The Effect of Music on Cognition and Task Performance

by

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Abstract

In this theoretical paper, a review of literature discussing the effect of music on cognition and task performance is conducted. Following this investigation, the prevailing explanation for how music impacts humans (namely, the mood/arousal hypothesis) and its supporting research is discussed. In brief, the mood/arousal hypothesis states that music affects cognition and task performance by influencing our mood and/or physiological arousal, which then influences our cognition and task performance. Subsequently, a section going over the neurochemical basis for the effect of music on cognition and task performance ensues. Specifically, literature examining what neurotransmitters and hormones are influenced by music, the effects of some of those neurotransmitters and hormones, and possible connections between neurochemical literature and mood/arousal hypothesis are discussed. Lastly, this paper concludes with a summary and paragraphs containing limitations and possible future research of interest to support findings within this paper.

Keywords: mood, arousal, music, cognition, task, task performance, neurotransmitters, hormones, neurochemicals, theory, theoretical

The Effect of Music on Cognition and Task Performance

Of the various common art forms, music is often the most prolific and most evocative within a culture. One need only examine its usage in mediums such as television, movies, video games, and music stations on the radio to name a few. That being said, it is also worth examining in what ways music impacts us and how it does so. Specifically, this paper will examine the effect of music on task performance. A task is simply a job, a duty, or an assignment that one decides to undertake.

As part of this paper, there will be an examination of two dimensions of musically-induced emotions - mood and arousal - with regards to cognition and task performance. Ultimately, while by no means exhaustive, this paper will look at the various types of tasks to which music has been applied, various theories as to the mechanisms through which music may impact task performance, and attempt to integrate ideas of past and current research to bring to light any true connections between music and task performance.

Origins of Music and Task Performance Research

It would be appropriate to commence by discussing early research with regards to music and task performance. One of the early studies that examined the relationship between music and task performance was conducted by Rauscher, Shaw, and Ky (1993), who examined the effect of listening to classical music (in particular, Mozart) on spatial task performance. The experiment was a within-subjects study; the same participants were a part of each condition. There were a total of three conditions: a music condition with a Mozart sonata, a relaxation condition in which instructions were given that were designed to lower the heart rate of the participants, and a silence condition. Before testing on the spatial task, participants were exposed to each condition for ten minutes. After ten minutes of each condition, the participants were given a spatial reasoning test from the Stanford-Binet Intelligence Scale. The results of the experiment showed that participants performed significantly better in the music condition compared to both the relaxation condition and the silence condition and that the relaxation condition did not differ significantly from the silence condition. In particular, the difference was comparable to that of having 8-9 points higher in spatial IQ based on the researchers' translation of the participants' scores. One important note, however, is that the effect only lasted for 10-15 minutes. As a result, while the effect may result in an impressive boost, its short duration brings into question what long-term value, if any, may be had.

In 1995, Rauscher, Shaw, and Ky once again looked at how listening to Mozart can benefit spatial-temporal task performance. The task set before participants was a common spatial-temporal task known as the Paper-Folding & Cutting task (PF&C) in which one would attempt to mentally unfold a paper after it has undergone a series of foldings and a piece is cut. An example is shown below.

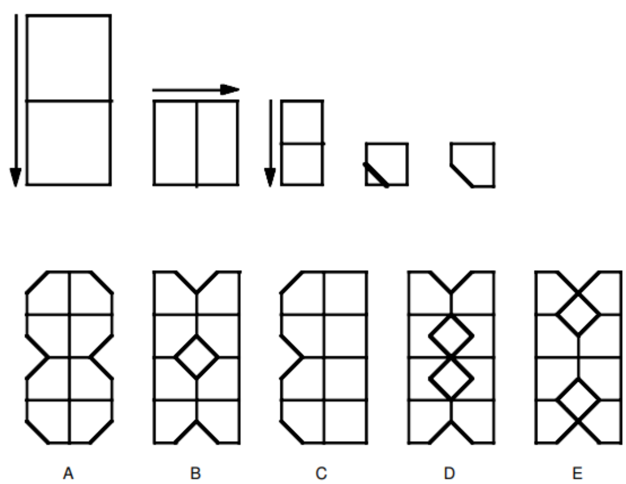


Figure 1. A demonstration of a typical PF&C task. The answer is B.

Participants were split into three groups: a music condition (that listened to a Mozart sonata), a mixed audio condition (that listened to different pieces of simplistic/repetitive music every day), and a silence condition. Over five consecutive days, each group was exposed to their condition for ten minutes and then tested on the PF&C task. Between days 1 and 2, the music condition had a significant improvement compared to the other two groups; however, this effect did not last. While the music condition still performed the best overall out of the three conditions, for days 3, 4, and 5 there was no significant difference between the music condition and the silence condition. The authors attributed this phenomenon to a normal learning curve and speculated that adding progressively difficult PF&C questions would likely have helped distinguish effects between conditions. Notably, the authors proposed that listening to music may improve spatial reasoning by helping to ‘organize’ cortical firing patterns so that other cortical patterns that might have occurred would not, thus focusing the brain, and perhaps consciousness, of the individual when it came time to perform the PF&C task.

As a result of these studies and the fact that they used a Mozart sonata as their stimulus, the notion of there being a “Mozart effect” took off. In fact, it was so popular that around 1998 Georgia Governor Zell Miller budgeted money so that a CD or cassette could be given to the family of each infant born in the state.

Despite the public interest in the Mozart effect, there was research that started to come out providing evidence that the Mozart effect was not quite what people had imagined it as being. In 1999, Nantais and Schellenberg proposed that the Mozart effect may actually be a result of a preference for the stimulus and not a result of anything inherent to Mozart’s music. In this study, the authors pointed out that successful replications of the Mozart effect only occurred in studies in which the control conditions sat in silence or listened to relaxation tapes or repetitive music. Such conditions are apt to be considered as less arousing and may induce boredom in participants. As a result, clarification as to which condition was preferred by the participants would help to distinguish if preference is a relevant factor when it comes to spatial-temporal task performance.

Nantais and Schellenberg (1999) published the results of two experiments exploring the potential mechanisms driving the earlier results of Rauscher, Shaw, and Ky (1993 & 1995). In their first experiment, participants were tested over two days. On the first day, the participants sat in silence for ten minutes and were then given PF&C tasks to complete. On the second day, one group of participants listened to a Mozart sonata for ten minutes while another group listened to a Schubert piece for ten minutes, and both were then given the PF&C task. Nantais and Schellenberg found a main effect of listening to music on scores of the spatial-temporal tasks when compared to sitting in silence; however, there was no difference between the Mozart and Schubert groups. In other words, the results of their first experiment showed that there was no effect of *what* music was listened to, essentially refuting the idea that Mozart's music has any intrinsic properties that boost spatial-temporal task performance. Rather, it is that listening to music rather than sitting in silence is better for spatial-temporal task performance. For the researchers' second experiment, the first day the participants listened to a Mozart sonata for ten minutes, then performed the PF&C task. On the second day, however, the participants listened to a short story for ten minutes then performed the PF&C task. Additionally, this time the researchers asked participants which condition they found preferred. Notably, the researchers found no significant difference between scores after the Mozart condition relative to the short story condition. However, there *was* a main effect for the participants' preferred condition on PF&C scores. That is, whichever condition participants preferred (Mozart's sonata *or* the short story), they performed significantly better after that condition compared to the condition which they preferred less.

Synthesizing both the results of the first and second experiments, Nantais and Schellenberg (1999) asserted that listening to something you enjoy may put you in a focused attentional state, thereby improving spatial-temporal task performance (e.g. performance on PF&C tasks). More generally, they asserted that any positive stimulus paired with a less engaging stimulus may lead to the “Mozart effect,” i.e., a notable improvement in task performance allegedly due to a given stimulus. Also of importance, the authors noted that one reason for the appearance of the Mozart effect in studies comparing a silence and music condition may be due more to the silence condition rather than the music condition. In other words, the silence condition may be detrimental rather than the music condition being beneficial (more generally, an unpleasant stimulus versus a pleasant stimulus condition), and therefore when the scores are compared there is the appearance that music induces a positive effect.

While only scratching the surface, the three aforementioned studies exemplify that the ways by which music impacts us are by no means simple, even though the research itself may appear to be. It should also be noted that the previous three studies looked exclusively at the effect of music on spatial-temporal task performance; there are many types of tasks where one might apply music. In addition, there are various properties of music to consider when discussing what may make one song more advantageous relative to another (e.g. tempo, modality, etc). Compounding the issue further, the interaction between different tasks and varied properties of music is the ultimate question to be investigated; by changing the task or a property of the music to be heard, it is likely the result will be different even if all else is held constant. Thus, the goal of the next sections will be to investigate the aforementioned notions, while also examining research under a variety of perspectives to clarify potential mechanisms of music’s influence on task performance.

Timing of Music in Relation to Tasks

It should be noted that the studies examined so far have only tested the influence of music when the music was played *prior* to task performance (Nantais & Schellenberg, 1999; Rauscher, Shaw, Ky, 1993,1995). Fortunately, other studies have examined how music influences task performance when participants listened to music *during* task completion (Burleson, Center, & Reaves, 1989; Cassidy & MacDonald, 2007; Dalton & Behm, 2007; Mohan & Thomas, 2020; North & Hargreaves, 1997; Thompson et al., 2012).

For instance, Cassidy and MacDonald (2007) found that participants listening to music and noise performed worse than participants completing tasks in silence when comparing immediate recall, free recall, and delayed recall tasks, in addition to performing slower in a Stroop task. Using a reading comprehension task, Mohan and Thomas (2020) found that participants performed better listening to music compared with when they sat in silence. However, Thompson et al. (2012), also using a reading comprehension task, found that fast and loud classical music negatively impacted reading comprehension compared to silence and that otherwise, music did not have a significant effect.

In 1974, Baddeley and Hitch proposed the *Working Memory Model* for how memory works, most relevant of which distinguishes between how auditory information and visual information are processed differently. As suggested by the model, the visuo-spatial sketchpad processes visual information, whereas the phonological loop processes auditory information. According to this model, music would compete with incoming stimuli within the phonological loop; on the other hand, one would expect the visuo-spatial sketchpad to be virtually unaffected. This may explain the differences seen in research results demonstrating that music may help or harm task performance; the type of task being performed is likely relevant in determining whether music will improve or worsen performance on a given task. Research results where music has been found to be detrimental may also be explained by this model via executive function. Executive function, which directs attention, would likely be impacted by distractions (e.g., loud music), and therefore if music negatively impacts attention, one would expect negative effects on performance.

Other studies looking at less attentionally-controlled tasks have also found music to be beneficial. For example, Dalton and Behm (2007) conducted a meta-analysis of literature looking at the effect music has on driving. While not readily obvious, driving requires long periods of concentration, situational awareness, and making attentive decisions to name a few skills involved. Dalton and Behm wanted to examine whether music is more beneficial or detrimental to driving. Before examining the effect of music, the authors examined the effect that noise has on tasks involving similar skills as employed in driving such as vigilance and processing. Although driving tasks employing noise were not examined, the authors reported that noise (whether intermittent or continuous) can adversely affect vigilance, attention, concentration, and cognitive processing in other tasks. It’s possible, as previous studies have found, that music may help by blocking out noise that would’ve otherwise been heard and interfered with task performance (Burleson, Center, & Reeves, 1989). In relation to driving, Dalton and Behm relayed that music has been shown to affect driver stress, subjective anxiety, relaxation, and driving speed. Music may decrease frustration during heavy traffic and increase awareness and alertness while driving. On the other hand, the authors reported that listening to fast tempo music has been associated with an increased incidence of collisions, lateral weaving, and disregarding red lights. One potential mechanism for the effect of music on task performance is known as the mood/arousal hypothesis (Husain et al., 2002), which will be discussed in depth later on.

However, it should be noted that if one were to consider a piece of music arousing, it would explain various aforementioned effects, such as increased alertness/awareness, as well as increased risky behavior. Similarly, if a piece of music evokes a positive mood, this would explain the aforementioned effects such as decreased frustration or decreased stress/anxiety. It should be noted that with all tasks used in experiments, the underlying skills that are enhanced or detracted from may be transferable, and thus the research may be generalizable to other tasks as well. For example, if driving specifically is not of interest to a researcher, the skills involved such as vigilance and concentration, may be.

A brief distinction should be discussed in this sense with regards to the timing of music before compared to during a task. Logically speaking, any benefits derived from listening to music before performing a task would have to last long enough through the completion of the task, or at least be evoked initially through music and maintained through other means. Otherwise, the effect of music would be initially apparent but then taper off. Conversely, any benefits derived from listening to music during a task would have to be capable of being evoked in the presence of other stimuli, namely, the task to be performed and its stimuli. Relatedly, the properties of the specific music being listened to greatly influence how the listener is affected; a fast-paced heavy metal song and a slow-paced classical piece are likely to incur different effects in the same individual listening given that they are quite different. As a result of these differences, the following section will look into the properties of music and how research has found them to affect individuals.

Properties of Music (and Their Effects on Task Performance)

As previously stated, various properties of music can impact the individual listening to it. However, the two that will be examined in this paper are musical mode and tempo, as they appear to have the most distinct effects on cognition and task performance. Before delving into musical properties, an explanation of the mood/arousal hypothesis of music's effect on cognition and task performance will help understand why/how these properties are purported to affect listeners. There are two aspects to the mood/arousal hypothesis, namely mood, and arousal.

Mood

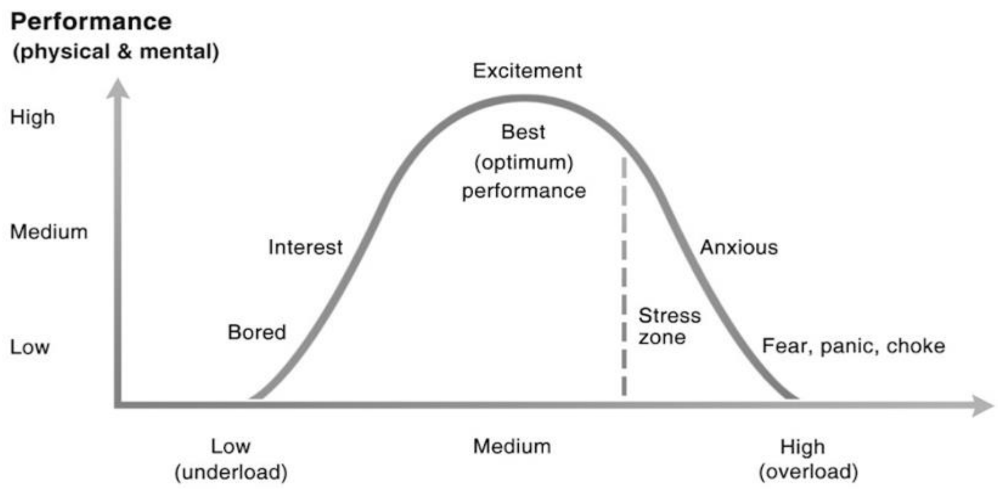
First, let us examine mood. The idea proposed by the mood/arousal hypothesis is that by listening to music, one's mood can be affected; various studies have demonstrated that such is the case (Husain et al., 2002; Thompson et al., 2001; Dalton & Behm, 2007). From there, the idea is that one's mood will affect their cognition.

There is evidence that mood can influence cognitive performance. Across four different experiments, Isen et al. (1984) found that positive affect (i.e. mood), induced by having participants watch a humorous film or giving them candy, improved creative reasoning on Duncker's (1945) Candle Task and the Remote Associates Test (Mednick et al.,1964). Participants in the positive affect condition were significantly more likely to complete the Duncker task and to complete more questions from the Remote Associates Test compared to those in the control condition. Based on past research as well as their study, the authors posited that positive affect tends to change how we perceive the relatedness of stimuli. In the aforementioned tasks, the ability to relate words and combine materials in ways that aren't readily apparent is fundamental for task completion. In fact, in 1962, Mednick *defined* creative thinking as "the forming of associative elements into new combinations which either meet specific requirements or are in some way useful." Therefore, we begin to see the connection between positive affect and creativity, an aspect of cognition.

In addition to positive affective states, negative affective states also affect cognition. Shields et al. (2016) found that negative affect impaired cognition. Specifically, the authors found that anxiety impaired executive function as tested through the Wisconsin Card Sorting Test (WSCT; Berg, 1948). Participants first took a pre-affect induction WSCT to establish a baseline. Then, after a forty-minute filler task, depending on their assigned condition participants wrote a short autobiographical recount of an unresolved anxiety-provoking event, an unresolved anger-provoking event, or simply about their past day (control condition). Finally, the participants again took the WSCT to test post-induction executive function. The authors found that participants in the anxiety induction condition committed significantly more perseverative errors compared to the anger induction condition or the control. This means their executive function was not able to update to the implicit rule changes inherent to the WSCT as quickly as the participants in other conditions. One might generalize this as increased inability to adapt when circumstances require it. Naturally, such a skill would be important when one's schema needs to change to perform a task correctly or optimally. Therefore, with both positive and negative affect, we see there is indeed a connection between affect (i.e. mood) and cognition. Of importance to note was how affect was induced in both studies. The methods of inducing emotion in these studies were not particularly complex or unlikely to occur in daily life, such as receiving an unexpected gift, having a humorous conversation, or alternately, ruminating over a negative experience, etc. Therefore, it is likely that music can induce affect in a way similar to those used in these studies just as previous studies have shown (Husain et al., 2002; Thompson et al., 2001; Dalton & Behm, 2007).

Arousal

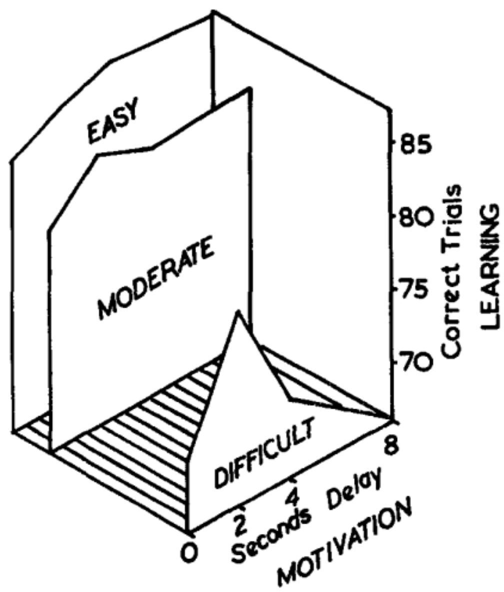
The second aspect of the mood/arousal hypothesis is that physiological arousal impacts cognition. The primary theory for this purported effect originates from the Yerkes-Dodson Law exemplified in the figure below.



In essence, the idea is that when someone is optimally aroused, then they will perform optimally. However, arousal has an inverse-U-shaped curve; optimal arousal, and thus optimal performance, lies between being under-aroused and over-aroused.

In 1957, Broadhurst used rats to design an experiment that provided great experimental support for the Yerkes-Dodson Law. The rats were placed in an underwater starting cage that would either be immediately open, or opened after 2, 4, or 8 seconds. This manipulation was meant to serve as air deprivation and was to create physiological arousal. Proceeding the underwater starting cage, two pathways, each with a distinct light source, were available to the rat to escape. The rats were to discriminate the greater amount of light coming from two pathways to correctly discriminate the exit. In addition to the air deprivation manipulation, there was also a manipulation for the difficulty of the light discrimination. All 120 rats were tested in

100 trials each, and results seemed to strongly support the existence of the Yerkes-Dodson Law. The manipulation of air deprivation was statistically significant. As shown in the figure below, the optimal amount of air deprivation was around 4 seconds, with both 0 seconds and 8 seconds being inferior in terms of learning over the 100 iterations of trials. This figure, particularly for the difficult condition, parallels the Yerkes-Dodson Law graph very closely.



Beyond demonstrating that physiological arousal affects cognition, research has shown music's ability to affect arousal, thus linking music and arousal to cognition (Husain et al., 2002; Mayfield et al., 1989). Having established the basis for the mood/arousal hypothesis by further investigating the impact mood and arousal have on cognition, we may now begin to link music to mood and arousal to investigate how music may impact us via these two mechanisms.

Mode

The musical mode of a song is determined by the mathematical relationships between the fundamental frequencies of the pitches used in a musical piece. The topic of interest when discussing musical mode is whether the song is in the major or minor mode, the two most common modes used in Western music. Perceptually, these modes tend to denote whether a song is perceived as ‘happy’ or ‘sad.’ The consequent idea is that the happiness or sadness of a song can impact the mood of the listener, and thus affect their cognition.

Since the connection between mood and cognition has already been discussed, it will suffice to demonstrate the link between music and mood. Various studies have shown the link between musical mode and mood (Husain et al., 2002; Thompson et al., 2001; for a review, see Bharucha, Curtis, & Paroo, 2006). For example, as part of their research, Thompson et al. (2001) found that participants in different music conditions (one “happy” and one “sad”) had their mood impacted in a statistically significant manner, even though there was no initial mood difference between both groups.

Tempo

The tempo of a song corresponds to the beats per minute (bpm) of a song. Perceptually, this is the speed at which music is played; music at a higher BPM is perceived as faster music, and vice versa. The consequent idea is that a song’s BPM will affect a listener’s physiological arousal and thus impact their performance (speed them up/slow them down, engage/bore them, provoke/calm them, etc). Multiple studies have found such a link between musical tempo and performance (Husain et al., 2002; Mayfield et al., 1989; Thompson et al., 2001).

Husain et al. (2002) examined the effects of tempo on arousal and spatial abilities. The researchers took a midi version of one piece of music, a Mozart sonata, and digitally edited it so that there would be a fast major version, a fast minor version, a slow major version, and a slow minor version (165 bpm and 60 bpm for fast and slow versions respectively). Researchers then separated the participants into each condition so that each group would listen to only one version of the piece for ten minutes, and then attempt the previously discussed Paper Folding and Cutting (PF&C) task. The results demonstrated that there was a significant effect of tempo, with higher scores in the fast tempo condition than the slow tempo condition, but no significant effect of mode on task performance. Their results are demonstrated below (figure from Husain et al., 2002).

The most notable difference was between the fast major condition and the slow minor condition, as the average score was double in the former compared to the latter (16 vs 8) despite all else being equal. Such results are likely explained by the previously discussed mood/arousal hypothesis; by listening to the fast version of the piece compared to the slow version, participants were more engaged with the PF&C test due to enhanced physiological arousal, thus explaining the mean differences.

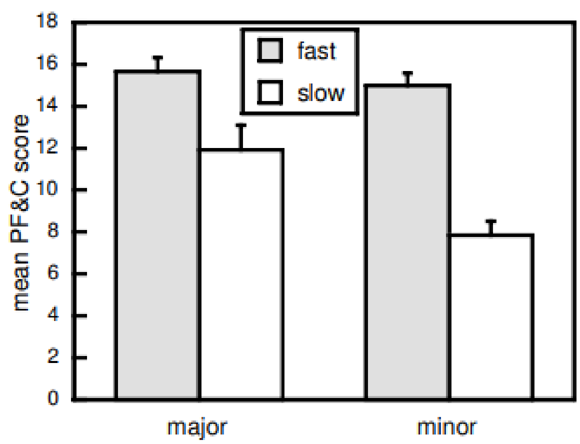


Fig. 3. Mean scores on the paper-folding-and-cutting (PF&C) task as a function of the tempo and mode manipulations. Error bars represent standard errors.

Neurochemical Basis

In an attempt to further establish the accuracy of the mood/arousal hypothesis, it is important to consider the underlying physiology by which music may influence mood; the human body uses neurotransmitters and hormones to communicate. Therefore, what follows in the next section will be an examination of the neurotransmitters and hormones that have been linked with music, describing their effects and possible applications, and lastly examining any potential link between the mood/arousal hypothesis and neurotransmitters and hormones.

Firstly, since research involving the introduction of exogenous neurotransmitters and hormones will be discussed later on, it should be established that there are multiple issues with regards to the validity of such research and their subsequent application to music and task performance. First, and perhaps most critically, is that the introduction of exogenous neurotransmitters produces a comparable effect to if the neurotransmitter had been increased by the body itself. This poses an issue for a few possible reasons; however, the greatest concern would likely be the crosstalk that can occur between certain neurotransmitters such as oxytocin and vasopressin (Baribeau & Anagnostou, 2015). These two neurotransmitters are both neuropeptides with nine amino acids and only differ by two amino acids. As a result of their similar chemical structure, vasopressin can act as an oxytocin agonist, albeit with less efficacy than oxytocin, and vice versa. This may be especially problematic when introducing exogenous neurotransmitters given that their introduction is analogous to a spontaneous spike in their production and subsequent distribution into the body. Notably, wherever the neurotransmitters first encounter receptors they can bind to is most likely subject to change depending on the means of introduction and site of introduction; using an intranasal spray versus a topical gel would almost certainly result in different receptors being encountered first. This crosstalk capability would thus make it difficult to parse out the combination of neurotransmitter and receptor that is producing a certain desired or undesired effect, or whether the effect is a result of instances of neurotransmitter-receptor and agonist-receptor binding, or whether the effect believed to be derived from one neurotransmitter is more aptly ascribed to another.

Secondly, within a given administration there is no accounting for the variation of transport; given multiple blood vessel pathways, it is unlikely that all neurotransmitters of a given administration would go down the same path. Certain neurotransmitters such as neuropeptides vasopressin and oxytocin cannot directly pass the blood-brain barrier; their exogenous administration results in detectable increases in the respective neuropeptides in blood plasma (Born et al., 2002; Gossen et al., 2012) and in the cerebrospinal fluid (Born et al., 2002). Although it has been found that neuropeptides do ultimately reach the brain (Chen et al., 1998; Martins et al., 2019), one would expect that for neuropeptides, or neurotransmitters and hormones that do not immediately cross the blood-brain barrier upon administration, that there would be some “lost” on the way to the brain, especially for those chemical messengers such as testosterone that have receptors within the body as well as the brain. This may also make it difficult to discern how much of a given neurotransmitter or hormone is needed to produce/avoid a given effect; for example, if administration of 50 ng of a neurotransmitter that does not cross the blood-brain barrier resulted in 30 ng reaching the brain, one would believe 50 ng was required whereas 30 ng directly reaching the site was required. Given multiple instances, it’s possible variations of 30 ng, 20 ng, 40 ng, etc would reach the brain, and that would again complicate achieving accuracy with regards to how much of a neurotransmitter is needed to elicit/avoid a given effect. While the aforementioned issues are not exhaustive of the list of potential issues within this field of study, they are especially relevant when trying to establish a connection between the neurotransmitter and hormone field of research and the music field of research.

Musical Elicitation of Hormones and Neurotransmitters

Since there is no uniformity with regards to the types of music that have been implemented within the following studies, the main point of this section will be to simply establish that music has been found to significantly influence neurotransmitter and hormone levels. That being said, an idea of the type of music used in the studies to be discussed will be noted for greater clarification.

Music has been found to significantly elicit a variety of neurotransmitters (Fukui, 2001; Fukui & Toyoshima, 2013; McKinney et al., 1997; Moraes et al., 2018; Ooishi et al., 2017; Qiu et al., 2017; Salimpoor et al., 2011; Yamamoto et al., 2003). Fukui and Toyoshima (2013) found that listening to music the participants preferred and music the participants disliked significantly reduced cortisol relative to baseline measures. Ooishi et al. (2017) found that fast-tempo music significantly lowered cortisol levels and did not significantly impact oxytocin when compared to baseline measures, whereas slow-tempo music significantly increased oxytocin but did not significantly impact cortisol when compared to baseline measures. In addition, Fukui and Toyoshima found estradiol significantly increased in males listening to both preferred music and disliked music, and in women listening to preferred music. Fukui (2001) found music across a variety of genres significantly decreased testosterone in males but significantly increased testosterone in females. Yamamoto et al. (2003) found that slow-tempo music significantly decreased norepinephrine levels whereas fast-tempo music significantly increased epinephrine levels. McKinney et al. (1997) and Qiu et al. (2017) found that music along with another therapeutic intervention significantly influenced β-endorphin. Lastly, and perhaps the strongest piece of evidence that music influences neurotransmitter and hormone levels are the results of Salimpoor et al. (2011). Using fMRI and PET technology, the authors found direct evidence that pleasurable feelings associated with music are due to dopamine release in the mesolimbic reward system.

Neurotransmitters, Hormones, and Cognition

Having therefore established that music influences neurotransmitters and hormone levels, the following section discusses what each neurotransmitter and hormone has been found to influence with regards to cognition and human behavior.

Oxytocin

Research has found that oxytocin has been linked with prosocial behavior (Domes et al., 2006; Israel et al., 2012; Riedl et al., 2017; Schulze et al., 2011), but not with the types of cognitive benefits associated with the mood/arousal hypothesis. For example, Riedl et al. (2017) found that oxytocin was significantly correlated with the initial trust of a partner in a monetarily based game. Similarly, in another monetarily based game, Israel et al. (2012) found that oxytocin significantly increased the willingness to donate instead of giving to oneself and significantly affected the perception that others would behave similarly. Additionally, Domes et al. (2006) and Schulze et al. (2011) found that intranasal spray of oxytocin led to an increase in emotion recognition compared to control groups. In particular, Domes et al. (2006) found that oxytocin helped with recognizing emotions based on facial cues of the eyes and that the effect was pronounced with the difficult task questions. Likewise, Schulze et al. (2011) found that oxytocin improved recognition of emotions in a task involving an emotionally charged face that would be masked by a neutral face after 20-50 milliseconds, and found that the effect was particularly pronounced for positive emotions (i.e. happy faces).

Given these effects, there are a couple of applications toward which one would expect music eliciting oxytocin to be useful. Generally speaking, it appears that oxytocin is strongly related to social behaviors. Therefore, jobs relying on social interaction would benefit the most from using music eliciting oxytocin. For example, those in managerial jobs would benefit from the emotion recognition aspect associated with oxytocin; one would have an increased capacity to deal with issues by recognizing negative emotions more often. In the long run, dealing with issues while they are small or that otherwise may not have been addressed would at the least maintain morale and group cohesion, if not improve them, given fewer issues in the background. Similarly, when negotiating, increased trust and emotion recognition would benefit both parties as it would decrease the likelihood of disagreements based on mistrust rather than logic/argumentation, and likewise, the increased emotion recognition would enable both parties to work around negative emotion indicators as they appear. While oxytocin appears to have benefits for social interaction, the reported effects do not make it a good candidate for explaining the cognitive benefits reported with the mood/arousal hypothesis.

Testosterone

Testosterone has been linked with a variety of behaviors such as dominance, anxiety, reactivity to threats, etc. (Boksem et al., 2013; Carré et al., 2017; Goetz et al., 2014; Knight et al., 2017; Mehta et al., 2017; Terburg et al., 2016; Wagels et al., 2017; Welling et al., 2016). However, Boksem et al. (2013) suggested that the overarching idea that seems to tie its associated behaviors together is status. Particularly, the achievement and maintenance of status seem reflective of the behaviors/perceptions in the following literature to be discussed.

For example, various studies have associated testosterone with dominance and self-perception with regards to dominance (Mehta et al., 2017; Terburg et al., 2016; Wagels et al., 2017; Welling et al., 2016). In a personal distancing task, Wagels et al. (2017) found that exogenous testosterone decreased the space men would distance themselves from angry men, women, and animals when compared with the control group. Welling et al. (2016) found that men naturally higher in testosterone and men low in testosterone but administered exogenous testosterone were more likely to choose a more masculine image than they themselves actually appear, given a slew of self-pictures that were edited to be various levels of masculine and feminine. In conjunction, the notion that testosterone increases the self-perception that one is dominant begins to appear. Terburg et al. (2016) found that socially anxious men that were administered exogenous testosterone had their social anxiety abolished as shown in an eye-gaze aversion task; that is, socially anxious men had significantly faster eye-gaze aversion with angry faces compared to neutral/happy faces, and post testosterone administration this effect was negated and, in fact, reversed such that gaze time at angry faces was increased compared to neutral/happy faces. Mehta et al. (2017) found a significant association between basal testosterone levels (naturally occurring testosterone) and frequency of making dominating choices in an economic game; higher basal testosterone led to making more dominance choices whereas lower basal testosterone led to more deference choices. This was interesting given that both the reward (4) and cost (0) of playing the dominance choice was greater than playing the deference choice (2 if both played deference choice, 1 if the other played dominance choice). In other words, testosterone made the participants more likely to play the high-risk-high-reward option over the low-risk-moderate-reward option. Thus, to tie it back to status, the previously mentioned studies display the association between testosterone and dominance/willingness to aggression.

A few studies have found that testosterone seems to be associated with higher reactivity towards negative stimuli (Carre et al., 2017; Goetz et al., 2014; Knight et al., 2017), and this too can be explained with the status explanation Boksem et al. (2013) suggested. Particularly, with the preservation of status. For example, Knight et al. (2017) found that men high in dominance that received exogenous testosterone had significantly higher cortisol in response to social evaluation when compared with men high in dominance that did not receive testosterone, and when compared with men low in dominance (regardless of condition). Similarly, Carre et al. (2017) found that males high in dominance administered exogenous testosterone were more likely to employ hostile aggression (of no personal benefit) in response to perceived aggression. Lastly, and perhaps of most relevance, Goetz et al. (2014) found that exogenous testosterone administration led to significantly higher activation of the amygdala toward angry faces when compared with those not administered exogenous testosterone.

In terms of status, increased reactivity toward negative stimuli may be explained as a heightened sensitivity toward status threats, and thus serve as signaling to the body/self of a status challenge. For example, typically angry faces are associated with arguing/fighting, which are themselves a form of a status challenge; one who is subordinate would not argue/fight with a superior without expressing a challenge to their authority.

In addition to the previous benefits discussed, testosterone has also been tied with cognitive benefits, particularly with spatial reasoning (Janowsky et al., 1994; Lu et al., 2006; Perry et al., 2001). Lu et al. (2006) found that healthy participants treated with testosterone demonstrated a statistically significant improvement on the Developmental Test of Visual Motor Integration (a spatial task) when compared with baseline, whereas the placebo group remained near baseline levels. Perry et al. (2001) found insignificant correlations relating bioavailable testosterone and cognition, but a near significant trend ($p = 0.051$) that declining bioavailable testosterone was associated with impaired executive function based on the EXIT25 executive function interview, as well as impairment in cognitive flexibility based on the Trail Making Test. Lastly, through administration of exogenous testosterone, Janowsky et al. (1994) found a relatively strong inverse relationship ($r = -0.52$, p = 0.006) between estradiol (an estrogen hormone) and performance in the Block Design task; crucially, the authors noted that testosterone is known to have inhibitory effects on estrogen. Taken together, these studies support a link between testosterone and cognition.

Thus, it appears testosterone may be useful in settings where competition is beneficial to the individual/organization. For example, a professional athlete would likely benefit from the desire for status and the subsequent maintenance of that status. This desire for status would serve as an impetus for the athlete. In a less obvious manner, framed differently testosterone may also be a boost in other “competitive” settings. If one’s “competition” is oneself, by seeking to improve self-performance one achieves status by increased productivity and efficiency. Given success, testosterone would also help with the desire to maintain that status and a heightened awareness of other status threats (in this context, things that impair productivity/efficiency). Alternatively, testosterone would likely improve performance in tasks requiring spatial reasoning such as navigation or spatial learning in a given area. Despite these benefits, it does not appear that testosterone is a good candidate hormone for explaining the impact of mood and arousal on cognitive performance given its effects seem to be primarily social in nature, not cognitive, and given that the benefits do not seem to arise through the influence of mood or arousal.

Epinephrine/Norepinephrine

Epinephrine and norepinephrine (otherwise known as adrenaline and noradrenaline) have been strongly linked with memory enhancement (Flint et al., 2006; Jurado-Berbel et al., 2010; Liang et al., 1990; Loron-Sanchez et al., 2016; Mcgaugh, 2000). It seems that the way that epinephrine affects memory is by influencing the amygdala (Mcgaugh, 2000). Specifically, it does so by acting on beta-adrenergic receptors located peripherally as epinephrine is not capable of crossing the blood-brain barrier (Mcgaugh, 2000); however, administration of epinephrine also appears to increase norepinephrine in the amygdala (Mcgaugh, 2000). Conversely, lesions of the amygdala prevent the memory-enhancing effects of epinephrine and norepinephrine (Mcgaugh, 2000).

To reiterate, epinephrine and norepinephrine have been linked with enhancing memory. For example, Jurado-Berbel et al. (2010) found that by giving rats epinephrine, they performed significantly better in a memory task in both the short term and the long term when compared with rats that were not given epinephrine. Liang et al. (1990) found that both epinephrine and norepinephrine were found to improve the rate of learning on an inhibitory avoidance task (learning to inhibit the desire to explore to avoid a shock). Liang et al. (1990) also found that by lesioning a brain area known as the stria terminalis, which has pathways to the amygdala, the memory effects of epinephrine and norepinephrine were absent. Similarly, Flint et al. (2006) found that even in very young rats with infantile amnesia (memory loss simply due to not having fully developed brains), epinephrine was able to attenuate the effects of, but not negate, infantile amnesia when compared with adult rats. Hence, it appears that structural foundations are important for epinephrine and norepinephrine, if not all neurotransmitters and hormones, to take effect. Conversely, Loron-Sanchez et al. (2016) found that epinephrine was able to reverse the memory impairment associated with surgically induced traumatic brain injury (TBI). When compared with rats who received surgically induced TBI but no epinephrine, rats with surgically induced TBI and epinephrine did significantly better. In fact, the authors found there was no significant difference between the rats with TBI and epinephrine and the rats that were only sham-operated; epinephrine effectively negated the memory impairment associated with TBI.

Epinephrine/norepinephrine have also been implicated with attention (Hanna et al., 1996). Hanna et al. found that boys with attention-deficit hyperactivity disorder (ADHD) had significantly lower levels of urinary epinephrine when compared with control groups. Similarly, one of the treatments for ADHD is prescription medication that works by inhibiting the reuptake of norepinephrine, such as Atomoxetine. This would, at the least, suggest that abnormally low amounts of epinephrine are linked with attention disorders.

Having discussed the effects of epinephrine and norepinephrine on memory and attention, the applications are simple. It is rare that any individual or organization would not benefit from enhanced memory. Therefore, the only consideration noted will be in cases where the task itself evokes epinephrine and norepinephrine; it's possible having too much epinephrine and norepinephrine would be detrimental. Epinephrine and norepinephrine appear to be great candidates for explaining the impact of mood and arousal on cognitive performance and therefore may play a role in producing the cognitive benefits associated with listening to music.

Dopamine

Dopamine has been strongly linked with reward-seeking behaviors and the modification thereof (Chowdhury et al, 2013; du Hoffmann & Nicola, 2014; Pessiglione et al., 2006; Weiland et al., 2014). For example, Weiland et al. (2014) found a correlation between positron emission tomography (PET) scans and functional magnetic resonance imaging scans between dopamine release and activation in reward-anticipation regions when participants undertook monetary incentive delay tasks. Chowdhury et al. (2013) found that when older adults were given a drug to increase dopamine, there was no significant difference when compared to young adults given no treatment in a reward association task. Importantly, there *was* a significant difference between the older adults given a placebo drug and the young adults. According to the authors, this is particularly notable given that as one ages they also tend to lose dopamine neurons within the substantia nigra and ventral tegmental area, both regions involved with the production and projection of dopamine. Therefore, the increased dopamine provided via the drug helped to substitute for the loss of dopamine neurons within these areas and helped improve the performance of the older adults receiving the drug treatment. Pessiglione et al. (2006) found that in a financial choice game based on probability, there was a significant difference between the group given a drug to increase dopamine, and the group given a dopamine antagonist. Notably, the drug differences did not impact losses between groups, resulting in similar losses between both groups, but resulted in increased gains in the group given the dopamine increasing drug. du Hoffman & Nicola (2014) found that bilateral injection of a dopamine antagonist into the nucleus accumbens significantly reduced the abilities of rats to associate a stimulus with reward, and significantly increased the physical response time when responding to the reward stimulus vs non-reward stimulus. Similar to Pessiglione et al. (2006), du Hoffman & Nicola (2014) found that losses due to inhibition failure were not impacted. In conjunction, both studies suggest that dopamine influences reward acquisition behavior, but not inhibition against reward-reducing stimuli.

Dopamine has also been linked with cognition and attention (Dang et al., 2012; Dougherty et al., 1999; Klostermann et al, 2012). For example, medications that inhibit the reuptake of dopamine, such as Methylphenidate, are commonly used in treating ADHD. Using SPECT scans, Dougherty et al. (1999) found that people with ADHD had greater amounts of dopamine transporter availability by two standard deviations, meaning their body was more readily able to transport dopamine given a dopamine-eliciting stimulus. Using PET and fMRI scans, Dang et al. (2012) found support that dopamine is the neurotransmitter used in modulating attention; dopamine appears to be the neurotransmitter used to transition the brain from internal attention to external attention. On the other hand, results of Klostermann et al. (2012) suggested that less dopamine synthesis in younger adults' caudates was correlated with greater working memory in a delayed recall task. Therefore, it is possible that despite dopamine's links with attention, there may be negative impacts on other cognitive processes, such as working memory, by having a certain threshold amount present.

Given dopamine's strong connection with reward-seeking behavior, tasks in which rewards are salient/more frequent are most likely to benefit from dopamine increases. One example of this might be in a job providing frequent bonuses as an incentive for exceptional performance/behavior. However, it may not be the case that dopamine is always beneficial. Chowdhury et al. (2013) found that dopamine appears to have a biphasic effect in that too little or too much is harmful to performance. That being said, there is no denying the impact that dopamine appears to have on improving behavior that will lead to increased reward gains. Therefore, one potential solution, in this case, would be to introduce dopamine increasing measures (such as music) for some time on an individual basis, and then comparing the individual's performance with that dopamine increasing measure versus without it. Dopamine also appears to be a good candidate for explaining the impact of mood and arousal on cognitive performance and may also play a part in the cognitive benefits associated with listening to music.

The Connection Between Neurotransmitters, Hormones, and the Mood/Arousal Hypothesis

Having discussed the effects that various neurotransmitters and hormones have on human performance/behavior, sufficient foundations have been laid to discuss the culmination of this paper; that is, attempting to establish connections between the neurotransmitter/hormone field and that of research espousing the mood/arousal hypothesis for the effect of music on task performance.

Firstly, to form a clear connection that music impacts cognition, the relevant research will be laid out explicitly. Music has been known to impact hormone and neurotransmitter release, such as norepinephrine/epinephrine (Yamamoto et al., 2003) and dopamine (Salimpoor et al., 2011). These neurotransmitters have been linked with attention (Dang et al., 2012 for dopamine; Hanna et al., 1996 for epinephrine), one aspect of cognition. One conclusion, therefore, is that music should be expected to influence cognition. As previously discussed using the *Working Memory Model* (Baddeley & Hitch, 1974), listening to music during a task may impair the phonological loop and therefore negatively impact working memory, another aspect of cognition. Therefore, it should be investigated for how long hormones and neurotransmitters remain affected after listening to music; such research would help to clarify how actionable the effects of music on cognition should be.

Mood Connection

For the mood portion of the mood/arousal hypothesis, it seems that dopamine is the most viable candidate with regards to explaining the effect of positive affect on cognition and with regards to connecting neurotransmitter research to research supporting the mood/arousal hypothesis. A previous section (see ***Dopamine***, page 26) and previous studies (Chowdhury et al, 2013; du Hoffmann & Nicola, 2014; Pessiglione et al., 2006; Weiland et al., 2014) have established that dopamine has been associated with rewards and reward-seeking behavior. In a widely cited paper positing a neuropsychological theory of positive affect, Ashby et al. (1999) theorized that the mechanism through which positive affect influences cognition is through increased dopamine. In fact, according to Ashby et al. (1999) and as seen in Isen et al. (1984), one common method of inducing positive affect is by giving participants an unexpected gift (i.e. reward). This unexpected gift, even something small such as watching a humorous film or receiving candy, can induce a positive affect, and even small changes in positive affect have been associated with changes in cognition according to Ashby et al. (1999). In a previous section (see ***Mode***, page 14), musical mode has been established as capable of eliciting positive affect typically via a song in a major mode. It seems highly plausible then that mode influences cognition through dopamine release, given that music is capable of influencing neurotransmitter/hormone levels (see **Musical Elicitation of Hormones and Neurotransmitters**, page 18), and given that it can induce positive affect. Thus is the case establishing that dopamine may be the candidate neurotransmitter for explaining the neurochemical basis of the mood/arousal hypothesis.

Arousal Connection

For the arousal portion, epinephrine/norepinephrine appear to be the best candidate neurotransmitters in terms of explaining the neurochemical basis for the beneficial effect of arousal on cognition and connecting these two fields of research. A previous section (see ***Epinephrine/Norepinephrine***, page 24), and previous studies (Flint et al., 2006; Jurado-Berbel et al., 2010; Liang et al., 1990; Loron-Sanchez et al., 2016; Mcgaugh, 2000) have linked epinephrine/norepinephrine to memory enhancement. Additionally, other studies (Evans et al., 2000; Maduka et al., 2015; Ward et al, 1983) have found epinephrine/norepinephrine to significantly increase with physical stressors (such as squeezing a handgrip for 2 minutes) and cognitive stressors (performing a difficult subtraction task continuously), as well as long and continuous background noise. Therefore, it is reasonable to conclude that epinephrine/norepinephrine is to be associated with stress, and therefore arousal. However, for arousal, it may not be possible to single down only epinephrine/norepinephrine. Cortisol is another hormone that has been closely linked with stress in research (Bohnen et al., 1990;

Buchanan & Tranel, 2008; Maduka et al., 2015; Vedhara et al., 1999), and thus it's likely epinephrine/norepinephrine and cortisol are capable of appearing depending on the level of stress induced by a stimulus. Research by Maduka et al. (2015) corroborates the previous idea; the authors found a significant increase in both cortisol and epinephrine in undergraduate students in response to an upcoming examination when compared with the same undergraduate students in a time when there were no examinations for at least the next month. Calling back to a previous section (see ***Arousal***, page 13), the bi-phasic effect demonstrated by the Yerkes-Dodson Law is likely to be explained by epinephrine/norepinephrine and cortisol when seen with this knowledge. While epinephrine/norepinephrine have been associated with memory enhancement, too much cortisol has been associated with memory deterioration (Buchanan & Tranel, 2008; Vedhara et al., 1999). Buchanan and Tranel (2008) found that when exposed to stressors, participants who produced a cortisol response displayed reduced memory capability, whereas participants exposed to the same stressors that did not produce a cortisol response displayed enhanced memory. Thus is the case establishing that epinephrine/norepinephrine are the candidate hormones/neurotransmitters (respectively) responsible for the observed benefits of arousal on cognition, whereas cortisol is likely also a candidate hormone with regards to explaining the detrimental effects arousal can have on cognition.

Conclusion

In conclusion, it would appear that the neurochemical basis for the mood/arousal hypothesis of music's effect on task performance is best explained by dopamine (for mood), epinephrine/norepinephrine (for arousal), and cortisol (for arousal). One weakness with this current paper is that no explanation for the lack of arousal seen in the Yerkes-Dodson Law is provided. One possible explanation may be that the absence of arousal is analogous to limited brain activation/neural firing, and therefore it is precisely the absence of neurotransmitter/hormones (in this case, epinephrine/norepinephrine) that explains the reduced performance seen in the Yerkes-Dodson Law graph with lack of arousal. Another weakness would be that negative affect is not examined, nor is a neurochemical explanation for negative affect is provided. As of this time, a candidate neurotransmitter/hormone directly responsible for causing negative affect does not seem likely. Rather, it is the low levels of certain neurotransmitters/hormones that likely cause negative affect, such as how depression is commonly associated with low serotonin levels.

It would be beneficial for future research to further strengthen the link between music and the neurotransmitters/hormones that can be elicited. Additionally, clarifying the properties of music that influence neurotransmitters/hormones would be useful for creating desired effects. For example, if fast tempo music was more strongly linked with increased epinephrine as it has been in the past (Yamamoto, 2003), one could reliably expect fast tempo music to aid with memory since epinephrine/norepinephrine have been linked with enhancing memory storage/retrieval (Flint et al. 2006; Jurado-Berbel et al., 2010; Liang et al., 1990; Lorón-Sánchez et al., 2016; Mcgaugh, 2000). Additionally, research delving into unexamined neurotransmitters/hormones that may be influenced by music may further clarify the effects that music has on us. Another point of interest for future research may be the long-term effects of music on the brain. Given that music can be listened to consistently and can elicit an increase/decrease of a given neurotransmitter/hormone, it is probable that the increased/decreased presence of a given neurotransmitter/hormone would have long-term effects on the brain/body respectively.

In summary, dopamine, epinephrine/norepinephrine, and cortisol appear to be strong candidates for explaining the neurochemical basis of the mood/arousal hypothesis of music's effect on task performance.

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