what I want to turn to next. We know that music is quite effective at driving sensorimotor coupling, especially auditory-motor coupling, and rhythm is an important driver of that. And among different rhythmic patterns there are some that are more effective at driving sensorimotor coupling. We might call them groovy music. Groovy music is what makes you want to dance, the kind of music that when you listen to it, there's something about the auditory features that seem to compel your motor urge to move. One group of people that suffer from a motor disorder are people with Parkinson's disease. Parkinson's disease is characterized by movement problems, including difficulty with initiating movement and difficulty in maintaining rhythmic movement. There is good anecdotal evidence that dancing can really help the impaired movements in Parkinson's disease.

We started to ask the question, what is it that dance experience might do? Can we look at the effects of an intervention that uses dance, on people with Parkinson's disease, and can we actually assess how rhythm might mediate the way dance might help improve the motor symptoms of people with Parkinson's disease?

We used various gold standards to assess rhythm, motor symptoms, and sensorimotor coupling in Parkinson's disease. To assess the motor problems in Parkinson's disease, we used the UPDRS, which stands for the Unified Parkinson's Disease Rating Scale (Goetz et al., 2008), which assesses a variety of different motor as well as non-motor symptoms, that are part of Parkinson's disease. To look at rhythmic ability we looked at the Beat Assessment Test (BAT) (Iversen & Patel, 2010). To look at sensorimotor coupling, we looked at tapping entropy: participants had to listen to music that was either highly groovy or more chill, and they had to tap their fingers in time to the music. And we looked at how much variability there was in the tapping. Participants who are better at synchronizing to music tend to have lower variability, or lower entropy in their tapping data.

Does a dance intervention for Parkinson's disease actually reduce your Parkinsonian symptoms? Anna Krotinger and I saw a reduction in Parkinson's symptoms, that is an improvement in behavior, following four months of a dance intervention as assessed using the gold standard UPDRS score (Krotinger & Loui, 2021). Does sensory-motor coupling have anything to do with it? To look at that, we looked at finger tapping for high-groove songs and for low-groove songs. Some high-groove songs are Superstition, Sing, sing, sing, In the mood, Cheek to cheek. Some low-groove songs are Carolina on my mind, Till there was you, and Comfortably numb.

Parkinson's patients showed a reduction in tapping entropy after the intervention, suggesting that sensory motor coupling ability might be tuned or be improved. Furthermore, dance experience predicted how successful dancing intervention was at reducing symptoms of Parkinson's disease. People who had more dance experience coming in to the intervention tended to show more of an improvement in UPRS. In other words, both dance intervention and dance experience are important for the reduction of symptoms in Parkinson's disease. And we think that the underlying mechanism involves perception and action, or the ability for rhythm to engage sensorimotor coupling.

Music as Brain Stimulation

Music listening engages multiple areas of the brain. From recent work in auditory neuroscience, we know that neural oscillations, rhythmic bands of brain activity, are linked to cognitive behavior by tuning different networks of the brain. These different rhythmic oscillatory networks, observable using EEG, are important for aging, and show differences between healthy aging and Alzheimer's disease and related disorders. We did a review recently on the multiple scales of dementia and related pathologies (Tichko et al., 2020). At the top, the behavioral impairments from dementia include learning and memory impairments, as well as deficits of motivation. These are subserved by neural systems-level differences, including lower gamma-band activity and lower theta-band activity in healthy aging, but especially in Alzheimer's disease. The neural systems differences in turn are subserved by neuronal degradation and the loss of synaptic activity at the cellular level and then amyloid plaques and tau tangles, unwanted protein deposits that are at the molecular level. In recent years, exciting work had shown that gamma-band light stimulation, first optogenetically delivered directly to the brain and then visually delivered by flickering lights to the eyes, can reduce the levels of plaques and tangles that are in a mouse model of Alzheimer's disease, essentially reversing the biomarkers of Alzheimer's disease (Iaccarino et al., 2016). In humans, new research is emerging looking specifically at theta-gamma coupling, or the coupling between theta and gamma frequency bands, of rhythmic oscillatory brain activity in young adulthood and in older adults. Normally a young adult has theta-band and gamma-band activity that are well coupled together, and that enables good working memory performance. Now in older adults, there is a decrease in working memory performance; this is coupled with a decrease in the coupling between the theta band and the gamma band. Now, new research has shown that by restoring this theta and gamma coupling, by using transcranial alternating current stimulation, it was possible to reverse the working memory deficits so that the working memory performance of a 70 year old could match the level of a 20 year old. In other words, brain stimulation can revive working memory in older adults, specifically by synchronizing rhythmic brain circuits (Reinhart & Nguyen, 2019).

Now we know some ways to synchronize rhythmic brain circuits. We know that music is, of course, a very rich rhythmic stimulus. We can even simulate the patterns of brain activity under musical stimulation. Work by Ed Large and Ji Chul Kim, and their company Oscilloscape, has been able to make a neural network model that can find the beat from musical sounds. Starting from the acoustic stimulus, they can figure out the frequency of the beat and then deliver that beat frequency by flashing lights. And so you could be looking at lights that are smart, like Christmas lights, but that can detect the downbeat. This is possible even when there's no energy at the downbeat, such as in a syncopated piece of music. Then, by adding a level of gamma stimulation to lights that are already dancing to the music, we can use this system as a new form of brain stimulation. And in doing so we could take advantage of the natural phase-amplitude coupling that's in the brain, and also take advantage of the fact that people are already very motivated to listen to music, to use music-modulated lights as a form of brain stimulation and to test the ability of this system to affect cognitive behavior. We are currently testing this on young adults as well as on older adults. And then we hope to move on to people with mild cognitive impairment and with Alzheimer's disease.

Summary and Conclusions

I have reviewed a few examples of use-inspired cases for music cognition. The different projects that I have covered are all very new; they are all in different stages of completion.

To summarize, the music listening intervention project takes advantage of work from music and the reward system, and informs us about the role of agency in selecting stimuli. Again, we see evidence that not one size fits all, but the need to respect individuals' interest and desires and tastes in selecting music for an intervention that works. The work on dance for Parkinson's highlights the role of groove and sensorimotor coupling, and the possibility of harnessing that towards an intervention that helps reduce symptoms in a needy population.

The work on functional music for cognition, points at the role of oscillations and entrainment at both behavioral and neural levels for cognition. While these studies are just getting started, they highlight the need for designing control studies and asking tough questions that get at the active ingredients in an intervention, and the ways in which a research program may adequately control for extraneous factors that covary with the intervention in affecting outcomes.

To get back to the future directions of music cognition, I believe that music cognition research can be useful as

well as informative. While we pursue research for our own interests, it is also useful to be guided by other people's needs in identifying possible research questions. This understanding, when applied to one's preferred level of analysis, may yield important information for how we design interventions to help those who need it the most. Finally, working across disciplines and across different lines of inquiry will be useful for informing future musical experiences. In some ways, perhaps the best music might not have been heard yet, and perhaps the best musical experiences might not have happened yet. There is need for working with people from different backgrounds and training, such as with music therapy and with sound design, that can contribute towards useful research.

Acknowledgements

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