CHARACTERISTICS OF MUSICIANS’ EARPLUGS AS A FUNCTION OF JAW POSITION

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[Signatures]
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CHARACTERISTICS OF MUSICIANS' EARPLUGS AS A FUNCTION OF JAW POSITION

THESIS

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By

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Abstract

The position of the mandible alters the characteristics and volume of the external auditory meatus. The present study examined the effects of jaw position while obtaining an earplug impression on the functionality and comfort of musicians’ earplugs. Earmold impressions were made for each subject in up to three different jaw positions. The musicians’ earplugs were evaluated subjectively through a questionnaire and objectively through real-ear measurements. Real-ear measurements were tested under a variety of different jaw positions. Results revealed that jaw position while taking the impression for the musicians’ earplug affected the attenuation amount and configuration as well as the comfort of the earplug.
Literature Review

The ER-15

Since 1988, a variety of approximately 280 options of hearing protection devices have been offered to the public (Merry, Sizemore, & Franks, 1992). According to Berger (1994), hearing protection devices are primarily divided into two categories: earplugs and earmuffs. Earmuffs typically consist of a basic model that covers the entire pinna and fits tightly with the head due to the plastic or metal headband. Earplugs can be further categorized into three broad styles: formable, premolded, and custom molded. Silicone putty, slow recovery foam, spun fiberglass, and a mixture of cotton and wax are the most common forms of formable earplugs. Premolded earplugs consist of vinyl, cured silicones, or other flexible substances. Premolded plugs cause a congested feeling in the ear due to the tight fit that might cause an unpleasant resonance. Custom molded earplugs enable the user to have an individualized hearing protection device (Berger, 1994), which would be beneficial to many individuals, including musicians.

With such a large assortment, the user must know what will best meet his or her needs. As seen in appendix A, the earmuff, the premolded earplugs, the formable earplugs, and some custom molded earplugs attenuate more in the high frequencies than in the low frequencies (Berger, 1994), which is rather disadvantageous for musicians. If the high frequencies are attenuated more than the low frequencies, the flow of sounds will be disproportionate through the musician’s ears. A musician would benefit from an earplug that protects hearing while maintaining the sound. Earplugs and earmuffs especially designed for industrial sounds are created to reduce exceptionally loud noises as much as possible. These are not appropriate for musicians who still need to hear the music around them.
Etymotic Research (ER) created a series of earplugs that are referred to as musicians’ earplugs: the ER-15, the ER-25, the ER-9, and the ER-20 HI-FI. These earplugs serve as a solution for musicians to avoid the unneeded and unpleasant muffled attenuation caused by other types of earplugs or earmuffs. The musicians’ earplug mimics the natural curve of an unoccluded ear to best maintain the natural sounds. This is accomplished by providing a relatively flat frequency response. The ER-15 attenuates 15 dB, the ER-25 attenuates 25 dB, and the ER-9 reduces sound by 9 dB. The flat attenuation eliminates muffled sounds caused by earplugs with too much attenuation in the high frequencies (Briskey & Paulson, 1999; Santucci, 1990; Killion, DeVilbiss, & Stewart, 1988). According to Briskey & Paulson (1999), the flat attenuation maintains the clarity of the sound, which is critical for musicians.

The musicians’ earplug, typically made of silicone or vinyl, is custom molded for each person (Briskey & Paulson, 1999; Killion, DeVilbiss, & Stewart, 1988). The earplug has a hole in the center where the filter is placed. Different filters (15 dB, 25 dB, 9 dB) can be used interchangeably with the same earplug (Briskey & Paulson, 1999). The ER-20 HI-FI Earplugs work differently and are intended to be a less expensive substitute. Instead of the filter, attenuation is created through a tuned resonator and acoustic resistor. However, the HI-FI earplug still maintains the characteristic flat attenuation across the frequencies (Briskey & Paulson, 1999). Selection of the filter attenuation amount reflects the decibels of sound typically encountered and the level of sound the musician would like reduced.

Taking an accurate mold for the earplug is vital for proper attenuation and comfort. Even small deviations of the earplug impression in relation to the actual characteristics of the ear canal could cause soreness (Staab, 1995). According to Killion, DeVilbiss, & Stewart (1988), lack of an adequate seal and an undersized sound channel are two common inaccuracies while
constructing the mold. Both scenarios directly affect the performance of the earplug. A poor seal loses the natural assimilation to open-ear sound that the musicians' earplug is meant to achieve (Santucci, 1990; Killion, DeVilbiss, & Stewart, 1988). Some frequencies are attenuated more or less than others making the music seem to get softer and louder as the frequency changes. Undersized sound channels cause similar problems. A significant difference in attenuation consistency was noted when Killion, DeVilbiss, & Stewart (1988) used a 2 mm earplug diameter instead of the needed 3.5 mm diameter. There was little to no attenuation in the low frequencies with more attenuation in the high frequencies with the undersized sound channel (Killion, DeVilbiss, & Stewart, 1988). A deep seal is also necessary to avoid the occlusion effect, which is a loud hollow effect in the head (Santucci, 1990; Killion, DeVilbiss, & Stewart, 1988). This could be rather unpleasant for vocalists and musicians, especially musicians who play instruments with a mouthpiece.

**Ear Canal Characteristics During Jaw Movement**

When a musician plays an instrument with a mouthpiece such as the trumpet or saxophone, his or her mouth does not remain stationary. The same applies to singers. It is clear that the lips, cheek, and mandible all move along with the music; the ear canal might also move. Studies show that certain movements of the mandible directly affect the shape and volume of the ear canal (Oliveira et al., 1992; van Willigen, 1976; Oliveira, 1995; Staab, 1995; Ballachanda, 1995). If the jaw movement utilized by musicians while playing and/or singing does in fact affect the ear canal, then this movement could possibly alter the attenuation characteristics of the earplug. However, if earplugs are molded so that jaw movement is taken into account, then musicians might be more willing to use a hearing protection device.
The distance into the ear canal is rather significant when calculating the influence of mandible activity on ear canal characteristics. The portion of the canal that is entirely cartilaginous (start of canal to about 10 mm) and the section consisting of cartilage and bone are both inclined to be affected as the jaw moves (Oliveira et al., 1992; van Willigen, 1976; Staab, 1995; Oliveira, 1995). The 100% osseous section comprises about half of the ear canal (the part closest to the tympanic membrane) and is not susceptible to change during jaw movement (van Willigen, 1976; Oliveira, 1995). By approximately 10 mm, the ear canal (superior side) is partially entering the osseous, or bony portion, of the ear canal, and by approximately 16 mm, the entire canal is engulfed in the bony portion (Oliveira, 1995). The earplug rests in the cartilaginous portion; therefore, it is at risk for movement during jaw activity. This is supported by a study by van Willigen (1976). Using an impression paste, van Willigen measured movements in the ear canal at 6 mm, 8 mm, 10 mm, and 12 mm during different jaw activities. Ear canal characteristics changed at each of these levels, all of which were in the cartilaginous or partially cartilaginous sections.

The jaw moves in multiple directions. van Willigen (1976) studied three basic mandible movements: open, protrusion, and (maximal) occlusion. The open jaw was tested at 2.5 cm. Protrusion is the act of the mandible shifting forward while the maxilla remains inactive, and occlusion is defined, “to meet with the cusps fitting together” (Webster’s Dictionary, 1983). By layering photograph negatives of the ear canal, there was an apparent change in ear canal characteristics between the three jaw movements. The volume of the ear canal increased as the jaw moved from occluded to open, but even more so in the protruded position. Oliveira et al. (1992) used an MRI and silicone impressions to find that when the jaw opened to different degrees (from 0 mm to 5.5 mm) the ear canal ranged from 5.1 mm to as much as 6.4 mm in width.
This is a significant amount when dealing with earplugs that need a tight seal to attenuate properly (Briskey & Paulson, 1999; Santucci, 1990). As the mandible moves during routine activities, the seal of the earplug could break based on the ear canal transformation.

Although van Willigen (1976), Oliveira et al. (1992), Oliveira (1995), and Ballachanda (1995) all agree that the ear canal does shift in volume and change in form during various jaw movements, van Willigen (1976) states that change takes place in the total ear canal. Oliveira et al. (1992) and Oliveira (1995) contest that form is principally altered in the anterior and posterior dimension. Oliveira et al. (1992) claim that the superior and inferior positions are rather stable, and that the greatest variation in diameter transpires immediately after the first turn of the canal due to a shift in the anterior direction. Oliveira (1995) asserts that there is some inferior movement. It is possible that van Willigen’s discrepancy is due to the fact that he also tested the effects of a protruded mandible; which could cause superior and inferior changes. The dissimilarity could also be due to the methods used to obtain the information. Oliveira et al. (1992) used silicone ear impressions and an MRI study, whereas van Willigen utilized special impression paste. The relevance of this divergence is not as significant as the agreement between the three sources that a change in volume may develop.

Staab (1995) found that some ear canals could shift or push a device out of position with jaw movement. This could be detrimental to the functioning of the earplug for the musician during use. Cluff (1989) tested insert-type hearing protectors in relation to stability during jaw movement by monitoring thirty minutes of constant gum chewing (one jaw stroke per second). The subject was not permitted to move nor adjust the earplugs during this time. In more than one trial, an earplug completely fell out of the ear, but more importantly, there was overall evidence of lack of stability in earplug position (Cluff, 1989). While insert earplugs differ from
custom molded musicians' earplugs, the dynamics remain constant; jaw movement plays a critical role and influences the characteristics of the ear canal. If the earplug is not molded to withstand these changes, the performance of the device might falter.

Speed of mandible movement is another concern for the ear canal. Based on van Willigen's study (1976), the volume of the ear canal changes to a lesser degree when the jaw moves slowly after tooth contact. This study also shows that the ear canal goes through stages while opening and closing the jaw, alternating between more and less volume until finally returning to original volume. Overall, the opening actions generated an increase in volume (van Willigen, 1976). This is important not only for vocalists who clearly open their mouths, but also for instrumentalists who move their jaws at various rates depending on the piece.

The relationship between the mandible and the auditory meatus is interspersed with a complexity of muscles, tissue, and joints bringing the two together. At the peak of the mandible is the condylar process. The condylar process allows for the mandible to rotate. It shifts forward when the jaw opens (Oliveira, 1995; Seikel, King, & Drumright, 2000). When the mandible is thrust forward and open, the condyles move downward and forward (Parker, 1957). Motion of the condyle strains the anterior cartilage of the ear canal, pulling it in the direction of movement. The condyle shift only affects the cartilaginous portion of the ear canal (Oliveira, 1995; Oliveira et al., 1992), which directly impacts the earplug positioning. Less skin elasticity in the area of the canal increases the effect during jaw movement (Oliveira et al., 1992). Stress on the cartilage explains the change in shape and size of the ear canal wall during the open and protruding positions.

Howell, Williams, & Dix (1988) and Howell & Williams (1989) claim that when the cartilage of the ear canal moves in accordance with jaw movement, the surrounding air moves
and creates sound. They go on to state that this sound in an occluded ear canal contributes to the occlusion effect. The sound pressure level could be more than 10 dB higher in the lower frequencies, particularly 50 to 500 Hz where the sound is unable to escape from the occluded ear (Howell, Williams, & Dix, 1988; Howell & Williams, 1989). According to this theory, jaw movement in relation to the skull as a whole causes the compression in the ear canal and therefore the surplus of sound. Additional jaw movement means additional cartilage movement of the ear canal, and the sound within the ear canal will increase accordingly (Howell, Williams, & Dix, 1988).

Howell & Williams (1989) assert that when the jaw alternates from open (active) to closed positions (stationary), the amount of amplification in the ear canal varies. As the mouth opens, the sound in the ear canal intensifies in the low frequencies with a peak around 150 Hz for individuals with normal mandibles (Howell & Williams, 1989). Similarly, Howell, Williams, & Dix (1988) found that sound amplifies when the mandible moves out and in (protrudes and retracts), and sound is not additionally amplified while the mandible is stationary with the skull. This increase in amplification in the low frequencies could greatly distort the sounds while the ear is occluded with a flat-attenuation earplug; therefore, the need for an earplug designed according to the user's unique ear canal movement intensifies. A tight seal between the earmold and the ear canal could possibly hinder intensity deviations while moving the mandible.

Both lips rest on a cup-shaped mouthpiece while playing the trumpet, and the lower lip serves as a place for the mouthpiece (a single reed) to rest while playing the saxophone. The upper lip bulges out, and the lower lip bends over the front teeth. Several face muscles are used while forming these positions as well as playing the instruments. Trumpet players activate the pterygoideus externus (lateral pterygoid muscle) and pterygoideus internus (medial pterygoid
muscle) while creating the necessary thrust (protrusion) action also needed for many other
instruments (Parker, 1957). The pterygoideus externus attaches to the pterygoid fovea, which
connects the muscle with the condylar process (Seikel, King, & Drumright, 2000); therefore the
muscle utilized while playing many instruments is indirectly related to the process that alters the
characteristics of the ear canal.

While singing, the jaw can open to double the typical size during speech. Forward and
Howard (1994) relate the difference by the amount of fingers in between the teeth. During
speech and most singing conditions the jaw opens enough for one finger to be placed in between
the teeth, but during some moments of singing (mostly the vowels), it is two fingers. Singing is
basically speech with a larger variety of pitch levels and duration of syllabic sounds (Pfautsch,
1971); therefore, the jaw movements for speech should hold true for singing. The mandible
rotates, translates horizontally, and translates vertically for speech activity. These movements
use the pterygoideus externus (Edwards & Harris, 1990). As noted before through Seikel, King,
& Drumright (2000), movement of this muscle ultimately alters ear canal characteristics.

The purpose of the present study is to discover the impact, if any, of musicians' routine
jaw movements on the performance of the earplug and if this result could be altered. Based on
the research, it is clear that the jaw directly influences ear canal characteristics, but it is not yet
known if the changes in the ear canal are significant enough to hinder the functionality of the
musicians' earplug. If jaw movement is taken into account while obtaining the earplug
impression, it could possibly result in a solution and better earplug capability.
Method

The objective of the present investigation was to discover a possible relationship between the jaw position while obtaining the earmold impression and the final functionality of the musicians' earplug, the ER-15. Multiple earmold impressions were taken of each subject and sound pressure level measurements taken in the ear canal were later obtained. Subjective testing was done to determine the perceived quality of sound and perceived levels of comfort.

Subjects

Three subjects were chosen to participate in the investigation. Each had an extensive background with music. Two individuals were experienced with instruments, while the third person was a professional vocalist. They were chosen based on availability for the study and their enthusiasm relative to the use of hearing protection. Both instrumentalists were male and the vocalist was female. All subjects were familiar with a variety of musical settings for practice, rehearsal, and performance that varied in intensity levels during performance. Each individual had an extensive history of exposure to loud noises, and were eager for a possible solution to the excessive levels of noise. Two of the subjects had at least a mild hearing loss in the high frequencies. The third subject, the vocalist, had no hearing loss but had repeatedly experienced tinnitus for approximately six months before the study. All three subjects reported ringing or buzzing in their ears after a musical performance.

Each musician was chosen based on the instrument he or she played. The first subject played a trumpet as his primary instrument. The second subject played a Selmer balanced action tenor saxophone, and the third was a vocalist. Parker (1957) describes the trumpet as a brass instrument with a cup-shaped mouthpiece. Other brass instruments with a cup-shaped mouthpiece include the French horn, the German horn, the alto horn, the trombone, the baritone,
euphonium (tenor tuba), and the tuba. The saxophone is a brass instrument with a single reed for a mouthpiece. The “b flat” soprano saxophone, the “b flat” tenor saxophone, the bass saxophone, and the “e flat” baritone saxophone are all single reed instruments along with the “e flat” clarinet, the “b flat” clarinet, the “a” clarinet, the alto clarinet, and the bass clarinet (Parker, 1957).

The formation of the mouth around the mouthpiece of the instrument was extremely important for this experiment as it played a major role in the jaw movement; therefore, the trumpet and saxophone were chosen for this study due to their representation of a large amount of similar instruments (in terms of the mouthpiece). Instruments without a mouthpiece were not relevant to this study. The jaw movement of the vocalist was quite different from the movements of the instrumentalists and needed to be considered separately.

In addition, subjects were chosen based on a need for hearing protection. In a study by Chesky and Henoch (2000), it was found that 18 out of 53 (34%) non-classical saxophone players and 17 out of 45 (37.8%) non-classical trumpet players reported a hearing problem. Twenty-seven out of 127 (21.3%) non-classical vocalists reported a hearing loss. The saxophone and trumpet players reported the second and third highest rates of problems with hearing loss. The jazz and blues category had the second highest percentage of self-perceived hearing loss. In the present study, both the trumpet and the saxophone player performed in a jazz/blues setting. The saxophone player was also a music educator, a group which reported the third highest percentage of self-perceived hearing loss in the Chesky & Henoch (2000) study.

The trumpet player, 44 years old, and the saxophone player, 40 years old, were faculty members at the University of North Texas College of Music. Both of these subjects had a Class II malocclusion. The trumpet player had previously used musicians’ earplugs, but he reported
that there were issues with comfort and quality of sound. Regardless of past disappointment, the subject was still eager and open-minded about participation in the present study. The trumpet player played an average of seven hours per week. The saxophone player occasionally played the clarinet, the flute, and the electric bass. He played the saxophone an estimated six to twelve hours a week in rehearsal and performance and spent two to four hours per week listening to performances.

The vocalist, 26 years old, was a student at the University of Texas in Arlington. The vocalist performed in a variety of musical styles. She labeled it as, “party music”, which includes swing, jazz, music from the 1940’s and 1950’s, mambo, the cha-cha, and some from the 1980’s and 1990’s. The subject reported an average of ten hours of performance per week and six hours of solo practice. The subject showed no signs of malocclusion, but she did report previous jaw surgery to correct a slight under-bite. Six screws hold her upper and lower jaw in place.

Each subject served as his or her own control. The control condition consisted of earplugs made while the jaw was in a stationary, neutral position. The experimental condition was the musicians’ earplugs made while the jaw was in a position specific to the instrument being played. The trumpet and saxophone players had one set of earplugs made for the control condition and one set of earplugs for the experimental condition. The vocalist had one set of earplugs for the control and two sets of earplugs for the experimental condition. Each set of earplugs was worn in multiple settings for a substantial amount of time.
Instrumentation

Two different audiometers were used for the audiometric testing: the GSI 16 and the Orbiter 922. The impression material for the earplugs was Westone Laboratories, Inc Silicone Singles. Real ear measurements were made using a Madsen Aurical Real Ear analyzer.

Procedure

Earmold impressions were made of both ears. A soft foam block was placed in the ear canal just past the second bend. Silicone impression material was mixed, put into a syringe, and squeezed into the ear canal until the ear canal and the concha were filled. It took approximately five minutes for the impression material to completely harden. The impressions were then pulled out by the string of the foam block and immediately prepared for delivery to the manufacturer.

During the first condition, the control, each subject sat as still as possible with the jaw in a resting position. After careful explanation, each subject knew to relax the mandible in a neutral position and not to forcibly shut the jaw. This was imperative to the study for the first set of earplugs, the control condition, needed to represent, as closely as possible, a traditional procedure for obtaining the impressions. For each subject, the neutral molds were labeled earplug “A”.

For the experimental condition, the subject continued to sit in a stationary position, but the jaw was manipulated before the impression material was injected into the ear canal. In the neutral position (earplug A), the front maxillary teeth naturally fell over the mandibular teeth. This was especially the case for the subjects with an overbite. During the manipulated position, the teeth were positioned in such a way that the front maxillary and the front mandibular teeth fell into the same plane. This caused the jaw to protrude further than when in the neutral
position. Two tongue depressors were placed in between the upper and lower teeth at an angle to represent a basic jaw position while using a mouthpiece. This mold was labeled earplug “B”.

The position for earplug B was strategically chosen for a variety of reasons. According to van Willigen (1976), the volume of the ear canal increases as the jaw protrudes. If the ear canal were larger while taking the earplug impression, then presumably the earplug would be larger. A larger earplug would result in a better seal, less shifting in the ear canal, and possibly more reliable attenuation. The subjects were not asked to protrude their mandible fully because the position could be uncomfortable to hold for the approximate five minutes needed for molding. A drastic protrusion was also not realistic to the typical jaw movement of a musician. The two tongue depressors were used to hold the jaw position stationary during the entire molding. The two tongue depressors together opened the jaw approximately 3 mm.

Originally, earplug B was to be molded while the subject played his or her instrument. This proved complicated because the jaw moves differently based on the instrument and the piece of music played; therefore there was no uniform way to make the earmolds with this method. While playing the instrument was the most realistic jaw movement for the musicians, it would be impossible to monitor the actual jaw position during the critical moments of molding.

A third set of earplugs, earplug “C”, was made for the vocalist. During this setting, the subject held a position that was similar to singing with an open mouth as if singing the vowel sound “ah”. The findings of van Willigen (1976), Oliveira et al. (1992), Oliveira (1995), and Ballachanda (1995) that the open jaw changes ear canal characteristics as well as increases density justified this position for testing. A tongue depressor was placed in the mouth on its side in between the second bicuspids and the first molar of the subject and horizontally across the face. The tongue depressor opened the jaw approximately 17 mm. It was deemed necessary to
create a third earplug for this subject to capture a more representative model of jaw movement for singing.

**Testing**

**Objective Assessment**

A basic pure tone audiometric exam was administered on each subject to determine hearing thresholds. Thresholds were obtained for 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Although it was believed hearing loss would not directly affect the outcome of the study, hearing was tested to see if hearing loss, if present, would affect the musicians' perception of sound quality. Hearing loss would support the need for hearing protection as all of the subjects were accustomed to working in high intensity environments. Distortion product otoacoustic emissions tests were also administered.

The final earplugs were evaluated using real-ear measurements to find the attenuation characteristics of each earplug. The distance from the subjects' ear to the speaker of the real ear system was 40 inches. The subjects were required to maintain the same seated position throughout testing and to avoid moving their head. A sweep tone up to 8000 Hz at an intensity level of 70 dB was generated through the speaker. The probe microphone tube's measurement marker was set so that the length beginning at the intertrageal notch of the ear was 31 mm for the male musicians and 28 mm for the female musician. Before each earplug was tested, a baseline measurement was obtained of both unoccluded ears. Earplug set A was tested first, followed by set B. Set C was tested third when applicable. The earplugs were tested using a 15 dB filter.

Each earplug (both left and right of each set) was tested in a variety of jaw positions. Oliveira (1995) suggests that real-ear tests should not be measured in a stationary jaw position, because it is an unrealistic situation for use. This investigation tested the attenuation in the ear
canal for five different jaw positions to simulate jaw movements while playing an instrument. It was decided not to have the subjects actually play their instruments or sing while doing the real-ear measurements, for there would be no uniform position among the subjects.

The earplugs were tested in a neutral position, just as with the molding of earplug A. The subjects were instructed to stay stationary and to keep the mandible relaxed. The second through fifth positions required the jaw to be altered from the natural position. The second position was obtained with the mandible slightly protruded to create a smooth, flush plane of the front maxillary and mandibular teeth. This position was held with two tongue depressors lying flat across the teeth horizontally. The third position was the same as when acquiring the impression for earplug C. The jaw was opened the width of a tongue depressor lying on its side (17 mm) horizontally placed in between the second bicuspids and the first molar of each subject. The fourth and fifth positions were extreme jaw positions. In the fourth position, the mandible jetted outward as far as possible with the maxillary teeth tucked in. In the fifth position, the mandible jetted inward as far as possible with the maxillary teeth hanging over. The vocalist was tested under a sixth position in which she held her mouth open as wide as possible. This was measured to be approximately 4.9 cm.

Subjective Assessment

Initially, the subject was required to put in a set of earplugs without knowing which set of earplugs was being evaluated. Once it was established that the earplugs were inserted properly, the subject gave initial reactions to the feeling, level of comfort, and sound clarity. The responses were recorded. This procedure was repeated for each set of earplugs. This subjective evaluation was accomplished prior to using the earplugs during an actual musical performance.
The subjects tested each set of earplugs in their normal performance environments as often as possible for a time span of six to eight weeks. The subjects were not told which earplug was the control set and which was the experimental set. Each earplug was referred to by a marking. Earplug A had no marking, earplug B had a black marking, and earplug C had a white marking. During this evaluation period, each set of earplugs was used for an equivalent amount of time. Subjects recorded hours used, the general location (outdoors, classroom, etc) that the earplugs were used, the conditions of play, and general comments regarding each earplug (Appendix B, Figure 3). The subjects assessed levels of comfort, preferred attenuation, and quality of sound in an overall evaluation.

A trial period of six to eight weeks was selected on the basis of previous studies on hearing aid evaluations. These studies measured the stability between the satisfaction shortly after receiving the hearing aid as well as a significant amount of time after receiving the hearing aid. According to McLeod, Upfold & Broadbent (2001), studies based on hearing aid satisfaction recognize that assessments at four to six weeks after fitting maintain relative consistency to assessments given at a later time. The U.S. Food and Drug Administration supports a four to six week period for proper familiarization to a hearing aid (McLeod, Upfold, & Broadbent, 2001).

Each subject was asked to respond to a questionnaire (Appendix B, Figure 1) after the six to eight week trial period using the musicians’ earplugs. The questionnaire was not read verbally to the subjects to avoid variances in presentation of the questions and to avoid influencing the subjects’ answers. Subject three received a slightly modified questionnaire (Appendix B, Figure 2) to take into account the third set of earplugs.
The questionnaire for this study included questions regarding specific aspects of satisfaction in relation to comfort and sound quality as well as overall satisfaction. The survey consisted of questions based on the original Satisfaction with Amplification in Daily Life Scale (SADL) (Cox & Alexander, 1999), from the revised SADL scale (Cox & Alexander, 2001), and from the McGill Pain Questionnaire (Melzack & Torgerson, 1971).

The SADL was designed for hearing aid assessment, but many of the questions were revised for use in this study. The SADL was chosen as the model for this study's questionnaire because it included global satisfaction as well as questions relating to four specific factors: benefit and sound quality, physical and psychological comfort, value, and hearing aid stigma (Cox & Alexander, 1999; Cox & Alexander, 2001). A meticulous and extensive process was used to create the SADL. Originally, interviews with thirteen men and eight women were conducted. Fourteen questions were chosen and designed based on the input of the interviews on what was relevant for satisfaction. A list of 67 topics resulted and significant items were sent to two different focus groups for discussion of significance. Items with inconsistent ratings were removed. This resulted in 25 items that was later reduced to 15 questions for the final SADL scale (Cox & Alexander, 1999). Because the SADL has been shown to have both content and construct validity, the majority of the questions for this investigation were modeled after questions on the SADL.

Questions on the SADL are answered using a scale of A (Not at all) to G (Tremendously). To keep the survey for this study as simplistic as possible, the A – G scale was replaced with Yes and No options. An exploration aspect was added to gather more specific details. After most questions, the subject was asked to explain his or her response.
The original SADL did not offer a question on overall satisfaction, but the 2001 validation study included such an inquiry. This question was used to support the validity of the SADL (Cox & Alexander, 2001). The overall satisfaction question was deemed appropriate for this investigation, as it was extremely straightforward. The wording was altered from “hearing aids” to “musicians’ earplugs” and from “our clinic” to “this study”; otherwise, it was identical in nature and function. Additional questions on overall satisfaction were obtained for each earplug using a Visual Analog Scale. Subjects were asked to mark on a 93 mm line their satisfaction with each earplug within the extremes of very dissatisfied and very satisfied.

The McGill Pain Questionnaire has proven to be a reliable measurement of pain (Melzack, 1983). While the earplugs in this study did not necessarily produce pain in the ear canal, a question of this sort could prove beneficial to measure level of comfort. The McGill Pain Questionnaire contains a list of descriptive words grouped into classes and subclasses. The four main divisions are sensory, affective, evaluative, and miscellaneous (Melzack, 1983).

For the present study, it was found that parts of the evaluative and sensory categories were relevant to get a basic idea of whether or not pain was present and if so, the type of pain experienced. The first question regarding pain used the adjectives discomforting, distressing, horrible, and excruciating, which were taken from the McGill Pain Questionnaire. Extremely comfortable and mildly comfortable were added as options to take into account that pain might not be experienced. If subjects experienced pain, they were asked to give further detail by circling descriptors. Options of annoying, troublesome, miserable, intense, and unbearable were obtained from the evaluative section of the McGill Pain Questionnaire (Melzack, 1983). Two sections of the sensory category, the constrictive pressure section and the dullness section, were also used as possible descriptors. The constrictive pressure section listed pinching, pressing,
gnawing, cramping, or crushing as options, and the dullness section offered dull, sore, hurting, aching, and heavy as options (Melzack, 1983). These questions served to analyze possible discomfort in the ear canals caused by the different earplugs.

The questionnaire was divided into four sections. Section one consisted of questions about general satisfaction. Section two reflected sound quality. With the exception of number six, questions from section one and two were based on the SADL. Questions from section three inquired about the comfort of the musicians’ earplugs and were based on the McGill Pain Questionnaire. Section four asked about overall satisfaction and the probability of future use. All questions were asked in terms of overall experiences with the earplugs. When necessary, further probing was used to find the differences between each set of earplugs.
Results

The purpose of this investigation was to establish the effectiveness of the musicians' earplugs when different jaw positions were used to make the ear canal impressions. Objective and subjective measurements of sound quality, attenuation ability, and comfort were obtained for each of the three subjects. Objective testing included real-ear measurements and preliminary pure tone and otoacoustic emissions testing. Subjective testing included the subjects' initial reactions to the earplugs as well as a final questionnaire relating to their use during performance.

Objective Testing

Pure Tone testing and Otoacoustic Emissions Results

Subject one, the trumpet player, had no hearing loss in the right ear and a mild loss at 3000 and 4000 Hz in the left ear. Subject two had a sloping mild to moderate loss beginning at 3000 Hz in both the left and right ears. He reported that a 4000 Hz notch was also present in a hearing test done in 1998. Subject three, the vocalist, had normal hearing in both the left and right ears. Pure tone results were confirmed by otoacoustic emissions testing for all three subjects.

Real-ear Measurements

The insitu real-ear measurements were obtained in a quiet environment. The subject was seated a distance of 40 inches away from the loudspeaker. Earplug set A was tested first, and earplug set B was tested second. The real-ear measurement system was a Madsen Auricle. The real-ear measurements were tested in a variety of jaw positions. The Real Ear Occluded Response for the individual measurements for each earplug were compared to find the degree of attenuation during jaw movement. An approximate attenuation was determined at each of the primary frequencies (Figures 1, 2, and 3 in Appendix C). Attenuation at each frequency was
subtracted to decide which earplugs produced the least amount of fluctuation in attenuation across the frequency range.

Subject One: Trumpet Player.

Figures 1 and 2 illustrate that the two right earplugs produced similar insitu attenuation configurations, but earplug B showed more attenuation. Overall, earplug B showed less variability of attenuation between the different jaw positions. Earplug A measured in the right ear showed more variability in attenuation throughout the frequency range of 200 Hz to 8000 Hz as a function of different jaw positions.

As shown in figures 3 and 4, configurations were similar between earplug A and earplug B for the left ear. Earplug B had one minor difference in attenuation between jaw positions, while earplug A produced minor attenuation fluctuations between jaw position measurements from 500 to 1500 Hz and greater differences from 3000 to 6000 Hz.

Overall, for both the right ear and the left ear, subject one had better results with earplug B. In the right ear, earplug B had slightly flatter attenuation than earplug A. Earplug A had more fluctuation in attenuation resulting from the different jaw positions. In the left ear, earplug A and B both produced relatively flat attenuation across frequency, but earplug A produced more variability between jaw positions, while earplug B had relatively few deviations relative to jaw position.
Subject One Real-ear Measurements – Earplug A, Right Ear

**Real Ear Gain [Right]**

- UCL
- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level

**Insitu SPL [Right]**

- REUR – unoccluded
- REOR – natural position
- REIR 1 – slightly protruded mandible
- REIR 2 – jaw open 17 mm
- REIR 3 – mandible fully protruded
- REIR 4 – mandible fully tucked in
Figure 2

Subject One Real-ear Measurements – Earplug B, Right Ear

- UCL
- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level

REUR – unoccluded
REOR – natural position
REIR 1 – slightly protruded mandible

REIR 2 – jaw open 17 mm
REIR 3 – mandible fully protruded
REIR 4 – mandible fully tucked in
Figure 3

Subject One Real-ear Measurements – Earplug A, Left Ear

- UCL
- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level

REUR – unoccluded
REOR – natural position
REIR 1 – slightly protruded mandible
REIR 2 – jaw open 17 mm
REIR 3 – mandible fully protruded
REIR 4 – mandible fully tucked in
Figure 4

Subject One Real-ear Measurements – Earplug B, Left Ear

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>REUR</td>
<td>unoccluded</td>
</tr>
<tr>
<td>REOR</td>
<td>natural position</td>
</tr>
<tr>
<td>REIR 1</td>
<td>slightly protruded mandible</td>
</tr>
<tr>
<td>REIR 2</td>
<td>jaw open 17 mm</td>
</tr>
<tr>
<td>REIR 3</td>
<td>mandible fully protruded</td>
</tr>
<tr>
<td>REIR 4</td>
<td>mandible fully tucked in</td>
</tr>
</tbody>
</table>
Subject Two: Saxophone Player.

In the right ear, there was a large difference in the amount of attenuation between earplug A and earplug B. As shown in figures 5 and 6, the insitu configurations looked similar to one another, but earplug B produced attenuation throughout the frequency range that is more consistent with that expected for musicians' earplugs. For earplug A, the measurement taken while the jaw was in a relaxed position had more attenuation than the other four jaw positions. Measurements for earplug B were similar in attenuation for all jaw positions, with a minor exception at 6000 Hz.

There was little similarity between the frequency response of earplug A and earplug B in the left ear. Figures 7 and 8 illustrate that both earplugs generated differences in attenuation across the frequency range. The individual jaw position measurements of earplug A produced large variations of up to 12 dB from 4000 to 8000 Hz. Earplug B produced variations of up to 10 dB at 4000 Hz and from 6000 to 8000 Hz.

Overall, for subject two, earplug B appeared to have better results for both right and left ears. In the right ear, earplug A produced slightly flatter attenuation; however, earplug B produced dramatically more attenuation than earplug A. Earplug B produced more consistent attenuation between the jaw positions. In the left ear, both earplugs produced more attenuation in the high frequencies. Earplug B showed more consistent attenuation between individual jaw positions than earplug A.
Subject Two Real-ear Measurements – Earplug A, Right Ear

REUR – unoccluded
REOR – natural position
REIR 1 – slightly protruded mandible
REIR 2 – jaw open 17 mm
REIR 3 – mandible fully protruded
REIR 4 – mandible fully tucked in
Subject Two Real-ear Measurements – Earplug B, Right Ear

REUR – unoccluded
REOR – natural position
REIR 1 – slightly protruded mandible
REIR 2 – jaw open 17 mm
REIR 3 – mandible fully protruded
REIR 4 – mandible fully tucked in
Subject Two Real-ear Measurements – Earplug A, Left Ear

**Real Ear Gain [Left]**

- UCL
- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level

**Insitu SPL [Left]**

- REUR – unoccluded
- REOR – natural position
- REIR 1 – slightly protruded mandible
- REIR 2 – jaw open 17 mm
- REIR 3 – mandible fully protruded
- REIR 4 – mandible fully tucked in
Figure 8

Subject Two Real-ear Measurements – Earplug B, Left Ear

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>REUR</td>
<td>unoccluded</td>
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<tr>
<td>REOR</td>
<td>natural position</td>
</tr>
<tr>
<td>REIR 1</td>
<td>slightly protruded mandible</td>
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<tr>
<td>REIR 2</td>
<td>jaw open 17 mm</td>
</tr>
<tr>
<td>REIR 3</td>
<td>mandible fully protruded</td>
</tr>
<tr>
<td>REIR 4</td>
<td>mandible fully tucked in</td>
</tr>
</tbody>
</table>
Subject Three: Vocalist.

Three earplugs were made and evaluated for subject three. As illustrated in figures 9, 10, and 11, the results for all three earplugs were similar in the amount of attenuation as a function of frequency in the right ear. However, earplug A showed little similarity in the amount of attenuation between jaw positions in comparison to earplugs B and C. Earplug B produced the least amount of variability in attenuation between the different jaw positions.

In the left ear, the configurations were similar for all three earplugs. As can be seen in figures 12, 13 and 14, no one earplug continuously attenuated more than the others throughout the frequency range. Earplug A and earplug B showed more fluctuation of attenuation between individual measurements, particularly when the jaw was in a neutral position. The attenuation when the mandible was fully protruded was different than the other jaw positions for earplug B in the higher frequency range. Earplug C produced fairly consistent attenuation across frequency between the different jaw positions in comparison to earplug A and earplug B.

There was no earplug that clearly excelled in either ear for subject three; however, earplug B seemed to be somewhat improved overall. In the right ear, earplugs A and B were very similar to one another in frequency response. Earplug C produced more variation in attenuation across frequency. Earplug B had very similar attenuation between jaw positions, while earplug A had the most variability of attenuation between jaw positions. In the left ear, earplug B had the flattest frequency response, but all of the earplugs were relatively similar. Earplug C produced the least amount of variability between jaw positions, while earplug B showed little similarity in the amount of attenuation between jaw positions.
Figure 9

Subject Three Real-ear Measurements – Earplug A, Right Ear

- UCL
- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level
- REIR 5 at 70 dB Input Level

REUR – unoccluded
REOR – natural position
REIR 1 – slightly protruded mandible
REIR 2 – jaw open 17 mm

REIR 3 – mandible fully protruded
REIR 4 – mandible fully tucked in
REIR 5 – mandible fully open
Figure 10

Subject Three Real-ear Measurements – Earplug B, Right Ear

**Real Ear Gain [Right]**

- UCL
- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level
- REIR 5 at 70 dB Input Level

**In situ SPL [Right]**

- REUR - unoccluded
- REOR - natural position
- REIR 1 - slightly protruded mandible
- REIR 2 - jaw open 17 mm
- REIR 3 - mandible fully protruded
- REIR 4 - mandible fully tucked in
- REIR 5 - mandible fully open
Figure 11

Subject Three Real-ear Measurements – Earplug C, Right Ear

![Graph 1: Real Ear Gain (Right)]

- UCL
- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level
- REIR 5 at 70 dB Input Level

![Graph 2: In situ SPL (Right)]

- REUR - unoccluded
- REOR - natural position
- REIR 1 - slightly protruded mandible
- REIR 2 - jaw open 17 mm
- REIR 3 - mandible fully protruded
- REIR 4 - mandible fully tucked in
- REIR 5 - mandible fully open
Figure 12

Subject Three Real-ear Measurements – Earplug A, Left Ear

- UCL
- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level
- REIR 5 at 70 dB Input Level

Real Ear Gain [Left]

- REUR - unoccluded
- REOR - natural position
- REIR 1 - slightly protruded mandible
- REIR 2 - jaw open 17 mm
- REIR 3 - mandible fully protruded
- REIR 4 - mandible fully tucked in
- REIR 5 - mandible fully open
**Figure 13**

**Subject Three Real-ear Measurements – Earplug B, Left Ear**

---

**Real Ear Gain [Left]**

UCL

- REUR at 70 dB Input Level
- REOR at 70 dB Input Level
- REIR 1 at 70 dB Input Level
- REIR 2 at 70 dB Input Level
- REIR 3 at 70 dB Input Level
- REIR 4 at 70 dB Input Level
- REIR 5 at 70 dB Input Level

---

**Insitu SPL [Left]**

[dB-SPL]

- REUR - unoccluded
- REOR - natural position
- REIR 1 - slightly protruded mandible
- REIR 2 - jaw open 17 mm
- REIR 3 - mandible fully protruded
- REIR 4 - mandible fully tucked in
- REIR 5 - mandible fully open
Figure 14

Subject Three Real-ear Measurements – Earplug C, Left Ear

REUR - unoccluded
REOR - natural position
REIR 1 - slightly protruded mandible
REIR 2 - jaw open 17 mm
REIR 3 - mandible fully protruded
REIR 4 - mandible fully tucked in
REIR 5 - mandible fully open
Subjective Testing

Initial Reactions

The subjects were asked to try on each set of earplugs with the 15dB filter inserted and give initial reactions without knowing which earplug was being tested. They were asked for their subjective impressions of how the inserted plugs felt while the jaw was stationary and while moving their jaw. In addition, they were asked to judge the quality of sound as they heard it through the earplugs. Earplug A, the earplug created while the jaw was in a stationary position, was first, and earplug B, the earplug made while the jaw was protruded, was second fitted for each subject.

Subject One, the trumpet player, had previously used musicians’ earplugs; therefore, he was able to compare the new earplugs to his prior experiences, which had been unfavorable. The subject was pleased with earplug set A. He reported that the left earplug felt tighter than the right. The occlusion effect was evident for the subject, and he described a “wooh” sound in his ear when he moved his jaw. He further explained the sound was like a flow of moving air or water. The subject felt an immediate difference when earplug B replaced earplug A. He explained that in both ears the second set of earplugs was tighter than the first, not uncomfortable, merely “snugger”. This was perceived as a positive result as it implied a tighter seal, which is necessary for better attenuation. Subject one reported a softer level of the “wooh” sound when he moved his jaw while wearing earplug B.

Subject two, the saxophone player, was accustomed to using over the counter earplugs while listening to loud music; therefore, the musicians’ earplugs were not entirely foreign to him. He found both sets to be equally comfortable, but he sensed a difference in attenuation. He reported that earplug A made voices muffled, and he was not sure if he was talking loud enough.
He found that when he moved his jaw forward, noises became increasingly muted with increased attenuation. He believed that earplug B resulted in less muting with similar jaw movements.

Subject three, the vocalist, had never used earplugs before and commented that it would take time to adjust to having something in her ear. She felt that earplug A was the most comfortable out of the three earplugs, and earplug B was the least comfortable. She experienced the occlusion effect, nasality and more awareness of the low frequencies, with earplug A. She reported that earplug B was tighter and more uncomfortable, but she could hear other people better than with earplug A. Earplug C was not as uncomfortable as earplug B, but the right earplug did not seem to feel as tight as the left earplug. She stated that people did not seem as loud with earplug C. She could hear herself swallow and move her jaw with all three sets of earplugs.

Comments and Final Questionnaire

The Final Questionnaire was divided into three categories for evaluation purposes. Questions 3b, 4b, 5a, 5b, 6b, 7b, 8b, and 8c on all of the questionnaires and question 8d on the vocalist’s questionnaire did not ask for a straightforward positive or negative reaction to the earplugs. These questions were asked for the sole purpose of delving deeper into the subjects’ impressions of the individual sets of earplugs. With the exception of question 5a, these questions were exploration questions, in which answers provided insight, specificity, and support to the answers of the other questions.

The remaining questions were used to obtain a straightforward positive or negative reaction to the earplugs and/or the experience. In questions 1, 2, 3a, 4a, and 9 in all of the questionnaires, 8d in the questionnaire given to subjects one and two, and 8e in the vocalist’s questionnaire, an answer of yes was considered positive. In questions 7 and 8a an answer of A
or B was positive. In question 6a, an answer of no was deemed a positive response. Of the questions with a positive or negative response, the positive answers were totaled and converted to a percentage. A score of 80 to 100% was perceived as a very satisfying experience, 60 to 80% satisfied, 40 to 60% neutral, and 40% or below was interpreted as dissatisfied. This scale was designed to gain a perspective on the overall satisfaction of all of the earplugs.

All three subjects answered 7 out of the 9 questions with positive answers, which resulted in 78% satisfaction. This finding suggested that all three subjects were generally satisfied with the earplugs. All of the subjects responded negatively to question 4a that asked if the music they produced sounded natural while using the earplugs. Subject one and two indicated that there was a noticeable difference between the two sets of earplugs. Subject one commented that earplug B was more natural with less intra-oral sounds. Subject two noted that attenuation was less consistent with earplug A. Subjects two and three answered negatively to question 3a, which asked if the music around them sounded natural while using the musicians’ earplugs. Subject two explained that there was an unnatural, filtered sound. Subject one answered negatively to question 6a, which asked if the earplugs produced any unwanted sounds. He explained that the earplugs amplified intra-oral sounds such as tongue movements, and earplug A produced more intra-oral sounds.

Subjects two and three responded to question 5a that they were frustrated when the earplugs kept them from hearing what they wanted to hear. Subject two explained that earplug B attenuated the sound more consistently, which was an advantage in loud performances. However, subject two reported that earplug B attenuated too much in acoustic groups where the intensity levels were not as great. This problem might be alleviated if the 9 dB filters were used while playing in acoustic groups. Subject three commented that when the music was extremely
loud, she had trouble hearing herself sing. She indicated that all three earplugs produced the same sensation.

Questions 7a and 7b were obtained from the McGill Pain Questionnaire. The McGill Pain Questionnaire scores descriptors of discomfort in three ways. The first scoring method gives each word of a subclass a value. Words that imply the least amount of pain receive one point, the next word receives two points and so on. The scores for the subclass are accumulated for each category and then totaled for a final score. The second scoring method totals the number of words chosen, and the third technique combines the number and word methods (Melzack, 1983).

In question 7a, all of the subjects answered that the musicians’ earplugs were mildly comfortable. In 7b, subject one circled the words pressing, cramping, dull, and annoying to describe the feel of the earplugs. He circled four words altogether. Pressing was a score of two, the word cramping was a score of four, dull was one, and the term annoying was one. His overall total was a pain assessment of eight out of a possible 45. He did not explain if one earplug was different than the other. Subject two circled one word, the descriptor dull, and explained that there was a "dull reminder of their presence. Not painful. Fit is correct and comfortable. But I am not to the point where I forget I am wearing them." The word dull was worth one point; therefore, subject two had a total pain assessment of one out of a possible 45. Subject three circled the word pressing, and explained that one set was a little "snug". She did not specify which set. Pressing was worth two points; therefore, subject two had a total score of two out of 45 for overall pain assessment.

Questions 8b, 8c, and for the vocalist, 8d, required subjects to rate satisfaction of each set of earplugs on a Visual Analog Scale. The questions provided a comparison of the satisfaction
with each set of earplugs. A 93 mm line was provided. An option of "Very Dissatisfied" was on the left of the line and an option of "Very Satisfied" appeared on the right of the line. The subjects were asked to mark the point that represented their level of satisfaction with the earplugs. Points closer to the left signified more dissatisfaction, and closer to the right represented more satisfaction. An identical line was provided for each set of earplugs. The markings were measured and converted to a percentage from the 93 mm available. Subject one marked earplug A at 22 mm out of 93 mm, which translates to 24% satisfaction. He marked earplug B at 75 mm out of 93 mm, which translates to 81% satisfaction. Subject two marked earplug A at 22 mm (24% satisfaction) and marked earplug B at 72 mm out of 93 mm, a 77% satisfaction rate. Subject three did not follow the directions, and circled the words "Very Satisfied" for all three earplugs. The responses to the Visual Analog Scale clearly identified the earplug preference for two out of the three subjects. Earplug B, the earplug made with the jaw protruded, was rated over 50% higher in satisfaction for both the trumpet player and the saxophone player.

All three subjects believed that getting the musicians’ earplugs was in their best interest because they wanted to protect their hearing. Every subject reported that they would use the musicians’ earplugs in the future. Every subject indicated overall satisfaction with the musicians’ earplugs. Subjects one and two reported that they were certain the musicians’ earplugs would help protect their hearing.

Subject two documented each experience with the earplugs. He reported this was extremely helpful in answering the final questionnaire and for considering the pros and cons of the trials of each earplug. Based on his log, he used the earplugs often, in a variety of conditions including rehearsals, conducting a performance, playing a gig, playing tenor in a big band
setting, directing, and while listening. He played in classrooms, on a train, at a club, outdoors, and in a performance hall. He found that the earplugs performed differently based on the different environments and type of performance.

The results of this study showed that the two instrumentalists found a noticeable difference between the earplugs. The results suggested that earplug B was perceived as a better-quality earplug. Results for the vocalist were not as clear. More importantly, the results tended to support the original hypothesis that the position of the jaw while making the earplug impression directly affects the characteristics of the musicians' earplug.
Discussion

The purpose of this study was to ascertain if jaw position while making an earmold impression influences the overall performance and comfort of the finished earplug. More specifically, this study investigated the possibility of finding a set jaw position during the impression making process that could improve the quality of the musicians’ earplug. The subjective and objective findings lend some support to the notion that the position of the jaw while making the impression of the ear canal can play a role in the quality of the earplug. The earplugs made while the jaw was in a slightly protruded position seemed to provide a noticeable improvement over the earplugs made in a neutral jaw position for at least two of the subjects. Results were inconclusive for the third subject, the vocalist.

**Earplug A versus Earplug B**

The differences between real-ear measurements as a function of different jaw positions suggested jaw position was a factor in the attenuation characteristics of each earplug. Results showed differentiation between earplug B, made while the mandible was in a slightly protruded position, and earplug A, made while the jaw was in a natural position, in the attenuation of individual measurements. A better earplug would provide fewer changes in attenuation during jaw movement allowing for a perception of a more natural sound. Musicians also need an earplug that maintains a relatively flat attenuation. In the present study, neither earplug A nor earplug B showed consistent differences in the amount of attenuation or variation in attenuation between subjects. Regardless of which earplug was determined subjectively to provide superior results, it was evident that the earplugs made with different jaw positions functioned differently from one another for all three subjects when measured objectively. The subjects were able to make judgments relative to the qualities of the earplugs in a subjective report.
Set jaw position

Van Willigen (1976) found that the ear canal increases in volume when the mandible is in a protruded position. His study did not specify if the amount of protrusion affects the change in volume. In the present study, earplug B was made while the jaw was slightly protruded to make a flat plane with the maxillary and mandibular teeth; however, subject one and two had overbites. In order to make a flat plane with their teeth, their mandibles were most likely protruded more than subject three. Interestingly, the results for earplug B proved noticeably better to the results of earplug A for subjects one and two, but there was no obvious distinction of a better quality earplug for subject three. This could suggest that the more the jaw was protruded, the larger the ear canal volume became; therefore, making a larger earplug with a tighter seal when the jaw moved in a variety of positions.

The slightly protruded position to form a flat plane with the upper and lower teeth was initially chosen for earplug B so that the arrangement could be easily described and imitated for multiple subjects. This pose was also similar to that used with a mouthpiece when playing on an instrument. It was assumed that an earplug made in a jaw position that would be frequently used while wearing the earplugs would create an accurate fit within the ear canal while performing. It was further hypothesized that this would generate an attenuation and configuration that more closely represented manufacturer’s specifications for the musicians’ earplug. The amount the jaw was protruded was not originally taken into account while making the earplugs, but could explain why earplug B was judged better for subjects one and two than for subject three. A larger earplug could result in a better seal when the jaw is moved in a variety of positions.

A protruded mandible results in more of an increase in ear canal volume than an open jaw (van Willigen, 1976). If the earplug was made while the jaw was in the most protruded position
possible, the earplug would mimic one of the most voluminous positions of the ear canal. No matter what position the jaw later moved to, the earplug would secure a tight seal because it was created with the ear canal at its largest volume. When the jaw moved in a neutral or open position, it would create a smaller ear canal volume, thus the earplug would be snugger, not losing a tight seal. Even when the jaw was entirely protruded, the earplug would fit appropriately. Conversely, if the earplug was made while the jaw was in a neutral position, the custom made earplug might be too small to keep a tight seal with the ear canal when the jaw moved in a protruded or open position, movements that create a larger ear canal.

Earplug A for subjects one and two supported the need for a larger earplug. The real-ear measurement when the jaw was in a neutral position attenuated two to ten dB more than the other measurements across frequency for subject two in the right ear. When the earplug was tested in jaw positions that expanded the volume of the ear canal, the attenuation was approximately half of the suitable attenuation of a musicians’ earplug using a 15 dB filter. For subject two in the left ear, the jaw position held open by tongue depressors received less attenuation in the low frequencies. The extreme positions with the mandible forward as far as possible (protruded) and thrusted in as much as possible, produced less attenuation in the higher frequencies. Earplug A in the left ear for subject three produced increased attenuation when the jaw was in a neutral position for most frequencies. In the right ear of subject three, earplug A produced increased attenuation for the neutral jaw positions in the low frequencies and in some of the higher frequencies, while the protruded mandible and the thrusted-in mandible positions had the least amount of attenuation for the majority of the frequencies. It is thought that the open and protruded jaw positions expanded the size of the ear canal and that earplug A was too small to maintain a tight seal, thus providing less attenuation.
Berger (1994) stated that larger earplugs are often recommended over a smaller alternative because the larger size would provide better attenuation. However, if the earplug is too large, it might cause discomfort and not be used. Subject three, the vocalist, reported in her initial reactions that earplug A was the most comfortable and earplug B was the least comfortable. She found earplug B and C to be a tighter fit than earplug A. This might have been due to the fact that she tried earplug A first; therefore, earplug B and C were automatically considered more uncomfortable because they provided a tighter fit in the ear canal when compared to earplug A. Her final questionnaire response to question 7b reflected her discomfort with one earplug. She commented that one set of earplugs was "just a little snug" and described it as pressing.

Subject three was a prime example of the dilemma between attenuation and comfort. Increasing the volume of the ear canal while making the earplug might have jeopardized the level of comfort when the ear canal was less voluminous. Earplug A was made in a less voluminous condition and therefore was not perceived as so tight in normal conditions. Subject three had never used earplugs before; therefore the feeling was new to her thus more likely to be unpleasant. She might not use earplug B or C in the future because comfort might be more important than the amount of attenuation the earplug provides.

Subject three had a third earplug made for the study. The earplug was molded while a tongue depressor was placed sideways in the subject’s mouth between the second bicuspid and the first molar. This opened the mouth an approximate 17mm. Results were similar for the right and left ears. In both ears, earplug C produced less attenuation, but had similar attenuation across frequency as the jaw moved. Overall, for subject three, earplug C was perceived as less effective in terms of functionality than earplug B.
Conclusion

The purpose of the present study was to determine if the functionality and fit of the musicians’ earplugs were affected by jaw position while obtaining the ear canal impression. This study examined multiple jaw positions while molding the earplugs in an attempt to find an earplug with improved quality. The experimental hypotheses were:

1. The jaw position while taking the impression for the earplug would directly impact the performance of the earplugs; the earplugs molded during different jaw positions would have dissimilar characteristics in comfort and quality.

2. The jaw positions designed to mimic the use of a mouthpiece (earplug B) and singing (earplug C) while taking an impression of the ear canal would increase the volume of the ear canal and make more appropriate earplugs for the jaw movements necessary for performing.

Results supported the first hypothesis. Earplugs made with different jaw positions generated differing degrees of attenuation as well as different frequency responses. There was a great deal of variability between the earplugs relative to the amount of attenuation across frequency. Subjects were able to provide subjective comparisons that were consistent regarding the differences between each earplug.

The results did not entirely support the second hypothesis. Real-ear measurements were, to some extent, inconclusive for subject three as to which earplug had the best overall performance. Earplug B appeared to be a better option than earplug A for subjects one and two. The exact reason for the difference between earplugs was not clear. One explanation was that earplug B modeled a common jaw position in performance. On the other hand, the difference
might have been due to the fact that earplug B increased the ear canal volume more than a mold made in a neutral jaw position. This might explain why earplug B showed superiority over earplug A for subjects one and two and not for subject three. Subjects one and two had a class II malocclusion and subject three had normal occlusion; therefore, subjects one and two were required to protrude their jaws more to create a flat plane with the upper and lower teeth: the earplug B set jaw position. This would imply that the amount of protrusion played more of a significant role on the earplug performance than the similarity of the jaw position to a familiar pose while playing an instrument.

The end of study assessment suggested that all subjects were generally satisfied with the earplugs. This result could be slightly biased due to the fact that all of the subjects were initially concerned about their hearing and eager to protect it. Two of the subjects had already experienced some mild hearing loss, and the third subject knew the consequences of performing in loud conditions. The subjects may have been more open minded and tending to overlook possible discomfort because they were well aware of the benefits of wearing the musicians’ earplugs. If the subjects were not worried about their hearing, they might not have been as satisfied. The subjects might also have been more tolerant of the earplugs because they received the earplugs at no cost. While all of the subjects responded in the questionnaire that they would buy the musicians’ earplugs for an approximate $150, they might have been more critical if they actually had to purchase the earplugs.

It is clear from the findings of this investigation that further research is necessary to confirm an association between earplug functionality and jaw position held during the making of the earmold impression. Increasing the number of subjects and including a variety of subjects with and without jaw abnormalities would no doubt strengthen the study. Subjects lacking the
desire to protect their hearing might provide a less biased subjective satisfaction rating; therefore, subjects with an assortment of views on hearing protection devices would be necessary to provide a more representative sample. The results of this study support the need for further investigation into the methodologies appropriate for making custom ear protection for musicians.
Appendix A
Figure A1 (From Berger, 1994)

Real-world attenuation for five types of hearing protectors (from Berger, 1994a).
Figure A2 (From Berger, 1994)

Re-ear attenuation of five different formable earplugs.

Figure A3 (From Berger, 1994)

Re-ear attenuation of five different models of semi-aural devices.
Appendix B
Musicians’ Earplugs Questionnaire for Subjects One and Two

Musicians’ Earplugs Assessment

Please answer the following questions to the best of your ability based on your overall experiences with the musicians’ earplugs. Additional comments and opinions should be mentioned after each question. Comment on both the listening and performing situations in which the musicians’ earplugs were utilized.

Section One

1. Are you convinced that getting your musicians’ earplugs was in your best interest?

   YES  NO

   Explain

2. Do you think the process of obtaining and testing the musicians’ earplugs was worth the effort in relation to your experiences with the earplugs?

   YES  NO

   Explain

Section Two

3a. Does the music around you sound natural while using the musicians’ earplugs?

   YES  NO

3b. Is there a noticeable difference between the different sets of earplugs?

   YES  NO

   Explain

4a. Does the music you produce sound natural while using the musicians’ earplugs?

   YES  NO

4b. Is there a noticeable difference between the different sets of earplugs?

   YES  NO

   Explain
5a. Are you frustrated when your earplugs keep you from hearing what you want to hear?

YES       NO

5b. Is there a noticeable difference between the different sets of earplugs?

YES       NO

Explain

6a. Do the musicians’ earplugs produce any unwanted sounds that interfere with your experiences?

YES       NO

Explain

6b. Is there a noticeable difference between the different sets of earplugs?

YES       NO

Explain

Section Three

7. How would you describe the level of comfort of the musicians’ earplugs?

A. Extremely comfortable
B. Mildly comfortable
C. Discomforting
D. Distressing
E. Horrible
F. Excruciating

7b. If you answered B, C, D, E, or F in question 7a, circle any of the following that describe the feel of the musicians’ earplugs.
Pinching | Dull | Annoying
Pressing | Sore | Troublesome
Gnawing | Hurting | Miserable
Cramping | Aching | Intense
Crushing | Heavy | Unbearable

**Explain**

**Section Four**

8a. Overall, how satisfied are you with the musicians’ earplugs you obtained from this study?

A. Very Satisfied
B. Satisfied
C. Neutral (neither satisfied not dissatisfied)
D. Dissatisfied
E. Very Dissatisfied

**Explain**

8b. Please mark on the line your level of satisfaction with the earplugs with no markings. Further to the left signifies increased dissatisfaction, to the right signifies increase satisfaction, and the middle is neutral.

| Very Dissatisfied | Very Satisfied |

8c. Please mark on the line your level of satisfaction with the earplugs with the black markings. Further to the left signifies increased dissatisfaction, to the right signifies increase satisfaction, and the middle is neutral.

| Very Dissatisfied | Very Satisfied |
8d. Based on your satisfaction, will you use the musicians’ earplugs in the future to prevent hearing loss?

YES  NO

Explain

9. If the retail cost of the musicians’ earplugs is approximately $150, would you purchase the earplugs?

YES  NO

Explain
Musicians’ Earplugs Questionnaire for Subject Three

Musicians’ Earplugs Assessment

Please answer the following questions to the best of your ability based on your overall experiences with the musicians’ earplugs. Additional comments and opinions should be mentioned after each question. Comment on both the listening and performing situations in which the musicians’ earplugs were utilized.

Section One

1. Are you convinced that getting your musicians’ earplugs was in your best interest?  
   
   YES  NO

   Explain

2. Do you think the process of obtaining and testing the musicians’ earplugs was worth the effort in relation to your experiences with the earplugs?  
   
   YES  NO

   Explain

Section Two

3a. Does the music around you sound natural while using the musicians’ earplugs?  
   
   YES  NO

3b. Is there a noticeable difference between the different sets of earplugs?  
   
   YES  NO

   Explain

4a. Does the music you produce sound natural while using the musicians’ earplugs?  
   
   YES  NO

4b. Is there a noticeable difference between the different sets of earplugs?  
   
   YES  NO

   Explain
5a. Are you frustrated when your earplugs keep you from hearing what you want to hear?

YES  NO

5b. Is there a noticeable difference between the different sets of earplugs?

YES  NO

Explain

6a. Do the musicians’ earplugs produce any unwanted sounds that interfere with your experiences?

YES  NO

Explain

6b. Is there a noticeable difference between the different sets of earplugs?

YES  NO

Explain

Section Three

8. How would you describe the level of comfort of the musicians’ earplugs?

G. Extremely comfortable
H. Mildly comfortable
I. Discomforting
J. Distressing
K. Horrible
L. Excruciating

7b. If you answered B, C, D, E, or F in question 7a, circle any of the following that describe the feel of the musicians’ earplugs.
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<td>Gnawing</td>
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<tr>
<td>Crushing</td>
<td>Heavy</td>
<td>Unbearable</td>
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</table>

**Explain**

Section Four

8a. Overall, how satisfied are you with the musicians’ earplugs you obtained from this study?

B. Very Satisfied  
B. Satisfied  
C. Neutral (neither satisfied not dissatisfied)  
D. Dissatisfied  
E. Very Dissatisfied

**Explain**

8b. Please mark on the line your level of satisfaction with the earplugs with no markings. Further to the left signifies increased dissatisfaction, to the right signifies increase satisfaction, and the middle is neutral.

<table>
<thead>
<tr>
<th>Very Dissatisfied</th>
<th>Very Satisfied</th>
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</table>

8c. Please mark on the line your level of satisfaction with the earplugs with the black markings. Further to the left signifies increased dissatisfaction, to the right signifies increase satisfaction, and the middle is neutral.

| Very Dissatisfied | Very Satisfied |
8d. Please mark on the line your level of satisfaction with the earplugs with the white markings. Further to the left signifies increased dissatisfaction, to the right signifies increase satisfaction, and the middle is neutral.

| Very Dissatisfied | Very Satisfied |

8e. Based on your satisfaction, will you use the musicians’ earplugs in the future to prevent hearing loss?

   YES        NO

Explain

9. If the retail cost of the musicians’ earplugs is approximately $150, would you purchase the earplugs?

   YES        NO

Explain
### Daily Chart

<table>
<thead>
<tr>
<th>Earplug (with no marking)</th>
<th>Hours used</th>
<th>Where</th>
<th>Conditions (i.e. were you playing; was it a practice, rehearsal, performance, etc.)</th>
<th>General Comments</th>
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Appendix C
Table C1

Approximate Amounts of Attenuation for Subject One

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Table C3

Approximate Amounts of Attenuation for Subject Three

<table>
<thead>
<tr>
<th>Subject 3</th>
<th>Earplug A</th>
<th>Earplug B</th>
<th>Earplug C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right ear</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250 Hz</td>
<td>0 dB</td>
<td>0 dB</td>
<td>0 dB</td>
</tr>
<tr>
<td>500 Hz</td>
<td>2 dB</td>
<td>4 dB</td>
<td>0 dB</td>
</tr>
<tr>
<td>750 Hz</td>
<td>10 dB</td>
<td>12 dB</td>
<td>6 dB</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>14 dB</td>
<td>18 dB</td>
<td>12 dB</td>
</tr>
<tr>
<td>1500 Hz</td>
<td>15 dB</td>
<td>16 dB</td>
<td>18 dB</td>
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<tr>
<td>2000 Hz</td>
<td>14 dB</td>
<td>16 dB</td>
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</tr>
<tr>
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<td>13 dB</td>
<td>12 dB</td>
</tr>
<tr>
<td>6000 Hz</td>
<td>13 dB</td>
<td>10 dB</td>
<td>0 dB</td>
</tr>
<tr>
<td>8000 Hz</td>
<td>0 dB</td>
<td>0 dB</td>
<td>10 dB</td>
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References


