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Student musicians' perception of loudness and how it correlates to the measured level

Amanda Moore

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**STUDENT MUSICIANS' PERCEPTION OF LOUDNESS AND HOW IT CORRELATES
TO THE MEASURED LEVEL**

By

Amanda Moore

A Capstone Project

Submitted in partial fulfillment of the requirements for the degree of:

Doctorate of Audiology

Washington University School of Medicine
Program in Audiology and Communication Sciences

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Approved by:

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Abstract: The purpose of this project was to evaluate student musicians' perception of loudness and see how it relates to the measured sound level when playing an instrument alone and when playing in an orchestra. Perhaps by examining this relationship, strategies can be developed to educate musicians on the risk of excessive noise exposure and hearing protection options.

Acknowledgements

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CHAPTER I

Introduction and Literature Review

When a listener is asked to describe any noise that could damage hearing, he/she would likely describe the sound as being extremely loud, bothersome, and unwanted. Given this description, music, specifically orchestral music, would not be considered by most as harmful noise. But according to research, the sound level of the music emitting from orchestral instruments can range between 77-96 dBA, with peaks between 107 dBC-146 dBC (O'Brien, Wilson, & Bradley, 2008). These levels are in fact potentially dangerous to the hearing sensitivity of musicians. The risk of noise-induced hearing loss among musicians has received a lot of attention over the past two decades (Ostri, Eller, Dahlin, and Skylv, 1989; Royster, Royster and Killion, 1991; Zhao, Manchaiah, French, and Price, 2009). Currently, there has been a focus on hearing conservation programs for students in music education (National Association for Music Education, 2006; Palmer, 2007). Young musicians represent a special population in that as musicians they are potentially exposed to high levels of noise on a regular basis, and as young adults they may have a heightened sense of invincibility in which they don't believe that they are exposed to any harm (Wickham, Anderson, and Greenburg, 2008).

Hearing loss and other hearing-related symptoms among professional musicians has been documented in several different articles. Jansen, Helleman, Dreschler, and de Laat (2009) showed that even though most musicians had hearing within normal limits, most had poorer thresholds at 6000 Hz, which is indicative of noise-induced damage. In addition, most of the musicians reported having other related symptoms such as tinnitus and hyperacusis. Royster, Royster, and Killion (1991) worked with the Chicago Symphony Orchestra to conduct a study

that had a two-fold purpose. The first goal was to assess the risk of noise-induced hearing loss among professional musicians by making several sound-level measurements of orchestral performance. Their sound-level recordings showed that although most transient peaks were below the Occupational Safety and Health Administration's (OSHA) maximum permissible peak limit of 140 dBSPL (United States Department of Labor – Occupational Safety and Health Administration, 2009) the measured equivalent continuous sound level (L_{eq}) were between 79 and 99 dBA, with an average of 89.9 dBA. The authors concluded that based on the musician's average 15 hour work week, excluding the hours of personal practice, the eight-hour time weighted average noise exposure levels were 85.5 dBA. OSHA standards state that if individuals are subjected to sounds exceeding 85 dBA (eight hour time weighted average), a hearing conservation program must be in place for the employees (United States Department of Labor – Occupational Safety and Health Administration, 2009). The authors concluded that given these sound level measurements and the importance of accurate musical perception among musicians, a hearing conservation program is needed for the professional musicians of the Chicago Symphony.

In addition to measuring the risk of noise-induced hearing loss, Royster and colleagues wanted to examine the incidence of hearing loss by measuring the hearing sensitivity of each musician. Several musicians of the Chicago Symphony exhibited evidence of a cochlear noise-induced injury by having a notched hearing loss between 2000 Hz and 6000 Hz. The authors divided up these musicians into different instrumental sections to examine whether there was preponderance for hearing loss among musicians of differing instruments. The results revealed that when the audiometric thresholds were corrected for age-related hearing loss using the ISO 7029 presbycusis data, musicians in the brass, woodwinds, and percussion sections had on

average the most significant hearing loss, whereas cellists, pianists, and harpists had the least amount of hearing loss. Although this article addressed the risk and incidence of noise-induced hearing loss, it did not include data on the musician's personal listening or musical practice habits outside of the symphony or the personal use of hearing protection. It is unknown whether musicians, once aware of the noise-induced injury risk, would perceive benefit from wearing hearing protection.

In 2005, Laitinen and colleagues looked at factors affecting the use of hearing protectors among classical musicians because even though sound levels exceeded Finland's national action level of 85 dBA, most musicians did not seek the use of hearing protective devices. Results from a questionnaire showed that once musicians are affected by hearing loss or tinnitus, they sought the use of hearing protection. For musicians lacking any perceived symptoms of noise-induced hearing loss, there is a dramatic decline in the use of hearing protection. The questionnaire also showed that although musicians expressed concern regarding hearing loss, the number of musicians actually using protection is still small. When hearing protection is used, it is most commonly only during orchestra rehearsals, but not during their performances or their individual practices. The results from this study suggest that there is a need for hearing conservation awareness and education among musicians. It could be hypothesized that the musicians do not seek the use of hearing protection because a) they feel that the intensity from their instruments/sections is loud enough to cause cochlear damage b) they are not aware of proper hearing protection devices and methods or c) they feel that hearing protection plugs negatively impact their playing ability and perception of sound.

While research regarding hearing loss and noise exposure levels have focused on professional music groups, there is limited data on noise exposure levels for younger musicians.

Although many of the same musical instruments are used across the populations, factors such as skill level and the amount of playing time differ considerably. Phillips and Mace (2008) examined the average sound levels and percentage of daily dose of noise exposure in student practice rooms to determine the need for hearing conservation for musicians. Measurements were taken on 40 students with a dosimeter clipped to the musician's shoulder. With an average measurement time of 47 minutes, the authors found an average dBA of 87-95. Using the National Institute for Occupational Safety and Health's (NIOSH) standards for maximum allowable noise exposure doses, they found that 48% of participating musicians exceeded the allowable sound exposure when practicing in university practice rooms. NIOSH's recommended exposure limits centers around 85 dBA time weighted average for eight hours with a three dB exchange rate.

Miller, Stewart, and Lehman (2007) looked specifically at the student musician population to gain information about their musical practice and playing habits. Miller and colleagues found through their sound measurements that although student musicians are not subject to OSHA noise exposure regulations, they are still exposed to noise levels above 90 dBA, which exceeds the level that would mandate the use of hearing protective devices and require participation in a hearing conservation program.

In addition to their sound-level measurements, the authors distributed questionnaires to the student musicians to learn about their knowledge of hearing conservation and their use of hearing protective devices. Those results showed that although 74% of the participants had been taught about the effects of noise on hearing and health, 78% of the total respondents did not wear hearing protection. Of the 22% of participants that reported wearing hearing protection, none wore protection 100% of the time. This low use of hearing protection among student musicians

have been found in other studies as well (Chesky, Pair, Yoshinura, and Landford, 2009). In addition to low use of hearing protection Miller, Stewart, and Lehman (2007) found that 63% of student musicians reported tinnitus in their everyday lives, which suggests potential early damage to the auditory structures. Overall, the study indicated that university student musicians appear to be at risk for noise-induced hearing loss and supported the need for on-going hearing conservation programs to educate student musicians about the dangers of excessive exposure to loud music as well as on-going education and encouragement on the use of hearing protective devices.

In an interesting study that focused on the loudness perception and use of hearing protection among college students, Chesky et al (2009) asked college-aged participants to rate the loudness of simulated “nightclub” music with and without the use of ER-20 musician plugs. The average intensity level of the simulated nightclub environment was 96 dBA L_{eq} . They found that 79% of the total participants thought that the music used in the study was too loud without the use of hearing protective devices. The authors divided their group of college students into those that were declared music majors and those that were not declared music majors. The data showed that a larger majority of the music major group rated the music as too loud and would consider wearing hearing protection when in those situations. Although the results were not significant, there was a trend that the music majors may be able to approximate the intensity level of the music more accurately than the non-music major group. These findings suggest that those who have musical backgrounds might have an increased awareness or sensitivity compared to those who do not. There was a follow up questionnaire to the group of music majors to see if they are or would consider wearing the ER-20 earplugs while playing their own instrument. Although 85% of the 132 music majors stated that they have worn their earplugs since receiving

them, less than half (42%) of the student musicians reported that they used the earplugs during their musical practices. The group of student musicians did not view the use of ER-20 musician earplugs during musical performance favorably. Perhaps this negative view of the use of hearing protection during musical performance is related to physical effects such as the occlusion effect from the earplug, or related to perceptual effects such as the musicians have a harder time monitoring their own and other instruments. It is also possible that some student musicians do not perceive the intensity levels to be loud enough to warrant the use of hearing protection. In their study looking at the factors influencing use of hearing protection among professional musicians, Laitinen and colleagues (2005) found that over half of the musicians rated group rehearsals and performances “noisy.” Besides these two articles, little information is in the literature regarding musicians’ perception of loudness.

Because of the limited research in the area of student musicians, this research is focused on that specific population. The first aim of this project is to see if student musicians could reliably rate the loudness of their own music prior to examining the relationship between loudness and intensity. By verifying reliability, the researcher can feel confident that the loudness ratings from participants are accurate and repeatable and can, therefore, conclude that data is consistent.

Most musician-based research measures the intensity of orchestral music being played by professional musicians in acoustically treated concert halls. A second aim of this study is to collect a series of noise measures from student musicians playing in the classrooms or halls provided by their high school or university. These measures will not only add to the literature base pertaining to the intensity of various instruments played by a variety of musicians of differing skill levels, but will also add to the literature base regarding student-level musicians.

The third aim of this project is to evaluate student musicians' perception of loudness and how it relates to the measured sound level of their own instrument and the entire orchestra. It has been established that musicians represent a unique group when it comes to hearing conservation. Because musicians enjoy their craft, they may not be aware of the potential harm in the intensity level of their instruments. In addition, musicians may not be aware of appropriate hearing protection plugs that will allow them to monitor their instrument at a safe volume level. Perhaps in examining the relationship between the musician's perception of loudness and actual intensity, researchers can develop strategies in educating musicians on hearing protection options.

CHAPTER II

Methods

Participants

Criteria for Participant Inclusion

In order for individuals to be eligible to participate in this study, they had to be over the age of 18 and a musician in one of the participating orchestras. Participants were excluded if they fell below the desired age, were not a member of one of the participating orchestras, or requested to not be included in the study.

Participant Recruitment

Human Research Protection Office (HRPO) approved recruitment letters were electronically mailed to musical instructors of universities in the St. Louis area. Three university musical directors responded and agreed to participate. However, due to time constraints, data was collected from Washington University in St. Louis Symphony Orchestra only. Once permission was obtained from the Washington University Symphony Orchestra conductor, the author visited the first group rehearsal of the symphony orchestra to discuss the capstone project and recruit participants using the HRPO approved script. The participants were informed of the goal of the study, participant inclusion criteria, the methodology of the project, and information about the risks of participating. The individuals who agreed to participate in the study were asked to fill out the project's questionnaire as a form of consent to participate.

Participant Demographic Information

The Washington University in St. Louis Symphony Orchestra comprised of 102 musicians. Although all were encouraged to participate, only 23 musicians from the orchestra agreed to participate in this project. Participants ranged from age 18 to 39 with one individual who was 61 (16 males and 7 females). Though this participant was an outlier, he was still included in the study because he met all of the inclusion criteria. It is important to note that this musician verbally told the author that he suffers from presbycusis and constant bilateral tinnitus. Table 2.1 displays the age, instrument, orchestral section, and orchestra chair position within the section for each of the 23 participants.

Age of Participant	Instrument	Orchestral Section	Section Chair
21	Bass	String	2
19	Bassoon	Woodwind	3
19	Cello	String	7
20	Cello	String	3
21	Cello	String	6
22	Cello	String	1
19	Clarinet	Woodwind	2
26	Flute	Woodwind	1
21	French Horn	Brass	4
39	French Horn	Brass	2
19	Oboe	Woodwind	1
22	Trumpet	Brass	1
22	Trumpet	Brass	2
22	Trumpet	Brass	3
32	Tympani	Percussion	3
61	Viola	String	5
21	Viola	String	2
18	Violin	String	16
20	Violin	String	9
20	Violin	String	10
24	Violin	String	9
22	Violin	String	1
18	Violin	String	7

Table 2.1: Participant demographic information including participant's age, instrument, orchestral section, and orchestra chair number.

Experimental Procedures

Questionnaire

The first experiment of this capstone project involves testing the reliability of a created questionnaire. Each of the 23 musicians was required to complete a questionnaire containing questions related to the student musician's musical interests, how and when music is listened to, the musicians' current and past instrument selection, musical practice habits, loudness ratings of their own and other instruments, their hearing protection use, and whether or not they have experienced any otologic symptoms, such as temporary threshold shifts or tinnitus.

The questionnaire took five to ten minutes for the participant to complete and was completed either in person or via electronic mail. Approximately two to six weeks later, the same questionnaire was re-administered to participants in order to verify test-retest reliability of the participants' answers. Appendix A contains the complete questionnaire that was given to each participant. The questionnaire was comprised of individual questions the author had for the musicians as well specific questions from the Munich Music Questionnaire (MMQ) (Brockmeier, 2002) and loudness rating scales that were used in both the Loudness Contour Test (LCT) (Cox, Alexandar, Taylor, & Gray, 1997) and the Profile of Aided Loudness (PAL) (Palmer, Mueller, and Moriarty, 1999).

The Munich Music Questionnaire was developed by S.J. Brockmeier to record the music listening habits of individuals with post-lingual deafness after cochlear implantation. The questionnaire in its entirety includes sections covering past and present musical activities. It also gathers information on implant users' enjoyment of various types of music, different musical instruments, and the amount of participation in musical activities. Different styles of music, such as pop and jazz, were included in questions so as to provide a whole range of structural

characteristics found in music, such as rhythm and melody. In addition, users were also asked about specific instruments. The instruments chosen for the questionnaire covered a variety of sound production and frequency ranges (Brockmeier, Grasmeder, Passow, Mawmann, Vischer, Jappel, Baumgartner, Stark, Muller, Brill, Steffens, Strutz, Kiefer, Baumann, and Arnold, 2007). Currently, this questionnaire is distributed by Med-El Medical Electronics. The questions that were chosen from the MMQ provided information on musicians' musical preferences and background. These questions did require some rewording as the original questions were aimed at cochlear implant users rather than normal-hearing users. The altered MMQ questions are numbers one through six, eight, 13, and 14 in the current study's questionnaire (See Appendix A).

Because one of the aims of this study was to look at the musicians' perception of loudness in regards to their instrument and the entire orchestra, the questionnaire also asked the musicians to rate their perception of the loudness of their instrument, their section, the sections around them and the entire orchestra together. They were also asked to rate how loud they liked to listen to music using personal devices, such as MP3 players or Walkmans. To establish this perception, a loudness scale that was developed for the Loudness Contour Test (LCT) (Cox, Alexandar, Taylor, & Gray, 1997) and used by the Profile of Aided Loudness (PAL) was used to evaluate loudness perception (Palmer, Mueller, and Moriarty, 1999). Participants are asked to rate their perceived loudness of a sound on a seven-point scale with one being very soft and seven being uncomfortably loud. Table 2.2 contains the loudness rating scale from the LCT and the PAL.

Loudness Scale	Corresponding Description
1	Very soft
2	Soft
3	Comfortable, but slightly soft
4	Comfortable
5	Comfortable, but slightly loud
6	Loud, but OK
7	Uncomfortably loud

Table 2.2 - Loudness rating scale

While the LCT measures the loudness rating of participants right after they hear either a tonal stimulus or five seconds of connected discourse from the Connected Speech Test (Cox, Alexandar, Taylor, & Gray, 1997), the PAL is used for listeners to rate the loudness of specific environmental sounds from their auditory memory. The PAL had a good test-retest reliability, showing that participants were able to rate the loudness of specific sounds from auditory memory consistently (Palmer, Mueller, and Moriarty, 1999). Additional questions regarding incidence of tinnitus and temporary threshold shifts, use of hearing protection, and the musicians' perception of whether or not their music could cause hearing loss were also added to the questionnaire.

Sound Level Measurements

The second experiment of this project involved the sound level recordings from each of the participants. The sound level measurements included dBA L_{eq} , which is the equivalent sound level that contains the same energy as the variable sound level of the music, and a measurement of sound level peaks in peak dB SPL. These measurements were made over several individual

practice and group rehearsal sessions. Each measurement was approximately 15 minutes in length. A Larson Davis 706 noise dosimeter (serial number 17003) was used to record all sound levels for this project. Before each day of recording, the dosimeter was calibrated and pre-set to turn on and off. The recording parameters for the dosimeter were set as:

Weighting: A
Detector: Slow
Unweighted Peak: On
Threshold: 0 dB
Gain: 0
Criterion: 90 dB
Exchange Rate: 3 dB

A-weighted decibels were used because it correlates to how the human ear processes sound. It has also been proven to correspond well to the risk of injury to hearing from long exposure to loud noises of different spectral compositions (Davis and Silverman, 1978). In addition, a three dB exchange rate was used in order to meet NIOSH's recommended standards (NIOSH, 1998).

The recordings included measures of the musician playing his or her instrument alone, and the musician playing his or her instrument in the entire orchestra. During these measurements, the dosimeter microphone was placed on the right collar of the participant and the levels were recorded for fifteen minutes as this length of time was sufficient enough to capture the variety of levels in the musical piece. The collar was used for placement because the researcher felt that the collar best represented the musician's perception of their instrument. To be consistent, the right side collar was chosen for the microphone placement. Although authors Royster, Royster, and Killion, (1991) found a 6-8 dBA difference when they evaluated right- and left-side microphone placement with violin players, the right side was still chosen for those instruments that created an increased exposure on the left side due to ease of placement with

minimal distraction during the rehearsal recordings.

Figure 2.3 is a schematic representation of the orchestra stage that shows where participants were seated during orchestra measurements. It is important to note that most musicians are seated in the same chair for every rehearsal and performance. However, when musicians are missing from rehearsal, the conductor may request musicians to change seats in order for everyone to be closer together. Therefore, musicians' exposures may vary between rehearsals.

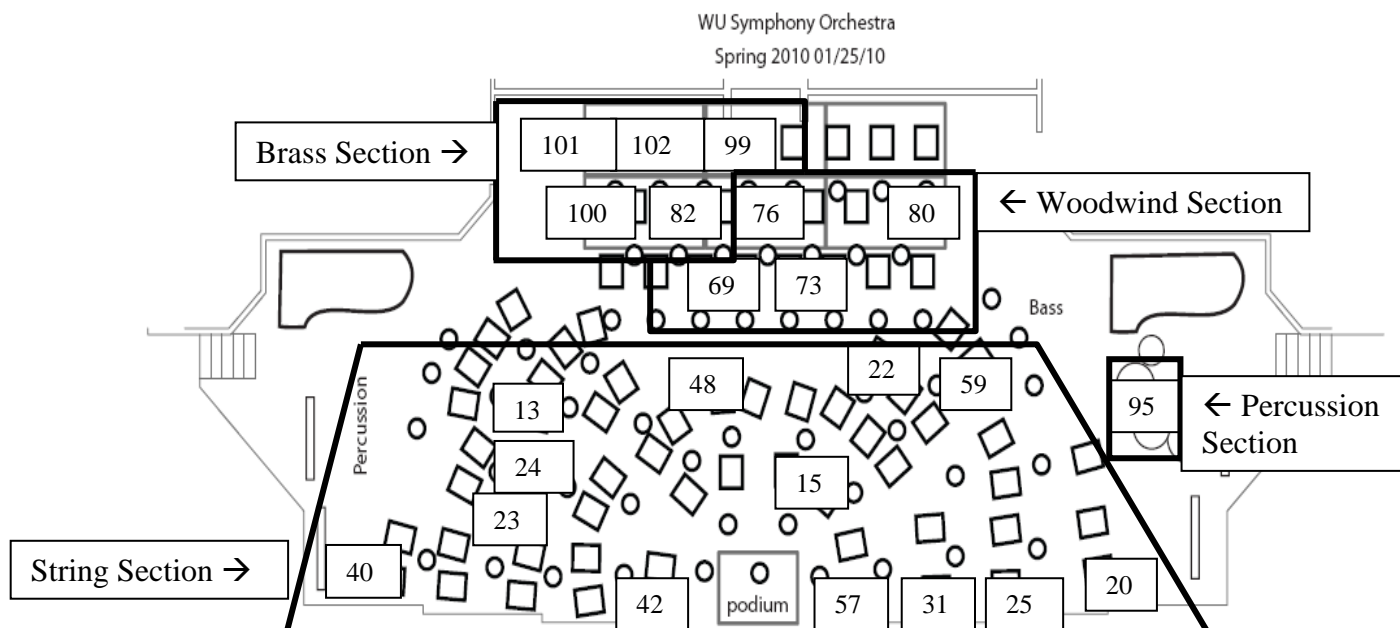


Figure 2.3 - Schematic drawing of the Washington University Symphony Orchestra stage and the location of participants. Participants are labeled by their participation number and each section is boxed with an arrow for indication.

Additional sound level recordings were measured from specific positions in the orchestra. These general measurements were made with the author holding the microphone at waist level at zero degrees azimuth in eight different positions on the stage. Two recordings were made at down center facing the orchestra. In addition, one recording was made at each of the following stage positions: down right, down left, right center, left center, up right and up left. All

measurements were made with the microphone facing towards the musicians. The recording length of the orchestra measurements was also similar to the length of the participant recordings. Figure 2.4 is a schematic drawing of the Washington University in St. Louis Symphony Orchestra stage. The icons on the layout indicate where the general orchestra measurements were made along with the direction of the recording microphone.

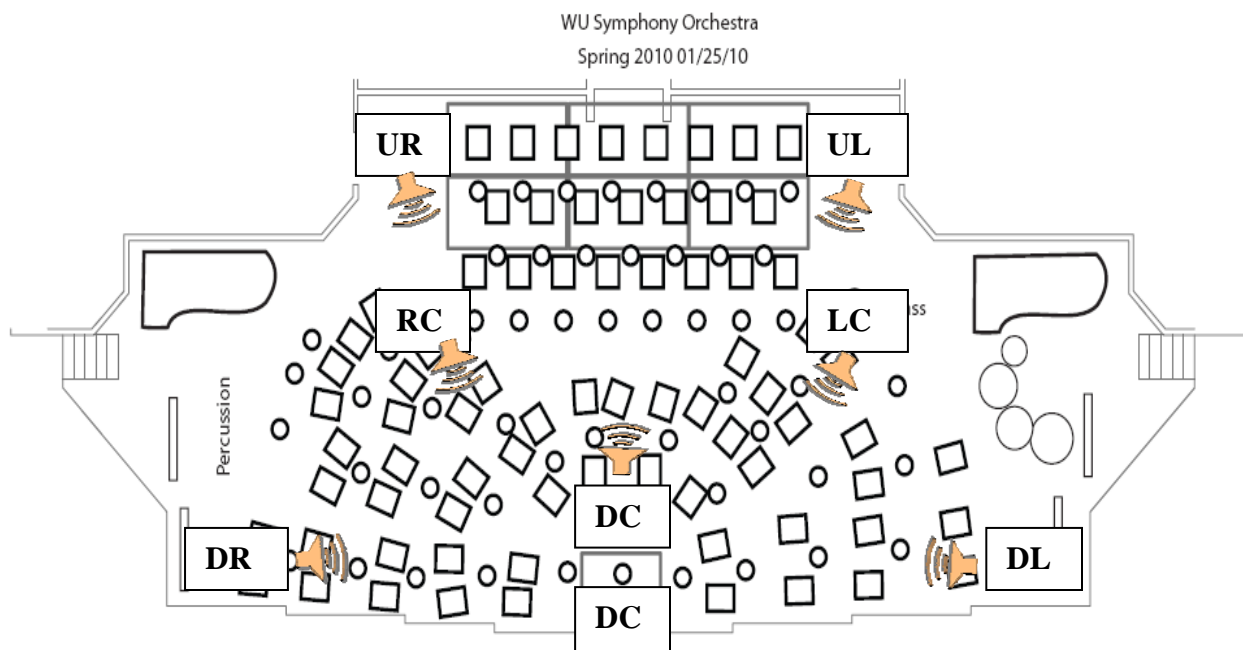


Figure 2.4 - Schematic of the orchestra stage. The icons mark the positions of the general measurements along with the direction of the recording microphone: down center (DC), down right (DR), down left (DL), right center (RC), left center (LC), up right (UR), and up left (UL).

Because the dosimeter was pre-set to turn on and off, all sound level measurements were timed by the researcher using a Seiko quartz wristwatch that included seconds displayed on the face. Once recording was finished for the day, data were downloaded in one-second increments via Blaze software into an Excel spreadsheet and stored into a password-locked computer.

The Blaze software calculated the average or equivalent continuous A-weighted sound

level (L_{eq}), for every recording (NIOSH, 1998).

$$dBA Leq = 10 * \log_{10} \frac{1}{n} \sum_{i=1}^n 10^{Li/10}$$

$i = \text{observations}$
 $Li = \text{SPL in dBA of each observation}$

(1)

However, because the dosimeter was used over several hours, not all recordings were relevant to this project. Therefore, each recording pertinent to this study had to be re-averaged to get an average L_{eq} of the desired participant recording. In order to do this, the author had to take the L_{eq} value (in decibels) for every second of the participant's recording and switch it from decibel form to linear form and re-average the data for the desired recording. That average was then converted back into decibels for a new L_{eq} value. This recalculation was done for all participant and general recordings.

Location

Orchestra measurements were made during orchestra rehearsal at the E. Desmond Lee Concert Hall at the 560 Trinity Avenue music building. Individual measurements were made in sound-treated practice booths either at the 560 Trinity Avenue music building or Tietjens Music Building on the Washington University in St. Louis Danforth Campus.

Music Recorded During Project

During the recordings, the Washington University in St. Louis Symphony Orchestra performed three different musical pieces: Tchaikovsky's Romeo and Juliet Suite, Rachmaninoff's Piano Concerto Number 2, and Tchaikovsky's Number 4.

CHAPTER III

Results

Questionnaire Analysis

The questionnaire data was analyzed using Pearson correlation to see if there was a strong correlation or good test-retest reliability between the first and second administration. Pearson correlation was used because it is the most common correlation test and best reflects the degree in which these variables are related. The questionnaires were also examined to measure the relationship between the perceived loudness measure and the actual intensity of the musicians' playing practices. All 23 participants completed the same questionnaire at two time points spaced two to six weeks apart. The results of each questionnaire were analyzed for test-retest reliability using an intraclass correlation (ICC). An ICC is a test of difference and correlation (Shrout and Fleiss, 1979). An ICC of 0.683 was obtained between the first and second administration of the questionnaire. The following labels are used to classify reliability ratings: 0.00 to 0.10-virtually none, 0.11 to 0.40-slight, 0.41-0.60-fair, 0.61-0.80-moderate, and 0.81-1.0-excellent (Shrout, 1998). When extracting only loudness ratings, ICC Pearson correlation was .754 which is also consistent with moderate test-retest reliability. Question 18 of the questionnaire regarding musicians' perception of loudness regarding their individual instrument had the highest test-retest reliability with .847 which is significant at the .01 level (2-tailed). Question 20 regarding the loudness perception of the percussion section had the lowest test-retest reliability with .487. However, that correlation is still significant at the .05 level (2-tailed). Overall, the questionnaire used in this study exhibited moderate test-retest reliability. In addition, no differences were found between the first and second administration of the

questionnaire. Therefore, the questionnaire was not only correlated but also similar between administrations.

Questions one through six asked the musicians about their musical interests and preferences. Results from these questions showed that musicians essentially enjoyed listening to music and listen to it in a variety of places, such as on an MP3 player or on the radio in the car. They also enjoyed listening to a variety of music. The subjects also did not have a preference for solo instruments versus an entire orchestra. In addition, musicians listened to music for a variety of reasons including for pleasure and emotional satisfaction. See Appendices B, C, and D for a breakdown of responses for questions one through six.

Question eight of the questionnaire asked participants what instruments they were fluent in playing. They were given 20 instrument options as well as an option to list additional instruments under “other.” The participants were encouraged to check all applicable answers for the question. Figure 3.1 shows the results for that question. Only seven participants noted that they were not fluent in any other instrument besides the one they play for the orchestra. Nine participants were fluent in two instruments while three participants were fluent in three instruments. Four subjects noted fluency in at least four instruments, including the instrument they play for the orchestra. The most common instrument musicians were fluent in playing apart from the one played with the orchestra was the piano. Seven individuals listed additional instruments under “other.” Those instruments include the viola, French horn, piccolo, English horn, percussion, and the steel pan. Some participants were fluent in instruments that were similar to the instrument they played for the orchestra. For example, the subject who played the tympani in the orchestra was also fluent in the drums, piano, xylophone, cymbals, and steel pan. In addition, the participant who played the flute was also fluent in the piccolo.

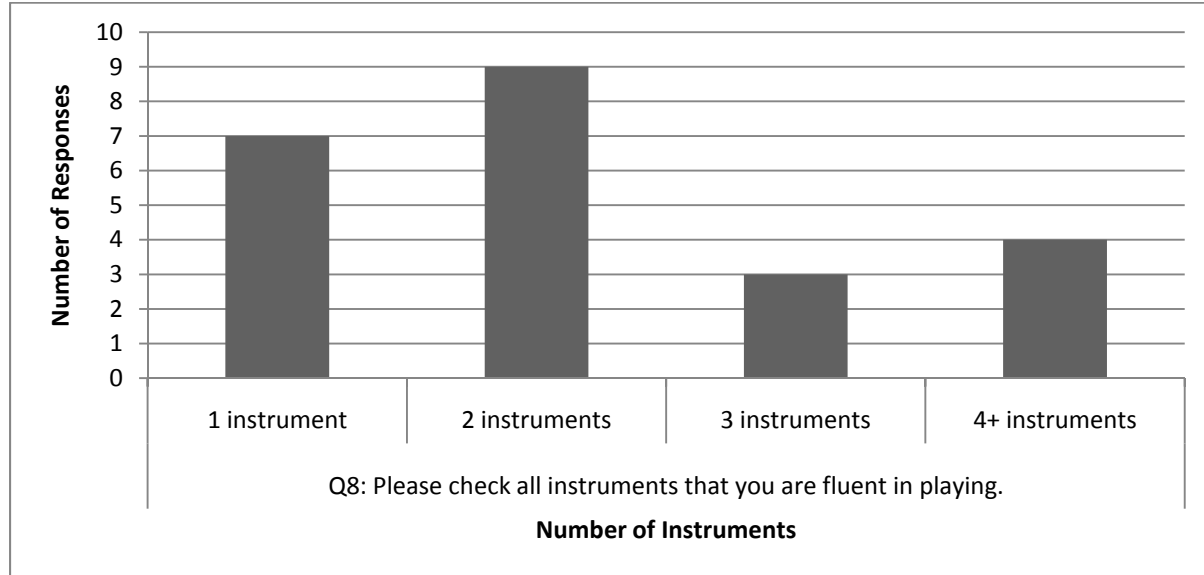


Figure 3.1 – Participants’ responses to Question 8 regarding fluency of instruments.

The participants were also asked in which section(s) they have previously played in question nine. For these questions, the brass, string, woodwind, and percussion sections were the choice options and subjects were allowed to check all applicable answers. 13 subjects had played in the string section while only seven subjects had previously played in the brass section. On the other hand, only six subjects had played in the woodwind section and only six subjects had previously played in the percussion section.

Questions 13 and 14 asked the musicians if they had received musical education outside of school, including instrument and voice lessons, and the length of that education. Results showed that 21 participants noted receiving training outside of school. Only 1 of those musicians had less than three years of training while the other 20 subjects had more than three years of training.

Question 15 was interested in whether or not the subjects played in other ensemble(s) or

band(s) outside of the participating orchestra. Of the 23 participants, only 15 of the musicians reported playing with another ensemble in addition to playing in the Washington University Symphony Orchestra.

If subjects answered that they did play with another ensemble, Questions 16 and 17 asked what type of music was played and how often the subject plays or practices with the other ensemble. Figure 3.2 shows the participants' responses regarding those questions related to other ensembles. For question 16 regarding type of music played, subjects were asked to check all applicable answers. All 15 participants noted classical music as a music genre of the other ensemble(s). Jazz/blues was the second most common with seven participants noting that variety of music. Religious and pop music each had three participants playing that genre. Two participants each noted playing rock and opera/opera music in their other ensembles. Only one participant noted playing music to dance to and only one subject reported playing folk/country music.

Question 17 wanted information about the total hours per week the subject plays with the other ensemble. Of the 15 participants, nine typically played between three and eight hours per week with the other ensemble or band while only six subjects played less than three hours per week. Only one subject noted playing more than eight hours per week with the other ensemble.

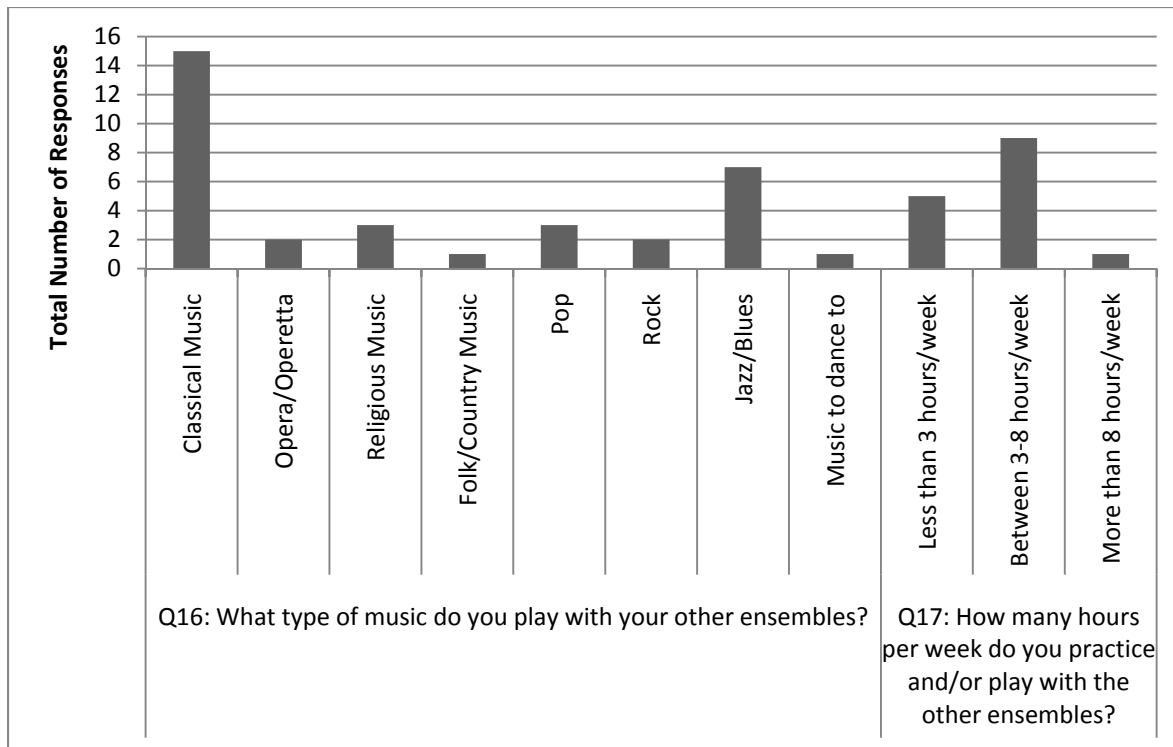


Figure 3.2 - Participants' responses to Questions 16 and 17 regarding playing with other ensembles/bands/etc...

Musicians were also asked to choose which of the twenty listed instruments they thought were the “softest” and “loudest” for questions 24 and 25. See Appendix A for a complete list of instruments. Figure 3.3a and 3.3b shows the participants' responses for the softest and loudest instrument. Results showed that only seven of the twenty instruments were chosen as the softest instrument. 39% of the 23 participants thought the harp was the softest instrument followed by the flute and clarinet each with 17%, the recorder and bass each with 9%, and the guitar and violin each with 4%. On the other hand, only six of the twenty instruments were chosen as the loudest instrument. 43% of the 23 participants thought the trumpet was the loudest instrument followed by the cymbals with 22%, the drum kit with 17%, the trombone with 9%, and tympani with 4%. One individual (4%) chose “other” as the loudest, specifying the English horn.

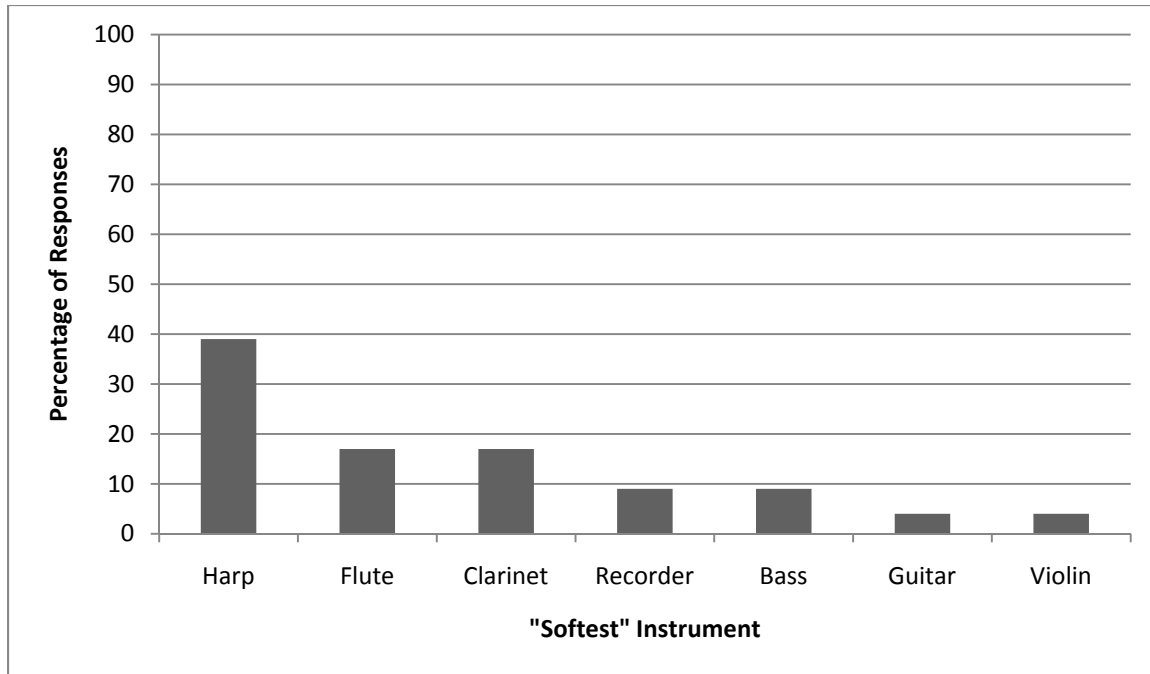


Figure 3.3a – Participants’ responses to Question 24 regarding their perception of the “softest” instrument

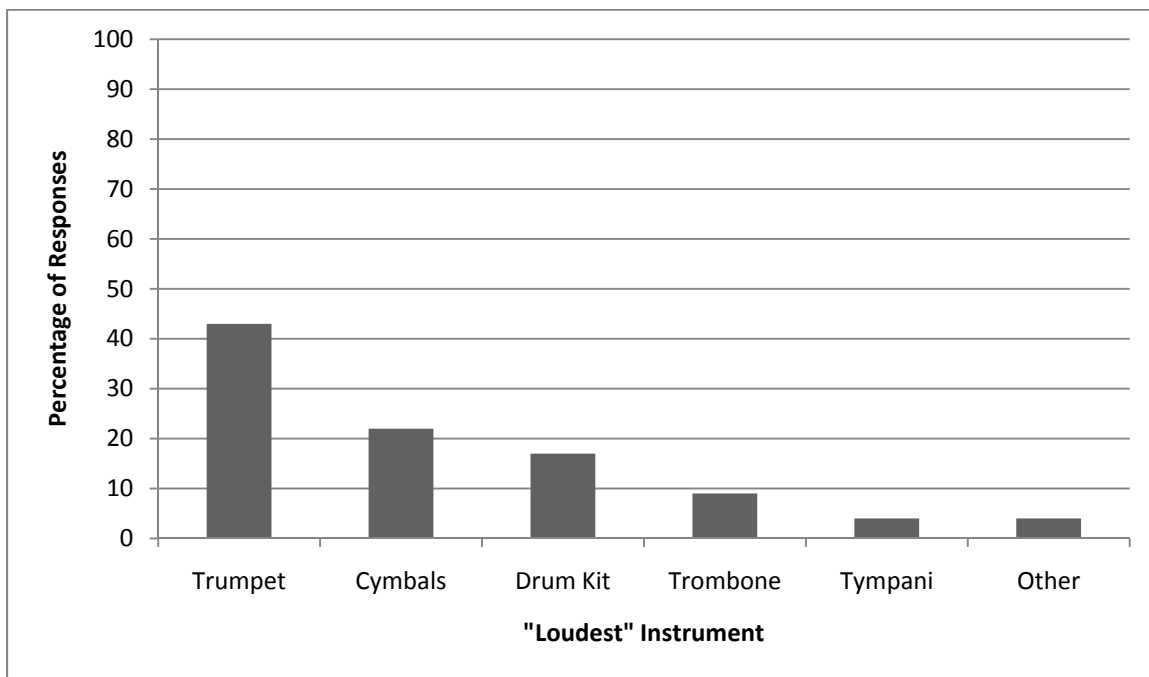


Figure 3.3b – Participants’ responses to Question 25 regarding their perception of the “loudest” instrument

Questions 26 through 29 of the questionnaire asked musicians about certain otologic

symptoms associated with noise exposure. Figure 3.4 shows the all of the responses to questions 26 through 29. Results showed that more than 90% of the musicians felt that they were “rarely” or “never” bothered by the loudness of their instrument. Only 9% noted that they were bothered “sometimes.” When asked if they ever experienced ringing in their ears or a temporary hearing loss after a rehearsal or performance, 52% said “never,” 30% said “rarely,” and 13% said “sometimes.” It is important to note that one participant (4%) said they “always” experience ringing. However, that participant verbally told the researcher that he had constant tinnitus and therefore, the ringing could not be attributed to playing alone. 96% of subjects answered “never” when asked about the frequency of temporary hearing loss after playing. Only 4% noted that they experience a temporary hearing loss after practicing or playing only one to two times per week.

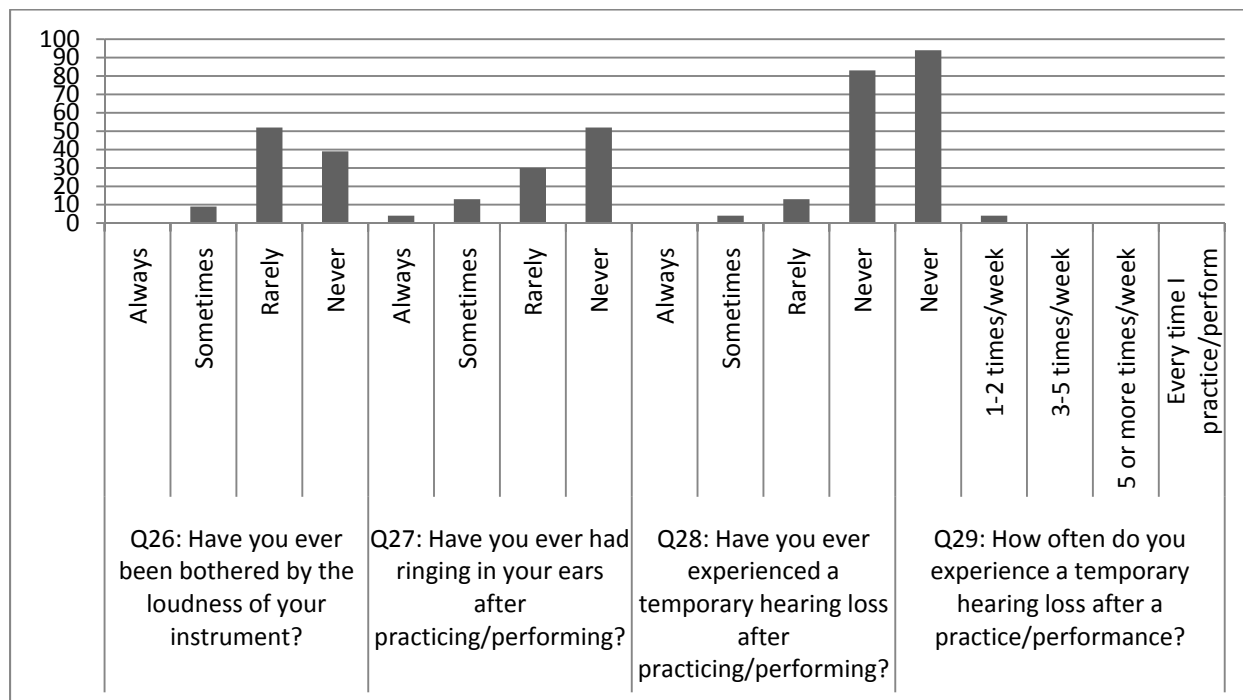


Figure 3.4 – Participants’ responses to Questions 26 through 29 regarding occurrence of otologic symptoms associated with noise exposure.

The researcher also wanted additional information on percentage and frequency of use of

hearing protective devices while practicing or performing. Questions 30 and 31 covered those topics. 19 of the 23 musicians do not wear hearing protection while practicing or performing. In addition, one musician “rarely” wears protection and two musicians “sometimes” wears hearing protection. When asked to provide information on what type of hearing protection is used, the three musicians that reported use of hearing protection noted that the foam or silicone hearing protection plugs were the most common.

The last question on the questionnaire was whether or not the musicians thought their music could cause hearing loss. The question was added to the questionnaire by the researcher to gauge the musicians’ opinion on the intensity of their music and its ability to cause damage to the body’s hearing structures. Results showed that thirteen participants said “yes” and thought their music could cause hearing loss while the remaining ten musicians said “no.”

Sound Level Measurement Analysis

Complete sound measurements for instruments and the orchestra were obtained from all 15 musicians. The other eight musicians have partial sound measurements. The sound level measurements were analyzed and tabulated so as to give the average dBA L_{eq} sound levels and peak levels of each instrument, as well as the entire orchestra. Table 3.9 shows the individual and orchestra average L_{eq} and peak level measurements by participant number and instrument for all 23 participants. Instrument L_{eq} levels ranged from 71.8 dBA to 101.1 dBA with an average peak range of 102.3 dBSPL to 131.6 dBSPL. There was one average peak level measured at 158.3 dBSPL. This level was contributed to microphone artifact. On the other hand, average orchestra L_{eq} levels ranged from 71.7 dBA to 93.1 dBA with an average peak range of 102.8 dBSPL to 130.1 dBSPL. The bass provided the softest measurement for average instrument L_{eq}

while the flute contributed the softest average orchestra L_{eq} . The trumpet measurements were the highest for both instrument and orchestra average L_{eq} . The viola had the highest average peak level for instrument recordings while the violin had the highest average peak level for orchestra recordings. It is important to note that Participant 99, who had the highest instrument L_{eq} average, told the author after the recording that he was purposefully playing as loud as possible instead of at the normal practice level that was requested by the researcher.

Participant Number	Instrument	Average Instrument Leq	Average Instrument Peak Level	Average Orchestra Leq	Average Orchestra Peak Level
13	Violin	87.2 dBA	111.0 dBSPL	84.5dBA	130.1 dBSPL
15	Viola	██████████	██████████	71.8dBA	111.7 dBSPL
20	Cello	83.8 dBA	107.5 dBSPL	78.1 dBA	102.8 dBSPL
22	Viola	91.0 dBA	131.6 dBSPL	85.7 dBA	110.7 dBSPL
23	Violin	84.8 dBA	129.5 dBSPL	87.4 dBA	128.2 dBSPL
24	Violin	86.5 dBA	118.3 dBSPL	90.4 dBA	108.9 dBSPL
25	Cello	██████████	██████████	84.3 dBA	105.0 dBSPL
31	Cello	84.4 dBA	107.4 dBSPL	██████████	██████████
40	Violin	72.0 dBA	127.9 dBSPL	79.5 dBA	110.8 dBSPL
42	Violin	86.4 dBA	105.5 dBSPL	88.0 dBA	110.0 dBSPL
48	Violin	94.8 dBA	126.9 dBSPL	72.2 dBA	104.0 dBSPL
57	Cello	86.5 dBA	105.4 dBSPL	86.1 dBA	108.5 dBSPL
59	Bass	71.8 dBA	102.3 dBSPL*	██████████	██████████
69	Flute	80.9 dBA	121.4 dBSPL*	71.7 dBA	111.8 dBSPL
73	Oboe	86.3 dBA	108.9 dBSPL	██████████	██████████
76	Clarinet	92.1 dBA	106.0 dBSPL	78.2 dBA	112.9 dBSPL
80	Bassoon	87.3 dBA	104.7 dBSPL	83.1 dBA	108.6 dBSPL
82	French Horn	██████████	██████████	92.4 dBA	120.1 dBSPL
95	Tympani	95.0 dBA	120.0 dBSPL	██████████	██████████
99	Trumpet	101.1 dBA	158.3 dBSPL	89.7 dBA	110.6 dBSPL
100	French Horn	96.0 dBA	114.6 dBSPL	91.7dBA	116.1 dBSPL
101	Trumpet	██████████	██████████	93.1 dBA	111.5 dBSPL
102	Trumpet	91.9 dBA	109.6 dBSPL	89.8 dBA	114.5 dBSPL

Table 3.9 - Average Leq (in dBA) and average peak (in dBSPL) levels for all participants. ██████████ = denotes missing data. * = data that had only one value and is, therefore, not averaged.

Figure 3.10 is a histogram that represents the number of total instrument and orchestra

measurements that fell into four dBA L_{eq} categories. The measurements are broken up by section and general orchestra measurements and include a total bar that combines everything in that decibel category. All 23 participants' measurements were included in the histogram. 11 of the recordings fell in the 71-80 dB range which correlates to a "5," or "comfortable, but slightly loud." 25 recordings fell in the 81-90 dB range which is associated with a "5" and "6" with "6" being "loud, but ok." The other 10 recordings fell in the 91-102 dB range which correlates to a "6" on the LCT.

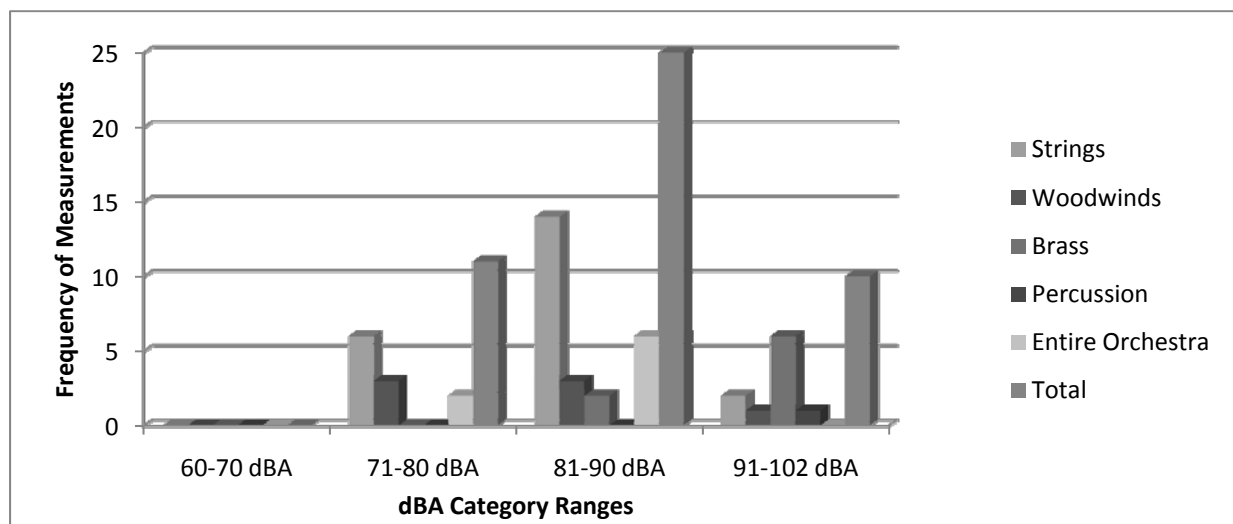


Figure 3.10 - Histogram of the measurements in each dBA L_{eq} set. All 23 participants' measurements were categorized by section. Entire orchestra measurements were measurements made by the author and those values can be seen in Table 3.25.

Because there were several participants that played the same instrument, the measured intensity of groups of instruments was taken. Table 3.11 shows those average L_{eq} and average peak levels. The average group L_{eq} ranged from 85.0 dBA to 98.6 dBA for instrument measurements and from 84.0 dBA to 92.0 dBA for orchestra measurements. Peak levels ranged from 106.9 to 125.4 dBA for instrument peak levels and from 106.1 dBSPL to 124.6 dBSPL for orchestra peak levels. The average peak level for trumpets was 155.4 dBSPL. However, that figure may be affected by microphone artifact and therefore may not be valid.

Instrument	Average Instrument Leq	Average Instrument Peak Levels	Average Orchestra Leq	Average Orchestra Peak Levels
Cello	85.0 dBA	106.9 dBSPL	84.0 dBA	106.1 dBSPL
French Horn	██████████	██████████	92.0 dBA	119.0 dBSPL
Trumpet	98.6 dBA	155.4 dBSPL	91.1 dBA	112.5 dBSPL
Viola	██████████	██████████	82.8 dBA	111.2 dBSPL
Violin	89.3 dBA	125.4 dBSPL	86.4 dBA	124.6 dBSPL

Table 3.11 - Average Leq (in dBA) and average peak (in dBSPL) levels for groups of instruments. █████ = denotes missing data.

L_{eq} measurements were also calculated to determine the L_{eq} value for two-hour and eight-hour equivalent exposures. Table 3.12 represents those values for the instrument measurements. L_{eq} two- and eight-hour equivalents were not calculated for the orchestra measurements because the values were similar to the L_{eq} 15-minute instrument recordings. Two-hour exposures were projected because the length of the Washington University Symphony Orchestra rehearsal is approximately two hours and ten minutes. Though the musicians do not play the entire rehearsal, rehearsal time combined with time in which subjects tune and/or practice their instruments equates to two hours. Eight-hour exposures were projected because that can more approximate exposure levels for an average work day. All L_{eq} measurements for the two-hour and eight-hour equivalents were calculated by using NIOSH's three dB exchange rate criteria (NIOSH, 1998). The average L_{eq} equivalent for a two-hour exposure ranged between 62.8 dBA to 92.1 dBA. On the other hand, the average L_{eq} equivalent for an eight-hour exposure for instruments ranged from 56.8 dBA to 86.1 dBA. When compared to NIOSH's criteria of 85 dBA for an eight-hour exposure, 1 of the 19 participants exceeded NIOSH's recommended level of 91 dBA at the two-hour equivalent exposure. That same participant exceeded the recommended level of 85 dBA at the eight-hour equivalent exposure (NIOSH, 1998).

Participant Number	Instrument	Average Instrument Leq– 15 minutes	Average Instrument Leq- 2-hour equivalent	Average Instrument Leq – 8-hour equivalent
13	Violin	87.2 dBA	78.2 dBA	72.2dBA
15	Viola	██████████	██████████	██████████
20	Cello	83.8 dBA	74.8 dBA	68.8 dBA
22	Viola	91.0 dBA	82.0 dBA	76.0 dBA
23	Violin	84.8 dBA	75.8 dBA	69.8 dBA
24	Violin	86.5 dBA	77.5 dBA	71.5 dBA
25	Cello	██████████	██████████	██████████
31	Cello	84.4 dBA	75.4 dBA	69.4 dBA
40	Violin	72.0 dBA	63.0 dBA	57.0 dBA
42	Violin	86.4 dBA	77.4 dBA	71.4 dBA
48	Violin	94.8 dBA	85.8 dBA	79.8 dBA
57	Cello	86.5 dBA	77.5 dBA	71.5 dBA
59	Bass	71.8 dBA	62.8 dBA	56.8 dBA
69	Flute	80.9 dBA	71.9 dBA	65.9 dBA
73	Oboe	86.3 dBA	77.3 dBA	71.3 dBA
76	Clarinet	92.1 dBA	83.1 dBA	77.1 dBA
80	Bassoon	87.3 dBA	78.3 dBA	72.3 dBA
82	French Horn	██████████	██████████	██████████
95	Tympani	95.0 dBA	86.0 dBA	80.0 dBA
99	Trumpet	101.1 dBA	92.1 dBA	86.1 dBA
100	French Horn	96.0 dBA	87.0 dBA	81.0 dBA
101	Trumpet	██████████	██████████	██████████
102	Trumpet	91.9 dBA	82.9 dBA	76.9 dBA

Table 3.12 – The Leq values for 15-minute recordings and the projected Leq values for 2-hour and 8-hour exposures for instrument measurements (in dBA). █████ = denotes missing data.

For all of the orchestra measurements, the recordings were left in its entirety so when the conductor stopped rehearsal to make comments or restart certain parts of the piece, those breaks were left in the recording. Analyses showed that if all breaks were removed from the recording,

the average L_{eq} changed by 1 dB and was, therefore, not significant.

In addition to making sound level measurements via participants, the author also made general orchestra measurements. Table 3.13 is a table of the general orchestra average L_{eq} and average peak levels. Refer to Figure 2.4 for a schematic representation of the general measurement positions in the orchestra. The average dBA L_{eq} for the general measurements ranged from 79.2 dBA to 87.7 dBA with an average peak level between 104.2 dBSPL to 122.3 dBSPL. The lowest measurement was in the down right position behind the violins. The highest measurement was right center in front of the brass section.

Dosimeter Placement	Average Leq Level	Average Peak Level
1A – Down Center (DC) – 1 st Conductor	82.9 dBA	122.0 dBSPL
1B – Down Left (DL) – 1 st Conductor	80.0 dBA	112.0 dBSPL
1C – Down Right (DR) – 1 st Conductor	79.2 dBA	105.0 dBSPL
1D – Up Right (UR) – 1 st Conductor	83.3 dBA	122.3 dBSPL
1E – Up Left (UL) – 1 st Conductor	82.1 dBA	125.5 dBSPL
2A – Down Center (DC) – 2 nd Conductor	81.5 dBA	104.2 dBSPL
2B – Left Center (LC) – 2 nd Conductor	81.0 dBA	106.1 dBSPL
2C – Right Center (RC) – 2 nd Conductor	87.7 dBA	107.8 dBSPL

Table 3.13 - Location, average Leq levels (in dBA), and average peak levels (in dBSPL) of general orchestra measurements.

Loudness Perception Rating

Though there were 23 musicians that filled out the questionnaire, only 15 of those 23 had complete sound level measurement data. Therefore, only those 15 participants' input will be used for descriptive purposes.

The first question in the loudness rating section of the questionnaire asked subjects to rate

the loudness of their own instrument on the seven-point scale. Figure 3.5 is a graphical representation of the participants’ categorizations of their instruments’ loudness. Individual instruments were rated between “3” and “7” with no ratings in the “6” category. Though the “7” category was chosen, most musicians rated their instrument between “3” and “5.”

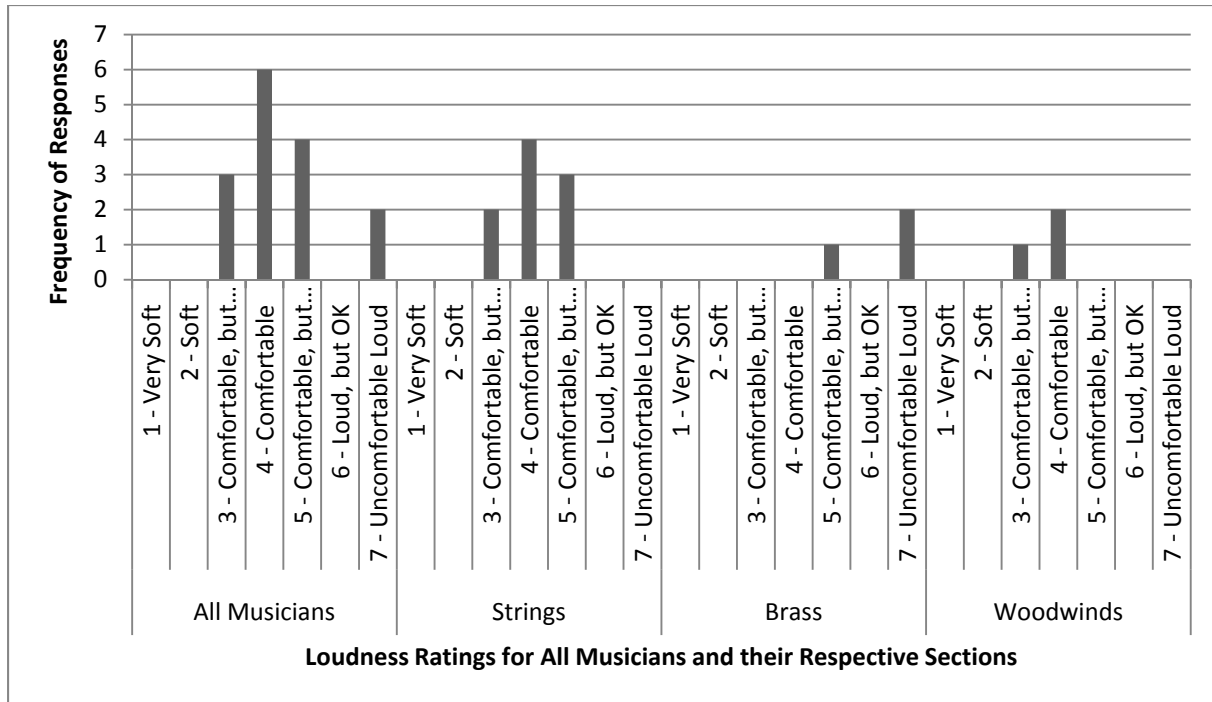


Figure 3.5 – Participants’ loudness rating responses for individual instruments

The following four questions in the loudness rating section of the questionnaire asked participants to rate the loudness of each orchestral section. Figure 3.6 shows the loudness ratings for the brass, percussion, string, and woodwind sections. Overall, results showed the brass section was rated between “5” and “7.” However, over half of the musicians rated the brass section in the “6” category. On the other hand, the percussion section was rated between “4” and “6.” Though responses ranged between the three categories, over 50% of subjects rated the percussion section in the “6” category. Only one participant in this study played in the percussion section and that individual’s loudness rating could not be included in the results due

to incomplete sound level measurement data. In addition, when asked about the string section, participants rated between “3” and “6” though 86% of the participants stayed within the “3” and “4” category. Finally, results for the woodwind section showed the woodwind section was rated between “3” and “5,” with 60% of the subjects rating in the “3” category.

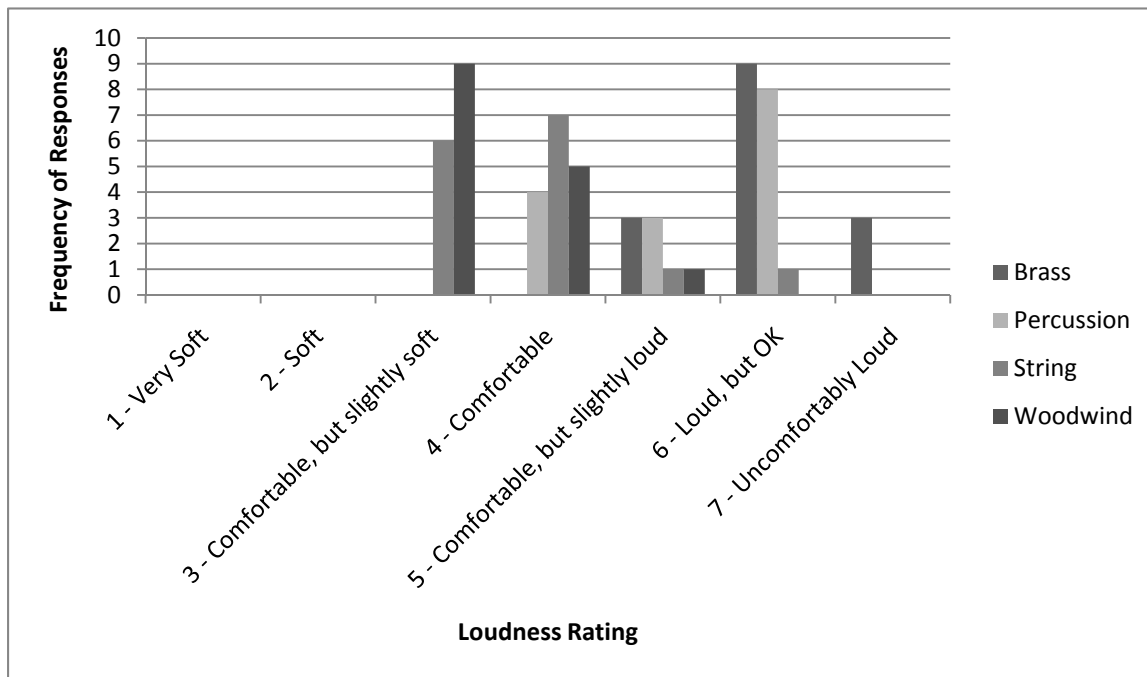


Figure 3.6 - All musicians' loudness ratings for all four sections

The last question related to loudness perception asked subject to rate the loudness of the entire orchestra. Figure 3.7 shows all of the participants’ loudness ratings for the orchestra. The entire orchestra was rated between “4” and “6,” with over 50% of participants rating the orchestra in the “5” category.

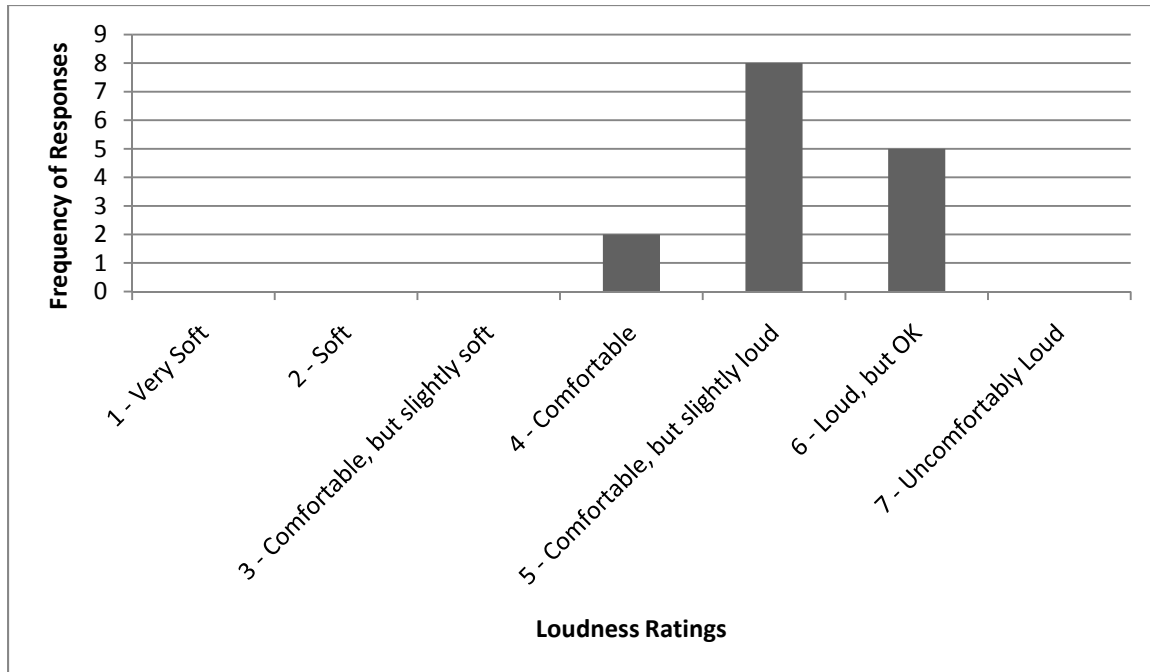


Figure 3.7 – Participants’ loudness rating responses for the entire orchestra.

Question 7 also asked participants to use the same seven-point scale from the LCT to rate how loud they preferred to listen to music on an iPod/MP3 player/CD player/Walkman. Because this question did not relate to loudness of instruments, all 23 participants were included in the analysis. Figure 3.8 shows all 23 musicians’ ratings regarding the perceived intensity level of their personal music device. Results showed that nine of the participants listened at a “comfortable, but slightly loud level.” 8 participants listened at a “comfortable” level. The remaining five participants responded between “very soft,” “soft,” or “comfortable, but slightly soft” while one remaining participant responded “loud, but OK.”

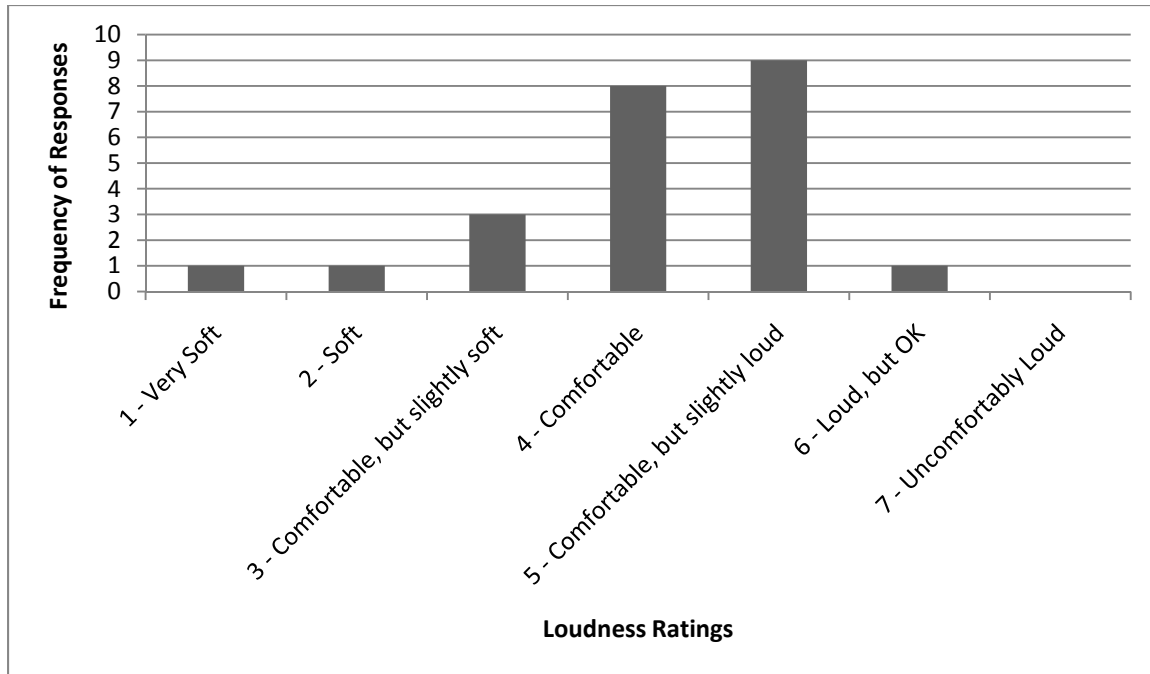


Figure 3.8 – Loudness ratings regarding musicians' perception of how loud they listen to music on their iPod/MP3 player/CD player/Walkman from Question 7

Relationship between Loudness Ratings and Measured Intensity

The second part of the questionnaire involved having the participants rate, using the seven-point scale found in the Loudness Contour Test (LCT) (Cox, Alexandar, Taylor, and Gray, 1997) and the Profile of Aided Loudness (PAL) (Palmer, Mueller, and Moriarty, 1999), how loud they thought their instrument, each section, and the entire orchestra was on a scale of one (very soft) to seven (uncomfortably loud). Cox and colleagues found the average loudness ratings for connected discourse for a group of normal hearing listeners. These values were used as a reference point for comparison of musicians' loudness ratings of their instrument and the orchestra (Cox, Alexandar, Taylor, and Gray, 1997). Table 3.14 shows those values in decibels for each of the seven ratings.

Number	Decibel (dB) Value	Standard Deviation
1 – Very Soft	20.3 dB	4.6
2 – Soft	32.5 dB	6.0
3 – Comfortable, but slightly soft	41.9 dB	6.3
4 – Comfortable	58.6 dB	7.7
5 – Comfortable, but slightly loud	77.0 dB	10.3
6 – Loud, but OK	91.7 dB	10.9
7 – Uncomfortably Loud	101.9 dB	12.4

Table 3.14 – Loudness contour test results and standard deviations (in dB) for each of the loudness ratings for broadband speech noise.

CHAPTER IV

Discussion and Conclusion

Discussion

One of the main questions of this project was whether or not student musicians could reliably rate loudness. Based on the Pearson correlation analyses of the specific loudness rating questions, questions 18 through 23 had moderate test-retest reliability. Overall, the entire questionnaire also exhibited moderate test-retest reliability. Therefore, the musicians were able to reliably answer questions on the questionnaire and rate loudness.

The second aim of this study was to collect a series of noise measures from student musicians playing in the classrooms, practice rooms, or halls provided by their high school or university. As mentioned previously, all measurements were taken at either the E. Desmond Lee Concert Hall at the 560 Trinity Avenue music building or sound-treated practice booths either at the 560 Trinity Avenue music building or Tietjens Music Building on the Washington University in St. Louis Danforth Campus. The range of instrument measurements was from 71.8 dBA to 101.1 dBA while the range of orchestra measurements was from 71.7 dBA to 93.1 dBA. Compared to previous literature, there does not seem to be a significant difference between the sound measurements made with professional musicians and this study's sound measurements with student-level musicians (Royster, Royster, & Killion, 1991, Phillips & Mace, 2007, O'Brien, Wilson, & Bradley, 2008).

In addition, the average L_{eq} for all of the measurements were softer than the researcher originally anticipated. This could be due to the fact that not all instruments play at the same time or at the same intensity. During individual measurements, the participants were asked to play

fifteen minutes straight at a typical practice level. However, during performances, not all instruments play fifteen minutes straight. Also, certain pieces required instruments to be softer or louder at different times. Overall, this could account for the variation between individual and orchestra measurements.

L_{eq} measurements for two-hour and eight-hour equivalent exposures were also calculated to determine the subjects' exposure during a traditional rehearsal period and during a projected playing period of eight hours. Two-hour exposures ranged from 62.8 dBA to 92.1 dBA. Out of the 19 participants who had instrument data, only one participant exceeded NIOSH's recommended two-hour exposure level of 91 dBA (NIOSH, 1998). Eight-hour exposures ranged from 56.8 dBA to 86.1 dBA with the same participant exceeding the recommended NIOSH level for eight-hour exposures of 85 dBA (NIOSH, 1998). However, these values are strictly representing the projected amount of time the musician plays his or her instrument alone for the Washington University Symphony Orchestra. These calculations do not take into account other factors, such as time played with other ensembles and personal listening habits. Questionnaire results showed that most musicians are fluent in more than one instrument. Therefore, they may practice their other instruments. In addition, a majority of student musicians play with other ensembles or bands between one to three hours per week. It was also found that musicians listen to music in a variety of different manners, including on personal listening devices. When asked to rate the loudness of their personal listening devices, most participants noted listening at a "comfortable, but slightly loud" level. Therefore, the subjects' two-hour and eight-hour equivalent exposure values could be dramatically increased if these factors were also taken into consideration.

The third aim of this project was to assess student musicians' perception of loudness and

how it relates to the measured intensity. Figure 4.1 shows the participants' loudness ratings for their instrument and the orchestra along with and the normative loudness ratings for speech from the LCT. For individual instruments, all 15 participants rated their instruments between "3" and "7," though no participants categorized them in the "6" category. This is related to 35.6 dB to 77.0 dB and 89.5 dB to 114.3 dB on the LCT (when applying the standard deviation). However, the individual instrument measurements ranged from 71.8 dBA to 96.0 dBA which was associated with "5" and "6" on the LCT. Overall, 11 of the 15 participants rated their instrument as softer than what would be expected of a normal hearing listener rating a broadband signal according to the LCT. Two musicians were able to rate the loudness of their instrument similar to the LCT values for connected speech. The other two individuals rated their instrument louder than the normative values. One of those two participants who rated their instrument louder played the trumpet and stated after the sound level recording that he was purposely playing as loud as he could as mentioned previously in the results section. His average L_{eq} was 101.1 dBA, which was the loudest recording overall. Therefore, his perceived loudness rating may be skewed.

Orchestra ratings were between "4" and "6" on the LCT which corresponded to between 50.9 dB to 102.6 dB when applying standard deviations. However, the orchestra measurements (including general orchestra measurements made by the author) were between 71.7 dBA to 93.1 dBA which falls in "5" and "6" of the LCT. Table 4.2 shows the musicians' loudness ratings for the orchestra, the average dBA L_{eq} for their orchestra measurements, and the normative loudness rating for speech signals from the LCT for the measurements. Ten of the 15 participants were able to rate the loudness of the orchestra similar to normal hearing listeners rating the loudness for connected speech. Four of the musicians rated the orchestra softer than the normative values

while only one subject rated the orchestra louder.

As mentioned previously, the loudness contour values used for this project are based on normal hearing listeners listening to five seconds of connected speech from the Connected Speech Test because there are currently no normative loudness contour values for orchestral music. The instrument and orchestra ratings on the graph show that musicians considered louder stimuli to be softer than the measured sound level. For example, the corresponding decibel value for the loudness rating of "comfortable, but slightly soft" is around 40 dB. However, the 15 musicians that were included in the loudness ratings rated their instruments that had an average L_{eq} of 83 dB as "comfortable, but slightly soft." Therefore, even though their instruments are 23 dB louder than the level of connected discourse from the LCT, both groups rated the sound as being "comfortable, but slightly soft." For the "comfortable" rating, there is roughly a 26 dB difference in ratings between the listeners in the LCT listening to connected speech and this project's subjects' music from their instrument alone. "For comfortable, but slightly loud" ratings, there is a 12 dB difference between the LCT norms for speech and the ratings of the musicians. However, for ratings "loud but ok" and "uncomfortably loud," differences in ratings begin to diminish to where there is only 2-7 dB in difference between the LCT values for connected speech and the musicians' loudness ratings.

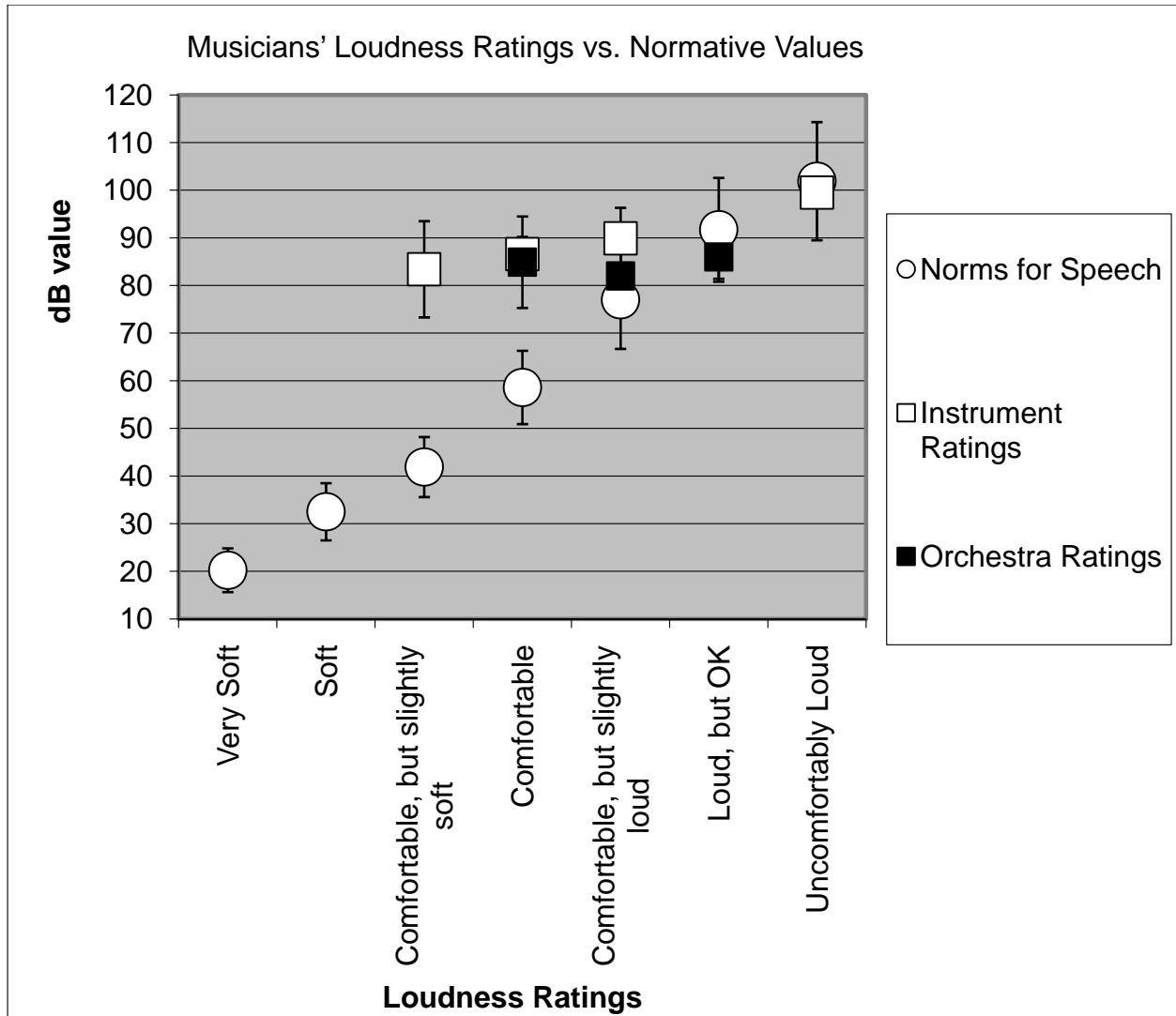


Figure 4.1 – Musicians' loudness ratings versus normative loudness contour data for speech.

In general, a majority of musicians were able to reliably rate the loudness of their instrument and/or the orchestra. These findings are in agreement with Chesky et al's (2009) findings that showed music majors may be able to approximate the intensity level of music more accurately than non-music majors. For the musicians that did not rate the loudness similar to the values for connected speech, most of them rated the instrument and orchestra softer than the norms. There are several reasons as to why these musicians may have an altered loudness perception. One theory is that the LCT is based on broadband speech signals and not music

(Cox, Alexandar, Taylor, & Gray, 1997). These speech signals are dramatically different in composition than orchestral music and therefore, these values from the LCT may not accurately represent the loudness ratings of music. In addition, there is the possibility that participants in the loudness contour test study found the five seconds of connected speech from the Connect Speech Test either annoying or bothersome and therefore rated the stimulus louder than its actual intensity. Another theory has to do with the between-subject variability of the LCT. The standard deviations for the LCT increased as each loudness rating increased, showing this variability. This created difficulty when looking at the relationship between the musicians' loudness perception and the measured intensity for categories "5" through "7" because the standard deviations overlapped each other. A final theory behind the trend of altered loudness perception is that musicians rate their instruments and orchestra softer because they enjoy their craft. If a musician enjoys the music that is played, he or she may be less likely to rate it as accurately as they would rate a genre of music that he or she does not like.

Additional information gained by the author apart from the aims of the study came from the questionnaire data. 19 of the 23 musicians noted that they did not wear hearing protection while practicing or performing. This finding supports Laitinen's (2005) and Chesky et. al's (2009) studies that showed most musicians do not wear hearing protection during rehearsal and performances. However, unlike previous research, the author did not ask the musicians to discuss their reasoning for not wearing hearing protective devices. Therefore, no speculations can be made as to why the majority of musicians do not utilize hearing protection.

Two questions from the questionnaire asked musicians to choose what they thought was the loudest and softest instrument. The trumpet was chosen by the most participants as the loudest instrument. This finding is in agreement with the sound level measurements made in this

project because the trumpet was found to be the loudest instrument of those recorded. However, not all of the instruments were included in this project due to limitations of participation so it cannot be concluded that it is in fact the loudest instrument in the orchestra. The instrument that was picked by five of the 23 participants was the cymbal. However, due to recruitment issues, sound level measurements for the cymbals are not available. In addition, other instruments in the brass section, such as the trombone and tuba, are not included in this study due to participation limitations. However, these instruments have demonstrated in previous literature that they could have dBA L_{eq} values comparable to the trumpet (O'Brien, Wilson, & Bradley, 2008). Participants choosing the trumpet as the loudest instrument in the orchestra may be perceptually accurate, but additional measurements are necessary to see if in fact this instrument has the highest intensity.

The harp was chosen by the most participants as the softest instrument. After the harp, the flute and clarinet were both the second most picked from the questionnaire choices with four participants choosing each. However, a harpist was not included in the Washington University Symphony Orchestra. O'Brien, Wilson, and Bradley (2008) found an average dB L_{eq} of 84.3 for the harp in their study. From this project, the flute was found to have an average L_{eq} of 80.9 dBA while the clarinet had an average L_{eq} of 92.1 dBA. Using the values above, the harp, flute, and clarinet would not be considered the softest instruments for this project. The bass was actually found to be the softest instrument with an average instrument L_{eq} of 71.8 dBA. However, the bass dBA L_{eq} value is not in agreement with previous research and cannot be concluded as the softest instrument without future investigation (O'Brien, Wilson, & Bradley, 2008).

One area of interest was whether or not participants rated a certain section louder than

others due to their proximity to that section. Analyses of the loudness scaling in conjunction with placement in the orchestra were done and no trends were noted. Therefore, it cannot be concluded that an altered perception of loudness can occur depending on the musician's position within the orchestra.

Project Limitations

Though there were some interesting trends found from this project, there were several limitations to this study. One major limitation was the amount of time to complete this research project. By the time this project was approved by the Human Research Protection Office, there were only four months to recruit subjects, complete data collection, and complete data analyses before final reports were due to Washington University School of Medicine's Program in Audiology and Communication Sciences. For future research in this area, a full academic year would be more appropriate for completion. In addition to a limited timeline for this project, there was also a restriction on the amount of time the research had with the orchestra. The Washington University in St. Louis Symphony Orchestra only rehearsed once a week for approximately two hours. Therefore, the amount of time to collect data from this orchestra was reduced.

Though there were time constraints for this study, there were also limitations with participation recruitment. Though several orchestras originally agreed to participate in this study, the author was only able to use one orchestra due to time limitations. Therefore, the number of participants was limited to the one symphony. This was problematic in the fact that not all instruments agreed to participate and the researcher was not able to recruit those specific instruments from another orchestra in order to get complete information. As a result of this,

those specific instruments had to be excluded from the study and could not be commented on during the analyses.

Another variable of this project had to do with the conductors of the orchestra. Though there is typically one conductor used for the symphony orchestra, two different conductors were used during the academic year for reasons unknown to the researcher. This caused the measurements during data collection to be slightly different because each conductor had his own style for going through rehearsal. For example, one conductor took time to focus on different sections of the orchestra whereas the other conductor did not. In addition, one of the conductors frequently stopped and restarted rehearsals while the other conductor offered fewer breaks through each musical piece.

There were also limitations regarding the questionnaires. Some of the questions were pulled from the Munich Music Questionnaire. A few of those questions included instruments that were not in the Washington University Symphony Orchestra, such as the harp and cymbal. Therefore, when analyzing questionnaire data, the author was unable to make general statements about some of the answers to the questionnaire because no information regarding those instruments was obtained. This was proven difficult for the 24th and 25th questions of the questionnaire where participants were asked to choose the “softest” and “loudest” instrument. Both the harp and cymbals were in the top answers for those questions, but no sound level measurements were made with those instruments because they were not a part of the symphony orchestra. In addition, some participants were upset that their instrument was not included in some of the questions. For example, the questionnaire choices did not include the viola or French horn. However, there were five participants who either played or were fluent in playing that instrument

Participant cooperation was also another limitation to the project. One goal of this research project was to have the musicians fill out a questionnaire about their musical practices and fill it out again approximately two weeks later to verify test-retest reliability. However, it was difficult to get the participants to fill out the questionnaires in that time frame. Some musicians did not come to every rehearsal while some musicians would not remember to bring back the questionnaire to the next rehearsal. Therefore, the second round of questionnaires was filled out between two and six weeks after the initial questionnaire was completed. As well as questionnaire difficulties, because musicians did not come to every rehearsal, it took more time to get all of the sound level measurements completed.

Areas of Future Research

There are several areas of future research regarding musicians' loudness perception that could be extremely beneficial to the audiology community. One particular project would be to use the same study design, but recruit from multiple orchestras and ensembles. By having a larger musician sample, statistical correlation analyses could be applied to the loudness scaling in order to see if the differences are statistically significant.

Another project that could provide useful insight would be to look at the perception of loudness in professional musicians. The purpose of this project was to look at student musicians because there is little in the literature regarding this population. But professional musicians may have more knowledge and expertise in not only music in general, but also loudness perception and might, therefore, provide different outcomes. In addition, there is a plethora of literature regarding professional musicians. However, none of those studies looked specifically out musicians' perception of loudness.

It would be interesting for a project to compare these results with results take from ensembles that play different genres of music, such as jazz, pop, folk, and rock music since this research study focused on classical musicians. Because different styles are played differently, the loudness rating results may be varied between each type of music.

A final project that would prove most beneficial would be to obtain normative loudness contour data for music. It is unclear whether or not the loudness ratings were different than expected because of the musician's enjoyment of the music or because the connected discourse speech signal used for the normative data in the LCT was different in composition than the music played by the orchestra. If normative values were obtained for music signals, those findings could provide informational data and would be useful for future endeavors in loudness perception testing.

Conclusion

It has been well-documented that musicians are exposed to levels that exceed both NIOSH and OSHA standards in regards to occupational noise though they are not required to abide by those standards (Jansson & Karlsson, 1983, Jansen et. al., 2009, Laitinen et. al., 2003, Miller, Stewart, & Lehman, 2007, Royster, Royster, & Killion, 1991). Other research has also shown that though musicians are at risk for noise-induced hearing loss, most do not wear hearing protection while playing or performing (Chesky et. al., 2009, Laitinen, 2005, Miller, Stewart, & Lehman, 2007). The purpose of this project was to analyze musicians' perception of loudness in an effort to learn more about musicians as a group in order to determine how to create a hearing conservation program that is customized to those specific needs. Though some musicians were able to reliably rate loudness for instruments, sections, and the entire orchestra, some musicians

were not. Though reasons for not using hearing protection have been documented in previous literature (Chesky et.al., 2009) (Laitinen, 2005), this study suggests that musicians' altered perception of loudness could also be a contributing factor. If musicians in general do have an altered loudness perception, this may be an area that should be focused on in a musician hearing conservation program. By identifying real world objects and correlating their loudness to the loudness of instruments, musicians might be able to understand the importance of using hearing protection while playing their music and be more open to wearing hearing protection in order to reduce their exposure.

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Appendix A

Questionnaire

Date: _____

Age: _____

ID _____

PLEASE CHECK THE BEST ANSWER

1) How do you listen to music?

<input type="checkbox"/> In the background	<input type="checkbox"/> As my only focus of concentration/without distraction	<input type="checkbox"/> Both
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2) Why do you listen to music? Please check all applicable answers.

<input type="checkbox"/> For pleasure	<input type="checkbox"/> Professional reasons	<input type="checkbox"/> Emotional satisfaction	<input type="checkbox"/> To relax
<input type="checkbox"/> To improve my mood	<input type="checkbox"/> To stay awake	<input type="checkbox"/> To dance	

3) Do you prefer to listen to solo instruments or an orchestra/ band?

<input type="checkbox"/> Solo instruments	<input type="checkbox"/> Orchestra/Band	<input type="checkbox"/> No preference
---	---	--

4) Which instruments do you like listening to? Please check all applicable answers.

<input type="checkbox"/> Flute	<input type="checkbox"/> Oboe	<input type="checkbox"/> Clarinet	<input type="checkbox"/> Tuba	<input type="checkbox"/> Trumpet
<input type="checkbox"/> Violin	<input type="checkbox"/> Cello	<input type="checkbox"/> Bassoon	<input type="checkbox"/> Trombone	<input type="checkbox"/> Accordion
<input type="checkbox"/> Harp	<input type="checkbox"/> Bass	<input type="checkbox"/> Guitar	<input type="checkbox"/> Saxophone	<input type="checkbox"/> Drum Kit
<input type="checkbox"/> Recorder	<input type="checkbox"/> Piano	<input type="checkbox"/> Xylophone	<input type="checkbox"/> Tympani	<input type="checkbox"/> Cymbals
<input type="checkbox"/> Other – please specify.				

5) Where have you listened to or do you currently listen to music? Please check all applicable answers.

<input type="checkbox"/> On the radio at home	<input type="checkbox"/> On the radio in the car	<input type="checkbox"/> At social events
<input type="checkbox"/> On television	<input type="checkbox"/> LP/CD/MC/MP3	<input type="checkbox"/> At religious institutions

6) Which musical genre do you listen to? Please check all applicable answers.

<input type="checkbox"/> Classical music	<input type="checkbox"/> Opera/Operetta	<input type="checkbox"/> Religious Music	<input type="checkbox"/> Folk/Country Music
<input type="checkbox"/> Pop	<input type="checkbox"/> Rock	<input type="checkbox"/> Jazz/Blues	<input type="checkbox"/> Music to dance to

7) On a scale of 1 to 7, how loud do you like to listen to your music in your iPod/MP3 player/CD player/Walkman? Please circle the best answer.

- 1 – Very Soft
- 2 – Soft
- 3 – Comfortable, but slightly soft
- 4 – Comfortable
- 5 – Comfortable, but slightly loud
- 6 – Loud, but OK
- 7 – Uncomfortably loud

8) Please check all instruments that you are fluent in playing.

<input type="checkbox"/> Flute	<input type="checkbox"/> Oboe	<input type="checkbox"/> Clarinet	<input type="checkbox"/> Tuba	<input type="checkbox"/> Trumpet
<input type="checkbox"/> Violin	<input type="checkbox"/> Cello	<input type="checkbox"/> Bassoon	<input type="checkbox"/> Trombone	<input type="checkbox"/> Accordion
<input type="checkbox"/> Harp	<input type="checkbox"/> Bass	<input type="checkbox"/> Guitar	<input type="checkbox"/> Saxophone	<input type="checkbox"/> Drum Kit
<input type="checkbox"/> Recorder	<input type="checkbox"/> Piano	<input type="checkbox"/> Xylophone	<input type="checkbox"/> Tympani	<input type="checkbox"/> Cymbals
<input type="checkbox"/> Other – please specify.				

9) In which section(s) have you played in the past? Please check all applicable answers.

<input type="checkbox"/> Brass section	<input type="checkbox"/> Percussion section
<input type="checkbox"/> String section	<input type="checkbox"/> Woodwind section

10) What instrument are you currently playing in this orchestra/band?

<input type="checkbox"/> Flute	<input type="checkbox"/> Oboe	<input type="checkbox"/> Clarinet	<input type="checkbox"/> Tuba	<input type="checkbox"/> Trumpet
<input type="checkbox"/> Violin	<input type="checkbox"/> Cello	<input type="checkbox"/> Bassoon	<input type="checkbox"/> Trombone	<input type="checkbox"/> Accordion
<input type="checkbox"/> Harp	<input type="checkbox"/> Bass	<input type="checkbox"/> Guitar	<input type="checkbox"/> Saxophone	<input type="checkbox"/> Drum Kit
<input type="checkbox"/> Recorder	<input type="checkbox"/> Piano	<input type="checkbox"/> Xylophone	<input type="checkbox"/> Tympani	<input type="checkbox"/> Cymbals
<input type="checkbox"/> Other – please specify.				

11) What section are you currently playing in this orchestra/band?

<input type="checkbox"/> Brass section	<input type="checkbox"/> Percussion section
<input type="checkbox"/> String section	<input type="checkbox"/> Woodwind section

12) Which chair do you play?

<input type="checkbox"/> 1 st chair	<input type="checkbox"/> 2 nd chair	<input type="checkbox"/> 3 rd chair
<input type="checkbox"/> 4 th chair	<input type="checkbox"/> Other – please specify	<input type="checkbox"/> Not applicable

13) Did you receive any musical education outside of school (instrument and/or voice lessons)?

<input type="checkbox"/> Yes	<input type="checkbox"/> No
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14) For how long did you receive musical education outside school (instrument and/or voice lessons)?

<input type="checkbox"/> Less than 3 years	<input type="checkbox"/> More than 3 years	<input type="checkbox"/> Not applicable
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15) Do you currently play with any other ensembles/bands/etc... other than this one?

<input type="checkbox"/> Yes	<input type="checkbox"/> No
------------------------------	-----------------------------

16) What type of music do you play with your other ensembles/bands/etc...? Please check all applicable answers.

<input type="checkbox"/> Classical music	<input type="checkbox"/> Opera/Operetta	<input type="checkbox"/> Religious Music	<input type="checkbox"/> Folk/Country Music
<input type="checkbox"/> Pop	<input type="checkbox"/> Rock	<input type="checkbox"/> Jazz/Blues	<input type="checkbox"/> Music to dance to
<input type="checkbox"/> Not applicable			

17) How many hours per week do you practice and/or play with the other ensembles/bands/etc..?

<input type="checkbox"/> Less than 3 hours per week	<input type="checkbox"/> Between 3 and 8 hours per week	<input type="checkbox"/> More than 8 hours per week	<input type="checkbox"/> Not applicable
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The following questions are in regards to your perception of how loud things are. Please circle the number that best corresponds with your answer. Only circle ONE number.

- 18) On a scale of 1 to 7 with 1 being very soft and 7 being uncomfortably loud, how loud do you think your instrument is when you practice/play solo?

1 – Very Soft
 2 – Soft
 3 – Comfortable, but slightly soft
 4 – Comfortable
 5 – Comfortable, but slightly loud
 6 – Loud, but OK
 7 – Uncomfortably loud

- 19) On a scale of 1 to 7 with 1 being very soft and 7 being uncomfortably loud, how loud do you think the brass section is by itself?

1 – Very Soft
 2 – Soft
 3 – Comfortable, but slightly soft
 4 – Comfortable
 5 – Comfortable, but slightly loud
 6 – Loud, but OK
 7 – Uncomfortably loud

- 20) On a scale of 1 to 7 with 1 being very soft and 7 being uncomfortably loud, how loud do you think the percussion section is by itself?

1 – Very Soft
 2 – Soft
 3 – Comfortable, but slightly soft
 4 – Comfortable
 5 – Comfortable, but slightly loud
 6 – Loud, but OK
 7 – Uncomfortably loud

- 21) On a scale of 1 to 7 with 1 being very soft and 7 being uncomfortably loud, how loud do you think the string section is by itself?

1 – Very Soft
 2 – Soft
 3 – Comfortable, but slightly soft
 4 – Comfortable
 5 – Comfortable, but slightly loud
 6 – Loud, but OK
 7 – Uncomfortably loud

- 22) On a scale of 1 to 7 with 1 being very soft and 7 being uncomfortably loud, how loud do you think the woodwind section is by itself?

1 – Very Soft
 2 – Soft
 3 – Comfortable, but slightly soft
 4 – Comfortable
 5 – Comfortable, but slightly loud
 6 – Loud, but OK
 7 – Uncomfortably loud

- 23) On a scale of 1 to 7 with 1 being very soft and 7 being uncomfortably loud, how loud do you think your entire orchestra/band is?

1 – Very Soft
 2 – Soft
 3 – Comfortable, but slightly soft
 4 – Comfortable
 5 – Comfortable, but slightly loud
 6 – Loud, but OK
 7 – Uncomfortably loud

24) Which instrument do you think is the softest? Please check ONE (1) answer.

<input type="checkbox"/> Flute	<input type="checkbox"/> Oboe	<input type="checkbox"/> Clarinet	<input type="checkbox"/> Tuba	<input type="checkbox"/> Trumpet
<input type="checkbox"/> Violin	<input type="checkbox"/> Cello	<input type="checkbox"/> Bassoon	<input type="checkbox"/> Trombone	<input type="checkbox"/> Accordion
<input type="checkbox"/> Harp	<input type="checkbox"/> Bass	<input type="checkbox"/> Guitar	<input type="checkbox"/> Saxophone	<input type="checkbox"/> Drum Kit
<input type="checkbox"/> Recorder	<input type="checkbox"/> Piano	<input type="checkbox"/> Xylophone	<input type="checkbox"/> Tympani	<input type="checkbox"/> Cymbals
<input type="checkbox"/> Other – please specify.				

25) Which instrument do you think is the loudest? Please check ONE (1) answer

<input type="checkbox"/> Flute	<input type="checkbox"/> Oboe	<input type="checkbox"/> Clarinet	<input type="checkbox"/> Tuba	<input type="checkbox"/> Trumpet
<input type="checkbox"/> Violin	<input type="checkbox"/> Cello	<input type="checkbox"/> Bassoon	<input type="checkbox"/> Trombone	<input type="checkbox"/> Accordion
<input type="checkbox"/> Harp	<input type="checkbox"/> Bass	<input type="checkbox"/> Guitar	<input type="checkbox"/> Saxophone	<input type="checkbox"/> Drum Kit
<input type="checkbox"/> Recorder	<input type="checkbox"/> Piano	<input type="checkbox"/> Xylophone	<input type="checkbox"/> Tympani	<input type="checkbox"/> Cymbals
<input type="checkbox"/> Other – please specify.				

26) Have you ever been bothered by the loudness of your instrument?

<input type="checkbox"/> Always	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Rarely	<input type="checkbox"/> Never
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27) Have you ever had ringing in your ears after a practice and/or performance?

<input type="checkbox"/> Always	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Rarely	<input type="checkbox"/> Never
---------------------------------	------------------------------------	---------------------------------	--------------------------------

28) Have you ever experience a temporary hearing loss after a practice and/or performance?

<input type="checkbox"/> Always	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Rarely	<input type="checkbox"/> Never
---------------------------------	------------------------------------	---------------------------------	--------------------------------

29) How often do you experience a temporary hearing loss after a practice and/or performance?

<input type="checkbox"/> Never	<input type="checkbox"/> 1-2 times per week	<input type="checkbox"/> 3-5 times per week	<input type="checkbox"/> More than 5 times per week	<input type="checkbox"/> Every time I practice and/or perform
--------------------------------	---	---	---	---

30) Do you wear hearing protection with practicing and/or performing?

<input type="checkbox"/> Always	<input type="checkbox"/> Sometimes	<input type="checkbox"/> Rarely	<input type="checkbox"/> Never
---------------------------------	------------------------------------	---------------------------------	--------------------------------

31) When you wear hearing protection, what type of hearing protection do you wear? Please check all applicable answers.

<input type="checkbox"/> Foam Plugs	<input type="checkbox"/> Ear Muffs	<input type="checkbox"/> Musicians' Plugs
<input type="checkbox"/> Cotton Plugs	<input type="checkbox"/> Custom noise reduction plugs	<input type="checkbox"/> Other – please specify
<input type="checkbox"/> Not applicable		

32) Do you think that your music could cause hearing loss?

<input type="checkbox"/> Yes	<input type="checkbox"/> No
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Appendix B

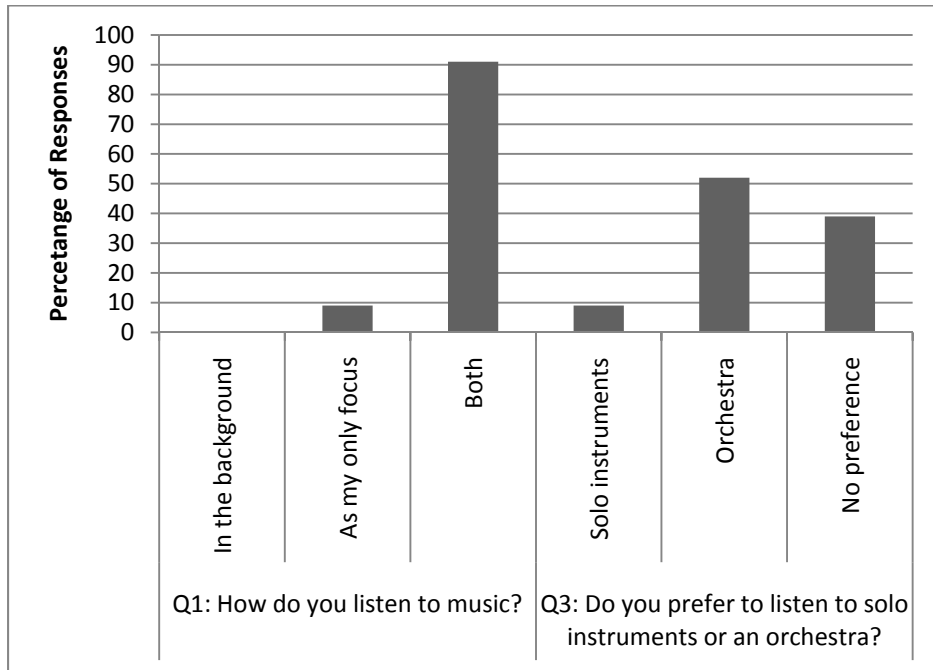


Figure B.1 – Participants’ responses to Questions 1 and 3 related to musical interests.

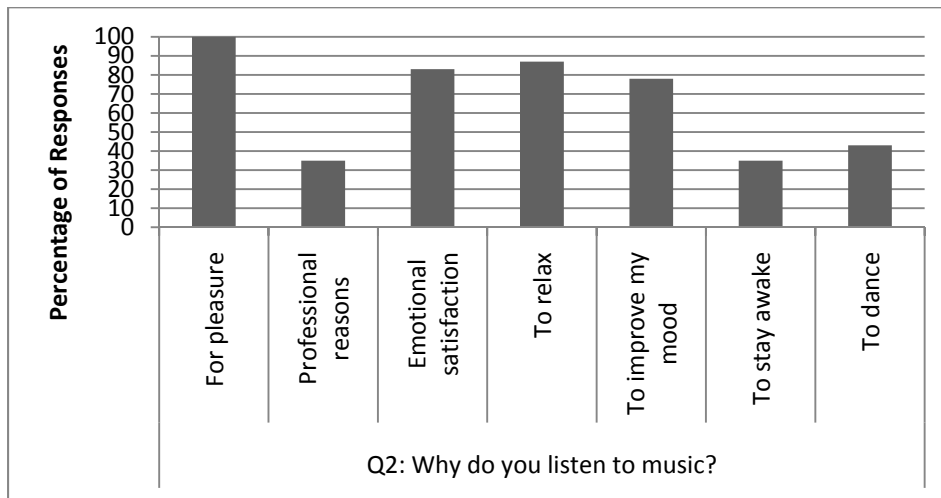


Figure B.2 – Participants’ responses to Question 2 regarding why they listen to music

Appendix C

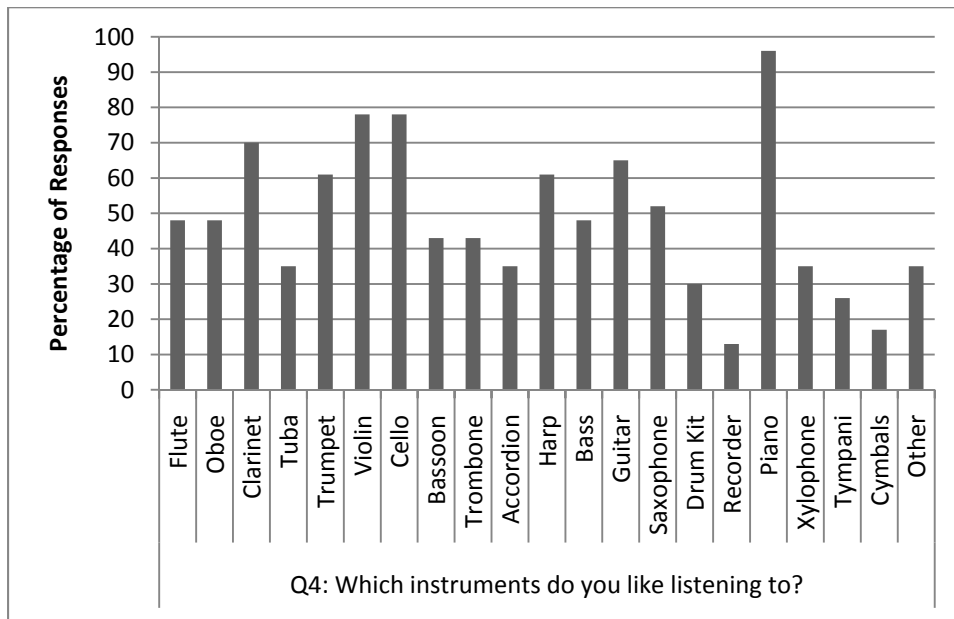


Figure C.1 –Participants’ responses to Question 4 related to which instrument they like listening to.

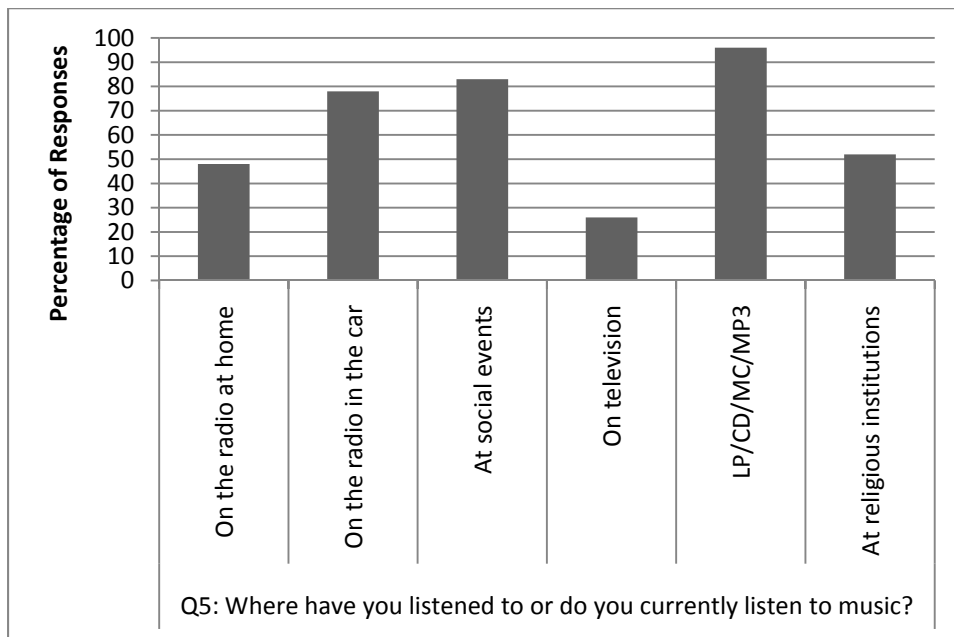


Figure C.2 – Participants’ responses to Question 5 regarding where they currently listen to music.

Appendix D

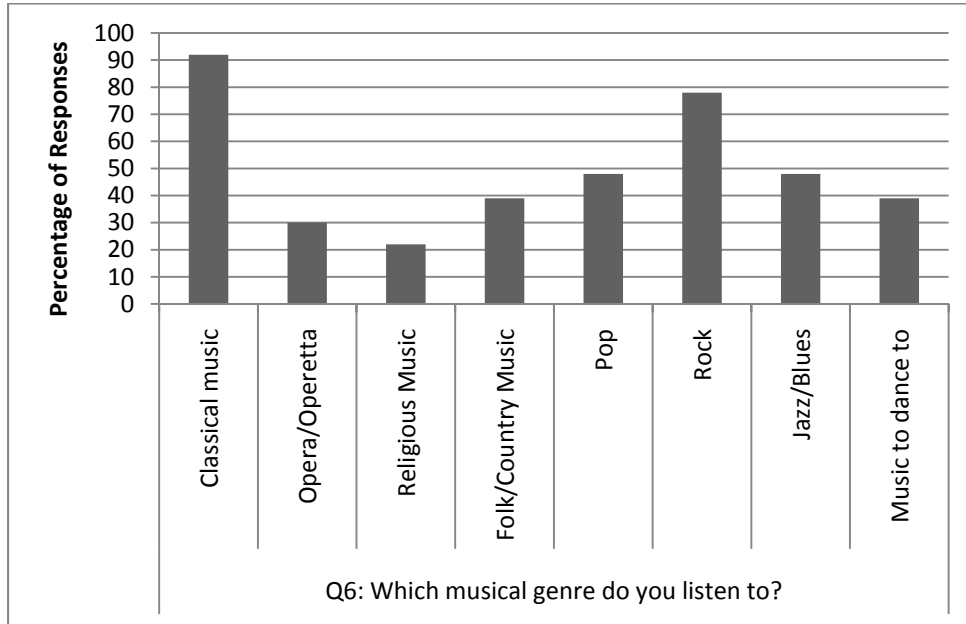


Figure D.1 – Participants’ responses to Question 6 regarding what musical genre is listened to