

**INDIVIDUAL DIFFERENCES IN COGNITIVE, MUSICAL, AND
PERCEPTUAL ABILITIES**

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**INDIVIDUAL DIFFERENCES IN COGNITIVE, MUSICAL, AND
PERCEPTUAL ABILITIES**

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SUMMARY

The increasing use of auditory graphs and sonifications in technology is leading to a wider variety of system users, which, in turn, suggests a need for research in how differences between individual listeners affect sound interpretation. Frequency discrimination, tempo discrimination, working memory, and spatial reasoning are fundamental skills for interpreting auditory displays. As a first step in this arena, the current study investigates the question of whether or not cognitive abilities and musical experience predict frequency and tempo discrimination in individuals. Participants in the study were 30 undergraduate students from Georgia Institute of Technology and 20 adults from the Atlanta, Georgia community. These participants took part in two sessions of experiments, one that comprised the auditory discrimination task and the other that comprised the cognitive ability tasks. In the cognitive ability session, participants completed the Operation Span (Ospan) task as a measure of working memory capacity and the Raven's Progressive Matrices task as a measure of spatial reasoning. In the auditory discrimination session, participants performed a tempo and a frequency discrimination task that utilized the method of constant stimuli and required 2-alternative forced choice responses. The tempo discrimination task used standard tempo speeds of 150 ms inter-click interval (ICI), 250 ms ICI, and 350 ms ICI and required a decision to determine which interval contained the slower tempo or the faster tempo. The frequency discrimination task used standard tones of 250 Hz, 840 Hz, and 1600 Hz and required a decision to determine which interval contained the lower frequency or the higher frequency. The Quick function, a psychometric function, was used to find the difference

thresholds for the three standard tempos and the three standard frequencies.

Demographics on age, gender, handedness, years of playing a musical instrument, and years of formal musical training were also collected.

A correlational analysis of all variables (250 Hz, 840 Hz, 1600 Hz, 150 ms, 250 ms, 350 ms, Ospan, Raven's, age, gender, handedness, years of playing a musical instrument, years of formal musical experience) was performed. Paired-samples t-tests on the Weber fractions of the six threshold means were also performed to determine if there were any significant differences between the frequency thresholds and the tempo thresholds. Lastly, multiple hierarchical regressions were performed on each of the six dependent variables to identify significant predictors of frequency and tempo discrimination. The paired samples t-tests show a significant difference between 250 Hz and 840 Hz and between 250 Hz and 1600 Hz, a violation of Weber's Law. However, this violation of Weber's Law may be explained by the small sample size used in the study. The t-tests also show a significant difference between the means of 150 ms and 250 ms and between the means of 250 ms and 350 ms. The results of the regression analyses show that good performance on Raven's seems to predict lower thresholds at 1600 Hz. The results also show that good scores on Ospan appear to predict lower thresholds at 350 ms ICI. In addition to these significant predictors from the regression analyses, there are many significant correlations that provide further support that cognitive abilities are related to frequency and tempo discrimination.

CHAPTER 1

INTRODUCTION

Sonifications and Auditory Graphs

Large, multidimensional data sets are becoming increasingly common in classroom, research, and industry settings. Advances in technology are leading to a larger number of tools for analyzing these data sets. However, these tools are mostly visual in nature and fail to exploit the ability of the human auditory system to recognize temporal patterns and changes (Kramer et al., 1999; Moore, 2003; Walker, 2002). *Sonification* utilizes non-speech audio to convey information (Kramer et al., 1999). An *auditory graph* is a type of sonification that displays numerical information and includes design features to provide context to assist the user (Smith, 2003). Not only do sonifications and auditory graphs aid in comprehending and monitoring complex temporal data, they may also prove beneficial in situations where the operator cannot look at or is unable to see the visual information (e.g., visually impaired physically, or due to environmental factors such as smoke) (Kramer et al., 1999; Walker, 2002; Walker & Lane, 2001; Walker & Lindsay, 2004).

Individual Differences in Auditory Graph Interpretation

There has been little research on individual differences with respect to listening to and interpreting sonifications and auditory graphs. Research with an auditory magnitude estimation task has demonstrated that important differences in the interpretation of auditory information arise within and between groups of listeners (Walker, 2002; Walker & Lane, 2001; Walker & Mauney, in review). Walker (2002) found individual

differences in college students in the polarities of responses to data-to-sound mappings. The polarity of a mapping describes how changes in a display dimension signify changes in the data dimension. For example, if tempo increases to represent increasing urgency in a given data set, the mapping has a positive polarity. If the tempo *decreases* with increasing urgency, then the respective mapping would be classified as having a negative polarity. Walker (2002) found that in some cases a majority of the listeners clearly preferred either a positive or a negative polarity, whereas in other cases there was a split between positive and negative polarities being preferred for a given data-to-display mapping. Walker and Mauney (in review) and Walker and Lane (2001) found differences between groups of visually impaired and sighted listeners. Those two studies indicate that in some situations visually impaired and sighted listeners respond with similar polarities of data-to-display mappings, but in other cases different polarities result. For example, normal-sighted individuals preferred a positive polarity when mapping frequency to the data variable “number of dollars”, whereas visually impaired individuals preferred a negative polarity. Even within what may, on the surface, seem to be a homogeneous group of people (e.g, sighted persons or visually impaired persons), there can be notable differences between individuals of those groups. These differences demonstrate the importance of further inquiry into the topic of individual differences.

Neuhoff, Knight, and Wayand (2002) found differences in sighted listeners’ perceptual and conceptual responses to pitch change. That study indicates that listeners with more musical experience scale frequency change differently than listeners with no musical experience. Neuhoff et al. (2002) also found that greater musical expertise reduced the amount of errors in judging/labeling the direction of the pitch change.

These findings of a few select types of individual differences in interpreting auditory information have not been consistent nor replicated. Walker and Mauney (2004) looked at a wider variety of individual differences and used a more systematic approach to their investigation. The researchers focused specifically on cognitive abilities, musical experience, and a variety of demographics (age, gender, handedness) in their study of individual differences in the auditory magnitude estimation task mentioned previously. They used exploratory statistics and found some support for cognitive abilities affecting the interpretation of auditory graphs. Listeners with better scores on working memory capacity (WMC) and spatial reasoning measures performed more consistently (had higher R^2 values) on the magnitude estimation task than those listeners who had lower scores of WMC and spatial reasoning. However, the slope of the data-to-display mappings did not seem to be affected by cognitive abilities, musical experience, or demographic variables (Walker & Mauney, 2004). The literature discussed to this point does not yield an entirely consistent picture, but it does provide a starting point for a more thorough, systematic study of individual differences in auditory graph interpretation.

In order to investigate the relationship between various demographics, cognitive abilities, and auditory display interpretation, it is imperative to consider the specific cognitive tasks involved. Smith and Walker (2005) performed a task analysis of determining the value of a specific data point within a basic auditory graph when the data are mapped onto, or represented by, changes in pitch. This is a common data-to-sound mapping strategy in auditory graphs (Smith & Walker, 2005). In such a situation, the task of determining an auditory data point consists of the following perceptual and cognitive subtasks:

(1) listen to entire graph; (2) perform an interval division task to determine the part of the sound duration corresponding to the queried data point; (3) recall the pitches perceived both at the queried time and at the onset of the graph; (4) compare one pitch to the other and estimate the change in price represented by the difference...; and lastly, (5) recall the value of the initial data point, add or subtract the perceived change in price, and report the value. (p.8)

That task analysis will serve as a theoretical platform on which to base the current study. Of course, if the data are mapped onto another sound parameter like tempo, then subtasks 3-5 would involve estimating change in that other display dimension, rather than pitch.

The literature mentioned above indicates that individual differences are related to the interpretation of auditory graphs. However, in order to fully understand this relationship, we must first investigate individual differences between and within groups of listeners. The following three categories of individual differences seem particularly relevant to the study of auditory graphs—perceptual differences, cognitive differences, and differences in training or experience. The current study will investigate some perceptual individual differences (i.e., frequency and tempo discrimination), cognitive individual differences (i.e., WMC and spatial reasoning), and will loosely explore training (i.e., musical experience). However, before we can study the relationship of these individual differences with an applied auditory graphing task, we must first determine if and how these factors are interrelated.

Musical Abilities

When discussing musical abilities or musical experience, it is important to operationally define what is meant by that term. Drake (1939) defines *musical talent* as a “general musical capacity to succeed in any musical endeavor” (p. 9). Drake goes on to differentiate musical talent from *musicianship*, which he defines as “that ability to interpret and execute music so that it has meaning and beauty to the careful listener” (p. 10). Other researchers define *musical ability* as either musical training or a score on a “musical ability test,” one of the most common tests being the Seashore Measures of Musical Talent (Seashore, Lewis, & Saetveit, 1960). The Seashore test (originally developed by Carl Seashore in 1919) assesses musical ability based on several tests, including tests of pitch discrimination, tonal memory, rhythm, intensity, time, and timbre (Helmbold, Rammsayer, & Altenmuller, 2005). Another way that researchers study musical abilities is by distinguishing participants as either musicians or nonmusicians (or musically experienced versus musically naïve) (e.g., Helmbold et al., 2005; McRoberts & Sanders, 1992; Spiegel & Watson, 1984). However, the way that researchers separate participants into musicians and nonmusicians varies from study to study. One of the common ways of separating people into these two groups are by those who have *absolute pitch* (the ability to name or produce a note of particular pitch in the absence of a reference note) versus those who do not have absolute pitch (e.g., Deutsch, 2002; Fujisaki & Kashino, 2002). Another way to classify people is based on the amount of musical training they have had, including if they play in a professional orchestra or are in a special music program at school (e.g., Fujisaki & Kashino, 2002; Helmbold et al., 2005; McRoberts & Sanders, 1992; Spiegel & Watson, 1984). The importance of musical

experience to the current study is further explained in the remaining sections discussing perceptual and cognitive abilities.

Perceptual Abilities

Frequency Discrimination

The current study looks at frequency discrimination because it is one of the tasks required for interpreting an auditory graph when data are mapped onto pitch, described by Smith and Walker: “recall the pitches perceived both at the queried time and at the onset of the graph” and “compare one pitch to the other” (Smith & Walker, 2005). A review of frequency discrimination by Moore (2003) points out that the difference threshold, in Hertz, is smallest at low frequencies and increases with increasing frequency, consistent with the notion of the Weber fraction. This pattern is of significance to the present study in that participants’ thresholds may differ depending on the frequency of the comparison tone.

As mentioned above, one of the subtests of the Seashore Measures of Musical Talent is pitch discrimination, which implies that pitch discrimination is an element of musical talent. Drake (1939) also states that an important factor for musical talent is good pitch discrimination. Although no specific studies are mentioned, Drake states that musicians can detect smaller changes in pitch than non-musicians. He goes on to say that good pitch discrimination is important for singers and stringed instrument players who need to be able to perceive slight differences in intonation (R. M. Drake, 1939). This idea that musicians have better pitch discrimination than non-musicians has been studied by other researchers since Drake, including Spiegel and Watson (1984).

Spiegel and Watson (1984) administered a few tests of auditory discrimination to a group of musicians and non-musicians. Musicians were defined as being highly trained players in a major symphony orchestra. Non-musicians were defined as people who did not play instruments in that orchestra and who were randomly chosen among the graduate students, researchers, and staff of the Central Institute for the Deaf. All participants were also administered a 63-item questionnaire on their musical background, although these items were not used to further classify possible musicians amongst the non-musician group. This questionnaire contained “questions about early musical listening experience, attitudes and preferences regarding music, and the listener’s music training and habits of practice, as well as that of their parents and siblings” (Spiegel & Watson, 1984, p. 1691). One of the tests administered in that study was a simple frequency discrimination task involving pairs of sine-wave tones. The results showed that half of the non-musicians attained difference thresholds as low as the group of musicians (i.e., Weber fractions ranging from 0.0010 to 0.0045). However, the other half of the non-musicians had thresholds that were four to five times larger than the musicians and the other non-musicians (i.e., Weber fractions ranging from 0.005 to 0.0017) (Spiegel & Watson, 1984). An informal analysis by the experimenters indicated that the better half of the non-musicians (those who scored as well as the musicians) were more likely to have a high degree of musical or psychoacoustical experience, which was not controlled for prior to the start of the experiment. These “non-musicians” could possibly get considered musicians by other researchers’ standards. To further explain these differences in musicians and non-musicians, the experimenters compared those responses that were either musical-scale frequencies versus non-musical scale frequencies to see if the

musicians had lower thresholds for those frequencies on the equal tempered musical scale. However, that analysis did not result in differences between musicians and non-musicians in their thresholds (Spiegel & Watson, 1984). Despite the flawed classification of musicians versus non-musicians, that study does provide further evidence that musical ability or experience may play a role in frequency discrimination.

Fujisaki and Kashino (2002) also investigated the role of musical ability and frequency discrimination. In one experiment, participants were prescreened for absolute pitch using a specially designed test and were classified into four groups: absolute pitch (AP) musicians (scored 97% on absolute pitch test); partial absolute pitch (PAP) musicians (scored 65-85% on test); non-absolute pitch (NAP) musicians (scored under 25% on test); and non-absolute pitch (NAP) non-musicians (scored under 25% on test). Participants were administered an adaptive two-interval forced-choice frequency discrimination task. The test frequencies were either focused around 1000 Hz or 987.76 Hz (which corresponds to B5 on the equal tempered scale). These frequencies were chosen in order to test for differences between conditions where tones were either centered on an in-tune sound (i.e., 987.76 Hz) or an out-of-tune sound (Fujisaki & Kashino, 2002). The results of that study show that in the trials where 1000 Hz was the standard tone, there were significant differences between group thresholds. However, when the standard tone was 987.76 Hz, there were significant differences between the NAP non-musicians and all other groups. The results indicate that when the standard tone was in-tune on the equal tempered scale, non-musicians performed significantly worse (i.e., had larger difference thresholds) than all of the musicians, regardless of their absolute pitch abilities. Those results suggest that musical experience, but not absolute

pitch, play a role in frequency discrimination for certain tones. The above-mentioned studies lead to my hypothesis that musical experience will be related to frequency discrimination in the current study.

Tempo Discrimination

Although not specifically mentioned in the task analysis by Smith and Walker (2005), the current study also looked at tempo discrimination, since tempo is another sound dimension that can be used for representing data (Walker, Godfrey, Orlosky, Bruce, & Sanford, 2006). Schulze (1978) ran an experiment to compare three hypothesized processes for identifying irregular sequences. These three processes for identifying irregular sequences are: (1) successive interval discrimination; (2) comparison with an internal rhythm; and (3) the comparison with internal interval. During successive interval discrimination “the listener compares the durations of successive intervals and when at least one difference exceeds some threshold such a sequence is judged as irregular” (Schulze, 1978). Schulze states that when using comparison with an internal rhythm strategy the listener compares the actual sounds to an internal sequence the person generates. This comparing of the actual and internal rhythms is active, which means it is constantly updated and changed in “real” time. When using comparison with internal interval strategy the person listens to the first few intervals and develops a steady reference interval with which to compare new intervals (Schulze, 1978). Schulze found that a simple tempo change is the easiest type of sequence alteration for participants to detect. He also found that when the alteration of the rhythmic sequences happens later in the sequence it is easier for participants to detect an irregularity in the pattern. Through these findings, Schulze ruled out the successive interval discrimination theory and stated

that the most likely theory to apply to the data is the comparison with an internal rhythm theory. However, he does not completely rule out the comparison with internal interval theory, stressing the importance of more studies in this area. The importance of Schulze's findings to the current study is in relation to the possible strategies participants may use in detecting faster or slower tempos; more effective strategies may lead to better difference thresholds for tempo discrimination. The effectiveness of these strategies in the current study may also be affected by the working memory capacity (WMC) of the participants; participants with higher WMCs may more effectively use the above strategies to determine differences in tempos.

Hibi (1983) investigated tempo thresholds for both the perception and production of rhythmic sequences of tones. Specifically, Hibi investigated if there were differences between tempo discrimination in slow and fast tempos. The overall results indicate that Weber's Law (i.e., the relative JND is constant) holds for tempos in the slower ranges (1000 ms inter-tonal interval (ITI) to 400 ms ITI) and in the faster ranges (250 ms ITI to 143 ms ITI). The Weber fractions of these two tempo ranges are also statistically different from each other (Hibi, 1983). Based on self-report responses from participants, Hibi came up with theory for the differences between these two tempo ranges—the longer tempos are perceived on an ongoing or tone-by-tone basis of comparison and the shorter tempos are perceived wholistically (sic). For the longer tempos, the listener predicts when the next event or tone should occur and compares that with the actual occurrence of the next event. For the shorter tempos, the listener develops a template for an even tempo and then detects irregularities in this template. The turning point in these two processes occurs around 330 ms ITI, the point at which Weber's Law does not seem

to hold (Hibi, 1983). The implications of Hibi's findings to the current study are with respect to the differences in tempo discrimination that may be found between faster and slower tempos. That is, we may expect to see different patterns of responding with faster and slower tempos, which may also show different connections to cognitive measures.

Drake and Botte (1993) performed a series of tempo sensitivity experiments with musicians and nonmusicians. Drake and Botte defined nonmusicians as participants with no musical training and they defined musicians as those participants "who had at least 5 years of musical training and who played an instrument almost every day" (1993, p. 282). The experimenters presented pairs of regular and irregular tempo sequences, and asked participants to make judgments about which sequence was faster. Drake and Botte found that difference thresholds were lower for sequences than for single intervals. They also found that listeners are more sensitive to changes in regular tempo than they are for changes in irregular tempo and changes in single interval duration (Drake & Botte, 1993). Drake and Botte also found that musical training resulted in finer temporal discriminations (i.e., musicians could detect smaller changes in tempo than nonmusicians) and that musicians differed from nonmusicians in their optimal zone of sensitivity. They showed that the optimal zone of tempo sensitivity for musicians is faster and wider than the optimal zone for non-musicians.

Friberg and Sundberg (1995) looked at just noticeable differences (JNDs) of various tempos in participants. Using the method of adjustment, participants moved the fourth in a series of six notes, until they perceived a constant tempo (i.e., isochronous or equal interonset intervals (IOIs)). The authors also looked at musical experience to see if that variable plays a role in tempo discrimination (Friberg & Sundberg, 1995). The

results of the study show that Weber's law applies for IOIs greater than or equal to 240 ms; the average JND of the study was 2.5% for the before-mentioned IOIs. The 240 ms point is called the breakpoint where the JND curve changes direction. The absolute JND for IOIs of 100 to 240 ms was found to be a constant with an average value of 6 ms. Unlike Drake and Botte (1993), musical experience was not found to have a significant effect on tempo discrimination (Friberg & Sundberg, 1995). That study shows that the length of a sequence may play a bigger role in tempo discrimination than the method used to manipulate the sequences. The studies above lead to my hypothesis that musical experience will be related to tempo discrimination.

Cognitive Abilities

Working Memory Capacity

The current study looked at WMC because it is related to one of the tasks required for interpreting an auditory graph—"recall the pitches perceived both at the queried time and at the onset of the graph" and "recall the value of the initial data point, add or subtract the perceived change in price, and report the value" (Smith & Walker, 2005).

Baddeley and Hitch (1974) first proposed the concept of *working memory*, which is the system(s) involved in the temporary storage of information while utilizing cognitive skills. Baddeley and Hitch tested the theory in a series of experiments involving reasoning, language comprehension, and learning. Through traditional memory span tasks, free recall, memory preloads, and concurrent memory loads, Baddeley and Hitch found that performance was impaired when an additional memory load of six items was given, but was not impaired when a memory load of three items was given. They also found a phonemic similarity effect and articulatory suppression in performance

decrements of various tasks. From these studies, Baddeley and Hitch (1974) proposed the idea of a limited capacity working memory system with three components—the central executive, articulatory loop, and visuo-spatial scratch pad—which was later improved upon by Baddeley (1981). According to Baddeley and Hitch (1974) and Baddeley (1981), the central executive is the limited capacity control center that selects and operates control processes. The articulatory loop maintains verbal information through subvocal rehearsal, similar to the non-speech buffer proposed by Crowder and Morton (1969). The visuo-spatial scratch pad maintains spatial material through visualization (Baddeley, 1981; Baddeley & Hitch, 1974). These three components work together to determine whether a person can retain and recall information while processing other cognitive information. A person with a higher WMC is able to retain and recall more information than a person with a lower WMC; this can be tested in several ways.

One way to test WMC is to increase the memory load until the person is no longer able to repeat the information immediately and correctly, which is often called a self-terminating span test. Another method involves a pre-organized test where each participant undergoes all conditions, including stimuli that may be outside the limits of their WMC (Cornoldi & Vecchi, 2003). By looking at tests of reading span, listening span, reading comprehension, word span, and verbal SAT scores, Daneman and Carpenter (1980) studied the relationship between working memory and reading comprehension. They found that listening span and reading span, both measures of WMC, are correlated with performance on verbal SAT and with tests of reading comprehension that asked questions about facts and pronominal references in the passages. They found that readers and listeners with small spans performed significantly

worse than readers and listeners with larger spans. The word span test, however, was not found to be significantly related to reading comprehension (Daneman & Carpenter, 1980). Another important finding from the Daneman and Carpenter study was the strong correlation between the reader's and listener's span and the distance over which he could correctly answer pronoun reference questions. That finding means that the more sentences or space between the referent noun and pronoun, the worse participants with lower reading or listening spans performed, while participants with high spans performed at asymptote (Daneman & Carpenter, 1980). They also found that good readers made fewer errors than poor readers. The types of reading errors that were made also differed between span groups, with large span participants making more reasonable substitutions and incomplete answers, showing some understanding of the passages, and small span participants making more foils, fabrications, and confusions, showing a more fundamental misunderstanding of the passages (Daneman & Carpenter, 1980). The study demonstrates that high-span and low-span readers differ quantitatively (e.g., the speed or efficiency of the computations) and qualitatively (e.g., types of errors made) in their working memory capacities. Although not specifically looked at in the current study, differences in the education level and reading comprehension of the various participants may have an impact on their WMC and, therefore, their performance on the various tasks in the study.

Turner and Engle (1989) developed a complex working memory span task called Operation Span (Ospan), which is the measure of WMC used in the current study. Ospan consists of a series of arithmetic operations each followed by a to-be-remembered word. This task has been constantly used through the years and is now considered to be a

reliable measure of WMC (Turner & Engle, 1989; Unsworth & Engle, 2005). Through a series of experiments involving Ospan, other complex working memory spans tasks, simple span tasks, and reading comprehension tasks, Turner and Engle (1989) demonstrated that regardless of the secondary task, good readers remembered more words and digits than poor readers. They found that complex span tasks, but not simple span tasks, are significantly correlated with reading comprehension. These findings may be the result of complex working memory tasks preventing the use of memory strategies, such as grouping and rote rehearsal (Turner & Engle, 1989). That study confirms Daneman and Carpenter's (1980) research relating working memory and reading comprehension.

One study by Conway, Cowan, and Bunting (2001) investigated the role of WMC in a dichotic listening task. Cowan et al. divided undergraduate participants into those with low WMC and those with high WMC based on scores from the Ospan task developed by Turner and Engle (1989). Participants then performed a dichotic listening task where they had to attend to a message in one ear and shadow or repeat the message from that ear while ignoring an irrelevant message presented in the other ear. Each participant had their own name embedded into the irrelevant message, which acted as a distracter. After the messages were done being presented to the participants, a questionnaire was filled out about the content of the irrelevant message (Conway et al., 2001). Conway et al. were interested in how many people were distracted and reported hearing their own names in the irrelevant message. The results show that 20% of high-span participants and 65% of low-span participants reported hearing their name in the message (Conway et al., 2001). Also, low-span participants performed significantly more

poorly on the shadowing task than did high-span participants. For those participants (regardless of WMC span) who did report hearing their own name, shadowing errors were performed on the words concurrent with the presentation of their name as well as two words after the presentation of their name. That result demonstrates that people who heard their name were distracted from the task at hand and reallocated their attention to the irrelevant channel. This reallocation of attention was significantly more common in low-span participants (Conway et al., 2001). The ability to inhibit irrelevant information seems to be an important characteristic of those people with higher WMC. Also, Conway et al. note that while Ospan is a divided attention task, the dichotic listening task is a selective attention task. However, participants who performed well on one task performed well on the other task. Conway et al. argue that there appears to be a general cognitive ability linked to WMC which allows participants to perform well on both tasks (Conway et al., 2001). Other researchers, including Engle and colleagues, also support this idea that WMC is related to attentional control.

Heitz, Unsworth, and Engle (2005) and Heitz et al. (2006) review the literature on the link between WMC, attentional control, and intelligence. They also propose their stance on the topic and state that attentional control is “a voluntary, effortful cognitive act that serves to maintain information through activation of relevant brain circuitry” (p.63). Heitz et al. (Heitz et al., 2006, 2005) go on to state the attentional control is also important in inhibiting irrelevant information and as well as suppressing the response tendencies to act on this irrelevant information. The authors also stress that WMC is not a number or an amount, but is an ability to control attention, especially if there is interference from “competing information, activated representations, or task demands”

(Heitz et al., 2005, p. 64). So, in regards to the current study, I hypothesize that high scores on WMC will be related to good performance (low thresholds) on the auditory discrimination task because of this link between attentional control and WMC. I believe that participants with higher WMC will be able to attend to the information better in the discrimination tasks, thereby being able to make better judgments on what they hear.

Spatial Reasoning

Since interpreting auditory displays, especially trend analysis, involves sets of rules, it seems likely that spatial reasoning may play a role in interpreting auditory information. According to Cornoldi and Vecchi (2003), there are many aspects of spatial cognition that must be specified when discussing the literature and defining the concept of “spatial.” For example, spatial competence is associated with the comprehension of geometric properties. Spatial orientation is the ability to perceive and recall a particular spatial orientation or the ability to orient oneself generally in space. Spatial skills are related to the ability to move in space and navigate in the environment. Differences in spatial processes and spatial representation can also influence encoding processes and motor functions (e.g., grasping, reaching, navigating). Depending on body position, positions of objects in space, or self-centered systems, a person can encode spatial information differently, leading to either an egocentric or allocentric representation of space (Foreman & Gillet, 1997, as cited in Cornoldi & Vecchi, 2003). Cornoldi and Vecchi (2003) define *visual imagery* as “a mental process with output in an internal visuo-spatial representation, maintained and processed within a temporary memory store” (p. 7). They also suggest that mental imagery and visuo-spatial processes are part of working memory functions, suggesting a connection between spatial reasoning and

working memory capacity, which is further researched by Engle and colleagues (Engle, Kane, & Tuholski, 1999; Unsworth & Engle, 2005). Spatial abilities also seem to be a factor in intelligence. For example, the Raven's Progressive Matrices (Raven's), which is the measure of spatial reasoning in the current study, is considered to be one of the central factors in G_f (fluid intelligence) or g (general intelligence) (Carroll, 1993). According to Carroll, the Raven's Progressive Matrices is a type of reasoning that can be specifically classified as a factor of Induction (I). Induction tasks require a person to "inspect a set of materials and from this inspection induce a rule governing the materials, or a particular or common characteristic of one or more stimulus materials, such as a relation or trend" (1993, p. 211). This means that people who score high on Raven's are able to follow a set of rules to solve the incomplete matrices that are part of the task. Once again, it seems likely that spatial reasoning may play a role in interpreting auditory information because of its relationship with the use of rules in trend analysis.

Unsworth and Engle (2005) demonstrated that a known correlation between Raven's and Ospan remains constant across levels of item difficulty for both tasks. Although people with a low span tend to make more errors on Raven's than people with a high span, the errors did not differ between types of items on the task. This evidence suggests that the number of items/goals that can be held in working memory does not account for the link between working memory capacity and intelligence (Unsworth & Engle, 2005).

The literature on mental or cognitive abilities and musical ability seems to have mixed findings, even by the same researchers (Brandler & Rammsayer, 2003; Helmbold et al., 2005). Rammsayer and colleagues did a series of experiments with musicians and

non-musicians to test for differences in their primary mental abilities. In Brandler and Rammsayer (2003), the musician group consisted of musicians from either the Hochschule für Musik und Theater whose main subject was music or from the Göttingen Symphony Orchestra. All of the musicians already possessed degrees in music and had at least 14 years of instrument training. All non-musicians were students at the University of Göttingen, had never played any musical instrument, and were not especially interested in music. These participants were then given a comprehensive intelligence test battery that was composed of the Leistungsprüfsystem (a German intelligence test based on Thurstone's (1938) model of primary mental abilities), the German adaptation of the Cattell's Culture Free Intelligence Test (CFT), and the Berliner Intelligenzstruktur-Test—Form 4. The Leistungsprüfsystem was composed of several subtests including verbal comprehension, word fluency, space, closure, and perceptual speed. The CFT was a measure of reasoning and was considered a valid and reliable measure of general fluid intelligence (Cattell, 1961, as stated by Brandler & Rammsayer, 2003). The Berliner Intelligenzstruktur-Test consisted of tests of numerical intelligence, verbal memory, number memory, and spatial memory. The results of that study show that non-musicians scored significantly higher on all four reasoning subscales of the CFT than the musicians. Also, musicians scored significantly higher than non-musicians on verbal memory. There were no other statistically significant differences between the other mental abilities and the two groups of participants. That study indicates that while musicians are better at one aspect of intelligence (namely verbal memory), non-musicians are better at other aspects of intelligence (namely reasoning). Helmbold et al. (2005) sought to replicate the findings in the Brandler and Rammsayer study, but using twice as many participants. Helmbold et

al. obtained their musicians and non-musicians from the same schools as the prior study. They also administered the same intelligence test battery. Results of the Helmbold et al. (2005) study show completely different results than the Brandler and Rammsayer study—musicians performed significantly higher on Flexibility of Closure and Perceptual Speed than did non-musicians. Non-musicians did not score better than musicians on any of the tests of intelligence (Helmbold et al., 2005). Although there seems to be relationships between cognitive abilities and musical abilities, the results are inconsistent. However, those results do lead to my hypothesis that musical experience in the current study will be related to my measures of WMC and spatial reasoning.

Auditory Processing and Memory

Up to now I have only discussed the separate components of the current study—frequency discrimination, tempo discrimination, WMC, and spatial reasoning. Now I will present some of the research that has combined auditory discrimination tasks and cognitive ability measures.

Drake (1939) proposed the idea of *musical memory* as being one of the most important characteristics of a successful musician. According to Drake, musical memory allows the musician to play a piece of music with unity, meaning, variety, and individuality. Perceiving the musical composition as a whole as well as recognizing the relationship between all of the parts is important in the interpretation of a composition. Memory for notes is very important as well as challenging because no definite meaning is attached to each note (Drake, 1939). As mentioned earlier, Drake stated that pitch discrimination is important to musicians. He also said that people with good pitch discrimination tend to have a good memory for musical material and vice versa. So, even

though Drake did not discuss working memory specifically, the notion that pitch discrimination and memory are related was in the literature even in the 1930s.

Crowder and Morton (1969) proposed the existence of a memory component used to store precategorical information of an exclusively acoustic nature, which they called the Precategorical Acoustic Storage (PAS). To understand this system, it is important to make the distinction between information that has been categorized (i.e., identified or perceived) and information that has not been categorized. Categorized information has the potential for a direct linguistic response, whereas precategorical information has not yet made contact with a person's overlearned linguistic repertoire. However, preacoustic information may not be completely unprocessed (Crowder & Morton, 1969). According to Crowder and Morton, PAS is capable of holding information long enough, on the order of a few seconds, to affect an immediate memory task. Information in PAS may be lost due to (a) overwriting or displacement by subsequent auditory events, and/or (b) decay with the passage of time. When error rates for visual and auditory presentation are plotted in serial position curves, the above-mentioned lost information is restricted to the last few serial positions, indicating a superiority of auditory presentation (Crowder & Morton, 1969).

Durlach and Braida (1969) introduced their theory of intensity resolution, which includes the idea of “memory noise” interfering with the discrimination between two tones of different frequencies. According to Durlach and Braida, this memory noise is composed of two types of noise—a sensory-trace mode and a context-coding mode. The sensory-trace mode is initiated when a person attempts to rehearse the “image” or “trace” of the sound to retain it in memory for later recall. This rehearsing can be conscious or

unconscious and may result in noise if there is retroactive interference or when the person cannot keep track of the trace (i.e., the trace “wanders”) (Durlach & Braida, 1969). The context-coding mode is initiated when a person compares the two sounds and tries to give a verbal representation of this comparison. This verbal representation of the two sounds may introduce noise if this representation is not precise or appropriate for the context (i.e., range of intensities) of the presented sounds (Durlach & Braida, 1969). This context-coding noise may dominate the noise of the sounds if the context or range of presented intensities is large. The sensory-trace noise may dominate the noise of the sounds if interference is high. A person may use either or both of these memory modes in discriminating between two tones; the effectiveness of their strategy is influenced by the amount of context and interference in the presentation of the sounds. If the listener’s chosen strategy is not appropriate given the sound environment, then his ability to correctly discriminate between the sounds is poor (Durlach & Braida, 1969).

Massaro (1970) investigated frequency discrimination in a short-term recognition memory (STRM) task. He found that when tones were presented through headphones, the presence of an interstimulus tone aided frequency discrimination in relation to noise. However, when tones were presented over speakers, the presence of an interstimulus tone disrupted frequency discrimination compared to noise. Noise in the interstimulus interval (ISI) was also found to produce faster forgetting of the stimulus than a blank ISI. These results suggest that participants were able to ignore the interstimulus tone better when presented over speakers and that this tone was used as a reference point when the participants were unable to ignore the tone (i.e., when using headphones) (Massaro,

1970). Storage and forgetting, according to Massaro, are important processes that underlie STRM for frequency.

Keller and Cowan (1994) examined the persistence of memory for tone frequency developmentally and strategically. They found that the frequency difference required by each participant to achieve a predefined criterion level for comparing tones decreased with age. They also found that rehearsal of the standard tone during the intertonal interval (ITI) did not have a significant effect on auditory memory for frequency. Those results suggest that there is a developmental increase in the persistence of memory for frequency with age that is independent of a rehearsing strategy in adults.

Keller, Cowan, and Saults (1995) continued this line of research on the effects of tone rehearsal on tone recall, with and without distractor tasks. Participants were presented with either a verbal or auditory distractor task (they had to remember the order of either numbers or tones) before the presentation of the first tone in the comparison task. In the rehearsal conditions, participants did not have to recall the list of distractor stimuli before hearing the comparison tone, but in the distractor conditions, participants did have to recall the distractor stimuli before hearing the comparison tone. The tone comparison task required a response of either higher (i.e., comparison tone was higher in frequency) or lower (comparison tone was lower in frequency) (Keller et al., 1995). Results of that study show that performance on the tone comparison task with a longer ITI (10 seconds) was significantly better in the rehearsal conditions than the distractor conditions. In other words, when there was more time between the standard and comparison tones, rehearsing the standard tone before hearing the comparison tone resulted in more accurate comparisons of the two tones than when rehearsal was

suppressed by the recall of the distractor items (Keller et al., 1995). The implications of that study are that rehearsing tones is important to the discrimination process--if the rehearsal process is disrupted in some way, then frequency discrimination is more difficult. Although the studies investigated the ability to remember and recall prior tones, they did not actually measure the participants' WMC to see what its relationship would be with frequency discrimination.

Payne (2003) did focus on this idea that frequency discrimination is related to working memory capacity in a series of delayed match-to-sample experiments. Payne first screened adults and college students for their working memory capacities (using Ospan) and spatial abilities (using Raven's). Participants were categorized into three groups based on their WMC—low spans, mid spans, and high spans. Participants then completed a frequency discrimination task, focused in the 800 Hz – 900 Hz frequency range, that determined their frequency difference threshold, which was then correlated with their Ospan and Raven's scores. Payne (2003) found that with no delay between the presentation of the two tones, there were no differences in performance between groups (low spans, mid spans, high, spans). However, when a delay of 20 ms or more was introduced between tones, the participants with high WMC performed significantly better (i.e., smaller difference thresholds) than the mid or low spans. Payne concluded that a high WMC and spatial reasoning seems to predict good frequency discrimination in the 800 Hz range. By ruling out differences in hearing abilities, categorical encoding strategies, and active rehearsal maintenance, Payne proposed that the differences between high and low spans is due to differential encoding processes (2003). This relationship between frequency discrimination and cognitive abilities was replicated and extended in

the current study to include other frequency ranges (i.e., 250 Hz and 1600 Hz) as well as introducing tempo discrimination tasks.

CHAPTER 2

THE PRESENT STUDY

While data can certainly be represented by auditory displays, individual differences in the interpretation of these displays can complicate their design. Research has also shown a relationship between cognitive abilities and discriminating between various sounds. The research also indicates that various strategies are involved in this interpretation and discrimination of sounds, depending on the particulars of the sounds being presented. The purpose of the current study was to determine how cognitive abilities and musical experience predict performance on a frequency and tempo discrimination task.

Hypotheses

Figure 1 shows the expected and hypothesized relationships between the primary variables in this study, as well as possible secondary relationships. First, I expected to find working memory capacity and spatial reasoning to be correlated, as is typically found. Second, I expected to find that WMC predicts performance on frequency discrimination. Third, I hypothesized that WMC would predict performance on tempo discrimination. Fourth, I expected to find that spatial reasoning ability would predict performance on frequency discrimination. Fifth, I hypothesized that spatial reasoning ability would predict performance on tempo discrimination. Sixth, I expected to find that musical experience would predict performance on frequency discrimination. Seventh, I hypothesized that musical experience would predict performance on tempo

discrimination, and lastly, that demographic variables would predict performance on tempo and frequency discrimination.

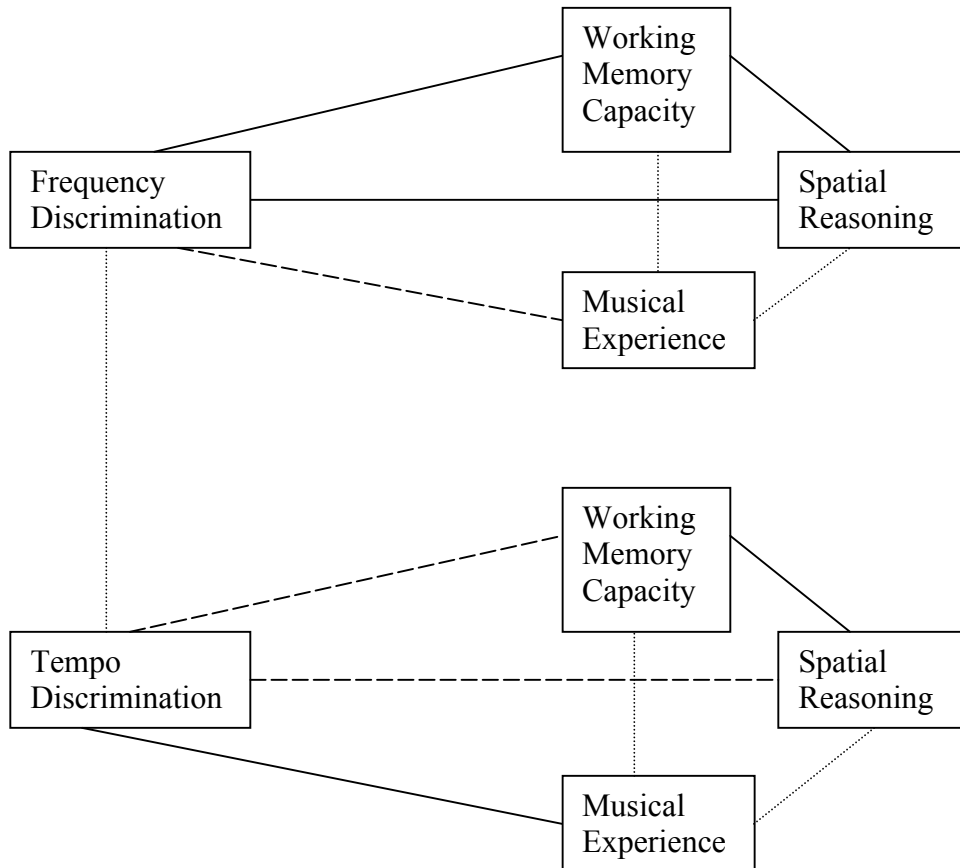


Figure 1. *Diagram of relationships between the proposed variables. The solid lines represent expected relationships supported by empirical results. The dashed lines represented hypothesized relationships. The gray dotted lines represent possible secondary relationships that are not the main focus of the proposed study.*

CHAPTER 3

METHOD

Participants

Thirty undergraduate students from Georgia Institute of Technology and twenty adults from the Atlanta, Georgia community participated in this study. This number was obtained from a power analysis requiring a power of 0.80, alpha of 0.05, six predictors, and a large effect size. The Atlanta community participants had already participated in a working memory study at Georgia Tech and were asked if they were willing to participate in another psychology study. The Georgia Tech student participants had an average age of 20 and included 17 males and 13 females. The Atlanta community participants had an average age of 25 and included 9 males and 11 females. The Georgia Tech participants were compensated with extra credit for psychology classes and the community participants were paid \$20 an hour for their time.

Participants were screened for normal or corrected-to-normal hearing using an automated hearing test using the E-Prime computer program. This test was composed of sounds from the 3 standard tones (250 Hz, 840 Hz, and 1600 Hz) and included 5 instances where no sound was played. Each sound, or lack thereof, was played one at a time with a large dot in the center of the screen to indicate that a sound was being played. Participants responded on the keyboard with either a “yes” if they heard a sound or a “no” they did not hear a sound. Correct answers were recorded as those responses that either correctly identified the presence of a tone (responded with a “yes”) or the absence

of a tone (responded with a “no”). A cutoff criterion of 80% accuracy was used and no participants were excluded based on the hearing test.

Apparatus and Stimuli

The tasks were programmed in E-Prime and were run on a PC. The current study consisted of four tasks: (1) Operation Span (Ospan); (2) Raven’s Progressive Matrices (Raven’s); (3) frequency discrimination; and (4) tempo discrimination. The sound stimuli for the tempo and frequency discrimination tasks were presented through Sennheiser HD202 headphones. A computerized version of the Edinburgh Handedness Test was also administered as part of the demographics.

Frequency Stimuli

The frequency discrimination task was a threshold task utilizing the method of constant stimuli. The stimuli were 500 ms long pure tones with 10 ms ramp up and ramp down. The tones were presented in 16-bit mono at a sampling rate of 44.1 kHz and had an amplitude of 70 dB. The three standard tones had frequencies of 250 Hz, 840 Hz, and 1600 Hz. These frequencies were chosen because they span the main frequency range of the human auditory system and are the central frequencies of their respective critical bands. In addition, 840 Hz is close to the center frequency used by Payne (2003).

Between the presentation of the standard and comparison tone was a 500 ms inter-tone interval of silence. There were also catch trials where the comparison tone was the same as the standard tone. See Table 1 for a list of standard and comparison tones.

Table 1. *Standard and comparison tones for the frequency discrimination task.*

Standard tone (Hz)	Comparison tones (Hz)
250	220, 230, 240, 245, 247, 248, 249, 250 , 251, 252, 253, 255, 260, 270, 280
840	810, 820, 830, 835, 837, 838, 839, 840 , 841, 842, 843, 845, 850, 860, 870
1600	1570, 1580, 1590, 1595, 1597, 1598, 1599, 1600 , 1601, 1602, 1603, 1605, 1610, 1620, 1630

Tempo Stimuli

The tempo discrimination task was another threshold task that utilized the method of constant stimuli. Each tempo stimulus was 3 s in length and consisted of a series of brief clicks (sounds without frequency that are 5 ms long). The duration of the inter-click interval (ICI) was measured as the length of time starting with the presentation of the onset of one click to the onset of the next click. The duration of the ICI was manipulated to vary the tempo. The standard tempos centered around 150 ms, 250 ms, or 350 ms ICI. Between the presentation of the standard and comparison tempos was a 3 s interval (gap) of silence, which was selected through pilot testing. There were also catch trials where the comparison tempo was the same as the standard tempo. See Table 2 for a list of standard and comparison tones.

Table 2. *Standard and comparison tempos for tempo discrimination task*

Standard ICIs (ms)	Comparison ICIs (ms)
150	110, 120, 130, 140, 144, 146, 148, 150 , 152, 154, 156, 160, 170, 180, 190
250	210, 220, 230, 240, 244, 246, 248, 250 , 252, 254, 256, 260, 270, 280, 290
350	310, 320, 330, 340, 344, 346, 348, 350 , 352, 354, 356, 360, 370, 380, 390

Discrimination Tasks

The procedure for both the frequency and tempo discrimination tasks was exactly the same except for the use of different sounds and intervals of silence for the two tasks (see above sections on stimuli). The directions also differed between the two tasks—the frequency task asked which interval had the higher or lower frequency and the tempo task asked which interval had the faster or slower tempo.

The standard stimulus was presented first in every trial and the comparison stimulus was always presented second. Participants were presented with a visual indication (“1” or “2”) of which sound was currently playing (i.e., first or second sound). Half of the participants were asked in which interval (i.e., first or second) was the higher tone or faster tempo and the other half were asked in which interval was the lower tone or slower tempo (the question was counterbalanced between groups). Participants pressed the “1” key if they thought the first interval had the desired sound and they pressed the “3” key if they thought the second interval had the desired sound. Participants had 10 seconds to respond to each stimuli pair before the computer would automatically move on to the next pair. After each response on the keyboard, a focus display (“+”) was presented between sound pairs to prepare the participant for the next presentation. Each

task consisted of 3 cycles made of 16 standard-comparison stimuli pairs, including 2 catch trials. There were a total of 144 trials for both the frequency and tempo discrimination tasks.

The practice session that came before the experimental session was similar to the experimental session, except only 1 cycle of 12 trials was presented—4 tone pairs for each central frequency. Also, feedback was given to the participants during the practice sessions, but not during the actual trials. Three possible feedback presentations could be shown on the computer screen depending on the participants' response—"Correct!", "Incorrect", or "No response detected." The feedback stayed on the screen for 1.5 seconds.

Operation Span

The automatic version of the Operation Span (Ospan) task (Unsworth, Heitz, Schrock, & Engle, 2005) that was used in the study was obtained from Randall Engle at the Georgia Institute of Technology. The following is a brief description of the task, but see Unsworth et al. (2005) for more information.

The Ospan task requires participants to solve a series of math problems while trying to remember a set of letters. In this study, participants were presented with each mathematical equation one at a time on a computer screen. Participants worked the math problem in their head and then clicked the computer mouse to move to the next screen. The next screen showed a number and two boxes, one labeled "TRUE" and the other "FALSE." Participants made a decision if the number on the screen was the correct answer to the previous math problem by selecting "TRUE" if it was correct or "FALSE" if it was not the correct answer. Then, a letter flashed on the screen for the participant to

memorize. Another math problem then appeared, followed by the decision screen, and then another letter. After each set of 2 to 7 math problems and letters, a screen was presented with 12 letter boxes on it. Participants were to click on all of the letters they had seen in the previous set, in order of presentation. After entering the letters, the next set of equations and letters were presented and participants followed the same protocol for the rest of the experiment.

Raven's Progressive Matrices

The automatic version of the Raven's Progressive Matrices (Raven's) task that was used in the proposed study was obtained from Randall Engle at the Georgia Institute of Technology.

Participants were shown a series of pictures, each with a piece missing in the bottom right corner of the picture. Their task was to fill in the missing part of the picture by selecting from the six or eight pieces below the picture. Participants clicked on the piece they thought was correct and the computer went to the next picture. There were 3 sets of 12 pictures to solve; participants had 5 minutes for each set. Note that, the community participants had only been run on Set A from Raven's when they previously participated in the study in another psychology lab. Thus, although the Georgia Tech students were run on all three sets of pictures, only their scores on Set A were included in the statistical analyses.

Procedure

The Georgia Tech students participated in two sessions—one for the cognitive ability tasks and one for the auditory threshold tasks. The total procedure for the Georgia Tech Students is summarized in Figure 2.

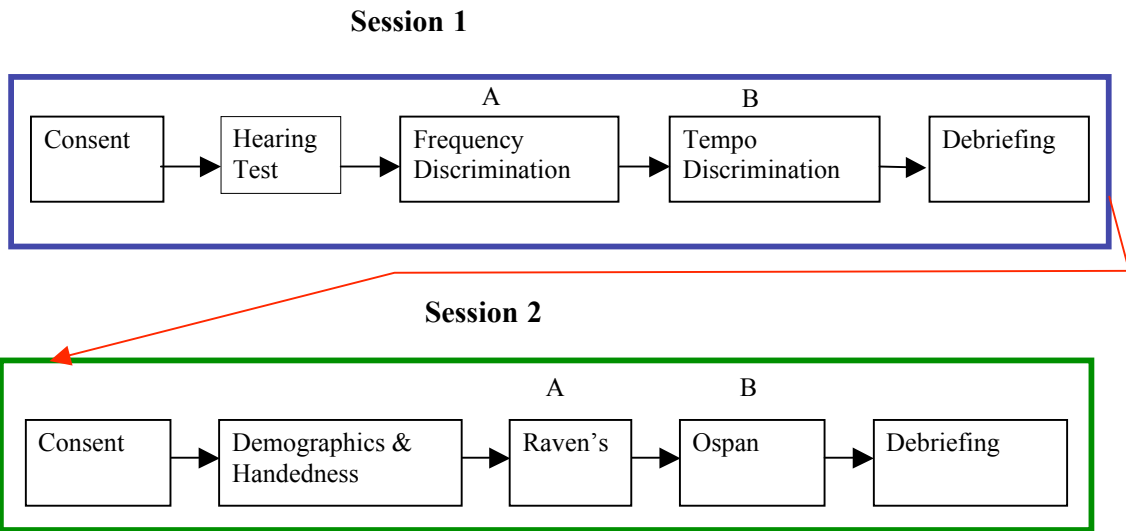


Figure 2. *Georgia Tech participant sessions--Sessions 1 and 2 are counterbalanced and Blocks A and B are counterbalanced.*

Since the Georgia Tech students sign up online for both sessions, some students signed up for the cognitive session first and others signed up for the auditory session first. In this respect, the sessions were pseudo-counterbalanced. The cognitive ability session consisted of a working memory capacity task (i.e., Ospan) and a spatial reasoning task (Raven’s), which was presented in a counterbalanced order. Data were also collected in the cognitive ability session about their age, gender, handedness (Edinburgh Handedness Test—on scale of –20 to +20), and musical experience (total years playing a musical instrument, years of formal musical training). The auditory threshold session consisted of the tempo discrimination and frequency discrimination task, which were presented in a counterbalanced order, as well as an automated hearing test before they began the discrimination tasks.

Since the participants from the Atlanta community had already completed the Ospan and Raven’s test when they participated in their previous study at Georgia Tech,

they only had to participate in the auditory tasks. Therefore, they only participated in Session 1 with the addition of the demographics and handedness sections.

CHAPTER 4

STATISTICAL ANALYSES

Difference Thresholds

The first analysis to be performed was finding the just noticeable difference (JND) thresholds for each participant for all central frequencies and tempos. Their data were recorded in percent correct at each frequency and tempo difference. For example, for each central frequency (250 Hz, 840 Hz, and 1600 Hz) each participant had a percent correct value for a 0 Hz, 1 Hz, 2 Hz, 3 Hz, 5 Hz, 10 Hz, 20 Hz, and 30 Hz difference from the standard tone. For each central tempo (150 ms, 250 ms, and 350 ms) each participant had a percent correct value for a 0 ms, 2 ms, 4 ms, 6 ms, 10 ms, 20 ms, 30 ms, and 40 ms difference from the standard tempo. So, for each central frequency and each central tempo, their eight percentage correct value were modeled using a Quick function (Quick, 1974) via an Excel program. The Quick function is one of the most widely used psychometric functions in psychophysics aside from the Gaussian, logistic, and Weibull functions (the Quick function is a modification of the Weibull function) (Gilchrist, Jerwood, & Ismaiel, 2005; Strasburger, 2001). The Quick function was chosen to measure the difference thresholds in the current study for four reasons: (1) it is suitable for n -alternative forced choice responses; (2) the slope parameter has the same value for both arithmetic and logarithmic scales; (3) its threshold lies at the median point of the probability range; and (4) it is easy to convert thresholds found from the Quick function to the other psychometric functions when making comparisons (Gilchrist et al., 2005; Strasburger, 2001).

Not only did the Excel program fit the data to the Quick function model, but it gave the value for their difference threshold at the 80% cutoff value that I used. This graphing technique was used to find all three of the frequency JNDs and all three of the tempo JNDs for each subject. See Figure 3 for example of a good (i.e., small) threshold graph.

Quick function graph of 150 ms threshold data for one participant

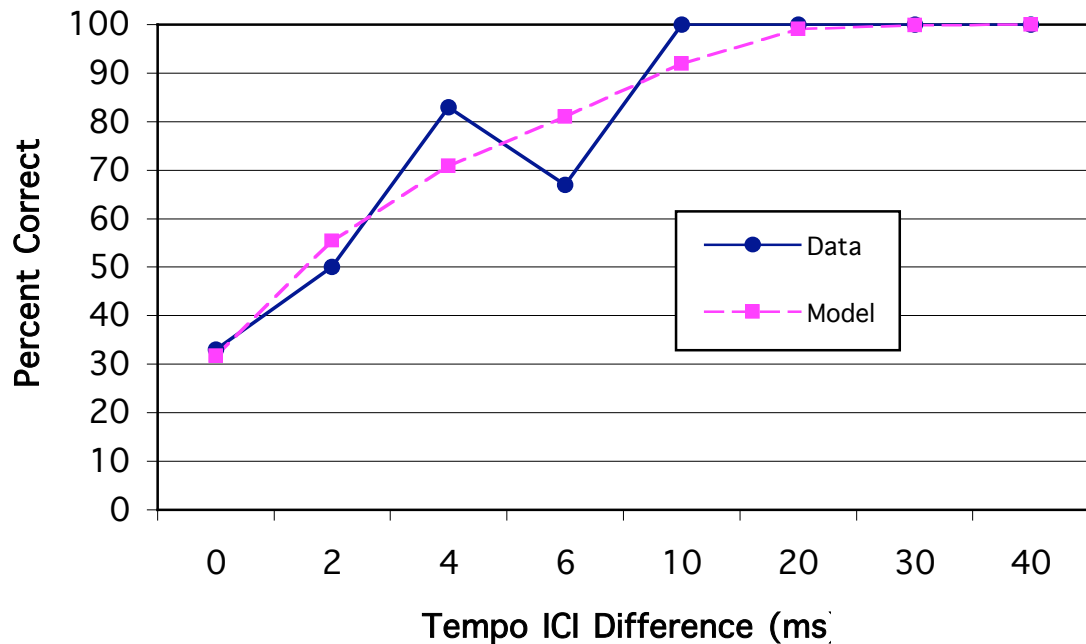


Figure 3. *Quick function graph of 150 ms threshold data for one participant. The solid line with the circles represents the actual data from the participant. The dashed line with the squares represents the Quick model fit of the data. Using an 80% threshold value, this participant has a difference threshold value of 5.8 ms, meaning that the tempos centered around 150 ms has to differ by 5.8 ms for the participant to detect the speeds were different.*

While determining the threshold values for each participant, I noticed some data series that did not look feasible, that is, some of the fitted Quick functions would require

a negative tempo or frequency value to be the 80% threshold value. This is impossible, and is often the result of the participant guessing or responding erratically. See Figure 4 for an example of an implausible (i.e., negative) threshold graph.

Quick graph function of 1600 Hz threshold data for one participant

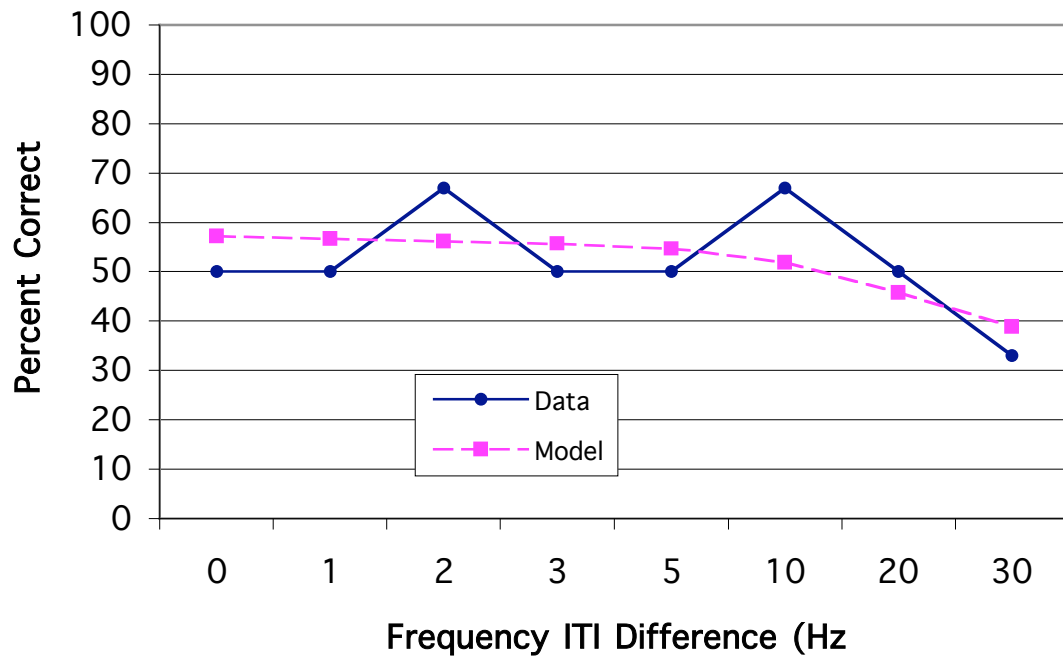


Figure 4. *Quick function graph of 1600 Hz threshold data for one participant. The solid line with the circles represents the actual data from the participant. The dashed line with the squares represents the Quick model fit of the data. Using an 80% threshold value, this participant would have to have a difference threshold value of -63.3 Hz, meaning that the frequencies centered around 1600 Hz would have to differ by -63.3 Hz for the participant to detect the frequencies are different. Such a result is nonsensical.*

The negative graphs would suggest that those individuals would only reach an 80% JND to the LEFT of the y-axis. This is clearly impossible, so the data from those frequencies or tempos were removed as a whole set. As a result of throwing out all the

negative thresholds, 5 data points were removed from the 250 Hz category, 2 from the 840 Hz category, 2 from the 1600 Hz category, 2 from the 150 ms category, 3 from the 250 ms category, and 3 data points were removed from the 350 ms category.

Using the data after the outliers were trimmed, the mean JNDs and standard deviations were calculated for each of the three central frequencies and three central tempos (see Table 3).

Table 3. *Number of cases, mean JNDs, and standard deviations for the six standard stimuli.*

<u>Standard Stimulus</u>	<u>N</u>	<u>Mean JND</u>	<u>SD</u>
250 Hz	45	31.0 Hz	116.8 Hz
840 Hz	48	40.6 Hz	138.5 Hz
1600 Hz	48	29.4 Hz	56.0 Hz
150 ms	48	17.2 ms	26.2 ms
250 ms	47	16.8 ms	21.3 ms
<u>350 ms</u>	<u>47</u>	<u>29.2 ms</u>	<u>27.5 ms</u>

After finding the mean JNDs and standard deviations, we calculated the value of 2 SD above the mean for each standard stimulus and discarded those extreme data points out as well. When using this 2 SD cutoff value, we excluded 2 more cases from 250 Hz, 2 more cases from 840 Hz, 2 more cases from 1600 Hz, 1 more case from 150 ms, 1 more case from 250 ms, and 2 more cases from 350 ms. See Figure 5 for an example of a bad (i.e., large) threshold graph that was above the 2 SD criterion value.

Quick function graph of 250 Hz threshold data for one participant

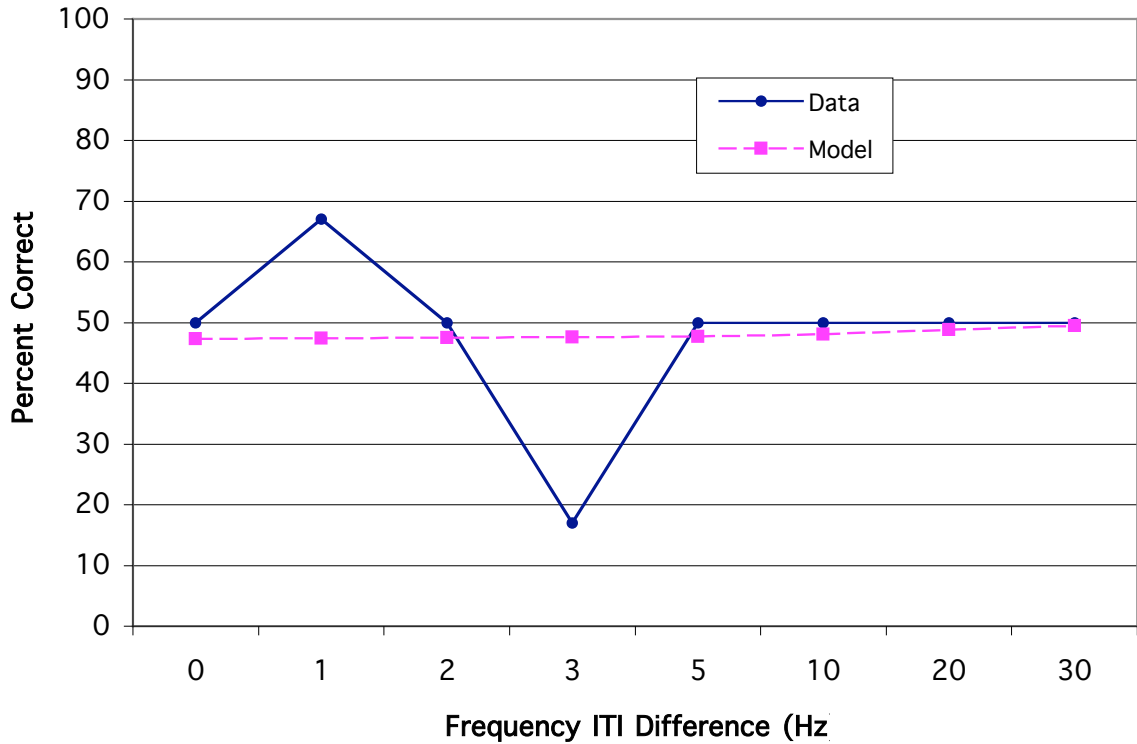


Figure 5. *Quick function graph of 250 Hz threshold data for one participant. The solid line with the circles represents the actual data from the participant. The dashed line with the squares represents the Quick model fit of the data. Using an 80% threshold value, this participant would have a difference threshold value of 687 Hz, meaning that the frequencies centered around 1600 Hz has to differ by 687 Hz for the participant to detect the frequencies are different. Clearly the result is nonsensical, arising from data that show no trend toward improvement.*

Correlations

Correlations were run on all the variables to identify any significant relationships between variables, especially to determine if there was a significant relationship between

scores on Osplan and Raven's. The details of these analyses are presented in the Results section.

T-Tests

Paired samples t-tests were also performed on the Weber fractions of all pairs of frequency means and all pairs of tempo means (see Table 4). The six t-tests were computed to see if there were any statistical differences between the various thresholds.

Table 4. *Number of cases, mean Weber fractions, and standard deviations for the six standard stimuli.*

<u>Standard Stimulus</u>	<u>N</u>	<u>Mean Weber Fraction (unitless)</u>	<u>SD</u>
250 Hz	43	.0284	.0493
840 Hz	46	.0151	.0212
1600 Hz	46	.0124	.0158
150 ms	47	.0931	.0869
250 ms	46	.0560	.0354
<u>350 ms</u>	<u>46</u>	<u>.0751</u>	<u>.0549</u>

Hierarchical Regressions

After finding the difference thresholds for all six standard stimuli, six hierarchical regressions were performed on the data to see if performance on the discrimination tasks was related to cognitive abilities and demographic variables. These six hierarchical regressions are for each of the difference thresholds at the central sounds (250 Hz, 840 Hz, 1600 Hz, 150 ms, 250 ms, and 350 ms). The dependent variables for each of these

regressions were the difference thresholds for each central sound, measured in either Hertz or milliseconds. The independent variables/predictors were performance on Ospan (Ospan score) and Raven's (number correct in Set A), musical experience (years), age (years), gender (male or female), and handedness (number on scale of -20 to 20). The first block of predictors in the hierarchical regressions contained Ospan scores (predicted to have the strongest relationship with the dependent variable). The second block of predictors contained Raven's scores (predicted to have the second strongest relationship with the dependent variable). The third block of predictors contained musical experience (predicted to be the next strongest relationship with the dependent variable). The last block of predictors contained age, handedness, and gender (predicted to have the weakest relationship with the dependent variable).

CHAPTER 5

RESULTS

Correlations

Table 5 below shows all correlations between the dependent and independent variables. There was a significant positive relationship between Ospan and Raven's which was expected based on past findings (Unsworth & Engle, 2005). Ospan also shows a significant negative correlation with frequency JND at 350 ms, which means that high scores on Ospan are related to low scores for the 350 ms threshold task (lower JNDs are better when talking about difference thresholds). Having good difference thresholds at 350 ms may be related to the strategy required to process slower tempos. According to Hibi (1983), around 350 ms is when people shift processing of rhythmic sequences from a wholistic process of the sounds to a more ongoing processing strategy. These results imply that WMC plays a role in the one-by-one processing of individual events in slower tempos.

Raven's also showed positive significant correlations with years playing a musical instrument and years of formal musical training. These findings may be related to the spatial nature of holding and playing an instrument. Raven's does show some significant negative correlations as well, such as with 250 Hz and 1600 Hz. The negative correlations between Raven's and 250 Hz and 1600 Hz are not surprising because this shows that a high score on Raven's is related to a low JND at these frequencies, which was a predicted result. However, there was not a significant relationship between Raven's and 840 Hz.

Some other significant positive correlations are between years playing a musical instrument and years of musical training. This finding also makes sense in that the longer a person plays an instrument, the more likely that person had the opportunity for more years of musical training. The years of musical training is also significantly correlated with 1600 Hz JND, which may be related to the idea that it takes more training to discriminate between higher frequencies. There was a significant positive correlation between gender and 250 ms JND (i.e., relationship between being a female and having a good JND for 250 ms). However, I do not really have an explanation for why this relationship exists.

All of the frequency thresholds were positively correlated with each other, which goes along with the idea that a person who has a higher frequency difference threshold should also have a higher difference threshold for other frequencies. Interestingly, 250 Hz and 1600 Hz were also highly correlated with all of the tempo thresholds and 840 Hz was correlated with 150 ms. These relationships between frequency and tempo may be explained by a person's overall sound discrimination ability or even WMC.

Although 150 ms and 250 ms were highly correlated, neither tempo was correlated with 350 ms. This finding falls in line with Hibi's theory that an ongoing processing strategy is used for slower tempos (i.e., 350 ms), but a more holistic processing strategy should be used for the faster tempos (i.e., 150 ms and 250 ms). The implications of Hibi's theory in relation to these findings is that people who can effectively apply a holistic strategy to 150 ms should also apply it effectively at 250 ms. However, the effectiveness of an ongoing processing strategy is not necessarily related to an effective use of the holistic processing strategy.

T-Tests

After running the paired samples t-tests on the Weber fractions of the frequency difference thresholds means, there was a significant difference between the mean Weber fractions at 250 Hz and 840 Hz ($t=3.300, p<.01$) and between those at 250 Hz and 1600 Hz ($t=3.540, p<.01$). According to Weber's Law, there should not be a significant difference between any of the Weber fractions. The finding that Weber's law was violated can, most likely, be explained by the small sample size used in the study, especially after the negative thresholds were excluded from the data set.

After running the paired samples t-tests on the tempo difference thresholds, there was a statistically significant difference between the mean Weber fractions at 150 ms and 250 ms ($t=3.383, p<.01$) and between the means of 250 ms and 350 ms ($t=-2.158, p<.05$). These proportions are larger than those found in Friberg and Sundberg (1995), but are closer to the proportions found in Hibi (1983). These proportions also do not closely follow the trends suggested by either Friberg and Sundberg (1995) or Hibi (1983). Friberg and Sundberg would predict that the proportions for 250 ms and 350 ms should be the same (follow Weber's Law) and that 150 ms should have a higher proportion than the other two. Hibi would predict that Weber's Law would hold for 150 ms and 250m, but not for 350 ms. Once again these findings may be impacted by the smaller sample size of the study.

Hierarchical Regressions

For all of the regression equations listed below, refer to Table 6 for the list of dependent variables and the labels given them in the regression equations.

Table 6. *Dependent variables and their appropriate regression variable labels for hierarchical regression equations.*

<u>Dependent Variable</u>	<u>Regression Label</u>
Ospan	X ₁
Raven's	X ₂
Years Played Instrument	X ₃
Years Musical Training	X ₄
Handedness	X ₅
Gender	X ₆
Age	X ₇

The final regression equation for the hierarchical regression where 250 Hz was the dependent variable is: $Y = 34.124 - 0.028X_1 - 2.427X_2 - 0.203X_3 + 0.045X_4 - 2.676X_5 - 0.088X_6 + 0.150X_7$. However, not one of the variables was responsible for significant increments in R^2 , which goes against our prediction that frequency discrimination at 250 Hz is related to the independent variables, especially Ospan and Raven's. Also, the variables only account for 14.3% of the variance in the difference thresholds for 250 Hz.

The final regression equation for the hierarchical regression where 840 Hz was the dependent variable is: $Y = 22.668 + 0.064X_1 - 1.859X_2 - 0.074X_3 - 0.777X_4 - 4.743X_5 + 0.367X_6 + 0.177X_7$. However, not one of the variables was responsible for significant increments in R^2 , which goes against our prediction that frequency discrimination at 840 Hz is related to the independent variables, especially Ospan and

Raven's. These results, specifically, counter the results found in Payne (2003). Also, the variables only account for 11.0% of the variance in the difference thresholds for 840 Hz.

The final regression equation for the hierarchical regression where 1600 Hz was the dependent variable is: $Y = 45.266 - 0.117X_1 - 3.700X_2 - 0.817X_3 + 0.095X_4 + 2.185X_5 + 0.782X_6 - 0.049X_7$. In the second model, Raven's (X_2) significantly accounts for 8.9% of the variance above and beyond that of Osplan in Model 1 ($p < .05$). Raven's can be represented by a significant beta weight of -5.120 ($t = -2.127, p < .05$). However, none of the other variables was responsible for significant increments in R^2 , which goes against our prediction that frequency discrimination at 1600 Hz is related to the independent variables. On the other hand, the finding that high scores on Raven's predicts lower JNDs at 1600 Hz (lower JNDs means better difference thresholds) was an expected finding. Since Raven's appears to be the only significant variable in the models, and only in step 2, then a more appropriate regression model to represent this data is $Y = 76.326 - 0.180X_1 - 5.120X_2$. Also, the variables account for 21.6% of the variance in the difference thresholds for 1600 Hz.

The final regression equation for the hierarchical regression where 150 ms was the dependent variable is: $Y = 20.788 - 0.053X_1 - 0.894X_2 - 0.102X_3 - 0.308X_4 + 1.159X_5 + 0.214X_6 + 0.026X_7$. However, none of the variables was responsible for significant increments in R^2 , which goes against our prediction that tempo discrimination at 150 ms is related to the independent variables, especially Osplan and Raven's. Also, the variables only account for 6.8% of the variance in the difference thresholds for 150 ms.

The final regression equation for the hierarchical regression where 250 ms was the dependent variable is: $Y = 12.266 - 0.035X_1 - 0.215X_2 - 0.354X_3 + 0.943X_4 +$

$5.509X_5 + 0.081X_6 - 0.056X_7$. Although overall the last model was not significant, gender (X_6) has a significant beta weight of 5.509 ($t=2.034, p<.05$). However, none of the variables, including gender, was responsible for significant increments in R^2 , including gender, which goes against our prediction that tempo discrimination at 250 ms is related to the independent variables, especially Ospan and Raven's. Also, the variables only account for 13.7% of the variance in the difference thresholds for 250 ms.

The final regression equation for the hierarchical regression where 350 ms was the dependent variable is: $Y = 32.702 - 0.222X_1 + 0.159X_2 - 0.444X_3 + 0.999X_4 - 3.026X_5 + 0.263X_6 - 0.464X_7$. In the first model, Ospan (X_1) significantly accounts for 8.8% of the variance ($p<.05$). Ospan can be represented by a significant beta weight of -0.231 ($t=-2.031, p<.05$). However, none of the other variables was responsible for significant increments in R^2 , which goes against our prediction that tempo discrimination at 350 ms is related to the independent variables. On the other hand, the finding that high scores on Ospan predicts lower JNDs at 350 ms (lower JNDs means better difference thresholds) makes sense in the context that WMC may play a role in the more ongoing processing of this slower tempo range. Since Ospan appears to be the only significant variable in the models, and only in step 1, then a more appropriate regression model to represent this data is $Y = 34.938 - 0.231X_1$. Also, the variables account for 19.1% of the variance in the difference thresholds for 350 ms.

CHAPTER 6

DISCUSSION

My first hypothesis, that WMC and spatial reasoning will be correlated, was confirmed by the present study, which was seen in the significant positive correlation between Ospan and Raven's. This replicates the findings of Payne (2003) and Unsworth and Engle (2005) showing a positive relationship between these two cognitive measures.

My second hypothesis that WMC would predict performance on frequency discrimination was neither confirmed by the regression analysis nor by the correlation analysis—no significant relationships was found between Ospan and any of the frequency thresholds in either analysis. We did not even find the significant relationship between high performance on Ospan and lower difference thresholds at 840 Hz that Payne discovered in her series of experiments. One explanation could be that the current study has some range restriction problems with Ospan scores, namely, the sample had more high spans than mid and low spans. This range restriction may be attributed to having more Georgia Tech students than Atlanta community participants. Another possible explanation for the difference is that Payne used the method of limits to find the difference thresholds and the current study used the method of constant stimuli. The different types of responses between the method of limits (i.e., is there a difference between the two sounds, yes or no) and the method of constant stimuli (i.e., in which interval, 1st or 2nd, is the higher or lower frequency) may have different relationships with WMC.

My third hypothesis that WMC would predict performance on tempo discrimination was only partially confirmed—there was only a significant relationship between Ospan and 350 ms. However, these results do seem to fit the processing models suggested by Hibi (1983). Only at the 350 ms difference threshold does WMC seem to play a role in tempo discrimination. This finding may be due to differences in the possible strategies used by the participants in the slower versus faster tempo discrimination tasks. The results indicate that WMC may play a bigger role in discriminating between slower tempos.

My fourth hypothesis that spatial reasoning ability would predict performance on frequency discrimination was only partially confirmed—there was only a significant relationship between Raven's and 1600 Hz. Although not found to be a significant predictor in the regression analysis, there was a significant correlation between Raven's and 250 Hz and 1600 Hz. One possible explanation for the general lack of significant relationships between Raven's and frequency discrimination, especially at 840 Hz, is that all three sets of responses for the Raven's were used by Payne, but only set A was used in the current study. The implication of using the smaller response set is that there is also a range restriction in Raven's scores with the current study. Once again, these unexpected results may be due to the range restriction of the cognitive ability scores for Raven's.

My fifth hypothesis that spatial reasoning ability would predict performance on tempo discrimination was neither confirmed by the regression analyses nor by the correlation analysis—no significant relationships was found between Raven's and any of the tempo thresholds in either analysis. Since no research has been done before the present study regarding the relationship between Raven's and tempo discrimination, we

were not sure if our results would support our hypothesis. This hypothesis was developed from extending Payne's findings with frequency discrimination to tempo discrimination, a relationship that does not seem to exist after all.

My sixth hypothesis that musical experience would predict performance on frequency discrimination was only partially confirmed—only a significant correlation was found between years of musical training and 1600 Hz. With respect to the predictions for musical experience, the literature has mixed findings for the relationship between musical experience and auditory discrimination tasks. This study showed that there was really no significant predictive relationship between musical experience and frequency discrimination, although the one correlation was found between 1600 Hz and years of musical training. The general lack of this relationship may be in part related to the very simple questions asked about musical experience, which may not be getting at the essence of the role musical background plays in frequency discrimination. Also, no real findings for the other demographic variables were found, but hypotheses on those relationships were not very strong to begin with.

My seventh hypothesis that musical experience would predict performance on tempo discrimination was neither confirmed by the regression analyses nor by the correlation analysis—no significant relationships existed between years playing a musical instrument or years of musical training with any of the tempo thresholds. As with the hypothesis of musical experience predicting frequency discrimination, there were mixed findings in the literature regarding the relationship between musical experience and tempo discrimination. Again, the very simple questions asked about musical experience

may not be getting at the essence of the role musical background plays in tempo discrimination.

My last hypothesis that demographic variables would predict performance on tempo and frequency discrimination was only partially confirmed—gender had a significant beta weight at 250 ms and a significant correlation also existed between these two variables. This finding that females seem to have better difference thresholds at 250 ms cannot really be explained by previous studies and may just be a random finding. Also, no real findings for the other demographic variables were found, which is not surprising because the hypotheses on those relationships were not very strong to begin with.

Although most of my predictions were not confirmed by the regression analyses, the many significant correlations that were found show that the hypothesized relationships may exist. Due to the small sample size and various range restrictions in certain variables, these relationships, in general, were not found to be significant. However, data will continue to be collected to help both of these limiting factors in hopes that the predicted relationships will show themselves.

CHAPTER 7

IMPLICATIONS

The theoretical implication of the current study is to gain better understanding of cognitive abilities in respect to listening to sounds. One of the practical implications of this study is finding characteristics of listeners that predict how they interpret auditory information—we can gain knowledge how to tailor or create auditory graphs specific for the user. Specifically, when designing an auditory graph, we may want to take into account speed of the data presentation. At slower presentations, a listener’s working memory may affect their decisions about the data; faster presentation of the data may prove to enhance trend detection. Another practical implication of the current study is gaining the ability to choose operators who are more able to interpret auditory graphs effectively (e.g., multi-modal watch stations). However, this study should be replicated before any of these suggestions should be carried out.

APPENDIX A

FREQUENCIES OF VARIABLES

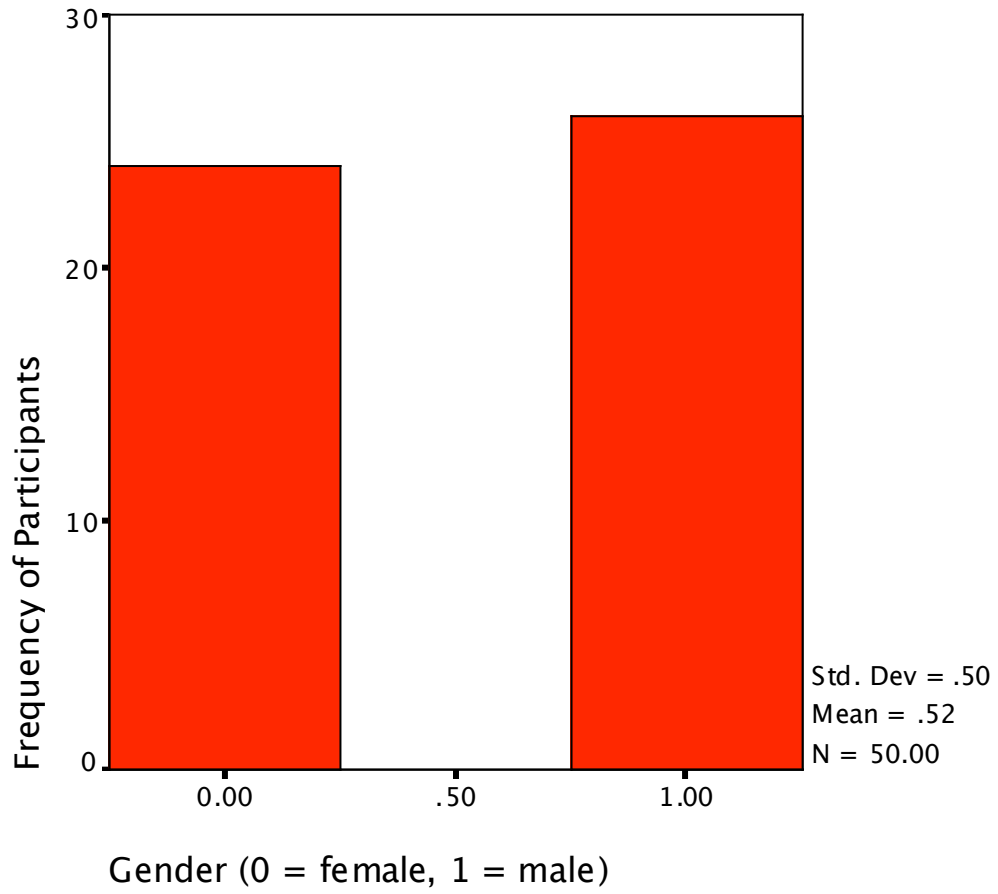


Figure A1. *Frequencies of participants' gender.*

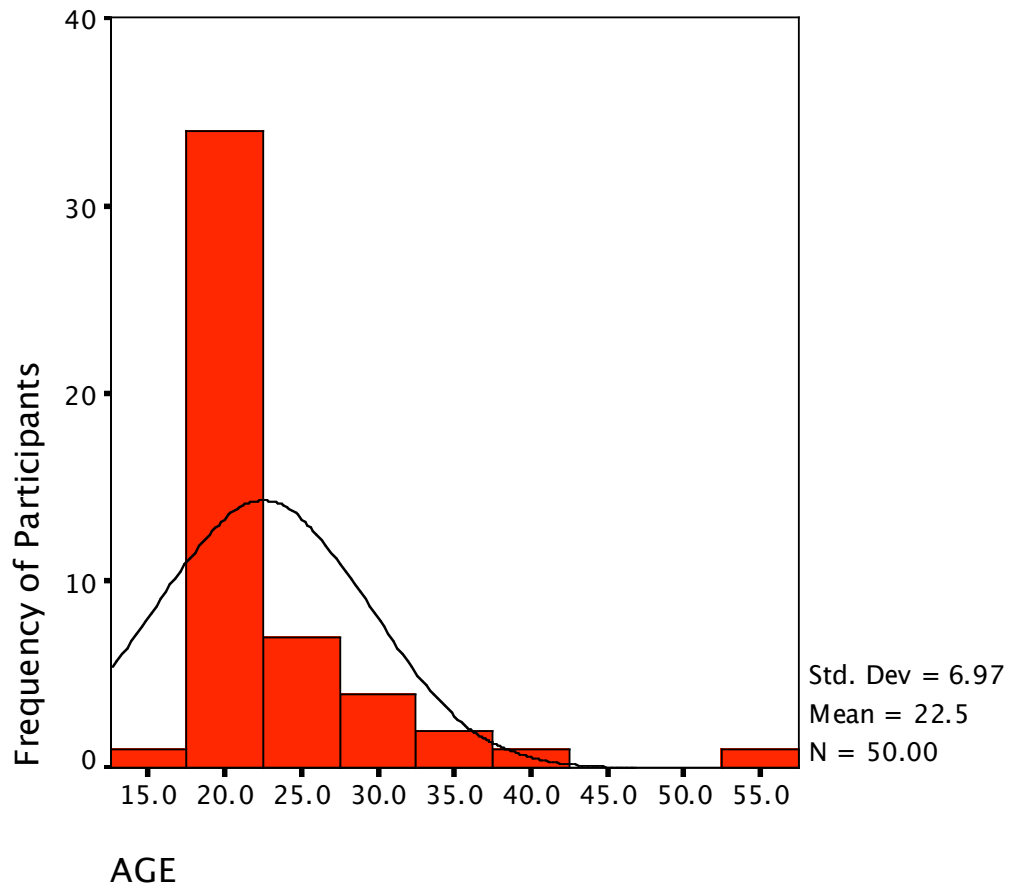


Figure A2. *Frequencies of participants' age.*

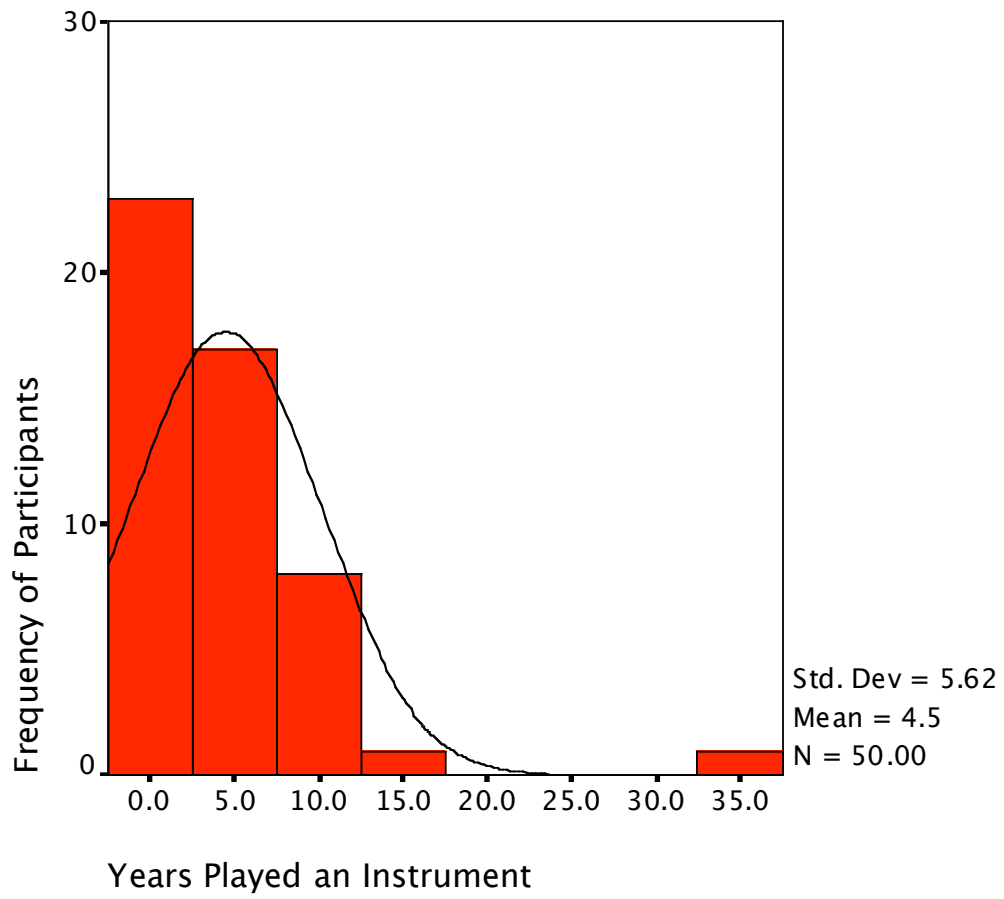


Figure A3. *Frequencies of participants' years playing a musical instrument.*

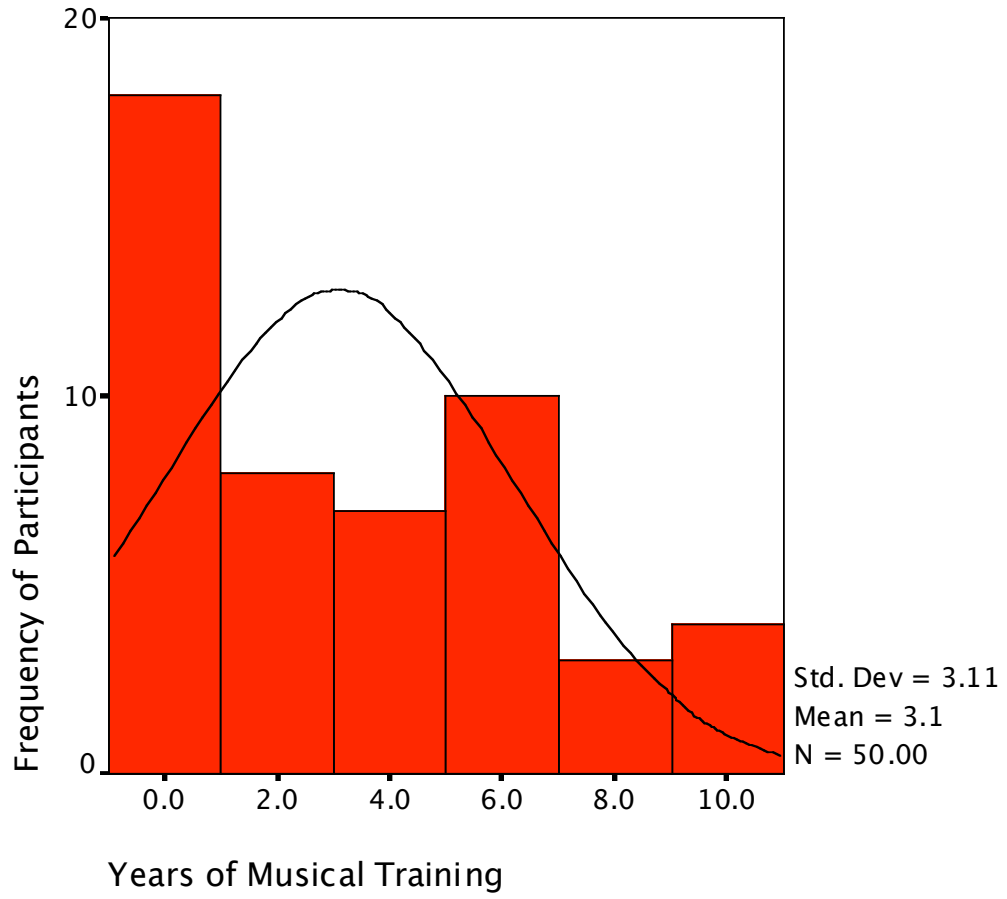


Figure A4. *Frequencies of participants' years of musical training.*

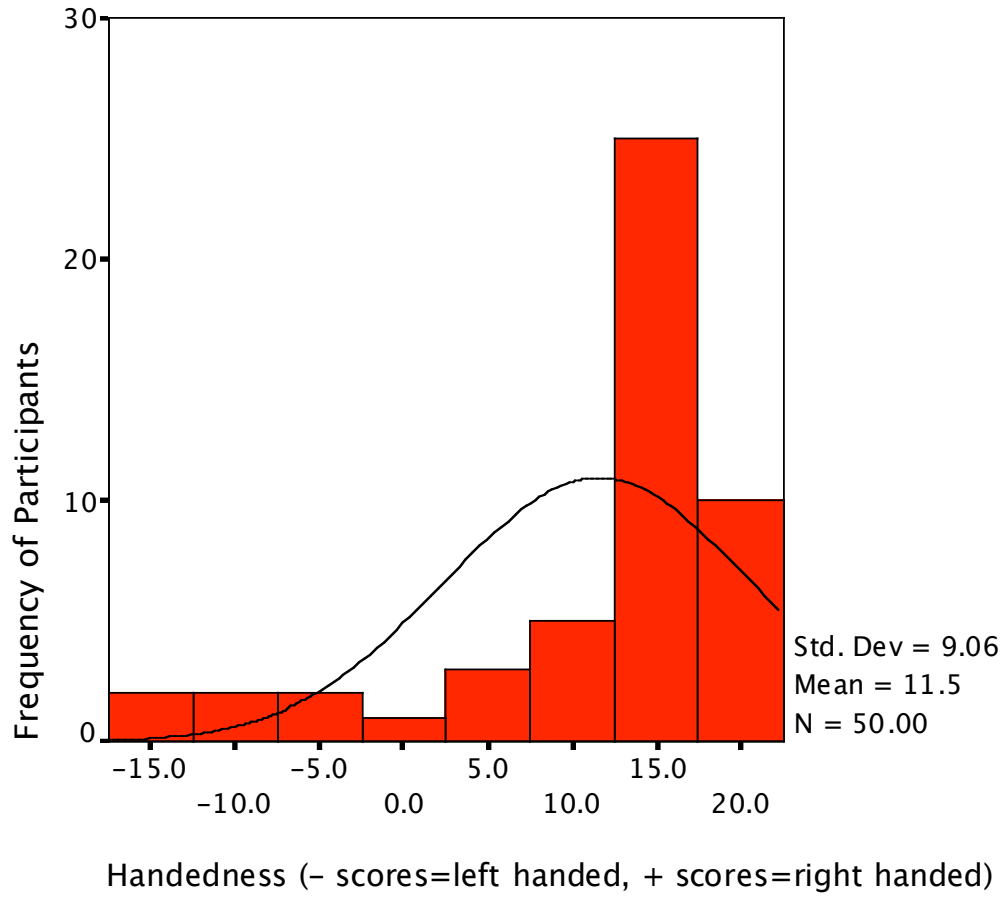


Figure A5. *Frequencies of participants' handedness.*

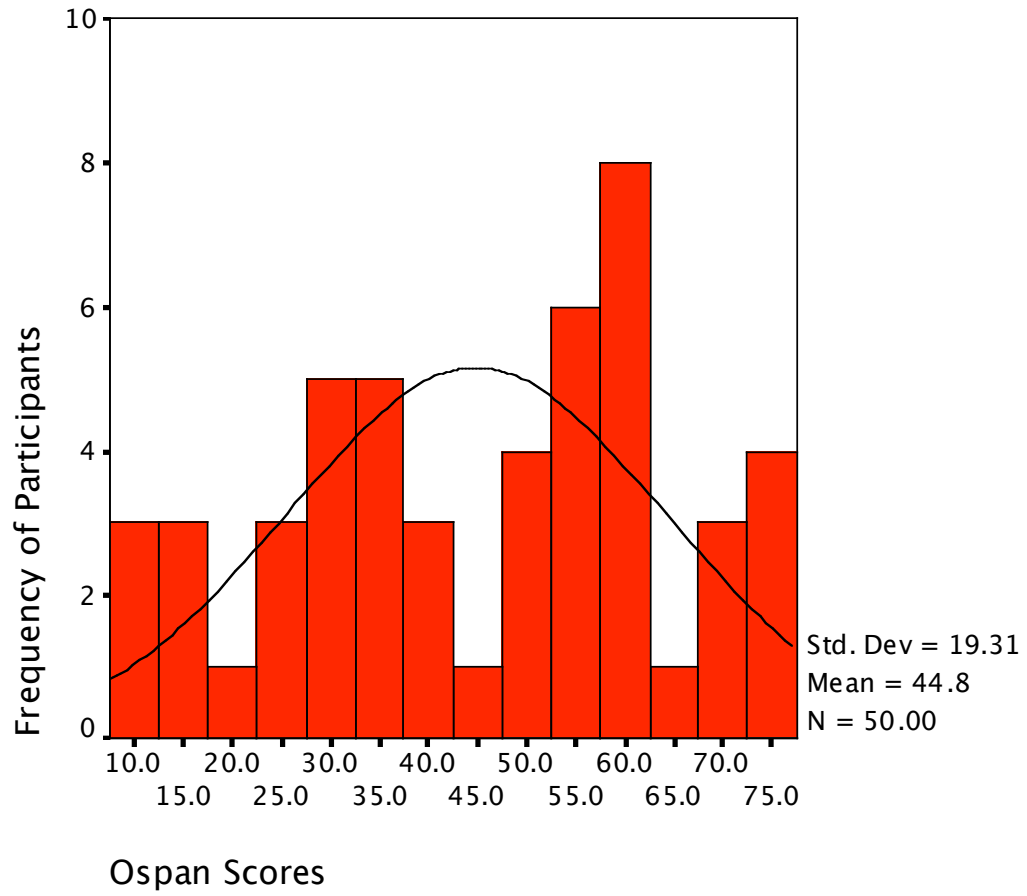


Figure A6. *Frequencies of participants' Ospan scores.*

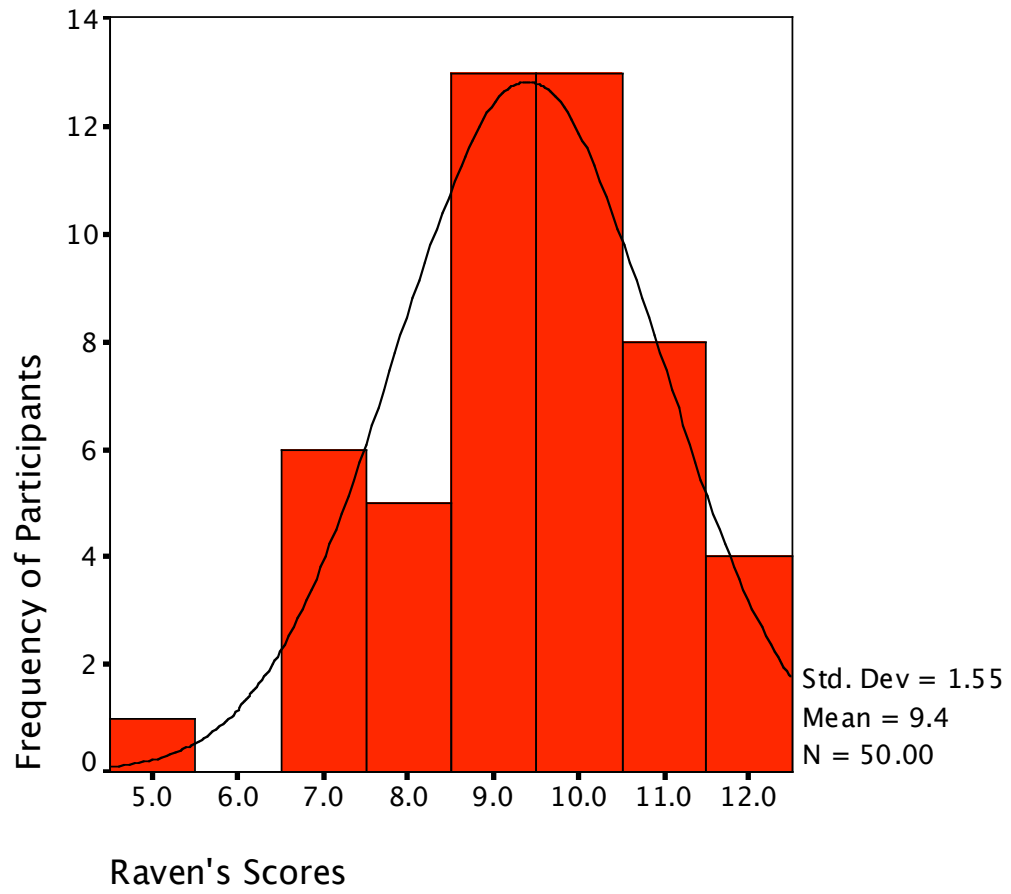


Figure A7. Frequencies of participants' Ravens scores.

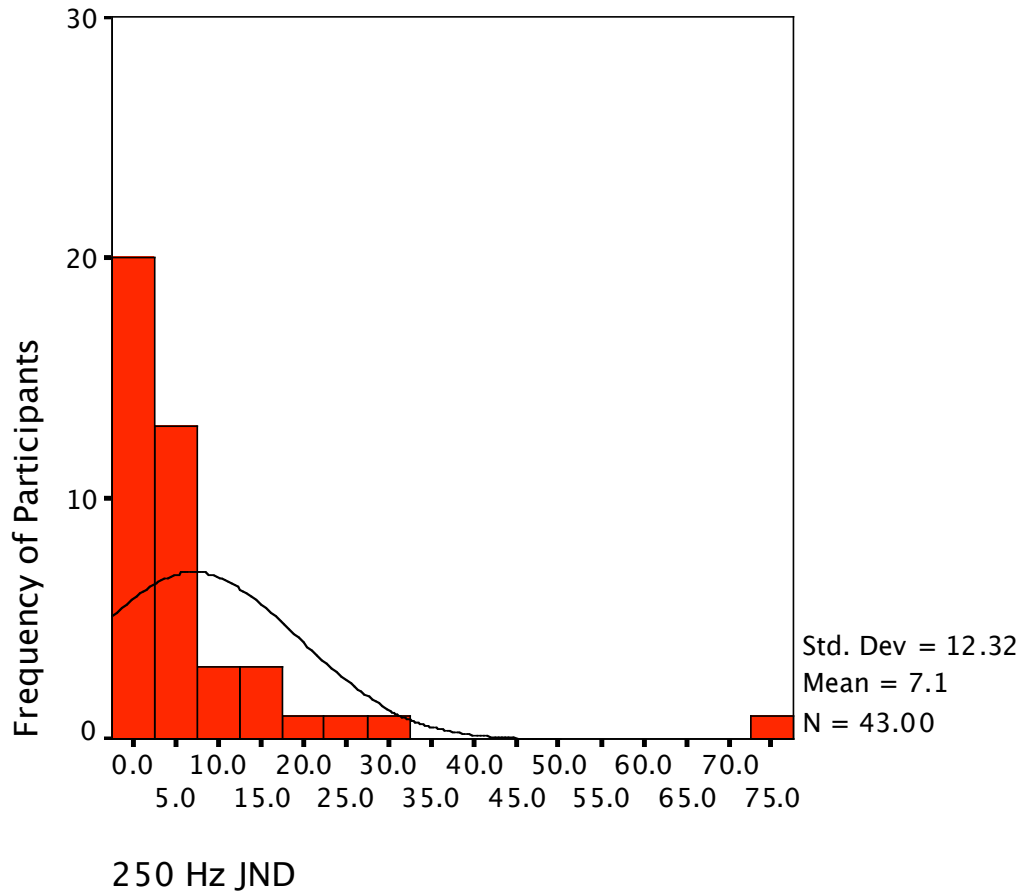


Figure A8. *Frequencies of participants' 250 Hz JNDs.*

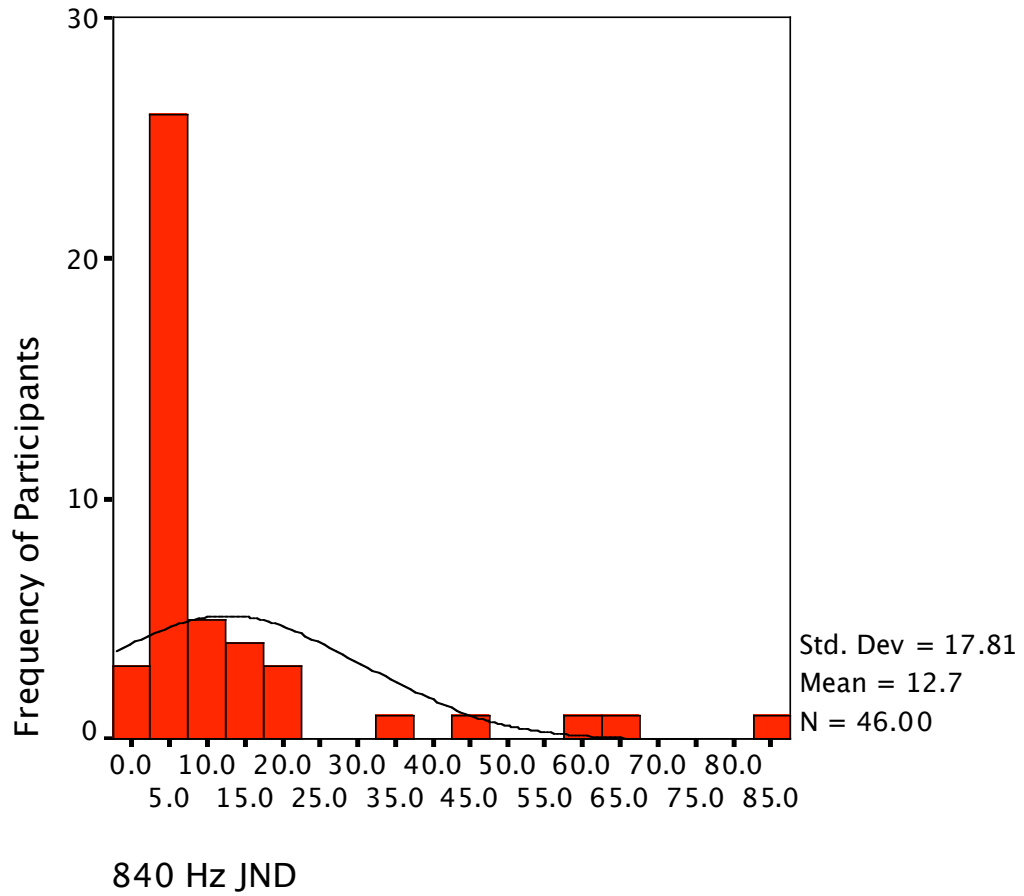


Figure A9. Frequencies of participants' 840 Hz JNDs.

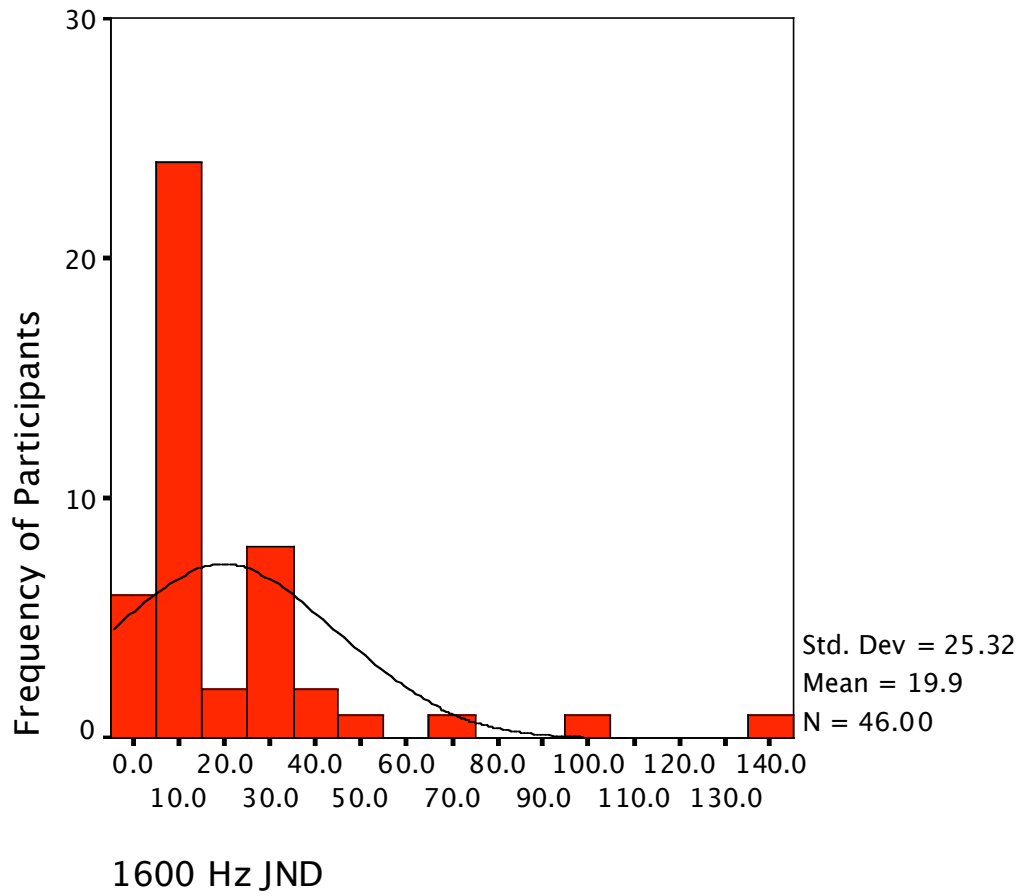


Figure A10. *Frequencies of participants' 1600 Hz JNDs.*

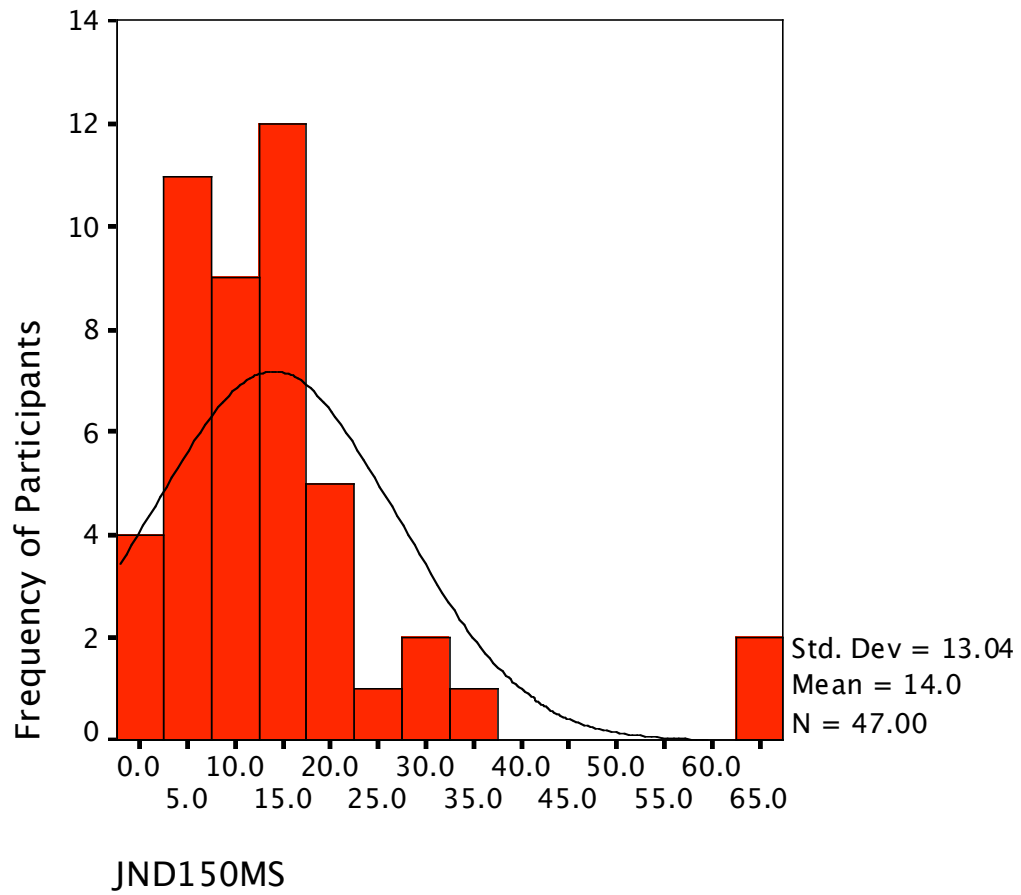


Figure A11. *Frequencies of participants' 150 ms JNDs.*

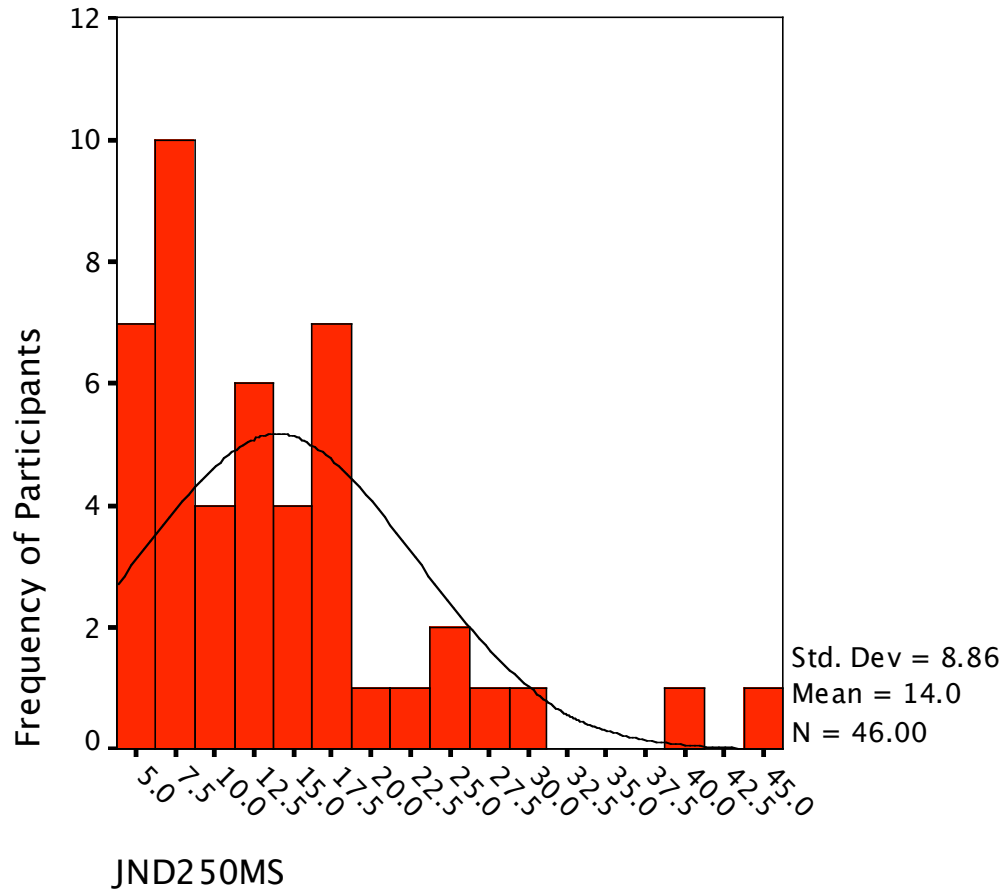


Figure A12. *Frequencies of participants' 250 ms JNDs.*

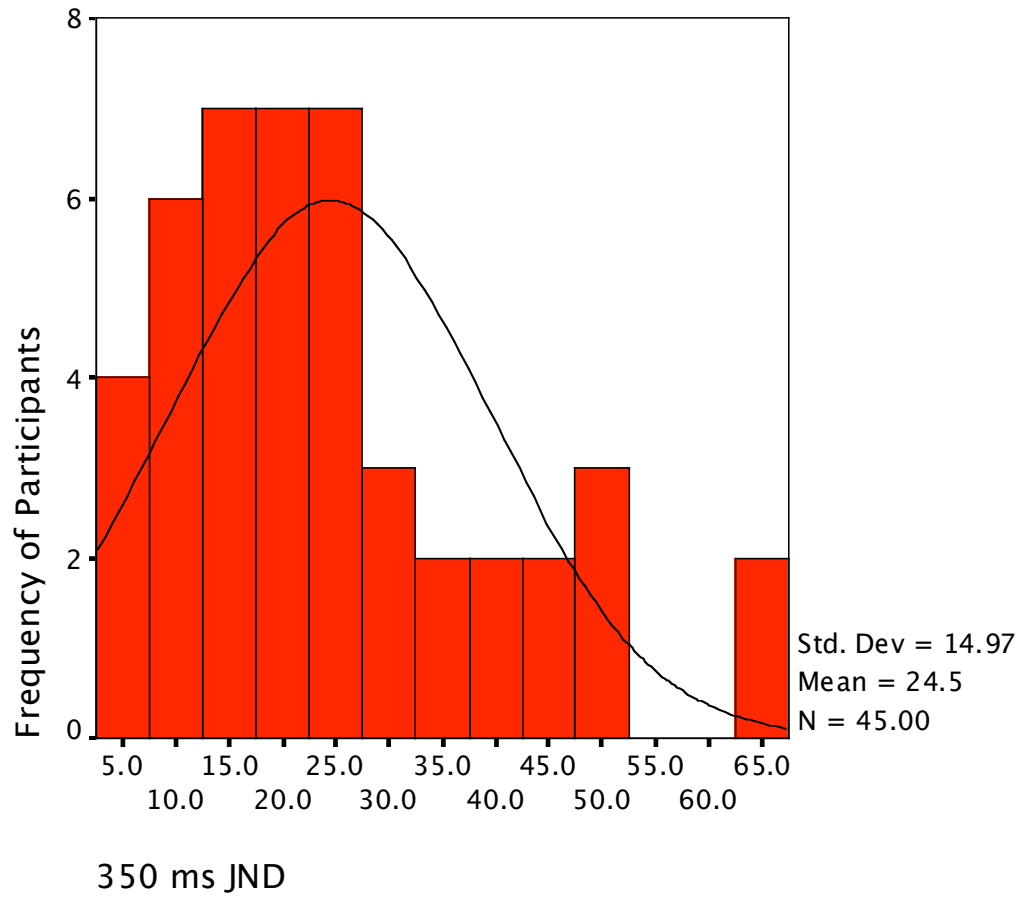


Figure A13. *Frequencies of participants' 350 ms JNDs.*

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