12-2023

Establishing Guidelines for Achieving Optimal Individual Posture In Hornists

Daniel Alan Nebel
University of Northern Colorado

UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

ESTABLISHING GUIDELINES FOR ACHIEVING OPTIMAL INDIVIDUAL POSTURE IN HORNISTS

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Arts

Daniel Alan Nebel

College of Performing and Visual Arts
School of Music
Music Performance Concentration

December 2023

This Dissertation by: Daniel Alan Nebel

Entitled: *Establishing Guidelines for Achieving Optimal Individual Posture in Hornists*

has been approved as meeting the requirement for the Degree of Doctor of Arts in the College of of Performing and Visual Arts in the School Music Program of Music Performance Accepted by the Doctoral Committee

____
Dr. Sara Winges, Ph. D. Co- Research Advisor

____
Dr. John Adler, D.M.A. Co-Research Advisor

____
Dr. Melissa Malde, D.M.A. Committee Member

____
Dr. Reiner Krämer, Ph. D. Committee Member

____
Dr. Gary Heise, Ph.D., Faculty Representative

Date of Dissertation Defense May 5, 2023

Accepted by the Graduate School

____

Jeri-Anne Lyons, Ph.D.
Dean of the Graduate School
Associate Vice President for Research

ABSTRACT

Nebel, Daniel. *Establishing Guidelines for Achieving Optimal Individual Posture in Hornists*. Published Doctor of Arts dissertation, University of Northern Colorado, 2023.

Potentially debilitating performance-related pain (PRP) is common among professional and aspiring instrumentalists, can lead to significant loss of income, and sometimes end a career. Postural misalignments that lead to PRP can develop early in students' training and is often successfully addressed by a music teacher recommending a change in technique. The nature of a musician's PRP is dependent on how their instrument is held; there has never been an in-depth study of PRP specifically for hornists. This dissertation summarizes the current relevant research of PRP in musicians and hornists, conducts and analyzes a comprehensive hornist-specific health survey, seeks to identify a common pattern of imbalances through an electromyography and posture study, establishes a detailed set of guidelines hornists may consider when optimizing their body positions, and describes some ergonomic aids that may be helpful to hornists. The study's goal is to define universal principles that all hornists and teachers should consider in order to optimize individuals' horn-playing posture,[1] mitigate current PRP and prevent the development of future PRP through better teaching and use of the body.

---

[1] The postural guidelines developed for this dissertation are primarily based in Alexander Technique and Body Mapping. The term *posture* is usually avoided in these practices because of the implications of immobility and stiffness many students associate with the word. In this document, the times the word *posture* is used, it is meant to encompass efficient, healthy movement in relation to the horn; it is not a static or stiff use of the body. The word *posture* also may simply mean a position of the body.

ACKNOWLEDGEMENTS

I would like to express my sincerest thanks to Dr. Sara Winges and Dr. John Adler for serving as co-research advisors for this dissertation. Additionally, I would like to thank Marian Hesse and Dr. Jason Byrnes who also served as co-research advisors for me prior to retiring from the University of Northern Colorado.

A huge thank you to Dr. Gary Heise, Dr. Melissa Malde, and Dr. Reiner Krämer for serving on my committee for this dissertation as well as Dr. Jonathan Bellman for serving on my Orals and Comprehensive Exam Committee. Thanks to Jouko Antere, the inventor of the ERGObrass™ for the use of one of his products in part of the research for this dissertation and permission to use photographs from his website in Chapter I. Thanks to Dr. Robert Fant, Dr. Randall Faust, Jeffrey Fowler, Susan McCoullough, and Dr. Jeb Wallace for listening to about 300 C Major scales to generate data for a portion of Chapter IV. Thank you to those who completed the survey presented in Chapter III and especially to the 10 participants who graciously helped with generating the data for Chapter IV. Thank you to the Graduate Student Association at the University of Northern Colorado for a generous grant in support of the research that forms a large part of this dissertation.

Additionally, thank you to my wonderful wife Erin, who has stuck by my side through me leaving a full-time performing job to complete this degree. My life is complete with you.

A thank you to my parents Rick and Kathy Nebel for the nurturing support you provided that set me up to flourish as a musician. Thank you to my previous mentors: Dr. Nicholas Smith,

Robert Ward, W. Peter Kurau, Jacek Muzyk, Chris Dwyer, Frances Meier, Chandra Backston, Deanna Teague, Jan McDonald, and the many others that have impacted my musicianship; I would not be where I am today without your influence.

This is dedicated to my mentors who have passed: my first horn teacher Karole Felts and her husband Tex, Marilyn LaForge who taught me to read music, Jane Gerheart who showed me the joy of making music with others, and Karolyn Coulter who taught me to sing.

TABLE OF CONTENTS

APPENDIX

LIST OF FIGURES

LIST OF TABLES

LIST OF ABREVIATIONS AND TERMS

ABI	Alexandrian-based instructions
AD	anterior deltoid
AT	Alexander Technique
BM	Body Mapping
Cal	calibration trial
Current PRP	playing-related pain experienced within the last week
EB	ERGObrass^{TM}
EMG	electromyography
LAD	left anterior deltoid
LES	lumbar erector spinae
Lifetime PRP	any experience with playing-related pain
LLES	left lumbar erector spinae
LPD	left posterior deltoid
L to L	distance between reflective markers on left shoulder and left sacrum
M to M	distance between reflective markers on C7 vertebrae and middle sacrum
nEMG	needle electromyography
NP	natural posture
PD	posterior deltoid
PRMD	playing-related musculoskeletal disorder
PRMDHP Survey	Playing-Related Musculoskeletal Disorder in Horn Players Health Survey
PRP	playing-related pain
RAD	right anterior deltoid
Recent PRP	playing-related pain experienced within the last year
RLES	right lumbar erector spinae

RPD	right posterior deltoid
R to R	distance between reflective markers on right shoulder and right sacrum
sEMG	surface electromyography
S to S	distance between reflective markers on right and left shoulders

CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

The majority of musicians will deal with playing-related pain (PRP) at some point in their lives, and all music educators will teach students suffering from PRP. While not all PRP is caused by how a musician holds their instrument, playing an instrument often exacerbates pain. Musicians dealing with PRP, especially when music is their career, face difficult emotional, financial, and social challenges while going through the healing process. Music teaching that incorporates principles of body mechanics could prevent the development of much PRP, and there are many avenues for alleviating PRP. Each instrument presents its own unique set of ergonomic challenges; many health studies have been conducted with musician populations, however "A comprehensive [wellness] study comprising of horn players alone giving clear-cut evidence upon which a horn teacher could found his teaching approach simply does not exist."[2]

The Problem with How Posture is Currently Taught

Few horn methods elaborate on the finer details of optimal posture,[3] which has led to a lack of understanding of body mechanics and how hornists interact with their instrument. Many hornists begin their studies without a private instructor and must rely on their beginning band methods and band directors to promote healthy postures, which is compounded by young

---

[2] Irena Marie Rieband, "The Pursuit of Confidence in Horn Playing: From Dis-ease to Ease, Sound Technique and Healthy Musicianship," M.A. Dissertation, Academy of Music Gdansk, 2008, 11.

[3] The postural guidelines developed for this dissertation are primarily based in Alexander Technique and Body Mapping. The term *posture* is usually avoided in these practices because of the implications of immobility and stiffness many students associate with the word. In this document, the word *posture* is meant to encompass efficient, healthy movement in relation to the horn; it is not a static or stiff use of the body.

students playing instruments that are often too large for them to easily hold. In a study of 330 incoming university freshmen music majors, Brandfonbrener demonstrated that most students enter their university study with significant playing-related musculoskeletal disorders (PRMDs) and habitual misalignments that they developed prior to attending college.[4]

A widely-used band method advises young hornists to:

- Rest the bottom edge of the bell on your right thigh. (Do not block the bell with your body.)
- Place your little left finger in the hook.
- Place your left thumb under the lead pipe.
- Place the fleshy part of you first three fingers of your left hand on the valves.
- Relax your left arm.
- Sit on the edge of your chair, spine straight, shoulders back, and both feet flat on the floor.[5]

Several more advanced instruction methods do address posture in more detail: Philip Farkas in his seminal horn guide *The Art of French Horn Playing* states: "The seated playing posture should not be slumped, but neither should it be of military erectness, as one would soon find this rigidity creeping into his playing. A moderately erect position which is still relaxed is right."[6] Wendell Rider offers three pages of explanation with pictures in his book *Real World Horn Playing* and emphasizes: "A good playing position is very important to success with the horn. Posture is important for good breathing… As in other areas of playing, we would like to have as little tension or imbalance as possible at all times."[7] In *The Efficient Approach: Accelerated Development for the Horn*, Richard Deane writes:

> At its most simple, our posture while playing the horn should not physically interfere with the relaxed balance which we create when we play. Therefore, it is clear that we

[4] Alice G. Brandfonbrener, "History of Playing-Related Pain in 330 University Freshman Music Students," *Medical Problems of Performing Artists*, March 2009, 35.
[5] Bruce Pearson, *Best in Class: Comprehensive Band Method, Book 1 French Horn* (San Diego, CA: Kjos West, 1982), 2-3.
[6] Philip Farkas, *The Art of French Horn Playing* (Secaucus NJ: Summy-Birchard, 1956), 11.
[7] Wendell Rider, *Real World Horn Playing*, (San Jose, CA: Wendell Rider Publications), 2006, 7.

> must sit in a way that balances the body. In other words, the demands of your particular instrument should not force you into a playing position which will be disadvantageous to overall relaxation and balance.
>
> A good rule of thumb is to relax the body first, and bring the horn to that position. If that cannot be done, then the horn itself must be changed. For the beginner, remember: Do not slouch. Do not cross your legs. Sit with your legs far enough apart so that you can get a balancing "tripod" effect with your lower body. Look at yourself in the mirror when you play. You should see a picture that looks very natural, with no crazy angles or parts of the body bent in irregular ways.[8]

There is no single optimal position for a horn player; everyone fits their instrument uniquely, but there are generalized healthier positions that all horn players may consider. Most hornists and teachers agree that a preferred posture maximizes the freedom of airflow from the lungs to the lips, which is essential for good tone production. The ability to optimally control airflow is the foundation for producing a beautiful tone throughout the instrument's range at every dynamic. Fortunately, most optimal positions lead to more balanced muscle tension and therefore greater dexterity and more efficient use of the body, which tends to produce more beautiful, relaxed, and accurate music.[9] As Dr. Melissa Malde stated in her Body Mapping class at the University of Northern Colorado, "There are many healthy positions for the body to pass through, but there are few that are ideal in which to remain for long periods of time."[10]

Changes in body position can have an immediate effect on tone quality but require a player's consistent attention to implement, because the body will tend to return to its habitual positioning when a musician is focused on other issues. As every player and horn will fit together uniquely, everyone will have to find their own optimal positions. It must be acknowledged that the shape of the horn is not ergonomically ideal; all positions will involve

---

[8] Richard Deane. *The Efficient Approach: Accelerated Development for the Horn*, (Atlanta, GA: Atlanta Brass Society Press) 2009, 5.
[9] Pedro de Alcantara, *Indirect* Procedures, (Oxford: Oxford University Press), 1997, 14-16.
[10] Dr. Melissa Malde, personal encounter during Body Mapping Class, (Greeley, CO: 18-19 January 2020).

some compromises. Playing the horn, despite its reputation as a difficult instrument, can be easy, and optimal body positioning is one of the first steps to finding ease in making music.

Detailed Overview of Suggested Positions

Six sites on the body should be vertically stacked in order to attain basic proper alignment when standing. When viewed from the side, the atlantooccipital joint (where the skull meets the spine), the acromion process (the top of the shoulder joint), sacroiliac joint (where the lumbar spine meets the pelvis), hip joint, knee joint, and ankle complex should all line up vertically (see figure 1.1). When seated, the torso should remain in the same alignment from the hip joint up through the skull. The shoulder girdle should be held so that the chest and back are equally wide and the pelvis should be level when viewed from the front.

Figure 1.1 Skeleton from lateral view with plumbline through the center and 6 joints of vertical alignment: (1.) Atlantooccipital joint (2.) Acromion process of the shoulder joint (3.) Sacroiliac joint (4.) Hip joint (5.) Knee joint (6.) Ankle complex. Skeleton image licensed through Shutterstock Images, plumbline and joint labels added by author.

In both standing and seated positions, both feet should ideally be flat on the floor. The most neutral position of the feet is parallel to each other, and the big toe should be in line with or slightly to the inside of the bend of the knee. Weight should be distributed evenly between the feet and centered over the arch of the foot, creating a tripod between the heel and edges of the ball of the foot (metatarsophalangeal joints of the big and little toes). See figure 1.2.

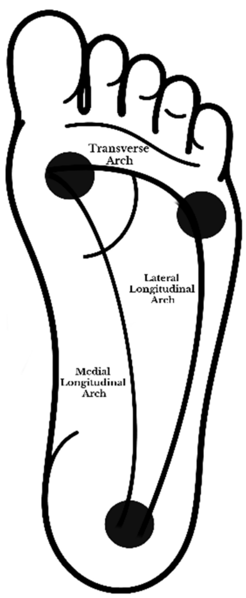


Figure 1.2 Tripod of the foot. Foot image licensed through Shutterstock Images, arches and tripod points added by author.

Some sway and shifting of weight throughout these 6 points of contact is normal and should not be suppressed. Foot problems can negatively influence posture throughout the body, especially while standing, which increases tension and affects horn playing. A common foot misalignment is a tendency to stand or walk duck-footed with both feet turned out. The arch of the foot collapses with this misalignment so that the ankles and knees collapse inward; this can cause pain in the ankles, knees, hips, and low back.[11] Wearing heels alters the entire body's

[11] Adam Felman, "What's to Know About Flat Feet?," *Medical News Today*, 27 July 2018, https://www.medicalnewstoday.com/articles/168608 (accessed 7 April 2020).

posture, both seated and standing, and can increase muscular tension[12] and affect horn playing. Hornists should consider performing in flats or minimizing the height of heels; if heels are necessary, one should practice with them on, giving special attention to the alignment of the spine and pelvis to ensure a neutral lower back is maintained.

When standing, the knees should be released. Locking the knees tends to also lock the hips forward and promote a swayback posture (see figure 1.3) that results in excessive lordosis (inward curve) in the lumbar spine and forward head posture. There is a tendency for standing brass players to move their hips forward underneath their instrument because the weight of the instrument held in front of them moves their center of gravity forward and upwards.

Figure 1.3 Author performing with a swayback posture. White line shows vertical alignment at shoulder: the hips, knee, ankle complex and ear should be close to in line with the white line; the hips and head are forward from neutral; the stripe on the leg should be more vertical.

[12] Nick A. Titley, "Heels and Your Posture," *National Posture Institute Online*, May 2015, https://www.npionline.org/articles/heels-and-your-posture.htm (accessed 7 April 2020).

In addition to the risk for developing pain, excessive lordosis in the lumbar spine can also have a negative impact on the breath control, due in part to reciprocal inhibition of antagonistic muscles. When a muscle is contracting, the antagonist muscle that performs the opposite movement in the body should be relaxing; this occurs on an unconscious, reflexive level; overactive muscles can alter this neurological relationship and cause dysfunction in both muscles.[13] The rectus abdominus (6-pack muscle) flexes the spine, mostly in the lumbar region while the lumbar erector spinae extend the spine. The rectus abdominus, among many muscles that assist in maintaining upright posture, also assists in exhalation and is engaged by musicians to help regulate the rate of exhalation (breath control). If the erector spinae are chronically over-contracted, it is impossible for the rectus abdominus to be optimally engaged in breath control.[14] When seated, some hornists also exhibit overactive lumbar contraction by bearing most of the weight of the torso on the back of the thighs instead of balancing on the ischial tuberosities (sitz bones) of the pelvis, which places the pelvis into anterior tilt and causes a similar diminishment of breath control as standing swayback posture.

The spine experiences significantly more strain and load when in the seated position; this tension is lessened with greater angles of hip flexion with studies showing that a 145º angle is optimal.[15] At the minimum, seated hornists should limit their hip flexion to a minimum of 90º and if possible, have their knees below the level of their hips when seated. The ideal chair rarely exists in an orchestra hall or music school because they are often designed primarily for stacking and storage, and given the range of height differences, everyone will have slightly different

[13] Michael A. Clark, Scott C. Lucett, Erin McGill, Ian Montel, and Brian Sutton, *NASM Essentials of Personal Fitness Training*, 6th Ed. (Burlington, MA: Jones and Bartlett Learning) 2018, 167.
[14] Theodore Dimon and G. David Brown, *Anatomy in Action: The Dynamic Muscular Systems that Create and Sustain the Moving Body*, (Berkeley, CA: North Atlantic Books) 2015, 150-151.
[15] Janet Horvath, *Playing (Less) Hurt: An Injury Prevention Guide for Musicians* (Milwaukee, WI: Hal Leonard Corporation, 2000), 112.

needs in optimal chair dimensions. An angled cushion can be helpful for changing seated hip-to-knee relationship when chair heights are too low or sloped backwards like most folding chairs.

Ideally, shoulders held statically should remain in the middle of their range of motion by keeping the chest as equally broad as the back. This ideal is difficult to achieve for hornists because the horn is held asymmetrically; the weight of the instrument is primarily to the right as players reach their left arm forward and around the horn to bring the mouthpiece into the center of the lips. The left scapula is protracted and left shoulder is flexed to bring the left hand up towards face level while the right scapula is retracted and the right shoulder is often slightly extended. Unless the player chooses to rest the bell of the horn on the right thigh, most of the weight of the horn is born on the right hand. Players should be wary of excessively abducting the shoulders (lifting away and out to the side), especially on the right side where the shoulder has a greater likelihood of being extended and internally rotated. Static shoulder abduction, especially with internal rotation, could lead to impingement in the shoulder. Conversely, the arms should not be held rigidly close to the body as this restricts inhalation as the ribs lift out and up.

The protracted left and retracted right scapulae position encourages the torso to twist towards the right and can lead to bilateral imbalances and strain on the left side of the body. One solution that has been suggested in the horn community for keeping the shoulders more neutral is to turn the neck to the left in order to play; however, this solution may lead to pain and dysfunction emanating from the cervical spine. Additionally, this solution restricts air flow through the throat and has an audibly detrimental effect on tone quality. A better solution to reduce torso twist when standing is to adopt a shallow lunge position with the left foot forward of the right and allow the right foot to turn outward up to a 45° angle. This brings the left hip forward and lessens the twist from the lumbar spine by extending the twist down into the lower extremities. The mini-lunge is one of the positions of mechanical advantage in Alexander Technique (AT) and allows the balance of the body to move easily and organically from foot to foot.[16]

In AT, the relationship between the head, neck, and back is considered the primary control and influences the use of the rest of the body. Players should balance the head over the spine, finding the position that requires the least amount of work. The most common misalignment in hornists is anteposition of the head, which often arises when the player unconsciously brings their face to the instrument instead of bringing the horn to the body. This is also the most common postural disorder in the general population and can develop with driving, computer screens sitting too low, constantly hunching over the phone, and a myriad of other habits most of us cultivate. Any static positioning of the neck outside of a neutral balance for long periods of time is likely to lead to pain in addition to constricting air flow through the throat.

The left hand and wrist are one of the highest-reported sites for pain in horn players.[17] Virtually all instruments come with a left-hand pinkie hook meant to help hold up the horn. Movement in the hand is most efficient with the least amount of tension when all fingers are flexing (curling) and coming together (grasping motions) or extending (straightening) and spreading. The use of the pinkie hook unnaturally and unevenly spreads the fingers while the other fingers are bending to work the levers; this is especially a problem if a player has smaller hands. The weighted, spread pinkie introduces unnecessary tension into the left hand, can become a source of pain, and causes reduced dexterity in operating the levers. Dexterity and

---

[16] de Alcatara, 108-120.

[17] Kris Chesky, Karendra Devroop, and James Ford, III, "Medical Problems of Brass Instrumentalists: Prevalence Rates for Trumpet, Trombone, French Horn, and Low Brass," *Medical Problems of Performing Artists*, June 2002, 96.

precision in the fingers are maximized when each joint in the fingers is flexed; thus, hornists should contact the levers with the tips of the fingers at the furthest point from the springs. If this hand position is difficult to attain, the horn should be adjusted to fit the hand of the player. Additionally, the strongest and safest wrist position is completely straight: without flexion, extension, nor any radial or ulnar deviation (see figure 1.4).

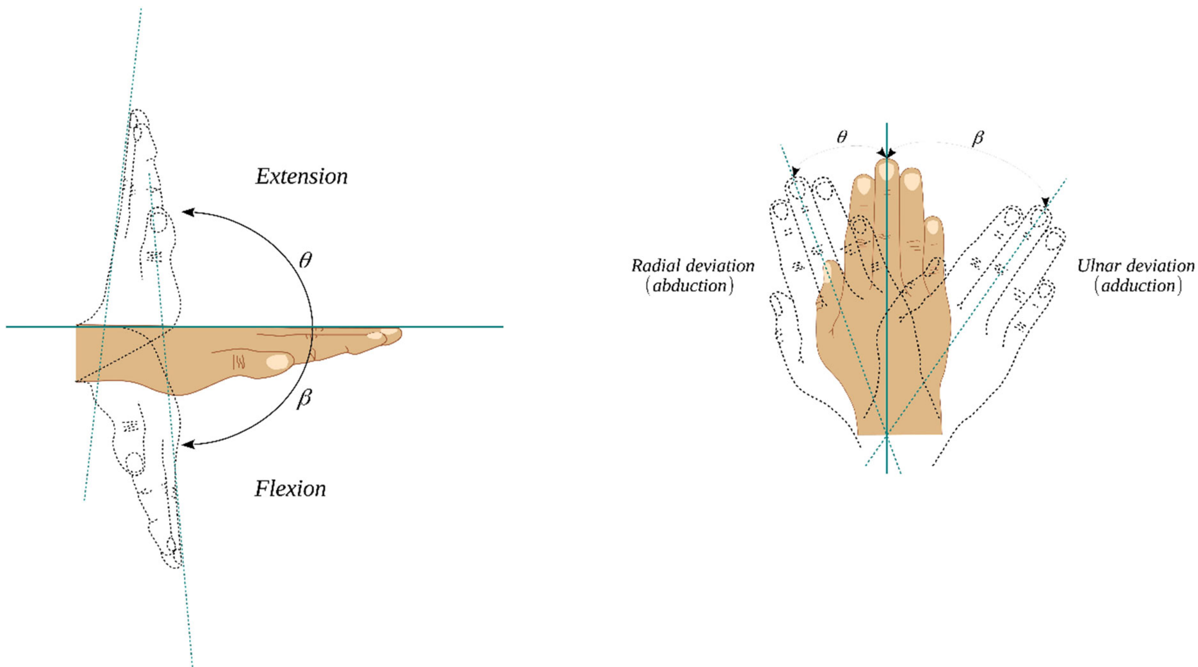


Figure 1.4 Movements of the wrist. Images licensed through Shutterstock.

Some hornists habitually extend the left wrist, which causes tension in the left hand and straighter, less dexterous, fingers. An overly flexed wrist when holding the horn is rare, but this position is also strenuous for the hand. If a player’s hand span on the horn necessitates placing the wrist into ulnar deviation (wrists bent laterally towards little fingers) so the thumb can meet reach the B-flat/F trigger, ergonomic changes to the horn must be made. Chronic ulnar deviation is the most common wrist position that leads to carpal tunnel syndrome. Hornists with a Schmidt style horn with a piston B-flat/F valve may experience difficulties with their left thumb. Pistons should be depressed with the pressure going straight down the shaft of the valve; consistent pressure at an angle will lead to problems with the mechanism of the piston, and this necessitates a more unnatural thumb motion, which naturally travels in an arc but now must go in a straight line to operate the thumb piston. See figure 1.5 for an optimal left-hand/wrist position.

Figure 1.5 *Left* Ideal left-hand position. *Right* Poor left-hand position.

The right-hand position also presents both musical and postural challenges. Philip Farkas describes proper right-hand position as:

> 1. Hold the right hand flat with the fingers held together so that absolutely no space occurs between the fingers. Pay particular attention to the thumb, which should lie along the <u>edge</u> of the hand, and in the same plane as the fingers. Now cup the hand lightly, in the same way that the hand would be held while swimming. Again watch the thumb. It should touch the side of the index finger, but not in such a manner as to form an opening between the thumb and the hand.
> 2. Now hold the hand in a <u>vertical</u> plane, with the little finger nearest the ground and the thumb uppermost. <u>Do</u> <u>not</u> hold the palm upward as though you were holding a handful of water, as this position does not permit the right hand to support the horn sufficiently.
> 3. Insert this slightly cupped, vertically-held hand in the horn bell so that only the backs of the fingers and the top of the thumb touch the metal. This means that the hand will be against the side of the bell farthest away from the body. The fingers should be lightly curved and the backs of them should hug the side of the horn bell, particularly at the tips. The curve of the hand then brings the thumb, in a natural resting manner, to the roof of the bell's throat. It rests against the top of the throat so that the horn is partially supported by it. Thus the feeling is one of holding the properly formed hand out from the body and up. This will enable the palm and the heel of the hand to swing shut [in order to produce stopped horn] like a door, the

> hinges being the knuckles of the thumb at the top and the little finger at the bottom of the bell.[18]

Players who hold the bell off the leg or stand to perform support the majority of the weight of the horn on the first metacarpal-phalangeal joint of the index finger and the proximal phalanx of the thumb, moving the thumb slightly into the palm provides more support than Farkas's description. Farkas's pictures also show a fairly extended wrist, which given the amount of weight supported on the hand is a mechanically weak position and could lead to wrist pain; a completely straight and neutral wrist is ideal.

Many players advocate changing the intonation of the horn with slightly different positions of the hand, as there are intonation tendencies due to fingering and partial combinations. However, in addition to better body mechanics, maintaining a straight wrist and open hand position produces a less-muffled tone; fine intonation changes can often be accomplished with the embouchure as easily as the right hand. Stopped horn technique is accomplished by completely sealing off the bell with the palm, usually by flexing at the metacarpal-phalangeal joints (knuckles at top of palm) and brining the base of the palm to the other side of the bell. This leaves the wrist in a very extended position and horn players often find it difficult to completely seal off the bell (see figure 1.6 for examples of right-hand positions). A more successful stopped horn position is to bring the hand, wrist, and inner part of the forearm all the way to the bell, which gives a much better seal at the base of the palm and allows the wrist to maintain a safer position. It is much easier to accomplish this maneuver when playing with the horn bell off the leg by bringing the bell upwards to meet the hand.

---

[18] Farkas, 13.

Figure 1.6 Author demonstrating right-hand positions. *Left* Optimal open position. *Center* Ideal stopped horn position. *Right* Typical non-optimal stopped horn position.

Few hornists naturally fit their instrument in a way that simultaneously allows for placing the bell on the leg, ideal spinal alignment for optimal breath support, and suitable leadpipe angles. Taller hornists especially may find it impossible to play with the bell on the leg while seated and maintain a posture that allows optimal breath support. Playing off the leg allows for a simpler transition between seated and standing, produces a more ringing tone that carries better in large concert halls, and allows the player to easily alter the leadpipe angle depending on what register they are playing. Not every horn player changes their leadpipe angle based on register, but it is widely taught that as one goes lower in register, the jaw should drop slightly down and forward to create more space in the oral cavity for a slower airstream. In order to maintain similar pressure on the top and bottom lips, the leadpipe should become more horizontal as the jaw comes down and forward as the pitches get lower. The ability to slightly adjust the leadpipe angle with the movement of the jaw can increase note security and match tone color between registers more easily. If resting the bell on the leg does not compromise spinal alignment, resting the bell on the leg is acceptable; many hornists swing the right leg out to the right while seated in order to find an ideal position for resting the bell on the leg and to avoid blocking the bell with their bodies.

A Note on Focal Dystonia

It has been suggested that poor posture is a risk factor for developing task-specific focal dystonia. Pianist Glenn Gould likely developed focal dystonia in his hands and had notoriously poor posture,[19] but the root cause of developing focal dystonia is not well understood. Most musicians develop focal dystonia with the fine motor movements of the fingers; brass musicians most often develop focal dystonia in the fine motor movements of the lips and jaw that form their embouchures. Focal dystonia is primarily a disorder of the central nervous system; specific regions in the primary motor cortex of the brain are responsible for causing specific muscle fibers to fire. These regions are arranged so that anatomically close body parts are also close together in the brain, so for instance, the areas of the primary motor cortex that cause movements in the fingers of the left hand will be grouped together and arranged in order.[20] In order to achieve smooth movement, many motor units need to fire in a coordinated fashion; this is accomplished by a neural spreading effect into adjacent anatomical features, which becomes more pronounced the more precise and complex a movement becomes.[21] Few movements are as precise and complex as those executed by highly-skilled musicians.

Focal dystonia occurs when these neural distinctions become blurred and nearby motor units involuntarily fire together. The afflicted musician experiences a loss of precise control, aberrant timing, and coordination, and sometimes the onset of tendonitis or pain due to opposing muscles firing together. This only occurs when a specific task is attempted and seems to be related to a problem with generalized motor programs – learned movement patterns that become

[19] Frank R. Wilson, "Glenn Gould's Hand," in *Medical Problems of the Instrumentalist Musician*, ed. Raoul Tubiana and Peter C. Amadio (London: Martin Dunitz, 2000), 379-398.
[20] Claudia Krebs, Joanne Weinberg, Elizabeth Akesson, and Esma Dilli, *Neuroscience* [2012], 2nd edition, (Philadelphia: Wolters Klewer, 2018), 266-269.
[21] Alan H.D. Watson, *The Biology of Musical Performance and Performance-related Injury* (Scarecrow Press: Lanham, MD. 2009), 263-266.

natural and automatic once initiated. Interestingly, if focal dystonia manifests in the right hand and the afflicted person switches hands to accomplish the dystonic task, the dystonia will often spread to the other hand as well.[22] Some risk factors have been identified; men in their forties seem to be the most prone to developing focal dystonia, and there may be a genetic predisposition as well. Another risk factor seems to be a perfectionist personality that spurs a musician to complete a high number of repetitions in an attempt to attain a flawless performance.[23] Focal dystonia is impossible to predict and extremely difficult to cure, especially in brass embouchures. Sub-optimal posture has not been clinically tied to focal dystonia; this would be a difficult proposition considering the high prevalence of musicians who present with postural disorders on their instruments.[24] The cure that has had the most success is the difficult process of retraining – learning to play the instrument in a different way that sidesteps the problematic area. On brass instruments this is quite difficult,[25] and few musicians with diagnosed task specific focal dystonia ever return to or exceed their previous abilities. On a more positive note, focal dystonia is a rare condition, affecting approximately 0.5% of musicians.[26]

Ergonomic Aids

In addition to the ERGObrass™ (EB) system that is described later and used in the research for Chapter III, there are several devices and horn modifications that can assist players in finding more optimal body positions. Various hand straps, duck foots, and lever extensions[27]

---

[22] Watson, 261.
[23] Ibid., 266-267.
[24] M. Ramella, F. Fronte, and R.M. Converti, "Postural Disorders in Conservatory Students: The Diesis Project," *Medical Problems of Performing Artists*, March 2014, 19.
[25] David Vining, *Notes of Hope: Stories by Musicians Coping with Injuries* (Flagstaff, AZ: Mountain Peak Music, 2014), 32-40.
[26] Watson, 262.
[27] John Ericson, "Horn Matters: Got Dimes?," https://www.hornmatters.com/2009/09/got-dimes/ (2009), accessed 1 April 2023.

can allow players to discontinue using pinkie hooks and relieve tension in the left hand. (See figure 1.7).


Figure 1.7 Velcro hand strap manufactured by Osmun Music.

Some hornists who place the bell on the leg but are a bit too tall to do so with good spinal posture may opt to raise the right foot with an adjustable classical guitarist footrest. An adjustable plexiglass lifter can be fixed to the bell as well to allow a tall player to rest the bell more comfortably on the leg.

A qualified repairman can make modifications to the horn by restringing the valves to a different height or bending the finger and thumb levers to increase hand comfort. Repairmen can also replace or bend the leadpipe to a different angle for better distance between the mouthpiece and bell. Young students often begin on a single F horn, which is significantly lighter but has the same general dimensions as a double horn; ¾-sized single F horns, such as the Verus Scholar available through Houghton Horns, are wrapped tighter than full-size horns and are ideal for smaller beginners but unfortunately are not as widely available as full-sized horns.

Literature Review of Musician Health Surveys

Numerous health surveys of musician populations have been conducted to determine pain prevalence and associate data with a variety of risk and protective measures. Reports of lifetime rates of pain related to playing an instrument among musicians have been vastly different, ranging from as low as 50%[28] to as high as 89%.[29] There are a variety of reasons for this discrepancy: small sample sizes make valid statistical assertions difficult;[30] low response rates may tend to create a volunteer bias causing studies to report higher prevalence rates than are actually present;[31] and different population targets such as music students versus full-time professionals may present different levels of prevalence due to chronically-injured musicians leaving the profession and dropping out of the subject pool. In addition to varied survey methods, distribution, and materials, the definition of pain varies quite a bit between surveys: in some studies, such as the 1988 ISCOM survey, all types of painful conditions were included whether or not they were playing-related.[32] Many studies also did not distinguish mild pain from more severe, debilitating pain in their prevalence rates.[33] Brass players regularly experience mild discomfort and swelling of their lips following intense performances, rehearsals, and practice sessions; this is a normal occurrence that generally subsides quickly and rarely prevents brass musicians from playing the next day. As any athlete can expect to experience some amount of delayed-onset muscle soreness with increases in training intensity, musicians experience similar sensations on a smaller scale when practicing to increase endurance, pitch range, and dynamic range. If musicians interpret survey questions to include these common, non-debilitating experiences of pain or discomfort, prevalence of playing-related pain (PRP) will be overreported.

For a variety of reasons, most studies fail to adequately address the population of horn players. Many general musician surveys are distributed through professional orchestras, which

[28] Janet Davies and Sandra Mangion, "Predictors of Pain and Other Musculoskeletal Symptoms among Professional Instrumental Musicians: Elucidating Specific Effects," *Medical Problems of Performing Artists*, December 2002, 156.
[29] Carl Zetterberg, Helena Backlund, Jenny Karlsson, Helen Werner, and Lars Olson, "Musculoskeletal Problems among Male and Female Music Students," *Medical Problems of Performing Artists*, December 1998, 161.
[30] Helen Zaza, *Musicians' Playing-Related Musculoskeletal Disorders: An Examination of Physical, Psychological, and Behavioural Factors* (Ph.D. Diss., University of Waterloo, 1995), 17-18.
[31] Zaza, 19.
[32] Ibid., 18.
[33] Ibid., 18-19.

are primarily made up of string players, so the data, such as prevalent sites of pain, tends to skew towards problems experienced by string players.[34] Since professional orchestras employ 4 to 6 hornists, their responses are almost always grouped with all brass players when survey sample sizes are large enough for different instruments to be discussed. Brass players do have many similarities in sound production and thus share some common health concerns, but differences in the size, shape, weight, and mechanisms of the trumpet, trombone, tuba, and horn cause different alignment challenges and strains on the body. Additionally, when only professional orchestral musicians are surveyed, populations of horn players, such as students, amateurs, military bandsmen, and aspiring musicians who have given up the horn, are left out. Orchestral musicians are an easy group to contact and a fulltime orchestral musician is generally viewed as having successfully reached the highest level of achievement within the music community, so the choice to survey them for health issues is certainly unsurprising and relevant.

There are also many surveys that sample students in music schools,[35] which provides a more comprehensive and instrumentally diverse subject pool, but offers its own drawbacks as well. Again, horn players are almost always grouped with brass players for any analysis, and a high percentage of students are string or keyboard players, whose complaints tend to be primarily in the upper extremities. Medical issues that are common in these populations have thus received the majority of attention in the literature; subsequently, most of the electromyography studies of musicians focus on muscles in the upper extremities and neck,[36] likely because these are the areas primarily reported as problematic in most health surveys.

---

[34] In bibliography, see studies by Ackermann, Andersen, Berque, Caldron, Davies, Kaneko, Fishbein, Fotiadis, James, Yeung, and many studies discussed by Zaza.

[35] In bibliography, see studies by Ajidahun, Baadjou, Brandfonbrener, Ramella, Nawrocka, Stanek, Zetterberg, and many studies discussed by Zaza.

[36] In bibliography, see studies by Kjelland, Philipson, Price, and Rumsey.

Musicians do not have higher lifetime prevalence rates of musculoskeletal pain compared with the general population. A general survey of 11,507 Japanese subjects reported an 86% lifetime prevalence of musculoskeletal pain and 15.4% prevalence rate of chronic pain. [37] One consistent trend between all studies, both general population and musician studies, is a greater tendency for women to report higher rates and intensities of musculoskeletal dysfunction and pain.[38] Women tend to be smaller, with less muscle mass than men, and considering that many instruments were developed and standardized in size and design before most women were afforded the opportunity to become professional musicians, the ergonomics of most instruments likely present more of a challenge to women. An equitable number of professional women musicians were not present in many symphony orchestras until well after blind auditions were widely instituted in the 1970s. This is still a problem in some regions today; as recently as 2005 only 30.3% of orchestral musicians in São Palo, Brazil were women.[39] Other possible explanations for this trend are: due to biological differences women may perceive pain more often and intensely than men, gender differences in psychology may lead women to be more likely to report pain and seek out help than men, and a higher prevalence of joint laxity or hypermobility in women has been associated with a greater predisposition to injury and pain.[40]

Several studies investigated physical activity levels and prevalence of PRP and exercise-related interventions meant to reduce PRP. Baadjou et al found no statistical relationship, protective or increased risk, between physical activity levels and reported PRP in a 2015 survey

---

[37] Masaya Nakamura, Yuji Nishiwaki, Takahiro Ushida, and Yoshiaki Toyama, "Prevalence and Characteristics of Chronic Musculoskeletal Pain in Japan," *Journal of Orthopedic Science*, July 2011, 424-432.
[38] Zetterberg et al., 160-165.
[39] Yumi Kaneko, Sergio Lianza, and William J. Dawson, "Pain as an Incapacitating Factor in Symphony Orchestra Musicians in São Palo, Brazil," *Medical Problems of Performing Artists*, December 2005, 168.
[40]Christopher Wynn Parry, "Clinical approaches," In *Medical Problems of the Instrumentalist Musician*, 203-218, Edited by Raoul Tubiana and Peter C. Amadio (London: Martin Dunitz, 2000), 205-206.

of 132 Dutch music students.[41] Physical activity among the students varied quite a bit and was estimated in METs (Metabolic Equivalent based on the level of oxygen a person consumes during exercise; it is a measurement that allows for comparisons of intensity between different modes of exercise) and number of exercise hours per week. It was observed that Dutch music students were generally less active than their non-musician peers. Similarly, a survey of 330 incoming freshman music students in the US found no statistical correlation between PRP and exercise habits.[42] Surveys, by necessity, had to inquire about general fitness encompassing a myriad of exercise modalities and intensities. Studies that explored exercise interventions for populations of musicians demonstrated no relationship between PRP prevalence and general fitness interventions; however, exercise interventions that were individually designed to specifically target areas of concern, such as strengthening the upper extremities in string players, were moderately effective are reducing PRP.[43] [44] [45]

A few postural studies on music students have been completed. Ramella et al found that out of 148 music students at the Giuseppe Verdi Conservatory of Milano 66.2% had a postural disorder without their instruments and 73.4% presented a non-optimal posture (defined as a clinically significant deviation from optimal posture established by previous studies of individual

---

[41] Vera A.E Baadjou, Jeanine A.M.C.F. Verbunt, Marjon D.F. Eijsden-Besseling, Stephanie M.D. Huysmans, and Rob J.M. Smeets, "The Musician as (In)Active Athlete? Exploring the Association Between Physical Activity and Musculoskeletal Complaints in Music Students," *Medical Problems of Performing Artists*, December 2015, 233-234.

[42] Brandfonbrener, 32.

[43] Mathieu de Greef, Ruud van Wijck, Koop Reynders, Joost Taussaint, and Rike Hessling, "Impact of Groningen Exercise Therapy for Symphony Orchestra Musicians Program on Perceived Physical Competence and Playing-Related Musculoskeletal Disorders of Professional Musicians," *Medical Problems of Performing Artists*, December 2003, 156-160.

[44] Lotte Nygaard Andersen, Stephanie Mann, Birgit Juul-Kristensen, and Karen Søgaard. "Comparing the Impact of Specific Strength Training vs General Fitness on Professional Symphony Orchestra Musicians: A Feasibility Study." *Medical Problems of Performing Artists*, June 2012, 94-100.

[45] Clifford Chan, Tim Driscoll, and Bronwen J. Ackermann, "Effect of a Musicians' Exercise Intervention on Performance-Related Musculoskeletal Disorders," *Medical Problems of Performing Artists*, December 2014, 181-188.

instruments) when playing their instrument.[46] Ramella found an increased likelihood of posture disorders and non-optimal posture with increased years of playing the instrument and for instrumentalists playing an asymmetrical instrument. Interestingly, Ramella classified the horn posture as symmetrical[47] despite its off-balance weight to the right, tendency to twist the torso to the right, and likelihood of uneven shoulders. Eijsden-Besseling compared prevalence of various postural disorders among 73 music students with 59 medical students in Rotterdam. Similar prevalence of postural disorders: 27% of music students and 31% of medical students were observed when musicians did not have their instruments.[48] Fifty-four percent of music students had a postural disorder with their instruments, and most music students who were diagnosed with a postural disorder without their instruments had more severe postural disorders when playing their instrument. Only 4 brass players were examined; with their instruments they presented postural disorders in order of prevalence: swayback, pelvic asymmetry, shoulder asymmetry, and anteposition of the head.

Kris Chesky, Karendra Devroop, and James Ford, III completed the most useful study that includes horn players' prevalence of PRP derived from the University of North Texas Musician Health Survey Dataset in 2002.[49] This survey included 167 French horn players; the subjects were 51% male, had a mean age of 34.08 years, had a mean of 3.67 college years of study, practiced 2.47 hours per day on average, and exercised 3.00 hours per week. The total prevalence rate of musculoskeletal problems was 62%. The top 5 areas of pain in female horn players were: (1.) right lower back at 27.3%, (2.) left lower back at 26.0% and left shoulder also

---

[46] Ramella et al., 19.
[47] Ibid., 20.
[48] M.D.F. Eijsdden-Besseling, M. Kujers, B. Kap, H. Stam, and E. Terpstra-Lindman, "Differences in Posture and Postural Disorders Between Music and Medical Students," *Medical Problems of Performing Artists*, September 1993, 110-114.
[49] Chesky et al, 93-98.

at 26.0%, (4.) left finger – likely the pinkie that is used hold up the horn at 24.7%, and (5.) left hand at 23.4%. The top 5 areas of pain for male horn players were (1.) left lower back at 16.3%, right lower back also at 16.3%, and left finger also at 16.3%, (4.) right side of the neck at 15.1%, and (5.) left side of the neck at 14.0%. Overall, the top 6 areas of concern were (1.) right lower back at 21% and left finger also at 21%, (3.) left lower back at 20.4%, (4.) left shoulder at 18%, (5.) left wrist at 16.2% and left hand also at 16.2%. Clearly, there tends to be high concentrations of pain in the lower back and the left upper extremity, and therefore these should be the focus of improving sub-optimal postural habits and relieving tension and pain in hornists. The highest severity of pain was reported in order at the (1.) left elbow, (2.) left upper back, (3.) right middle back, (4.) right side of the neck, and (5.) right lower back; the most serious pain for hornists is concentrated along the spine. Low back pain tends to be prevalent throughout all brass players; Chesky reported a prevalence of 20% of pain on the lower right side and 18.8% on the lower left. Ackermann reports a 50% prevalence of lower back pain among 38 brass players in Australian orchestras.[50]

Literature Review of Electromyography Studies in Musicians

Surface electromyography (sEMG) is the non-invasive application of electrodes to the skin in order to measure neural signals in the muscle tissue below the skin; it is a somewhat less accurate method than needle electromyography (nEMG), which places the electrode sensors directly in the muscle tissue. Due to its non-invasive nature, sEMG has been the preferred method of measuring muscle activity in musician wellness studies. In 2000, James M. Kjelland reviewed 15 years of musician-specific electromyography (EMG) studies; he divided the studies into 6 categories: validation of EMG for specific research applications, observations with EMG,

---

[50] Bronwen Ackermann, Tim Driscoll, and Dianna T. Kenny, "Musculoskeletal Pain and Injury in Professional Orchestral Musicians in Australia," *Medical Problems of Performing Artists*, December 2012, 185.

using EMG to establish norms for comparison, EMG as a diagnostic tool, using EMG to compare or validate methodologies and playing techniques, and EMG as part of biofeedback training.[51]

Lennert Philipson, Rolf Sörbye, Pål Larsson, and Stojan Kaladjev describe an EMG study of upper extremity muscles of 9 professional violinists.[52] At the time of the study, 5 of the subjects reported upper-extremity pain that prevented them from performing. At rest, EMG patterns and levels were equivalent between all 9 subjects, but while playing, the violinists experiencing pain demonstrated 2-5% higher activation levels in the left and right trapezius, right deltoid, and right bicep – the right arm is the bow arm and is more dynamically active in playing violin. Researchers also tested playing in various postural configurations: standing tense, standing relaxed, seated tense, and seated relaxed. They also recorded activity not playing, playing a détaché stroke, and playing a martellé stroke. Various strokes and postural positions did not reveal significant changes in EMG patterns in the muscles that were tested (bilaterally trapezius, biceps, triceps, and deltoids). Philipson et al demonstrated that higher muscle activations are associated with PRP; this suggests that finding a way to reduce these higher activations may also result in a reduction of pain. However, it should be noted that although self-reported pain is associated with higher muscle activations, this association is by no means a definitive diagnosis of the cause of the participants' pain.

---

[51] James M. Kjelland, "Application of Electromyography and Electromyographic Biofeedback in Music Performance Research: A Review of Literature since 1985," *Medical Problems of Performing Artists*, September 2000, 115-118.

[52] Lennart Philipson, Rolf Sörbye, Pål Larsson, and Stojan Kaladjev, "Muscular Load Levels in Performing Musicians as Monitored by Quantitative Electromyography," *Medical Problems of Performing Artists*, June 1990, 79-82.

Kevin Price and Alan Watson describe an EMG study of brass players to determine the effectiveness of the ERGObrass^{TM} (EB) system at reducing muscle tension.[53] The product is designed to transfer the weight of the instrument through a peg to the ground, chair, or belt (see figure 1.8).

Figure 1.8 *Left* ERGObrass^{TM} used by a seated horn player. *Right* ERGObrass^{TM} used by a standing horn player. Images reprinted with permission from https://www.ergobrass.com/frenchhorn/

Price and Watson recorded sEMG bilaterally on the sternocleidomastoid, trapezius, anterior and posterior deltoids, clavicular pectoralis, and biceps. All subjects demonstrated significantly less muscle activation in most muscles when using the EB support except for the sternocleidomastoid, which in brass playing, is activated mostly with inhalation rather than by supporting the instrument. The typical reduction in muscle activation when using the EB was 15-30%; 1 subject demonstrated 70% reduction.

As suggested by the manufacturer of the EB system, the subjects, were given 8 weeks to adjust to using an EB support system and fine-tune the device to comfortably fit their bodies and instruments prior to the sEMG study. It is not clear the percentage of playing time the subjects

[53] Kevin Price and Alan H.D. Watson, "Effect of Using Ergobrass Ergonomic Supports on Postural Muscles in Trumpet, Trombone, and French Horn Players," *Medical Problems of Performing Artists*, September 2018, 183-190.

used the device during the 8 weeks prior to the study. If participants made a complete switch for 8 weeks, as recommended by the manufacturer, changes in habits and muscle activation would likely occur as the body becomes more reliant on the EB, and this could result in higher sEMG readings without the EB than in a subject who had not become reliant on the EB.

One of the few musician-based EMG study that examined lower-back muscles was conducted by Alessandro Russo, Alejandra Arancets-Garza, Samuel D'Emanuele, Francesca Serafino, and Roberto Merletti with 9 violinists in 2019 to compare erector spinae activation when using a "standard" (but backless, which is not standard) orchestral chair with and ergonomic chair that had lumbar support and encouraged less hip flexion, which has been shown to put less strain on the lower back.[54] Eight of 9 subjects in this study were female, and 8 of 9 subjects were between 15 and 22 years of age, so the sample population is not representative of all violinists. None of the subjects had a history of PRP. Subjects played 2 Kreutzer studies for 2 hours straight; every 5 minutes they switched to play 20 seconds of a Rode study while EMG readings were recorded. The long duration was meant to induce fatigue in the postural muscles and mimic the repetitive task of playing violin that is common in orchestral rehearsals and practice sessions. Tests on the 2 different chairs occurred a week apart and subjects were instructed not to perform strenuous activities on the days prior to the test. The testing protocol of playing approximately 5 minutes of the same music constantly for 2 hours straight seems mind-numbingly boring – a situation that most musicians hopefully do not often experience.

The sEMG used in this study consisted of 2 arrays of 128 electrodes arranged in 16 rows of 8 columns placed bilaterally on the erector spinae in the low back. They recorded patterns of burst-like signals that have been observed in similar postural muscle studies with sEMG arrays in

---

[54] Alessandro Russo, Alejandra Arancets-Garza, Samuel D'Emanuele, Francesca Serafino, and Roberto Merletti, "HDsEMG Activity of the Lumbar Erector Spinae of Violin Players: Comparison of Two Chairs," *Medical Problems of Performing Artists*, December 2019, 205-214.

8 of the 9 subjects. The ergonomic chair had an average of 40.1% lower muscle activation levels as well as a significantly smaller region of activity in the lower back. The authors concluded that despite 2 hours of continuous playing, the muscles did not reach a fatigue level, which is unsurprising considering that erector spinae muscles constantly work to keep one upright throughout the day and musicians regularly participate in rehearsals and practice sessions that last similar durations. They concluded that "the perception of fatigue does not seem to have an electrophysiological counterpart."[55]

Dr. Lazaro reviewed 75 needle EMG (nEMG) and peripheral nerve conduction case studies of patients with low back pain from his practice who did not have underlying health conditions, such as diabetes, that would affect an nEMG study.[56] The nEMG tests were normal for these patients and were not helpful in diagnosing the radiculopathy, plexopathy, or myopathy that were diagnosed through patient history and other imaging techniques. Needle EMG is more accurate than sEMG at determining how motor units fire, so nEMG is more useful in a clinical setting focused on specific motor units. However, Lazaro questions the usefulness of nEMG and peripheral nerve conduction tests in diagnosing the cause of low back pain and suggests that a normal test cannot be used to eliminate structural problems, such as a herniated disc, as a possible diagnosis. Lazaro explains that EMG tests can only measure and detect problems with the efferent motor nerves; efferent nerves do not relay sensory pain signals, so nEMG can only indirectly diagnose a cause of pain if it involves a motor nerve unit in some way. This concept must be kept in mind when designing any EMG study.

---

[55] Russo et al., 212.
[56] R.P. Lazaro, "Electromyography in musculoskeletal pain: A reappraisal and practical considerations," *Surgical Neurology International*, 6:143 (2015).

CHAPTER II

METHODOLOGY

Playing-Related Musculoskeletal Disorders in Horn Players Health Survey Methodology

While the Chesky et al study[57] provides good data concerning Playing-Related Pain (PRP) in horn players, a more detailed study that investigates specific horn-related issues and reaches a larger, more diverse set of hornists is necessary to fully understand the challenges they face. The Playing-Related Musculoskeletal Disorders in Horn Players Health Survey (reproduced in full in Appendix A) was developed with detailed pain locations in the form of drawings similar to the study presented by Eric Wallace, Derek Klinge, and Kris Chesky,[58] combined with pain severity scales used by Chesky et al.[59] The questions make it clear that the pain levels of interest are debilitating – preventing the subject from playing at their accustomed level. Prevalence of lifetime, recent (within the last year), and current (within the last week) pain was determined. Demographic information collected on each horn player included: age, gender, years playing the instrument, years taking lessons, age started playing the horn, musician class (professional, student, amateur, etc.), type of ensemble playing (orchestra, band, solo, etc.), primary section part (principal, second, high, low, etc.), primary posture of playing (standing, sitting, both equally), when seated if the bell is held on or off the leg, and history of different

---

[57] Chesky et al., 93-98.
[58] Eric Wallace, Derek Klinge, and Kris Chesky, "Musculoskeletal Pain in Trombonists: Results from the UNT Trombone Health Survey," *Medical Problems of Performing Artists*, June 2016, 88.
[59] Chesky et al., 96.

ensemble experience. Information about how subjects cope with their pain (medicine, Alexander Technique, yoga, exercise, chiropractic, massage, etc.) as well as general treatment effectiveness was gathered. In 2017, Stanek reported that music students with PRP were most likely to consult their primary teacher, and the next-most-likely strategy in dealing with pain was not to seek help.[60] Respondents who reported they were teachers were asked to describe how they teach horn posture and what they look for to improve their students' postures.

The survey was approved by the Institutional Review Board at the University of Northern Colorado (Protocol Number: 2102022490, see Appendix F) and was delivered electronically through Qualtrics™ software. Participants were recruited through a variety of methods between August and December of 2022, including in-person interactions with attendees at the International Horn Society's 54th Annual Symposium in Kingsville, TX. Additionally, survey requests were made via multiple Facebook posts to horn interest groups. Survey request emails were sent to hornist acquaintances of the author, through the teacher database and member directory of International Horn Society, and to horn professors requesting them to take the survey and share it with students and colleagues. Finally, all participants in the Surface Electromyography of the Low Back in Horn Players (Institutional Review Board at the University of Northern Colorado Protocol Number: 2104025563, see Chapter IV and Appendix F) completed the survey.

For this survey, a hornist was defined as a person who regularly plays the horn in an ensemble or practices on their own. Due to the legal complications of distributing the survey to minors, juvenile hornists younger than 18 were excluded on question 2 by ending the survey if "younger than 18" was selected. Juvenile hornist responses, duplicate responses, and incomplete

---

[60] Jeremey L. Stanek, Kevin D. Komes, and Fred A. Murdock, "A Cross-Sectional Study of Pain Among U.S. College Music Students and Faculty," *Medical Problems of Performing Artists*, March 2017, 23.

responses were deleted from the response pool. At the beginning of the survey participants were asked to create a unique identifier of their initials and birth year, when matching identifiers were detected, the data between the 2 responses were compared to determine if the demographic responses were similar before eliminating 1 response. When a duplicate response was detected, both responses were examined to determine the most complete response, and if the responses were equally complete, the response with the most recent date was retained in the dataset. A survey was considered to have a complete response if participants answered question 18: “In your lifetime, have you experienced significant pain that made playing your instrument more difficult or uncomfortable?”

In the literature, the term “playing-related musculoskeletal disorder (PRMD)” is imprecise and has somewhat varied definitions between authors. In this study, only participants who believed that their PRP may be caused by playing their instrument were defined as having a PRMD. If respondents indicated their PRP was caused by something else, such as a car crash or heredity disease, they were reported as only suffering PRP. Pain from a non-music related event, however, can still be debilitating to a musician and exacerbated by playing an instrument. Individuals may unknowingly suffer from a PRMD if the pain that affects their playing is triggered by non-music-related events, but their misalignments reflect a pattern similar to holding the instrument. Despite the title of the survey, the reported results of this study focus primarily on playing-related pain (PRP) rather than playing-related musculoskeletal disorders (PRMD). Sufferers of PRP provided larger sample sizes to examine and seemed to be a more relevant subject than PRMD sufferers upon analysis of the responses.

The sample size for this survey was too small to establish statistical significance using chi-squared tests, especially among subsets of the sample such as age groups. Some significant results were shown using 90% confidence intervals ($p < .10$). Wider confidence intervals occur with smaller sample sizes, and if confidence intervals overlap between two categories, then they are not significantly different from each other.

Research Questions for Study One: Playing-Related Musculoskeletal Disorders in Horn Players Health Survey Study

Data generated by responses to the survey were analyzed to answer the following questions with respect to playing-related pain (PRP) in horn players (see Appendix A for survey questions).

Q1 Is there a relation between age and prevalence of lifetime, recent, or current PRP?

Q2 Is there a relation between gender and prevalence of lifetime PRP?

Q3 Is there a relation between number of years taking horn lessons and prevalence of lifetime, recent, or current PRP?

Q4 Is there a relation between the age respondents started the horn and prevalence of lifetime PRP?

Q5 Is there a relation between the number of years playing the horn and prevalence of lifetime PRP?

Q6 Is there a relation between musician class (undergraduate student, freelancer, professional, etc.) and prevalence of lifetime, recent, or current PRP?

Q7 Is there a relation between specializing in primarily high horn, low horn, or mixed and prevalence of lifetime PRP?

Q8 Is there a relation between a history of playing in a certain type of ensemble (i.e., marching band or orchestra) and prevalence of lifetime PRP?

Q9 Is there a relation between currently playing in certain ensembles (i.e., marching band or orchestra) and prevalence of current or recent PRP?

Q10 Is there a relation between playing multiple instruments and lifetime prevalence of PRP?

Q11 Is there a relation between typical number of hours playing the horn per week and prevalence of current or recent PRP?

Q12 Is there a relation between typical number of hours sitting in a week and prevalence of current or recent PRP?

Q13 Is practicing the horn sitting, standing, or both a risk or protective factor for lifetime prevalence of PRP?

Q14 Is performing the horn sitting, standing, or both a risk or protective factor for lifetime prevalence of PRP?

Q15 Is resting the horn on the leg when playing a risk or protective factor for lifetime prevalence of PRP?

Q16 How do horn teachers currently describe good posture or body use to their students?

Q17 What are the most common locations and intensities of pain reported by hornists suffering PRP during their lifetime?

Q18 What are the most common locations and intensities of pain reported by hornists suffering recent (in the last year) PRP?

Q19 What are the most common locations and intensities of pain reported by hornists suffering current (in the last week) PRP?

Q20 Are there age ranges where hornists suffering PRP are most likely to first experience symptoms?

Q21 What is the prevalence rate of receiving a satisfactory diagnosis for hornists suffering from PRP?

Q22 What professionals do hornists suffering from PRP consult for their conditions?

Q23 What are the experiences of receiving care for PRP?

Surface Electromyography of the Low Back in Horn Players Study General Methodology

The Surface Electromyography (EMG) of the Low Back in Horn Players study was approved by the Institutional Review Board at the University of Northern Colorado (Protocol Number: 2104025563, see Appendix F.) Ten participants, both professional and student hornists from Colorado, were recruited for the study at the University of Northern Colorado Biomechanics Laboratory. After completing the Playing-Related Musculoskeletal Disorders in

Horn Players Survey (see Chapter III.), participants provided written consent to participate in the study. Reflective markers were placed bilaterally on the acromion processes of the shoulders, the spinous process of the C7 vertebrae, and in a triangle on the waistband at the sacrum to record movement and body positions. Surface electromyography electrodes were placed bilaterally over the posterior and anterior deltoids and lumbar erector spinae (LES) muscles.

The anterior deltoids (ADs) are on the front part of the shoulder and primarily lift the arm forward; the posterior deltoids (PDs) are on the back part of the shoulder and lift the upper arm backwards.[61] They are considered antagonistic muscles, performing opposite movements, but can both be engaged with isometric contraction when stabilizing the shoulder joint. The erector spinae muscles run in strips bilaterally along the entire spine on the back.[62] This study investigates the erector spinae in the lumbar region, between the pelvis and the ribs. In addition to stabilizing the spine, the erector spinae's primary role is to keep the torso upright; when activated the lumbar erector spinae (LES) increase lordosis (the natural concave curve of the lower back) which occurs when the pelvis is rotated anteriorly but the torso remains upright.

Movement and muscle activity were recorded simultaneously with a Delsys Trigno EMG system and a Vicon Giganet running Vicon Nexus 2.12.1 software. At the beginning of data collection, 5-second calibration trials were taken of participants both standing and seated without their instruments. Then the participants were instructed to perform a 1-octave C major scale up and down in half notes (metronome at 80 beats per minute) while in 6 different situations; 5 iterative trials were taken of each situation for a total of 32 trials (including calibration). The 6 different situations were: seated in natural posture (NP), standing in NP, seated using an ERGObrass™ (EB) support, standing using an EB support, seated with Alexandrian-based

---

[61]Clark et al., 638-639.
[62] Ibid., 634.

instructions (ABI), and standing with ABI (see Appendix B to read the instructions). Instructions were drawn from the practice of Alexander Technique (AT) and were not identical between participants; they were chosen based on misalignments observed by the researcher. Instructions for most participants did not progress beyond the basic seated and standing posture instructions.

For the calibration trials participants were told to adopt the stance or seated position they would normally use during rests in a performance. Although the data in the calibration trials may suggest potential asymmetrical postures that likely exist in participants' daily lives, the calibration trials are considered participants' neutral position because inexact placement of reflective markers may be the source of measured asymmetrical postures in calibration trials. All data are reported as changes from this neutral position. To ensure the data captured participants performing on their instrument, recordings commenced after participants began to play. Participants were encouraged to move and relax between trials and to strive to play their most beautiful C Major scales in order to simulate a more natural and realistic playing experience.

In order to control for order bias, participants progressed through the 6 playing situations in the different orders. Odd numbered participants started seated and then alternated between seated and standing trials; even numbered participants started standing and then alternated with seated trials. All participants began with their NP (seated and standing); Participants 1-5 then used an EB (seated and standing) before receiving ABI, while Participants 6-10 received ABI prior to using an EB. The data collection process was audio-recorded for comparison of tone quality.

Finally, researchers recorded the self-reported height of the participants; previous experience, with AT, Body Mapping (a more musician-specific approach to AT), and using an EB. All seated trials occurred on a backless bench that was 18 inches high. Although backless seats are not standardly used by musicians, a backless seat was necessary for the visibility of the reflective markers placed on the lower back.

Electromyography Analysis

Electromyography (EMG) readings were recorded at 2000 Hz. Data from seconds 0-5 were extracted for calibration trials and seconds 1-16 was extracted for all other trials. Data for each trial were detrended by calculating the average and subtracting the average from each point, thus making the average for each trial 0. Data were then rectified by taking the absolute value of each point, so all negative numbers became positive. Then data were amplified by multiplying all numbers by 1,000 so that the differences between numbers are simpler to detect. Then the mean was taken to determine the average level of muscle activity for each muscle throughout the trial (muscle activity averages are shown in Appendix D).

Averages of the 5 trials in each of the 6 situations were taken for each muscle; NP trial averages were then compared to calibration trials and shown as a percentage of change; muscle activity in calibration trials was considered the participants' neutral activity level. Then EB and ABI trial averages were compared to NP averages and shown as a percentage of change. Bilateral changes of muscle activity were compared to determine if asymmetrical loading of the body occurred and look for trends between participants.

For each muscle in both seated and standing positions repeated measures ANOVAs were performed using SPSS software to compare the effect of the different situations on average muscle activity levels at a 95% confidence level ($p < .05$).

Reflective Marker Data Analysis Methods

Data matching the timeframes of the electromyography data (seconds 0-5 for calibration trials and seconds 1-16 for other trials) were selected. Trial number 7STI4 (see table C.1 in

Appendix C for trial number labeling key), participant 7's 4th standing trial with ABI, was the exception; due to missing data for the reflective marker on the left sacrum caused by clothing obscuring the reflective marker, the final 15 seconds of time, which had the greatest number of data points, were selected instead.

An X,Y,Z coordinate was recorded in every frame for each reflective marker; the coordinates from the selected frames were averaged and distances and angles were calculated from the average coordinates. (See tables C.2 and C.3 in Appendix C).

Shoulder to Hip Twisting

To measure shoulder to hip twisting, slopes between the reflective markers on the left and right sacrum and between the markers on the left and right shoulders were calculated in the X,Y-plane, using the formula:

Let X_1, Y_1 = position coordinates of right sacrum/shoulder
Let X_2, Y_2 = position coordinates of left shoulder/sacrum
$(Y_1-Y_2)/(X_1-X_2)$

The angle ($\tan\Theta$) between the slope of the sacrum and slope of the shoulders was calculated using the formula:

Let M_1 = slope of shoulders,
Let M_2 = slope of sacrum:
$\tan\Theta = (M_1-M_2)/(1+M_1M_2)$.

$\tan\Theta$ was converted to angle degrees using the formula: $\tan^{-1}(\tan\Theta)$. Because the participants were facing the y axis, a negative angle indicates a twist of the shoulder to the right in relation to the hips. A positive angle indicates a twist of the shoulders to the left in relation to the hips. The larger the angle, the more the participant is twisted.

The degrees of twisting were calculated for all trials, except participant 2's standing trials, where insufficient reflective marker data were recorded. For every participant, the angles of twisting of the 5 trials within each of the 6 situations were averaged. The difference in degrees of shoulder to hip angles from neutral was calculated by subtracting the calibration trials from the average of participants' seated and standing trials in NP, with an EB, and with ABI. A repeated measures ANOVA was performed using SPSS software to compare the effect of the different situations on the average change in angle degree of shoulder to hip twisting from Cal at a 95% confidence level ($p < .05$).

Distances between Points

For all trials, distances using the X,Y,Z-coordinates were calculated in millimeters between the C7 marker (referred to as middle shoulder) and middle sacrum, the right shoulder and right sacrum, the left shoulder and left sacrum, and the left and right shoulders using the formula:

Let $P_1 = (X_1, Y_1, Z_1)$
Let $P_2 = (X_2, Y_2, Z_2)$
distance between P_1 and $P_2 = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2}$

The calculated distances for the 5 trials in each situation were averaged and then compared to distances in the calibration trials. Percentages of change of length from the calibration to NP, using an EB, and after receiving ABI were calculated. AT generally encourages a lengthening and widening of the body; the goal of the ABI is to crystalize these principals into a method to teach hornists how to use their bodies with more ease and poise, so more shortening from neutral calibration trials is considered less successful body use. Asymmetrical shortening or shortening on one side while simultaneously lengthening on the other side is considered an increase in postural distortion due to either torso twisting or dipping of the shoulder.

A participant who exhibited an approximately equal amount of shortening between the shoulders and hips in all 3 distances likely shows increased anterior pelvic tilt. A repeated measures ANOVA was performed using SPSS software to compare the effect of the different situations on the average lengths between C7 vertebrae and center of the sacrum (M to M), right shoulder, and right sacrum (R to R), left shoulder and left sacrum (L to L), and between the shoulders (S to S) at a 95% confidence level ($p < .05$).

Audio Methodology and Analysis

Audio recordings of all the trials were created and labeled. Five professional hornists rated the tone quality of each trial on a scale of 1 to 10, 1 being poor and 10 being excellent. Judges were instructed to score each participant in one sitting because comparisons between trials of the same participant were the relevant data. Judges were instructed to go with their gut reactions; they were told that several different situations that were being compared but were not given details about those situations. In order to minimize trends due to playing order bias, trials were listened to by the judges in the same order for each participant, which was not the same order as they were performed. The 25 scores for of the 6 situations for each participant were averaged; ABI and EB trials were then compared to NP trials and shown as a percentage of change. Finally, the 250 scores for each situation across all participants were averaged, and ABI and EB trials were then compared to NP averages and shown as a percentage of change. A repeated measures ANOVA was performed using SPSS software to compare the effect of the different situations on tone quality at a 95% confidence level ($p < .05$).

Research Questions for Study Two: Surface Electromyography of the Low Back in Horn Players

Q24 Compared to neutral positions without the horn, how does playing the horn increase postural misalignments?

Q25 Does using an ERGObrass™ (EB) system or receiving Alexandrian-based instructions (ABI) on how to hold the horn help bring the body into better alignment compared to participants' natural posture (NP) with the horn?

Q26 Do misalignments associated with playing the horn occur with asymmetrical increases in muscle activity between the left and right sides of the body?

Q27 Do misalignments and increased asymmetrical muscle activation when playing the horn have any relation to lifetime, recent, or current playing-related pain (PRP)?

Q28 Confirming Watson and Price's study,[63] does the use of an ERGObrass™ (EB) system help reduced muscle activity in the deltoids compared to participants' natural posture (NP) with the horn?

Q29 Does the use of an ERGObrass™ (EB) system help reduce muscle activity in the lumbar erector spinae (LES) compared to participants' natural posture (NP) with the horn?

Q30 Do Alexandrian-based instructions (ABI) on how to hold the horn help reduce muscle activity in the deltoids and lumbar erector spinae (LES) compared to participants' natural posture with the horn?

Q31 Keeping changes in muscle activity, alignment, and tone quality in mind, is using an ERGObrass™ (EB) system or receiving Alexandrian-based instructions (ABI) a better intervention?

---

[63] Price and Watson, 183-190.

CHAPTER III

STUDY ONE: PLAYING-RELATED PAIN IN HORN PLAYERS SURVEY

Contribution of Authors and Co-Authors

Manuscript in Chapter III

Author: Daniel Nebel

Contributions: Conceived the study topic, developed, and implemented the study design. Generated and analyzed data. Wrote first draft of the manuscript.

Co-Author: Dr. Sara Winges

Contributions: Provided feedback on study design, statistical analysis, and drafts of manuscript.

Co-Author: Dr. Melissa Malde

Contributions: Provided feedback on study design, Body Mapping and Alexander Technique terminology, and drafts of manuscript.

Co-Author: Dr. Gary Heise

Contributions: Provided feedback on study design and drafts of manuscript.

Co-Author: Dr. John Adler

Contributions: Provided feedback on study design and drafts of manuscript.

Co-Author: Dr. Reiner Krämer

Contributions: Provided feedback on study design and drafts of manuscript.

Abstract

Potentially debilitating performance-related pain (PRP) is common among professional and aspiring instrumentalists, can lead to significant loss of income, and sometimes end a career. Postural misalignments that lead to PRP can develop early in students' training and are often best

addressed by a music teacher recommending a change in technique. The nature of a musician's PRP is dependent on how the instrument is held; however, previously, there has never been an in-depth study of PRP in hornists. This comprehensive hornist-specific health survey gathers hornist-specific data to identify common misalignments and areas of concern for developing PRP, possible demographical risk and protective factors, and understand current coping strategies for PRP.

Literature Review of Musician Health Surveys

Numerous health surveys of musician populations have been conducted to determine pain prevalence and associate data with a variety of risk and protective measures. Reports of lifetime rates of pain related to playing an instrument among musicians have been vastly different, ranging from as low as 50%[64] to as high as 89%.[65] There are a variety of reasons for this discrepancy: small sample sizes make valid statistical assertions difficult;[66] low response rates may tend to create a volunteer bias causing studies to report higher prevalence rates than are actually present;[67] and different population targets such as music students versus full-time professionals may present different levels of prevalence due to chronically-injured musicians leaving the profession and dropping out of the subject pool. In addition to varied survey methods, distribution, and materials, the definition of pain varies quite a bit between surveys: in some studies, such as the 1988 ISCOM survey, all types of painful conditions were included whether or not they were playing-related.[68] Many studies also did not distinguish mild pain from more severe, debilitating pain in their prevalence rates.[69] Brass players regularly experience mild

---

[64] Davies and Mangion, 156.
[65] Zetterberg et al., 161.
[66] Zaza, 17-18.
[67] Ibid., 19.
[68] Ibid., 18.
[69] Ibid., 18-19.

discomfort and swelling of their lips following intense performances, rehearsals, and practice sessions; this is a normal occurrence that generally subsides quickly and rarely prevents brass musicians from playing the next day. As any athlete can expect to experience some amount of delayed-onset muscle soreness with increases in training intensity, musicians experience similar sensations on a smaller scale when practicing to increase endurance, pitch range, and dynamic range. If musicians interpret survey questions to include these common, non-debilitating experiences of pain or discomfort, prevalence of playing-related pain (PRP) will be overreported.

For a variety of reasons, most studies fail to adequately address the population of horn players. Many general musician surveys are distributed through professional orchestras, which are primarily made up of string players, so the data, such as prevalent sites of pain, tends to skew towards problems experienced by string players.[70] Since professional orchestras employ 4 to 6 hornists, their responses are almost always grouped with all brass players when survey sample sizes are large enough for different instruments to be discussed. Brass players do have many similarities in sound production and thus share some common health concerns, but differences in the size, shape, weight, and mechanisms of the trumpet, trombone, tuba, and horn cause different alignment challenges and strains on the body. Additionally, when only professional orchestral musicians are surveyed, populations of horn players, such as students, amateurs, military bandsmen, and aspiring musicians who have given up the horn, are left out. Orchestral musicians are an easy group to contact and a fulltime orchestral musician is generally viewed as having successfully reached the highest level of achievement within the music community, so the choice to survey them for health issues is certainly unsurprising and relevant.

[70] In bibliography, see studies by Ackermann, Andersen, Berque, Caldron, Davies, Kaneko, Fishbein, Fotiadis, James, Yeung, and many studies discussed by Zaza.

There are also many surveys that sample students in music schools,[71] which provides a more comprehensive and instrumentally diverse subject pool, but offers its own drawbacks as well. Again, horn players are almost always grouped with brass players for any analysis, and a high percentage of students are string or keyboard players, whose complaints tend to be primarily in the upper extremities. Medical issues that are common in these populations have thus received the majority of attention in the literature; subsequently, most of the electromyography studies of musicians focus on muscles in the upper extremities and neck,[72] likely because these are the areas primarily reported as problematic in most health surveys.

Musicians do not have higher lifetime prevalence rates of musculoskeletal pain compared with the general population. A general survey of 11,507 Japanese subjects reported an 86% lifetime prevalence of musculoskeletal pain and 15.4% prevalence rate of chronic pain. [73] One consistent trend between all studies, both general population and musician studies, is a greater tendency for women to report higher rates and intensities of musculoskeletal dysfunction and pain.[74] Women tend to be smaller, with less muscle mass than men, and considering that many instruments were developed and standardized in size and design before most women were afforded the opportunity to become professional musicians, the ergonomics of most instruments likely present more of a challenge to women. An equitable number of professional women musicians were not present in many symphony orchestras until well after blind auditions were widely instituted in the 1970s. This is still a problem in some regions today; as recently as 2005 only 30.3% of orchestral musicians in São Palo, Brazil were women.[75] Other possible

---

[71] In bibliography, see studies by Ajidahun, Baadjou, Brandfonbrener, Ramella, Nawrocka, Stanek, Zetterberg, and many studies discussed by Zaza.
[72] In bibliography, see studies by Kjelland, Philipson, Price, and Rumsey
[73] Nakamura et al., 424-432.
[74] Zetterberg et al., 160-165.
[75] Kaneko et al., 168.

explanations for this trend are: due to biological differences women may perceive pain more often and intensely than men, gender differences in psychology may lead women to be more likely to report pain and seek out help than men, and a higher prevalence of joint laxity or hypermobility in women has been associated with a greater predisposition to injury and pain.[76]

Several studies investigated physical activity levels and prevalence of PRP and exercise-related interventions meant to reduce PRP. Baadjou et al found no statistical relationship, protective or increased risk, between physical activity levels and reported PRP in a 2015 survey of 132 Dutch music students.[77] Physical activity among the students varied quite a bit and was estimated in METs (Metabolic Equivalent based on the level of oxygen a person consumes during exercise; it is a measurement that allows for comparisons between different modes of exercise) and number of hours per week. It was observed that Dutch music students were generally less active than their non-musician peers. Similarly, a survey of 330 incoming freshman music students in the US found no statistical correlation between PRP and exercise habits.[78] Surveys, by necessity, had to inquire about general fitness encompassing a myriad of exercise modalities and intensities. Studies that explored exercise interventions for populations of musicians demonstrated no relationship between PRP prevalence and general fitness interventions; however, exercise interventions that were individually designed to specifically target areas of concern, such as strengthening the upper extremities in string players, were moderately effective are reducing PRP.[79] [80] [81]

---

[76]Parry, 205-206.
[77] Baadjou et al., 233-234.
[78] Brandfonbrener, 32.
[79] de Greef et al., 156-160.
[80] Andersen et al., 94-100.
[81] Chan et al., 181-188.

A few postural studies on music students have been completed. Ramella et al found that out of 148 music students at the Giuseppe Verdi Conservatory of Milano 66.2% had a postural disorder without their instruments and 73.4% presented a non-optimal posture (defined as a clinically significant deviation from optimal posture established by previous studies of individual instruments) when playing their instrument.[82] Ramella found an increased likelihood of posture disorders and non-optimal posture with increased years of playing the instrument and for instrumentalists playing an asymmetrical instrument. Interestingly, Ramella classified the horn posture as symmetrical[83] despite its off-balance weight to the right, tendency to twist the torso to the right, and likelihood of uneven shoulders. Eijsden-Besseling compared prevalence of various postural disorders among 73 music students with 59 medical students in Rotterdam. Similar prevalence of postural disorders: 27% of music students and 31% of medical students were observed when musicians did not have their instruments.[84] Fifty-four percent of music students had a postural disorder with their instruments, and most music students who were diagnosed with a postural disorder without their instruments had more severe postural disorders when playing their instrument. Only 4 brass players were examined; with their instruments they presented postural disorders in order of prevalence: swayback, pelvic asymmetry, shoulder asymmetry, and anteposition of the head.

Kris Chesky, Karendra Devroop, and James Ford, III completed the most useful study that includes horn players' prevalence of PRP derived from the University of North Texas Musician Health Survey Dataset in 2002.[85] This survey included 167 French horn players; the subjects were 51% male, had a mean age of 34.08 years, had a mean of 3.67 college years of

[82] Ramella et al., 19.
[83] Ibid., 20.
[84] Eijsdden-Besseling et al., 110-114.
[85] Chesky et al., 93-98.

study, practiced 2.47 hours per day on average, and exercised 3.00 hours per week. The total prevalence rate of musculoskeletal problems was 62%. The top 5 areas of pain in female horn players were: (1.) right lower back at 27.3%, (2.) left lower back at 26.0% and left shoulder also at 26.0%, (4.) left finger – likely the pinkie that is used hold up the horn at 24.7%, and (5.) left hand at 23.4%. The top 5 areas of pain for male horn players were (1.) left lower back at 16.3%, right lower back also at 16.3%, and left finger also at 16.3%, (4.) right side of the neck at 15.1%, and (5.) left side of the neck at 14.0%. Overall, the top 6 areas of concern were (1.) right lower back at 21% and left finger also at 21%, (3.) left lower back at 20.4%, (4.) left shoulder at 18%, (5.) left wrist at 16.2% and left hand also at 16.2%. Clearly, there tends to be high concentrations of pain in the lower back and the left upper extremity, and therefore these should be the focus of improving sub-optimal postural habits and relieving tension and pain in hornists. The highest severity of pain was reported in order at the (1.) left elbow, (2.) left upper back, (3.) right middle back, (4.) right side of the neck, and (5.) right lower back; the most serious pain for hornists is concentrated along the spine. Low back pain tends to be prevalent throughout all brass players; Chesky reported a prevalence of 20% of pain on the lower right side and 18.8% on the lower left. Ackermann reports a 50% prevalence of lower back pain among 38 brass players in Australian orchestras.[86]

Introduction and Survey Design

While the Chesky et al study[87] provides good data concerning Playing-Related Pain (PRP) in horn players, a more detailed study that investigates specific horn-related issues and reaches a larger, more diverse set of hornists is necessary to fully understand the challenges they face. The Playing-Related Musculoskeletal Disorders in Horn Players Health Survey (reproduced

[86] Ackermann et al., 185.
[87] Chesky et al., 93-98.

in full in Appendix A) was developed with detailed pain locations in the form of drawings similar to the study presented by Eric Wallace, Derek Klinge, and Kris Chesky,[88] combined with pain severity scales used by Chesky et al.[89] The questions make it clear that the pain levels of interest are debilitating – preventing the subject from playing at their accustomed level. Prevalence of lifetime, recent (within the last year), and current (within the last week) pain was determined. Demographic information collected on each horn player included: age, gender, years playing the instrument, years taking lessons, age started playing the horn, musician class (professional, student, amateur, etc.), type of ensemble playing (orchestra, band, solo, etc.), primary section part (principal, second, high, low, etc.), primary posture of playing (standing, sitting, both equally), when seated if the bell is held on or off the leg, and history of different ensemble experience. Information about how subjects cope with their pain (medicine, Alexander Technique, yoga, exercise, chiropractic, massage, etc.) as well as general treatment effectiveness was gathered. In 2017, Stanek reported that music students with PRP were most likely to consult their primary teacher, and the next-most-likely strategy in dealing with pain was not to seek help.[90] Respondents who reported they were teachers were asked to describe how they teach horn posture and what they look for to improve their students' postures.

The survey was approved by the Institutional Review Board at the University of Northern Colorado (Protocol Number: 2102022490, see Appendix F) and was delivered electronically through Qualtrics™ software. Participants were recruited through a variety of methods between August and December of 2022, including in-person interactions with attendees at the International Horn Society's 54th Annual Symposium in Kingsville, TX. Additionally, survey requests were made via multiple Facebook posts to horn interest groups. Survey request emails

88 Wallace et al., 88.
89 Chesky et al., 96.
90 Stanek et al., 23.

were sent to hornist acquaintances of the author, through the teacher database and member directory of International Horn Society, and to horn professors requesting them to take the survey and share it with students and colleagues. Finally, all participants in the Surface Electromyography of the Low Back in Horn Players (Institutional Review Board at the University of Northern Colorado Protocol Number: 2104025563, see Chapter IV and Appendix F) completed the survey.

For this survey, a hornist was defined as a person who regularly plays the horn in an ensemble or practices on their own. Due to the legal complications of distributing the survey to minors, juvenile hornists younger than 18 were excluded on question 2 by ending the survey if “younger than 18” was selected. Juvenile hornist responses, duplicate responses, and incomplete responses were deleted from the response pool. At the beginning of the survey participants were asked to create a unique identifier of their initials and birth year, when matching identifiers were detected, the data between the 2 responses were compared to determine if the demographic responses were similar before eliminating 1 response. When a duplicate response was detected, both responses were examined to determine the most complete response, and if the responses were equally complete, the response with the most recent date was retained in the dataset. A survey was considered to have a complete response if participants answered question 18: “In your lifetime, have you experienced significant pain that made playing your instrument more difficult or uncomfortable?”

In the literature, the term “playing-related musculoskeletal disorder (PRMD)” is imprecise and has somewhat varied definitions between authors. In this study, only participants who believed that their PRP may be caused by playing their instrument were defined as having a PRMD. If respondents indicated their PRP was caused by something else, such as a car crash or heredity disease, they were reported as only suffering PRP. Pain from a non-music related event, however, can still be debilitating to a musician and exacerbated by playing an instrument. Individuals may unknowingly suffer from a PRMD if the pain that affects their playing is triggered by non-music-related events, but their misalignments reflect a pattern similar to holding the instrument. Despite the title of the survey, the reported results of this study focus primarily on playing-related pain (PRP) rather than playing-related musculoskeletal disorders (PRMD). Sufferers of PRP provided larger sample sizes to examine and seemed to be a more relevant subject than PRMD sufferers upon analysis of the responses.

The sample size for this survey was too small to establish statistical significance using chi-squared tests, especially among subsets of the sample such as age groups. Some significant results were shown using 90% confidence intervals ($p < .10$). Wider confidence intervals occur with smaller sample sizes, and if confidence intervals overlap between two categories, they are not significantly different from each other.

Research Questions

Data were analyzed to answer the following questions with respect to playing-related pain (PRP) in horn players.

Q1 Is there a relation between age and prevalence of lifetime, recent, or current PRP?

Q2 Is there a relation between gender and prevalence of lifetime PRP?

Q3 Is there a relation between number of years taking horn lessons and prevalence of lifetime, recent, or current PRP?

Q4 Is there a relation between the age respondents started the horn and prevalence of lifetime PRP?

Q5 Is there a relation between the number of years playing the horn and prevalence of lifetime PRP?

Q6 Is there a relation between musician class (undergraduate student, freelancer, professional, etc.) and prevalence of lifetime, recent, or current PRP?

Q7 Is there a relation between specializing in primarily high horn, low horn, or mixed and prevalence of lifetime PRP?

Q8 Is there a relation between a history of playing in a certain type of ensemble (i.e., marching band or orchestra) and prevalence of lifetime PRP?

Q9 Is there a relation between currently playing in certain ensembles (i.e., marching band or orchestra) and prevalence of current or recent PRP?

Q10 Is there a relation between playing multiple instruments and lifetime prevalence of PRP?

Q11 Is there a relation between typical number of hours playing the horn per week and prevalence of current or recent PRP?

Q12 Is there a relation between typical number of hours sitting in a week and prevalence of current or recent PRP?

Q13 Is practicing the horn sitting, standing, or both a risk or protective factor for lifetime prevalence of PRP?

Q14 Is performing the horn sitting, standing, or both a risk or protective factor for lifetime prevalence of PRP?

Q15 Is resting the horn on the leg when playing a risk or protective factor for lifetime prevalence of PRP?

Q16 How do horn teachers currently describe good posture or body use to their students?

Q17 What are the most common locations and intensities of pain reported by hornists suffering PRP during their lifetime?

Q18 What are the most common locations and intensities of pain reported by hornists suffering recent (in the last year) PRP?

Q19 What are the most common locations and intensities of pain reported by hornists suffering current (in the last week) PRP?

Q20 Are there age ranges where hornists suffering PRP are most likely to first experience symptoms?

Q21 What is the prevalence rate of receiving a satisfactory diagnosis for hornists suffering from PRP?

Q22 What professionals do hornists suffering from PRP consult for their conditions?

Q23 What are the experiences of receiving care for PRP?

Results

The Playing-Related Musculoskeletal Disorders in Horn Players Survey (see Appendix A) received a total of 352 complete responses. Nine responses were determined to be duplicate responses and eliminated from the dataset. Three additional responses were eliminated from the dataset because the respondent did not complete the consent portion of the survey. Therefore, 340 complete responses were included in the final dataset.

Of the respondents, 51.91% identified as male, 45.16% identified as female, 2.64% identified as non-binary or third gender, and 0.29% preferred not to identify a gender. Figure 3.1 shows the age ranges of respondents; 1 respondent did not select an age.

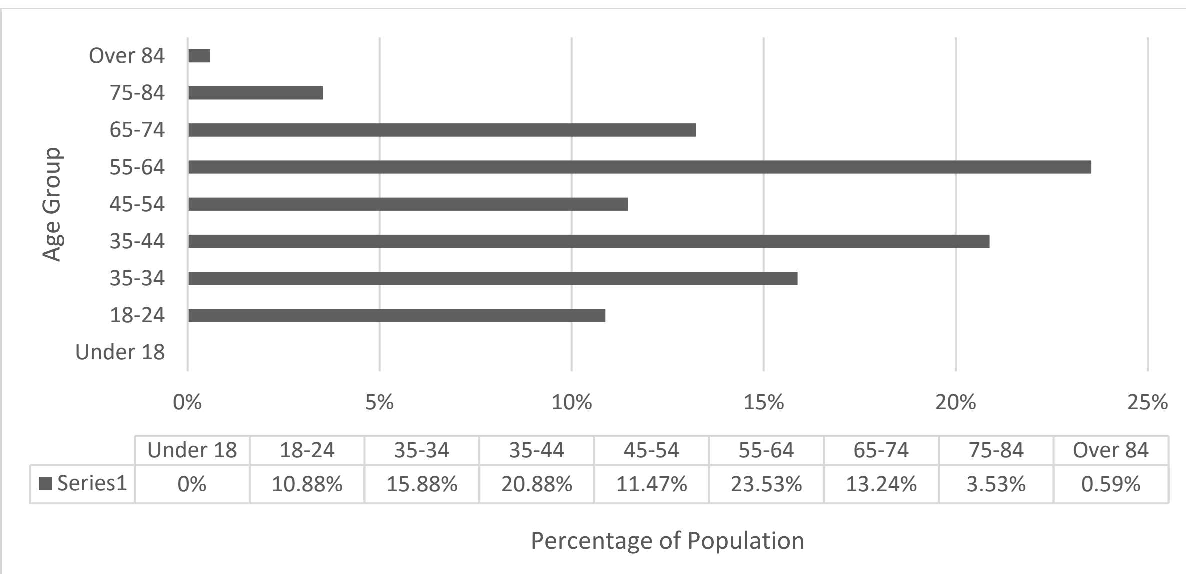


Figure 3.1 Age range percentages of respondents.

Out of the 340 respondents, 241 indicated they had experienced pain that made playing their instrument more difficult or uncomfortable at some point throughout their life, a 71.09% prevalence rate of playing-related pain (PRP). However, of those 241 respondents, 54 believed that their pain was not caused by horn playing and 59 were unsure if horn playing was the cause of their pain. The 54 respondents that felt their PRP was not caused horn playing were eliminated to calculate a lifetime prevalence of playing-related musculoskeletal disorders (PRMDs) of 55.29%. For this study, a PRMD is defined as playing-related pain (PRP) that may have a root cause in how hornists hold their instrument; respondents who answered “yes” to question 19 of the survey were determined to have PRP but not a PRMD. Respondents who experienced PRP but not a PRMD indicated that arthritis, various accidents, surgeries, and autoimmune degenerative diseases were some of the root causes of their PRP.

More detailed information about their pain experience in relation to the horn was provided by 229 respondents. Figure 3.2 details responses to the question: “Does horn playing make your pain worse?”

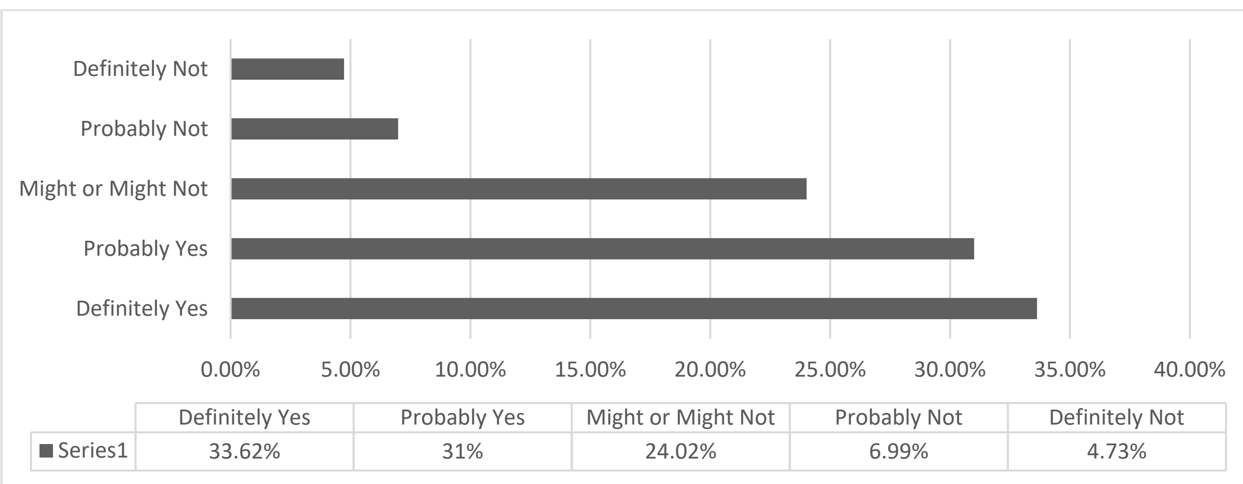


Figure 3.2 Percentages for responses to “Does horn playing make your pain worse?”

Of respondents with a *lifetime* history of PRP, 59.47% reported *recent* PRP (within the last year), a 39.59% prevalence rate of *recent* PRP out of the entire population. Of respondents with *recent* PRP, 52.3% reported *current* (within the last week) PRP, a prevalence rate of 19.94% out of the entire population. Out of the entire population, 12.53% reported *recent* PRMD (PRP possibly caused by horn playing) and 9.51% reported *current* PRMD. Lifetime, recent, and current prevalence rates of PRP of the entire population are shown in figure 3.3, and lifetime, recent, and current prevalence rates of PRMD of the entire population are shown in figure 3.4.

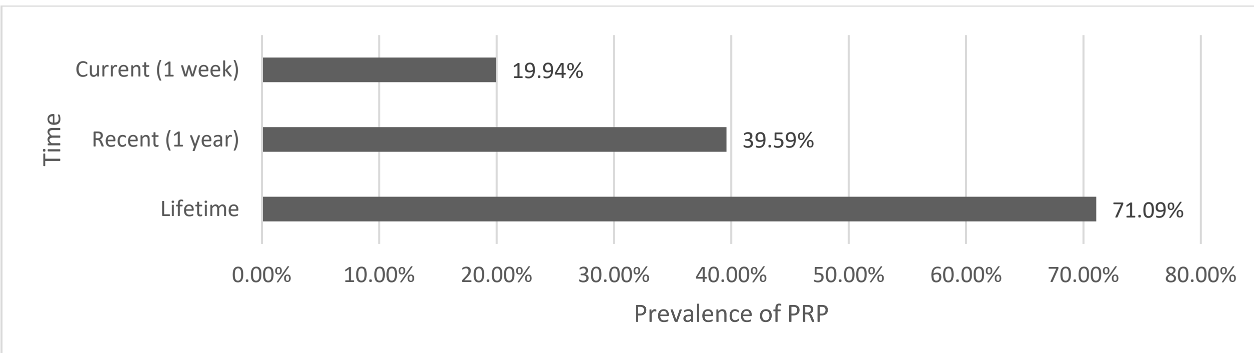


Figure 3.3 Percentage of respondents experiencing current, recent, and lifetime playing-related pain.

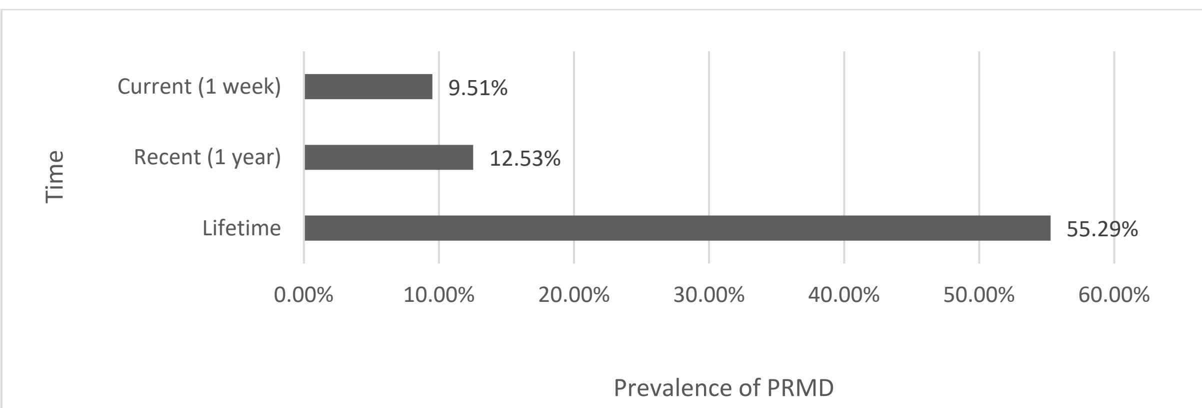
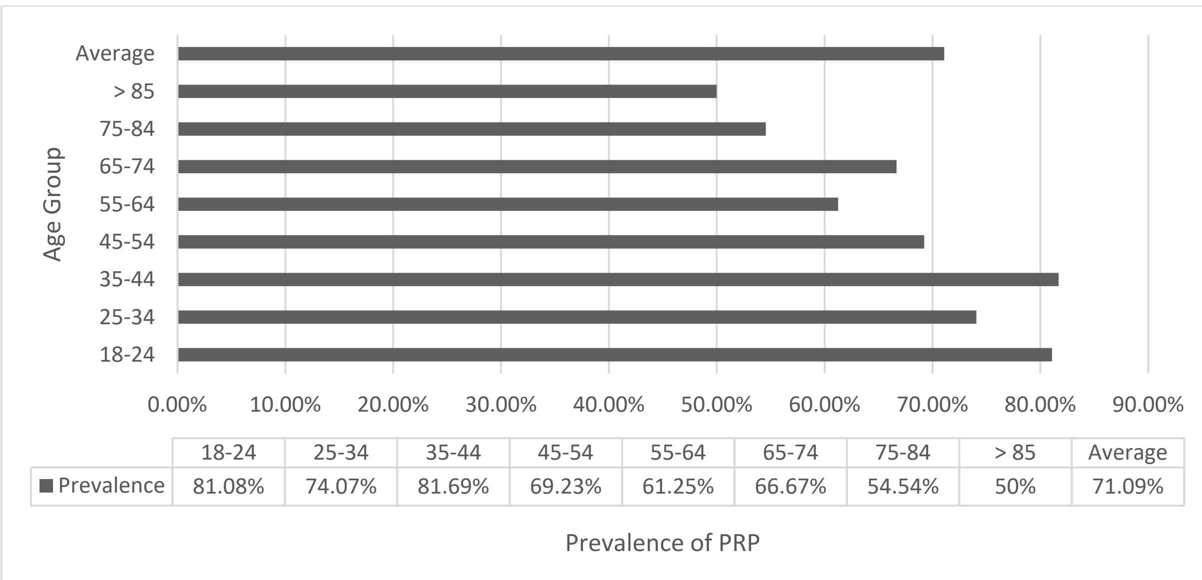


Figure 3.4 Percentage of respondents experiencing current, recent, and lifetime playing-related musculoskeletal disorders.

Research Question Results

Q1 Is there a relation between age and prevalence of lifetime, recent, or current PRP?

The overall lifetime prevalence rate of PRP is 71.09%; when broken down into age groups; younger players reported higher prevalence rates of pain than older players (see figure 3.5). Younger horn players appear more likely to report lifetime PRP. The most likely explanation for this data is survival of the fittest: people with chronic PRP drop out of the population of horn players as they age and were not reached by this survey.



	18-24	25-34	35-44	45-54	55-64	65-74	75-84	> 85	Average
■ Prevalence	81.08%	74.07%	81.69%	69.23%	61.25%	66.67%	54.54%	50%	71.09%

Figure 3.5 Lifetime prevalence of playing-related pain by age group.

Figure 3.6 shows 90% confidence intervals for the age groups and overall population; all intervals overlap, so with 90% confidence none of the prevalence rates for the age groups show any higher or lower likelihood of PRP.

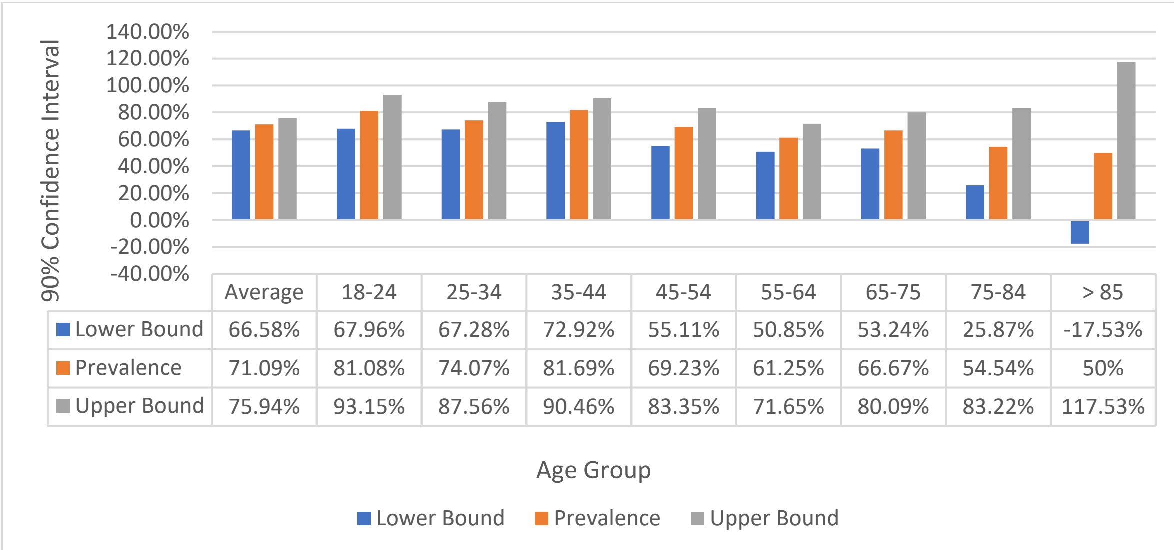


Figure 3.6 Ninety percent confidence intervals and average of lifetime playing-related pain by age group.

Figure 3.7 shows recent (within the last year) PRP in a population with a history of lifetime PRP broken down by age; 18–24-year-olds suffer from the highest prevalence of recent PRP followed by 45–54-year-olds, and 25–34-year-olds suffer from slightly higher-than-average rates of recent PRP.

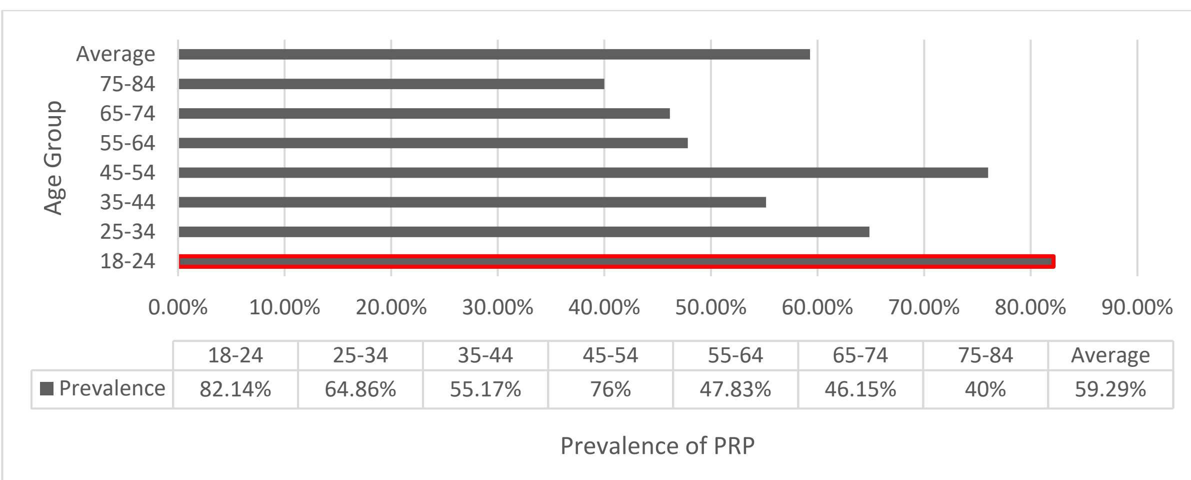
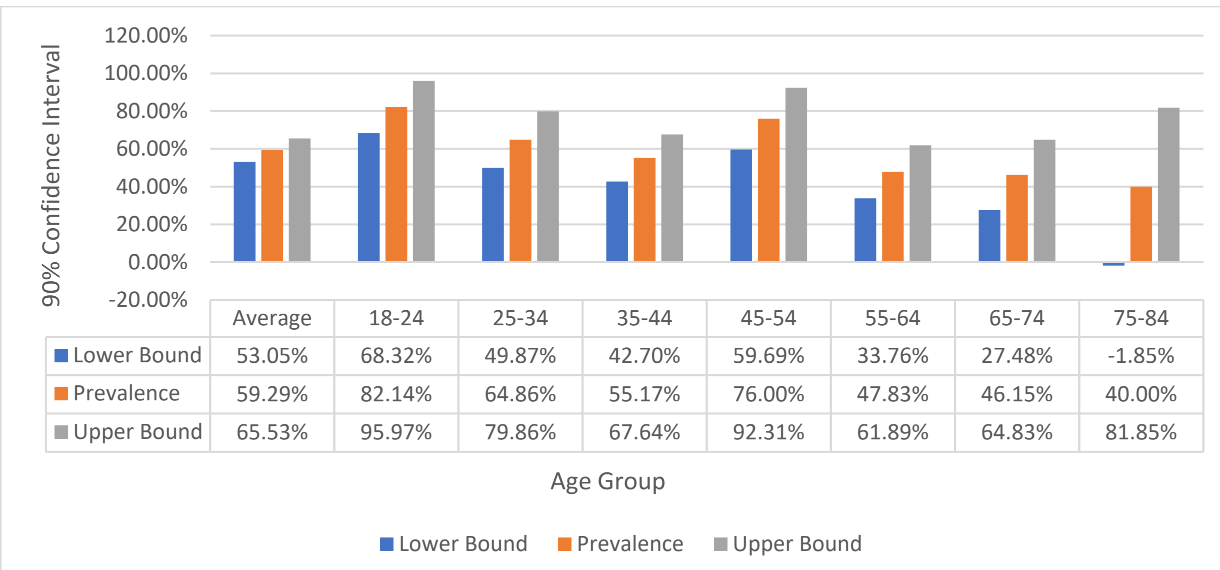


Figure 3.7 Prevalence of recent (within the last year) playing-related pain in a population with lifetime playing-related pain by age group.
Note: red border shows significant difference from the average population at $p < .10$.

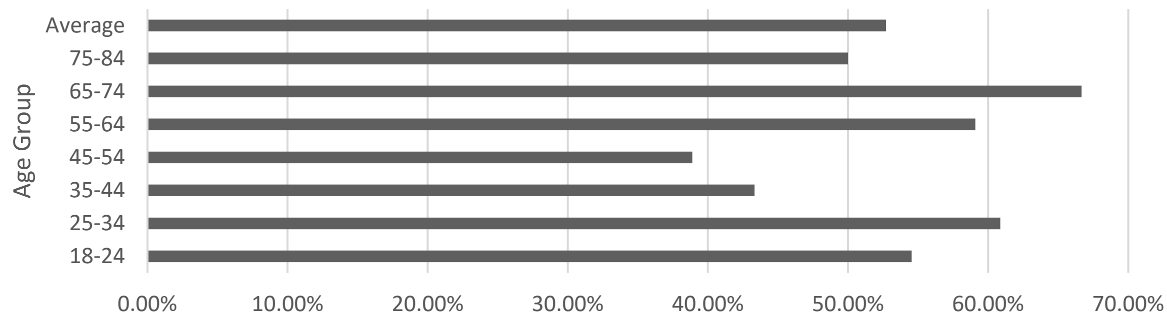
Figure 3.8 shows 90% confidence intervals for the prevalence of recent PRP in a population with lifetime PRP by age groups; most of the confidence intervals overlap, so at a 90% confidence interval, 18–24-year-olds are the only age group with a lifetime history of PRP that has statistically significant higher prevalence of recent PRP than the average population. This suggests that there is a tendency to develop PRP in the formative years of college, and then hornists either drop out of music or find ways to mitigate their symptoms. There may be a tendency to develop or redevelop PRP as the body reaches middle age, and again respondents either learn to manage the symptoms or retire from music.



	Average	18-24	25-34	35-44	45-54	55-64	65-74	75-84
Lower Bound	53.05%	68.32%	49.87%	42.70%	59.69%	33.76%	27.48%	-1.85%
Prevalence	59.29%	82.14%	64.86%	55.17%	76.00%	47.83%	46.15%	40.00%
Upper Bound	65.53%	95.97%	79.86%	67.64%	92.31%	61.89%	64.83%	81.85%

Figure 3.8 Ninety percent confidence intervals and average of recent (within the last year) playing-related pain in population with lifetime history of playing-related pain by age group.

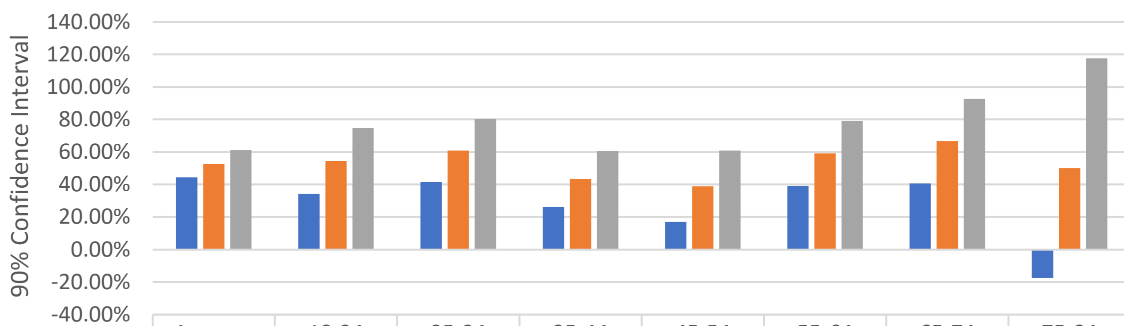
Figure 3.9 shows current (within the last week) PRP in a population with a history of recent PRP broken down by age group. Interestingly, the trend of older hornists with lower prevalence rates is absent from current PRP sufferers; 65–74-year-olds, 55–64-year-olds, and 25–34-year-olds showed higher than average PRP, although the sample sizes were too small to establish significance. Figure 3.10 shows the 90% confidence intervals for the population average and by age group. All the 90% confidence intervals overlap, so none of the prevalence by age group are significantly different.



	18-24	25-34	35-44	45-54	55-64	65-74	75-84	Average
Prevalence	54.55%	60.87%	43.33%	38.89%	59.09%	66.67%	50%	52.71%

Prevalence of PRP

Figure 3.9 Prevalence of current (within the last week) playing-related pain in a population with a history of recent playing-related pain by age group.



	Average	18-24	25-34	35-44	45-54	55-64	65-74	75-84
Lower Bound	44.32%	34.27%	41.43%	26.05%	16.94%	39.07%	40.67%	-17.53%
Pevalence	52.71%	54.55%	60.87%	43.33%	38.89%	59.09%	66.67%	50.00%
Upper Bound	61.11%	74.82%	80.31%	60.61%	60.84%	79.11%	92.66%	117.53%

Age Group

Lower Bound Pevalence Upper Bound

Figure 3.10 Ninety percent confidence intervals and average of current (within the last week) playing-related pain in population with recent history of playing-related pain by age group.

Q2 Is there a relation between gender identity and prevalence of lifetime PRP**?**

Figure 3.11 shows the lifetime prevalence of PRP by gender identification. Similar to previous studies,[91] female hornists showed a higher prevalence rate for PRP than male hornists. Figure 3.12 shows 90% confidence intervals by gender identity; male and female confidence intervals do not overlap, so at a 90% confidence interval, respondents who identify as female are have statistically higher prevalence rates of lifetime PRP than those who identify as male.

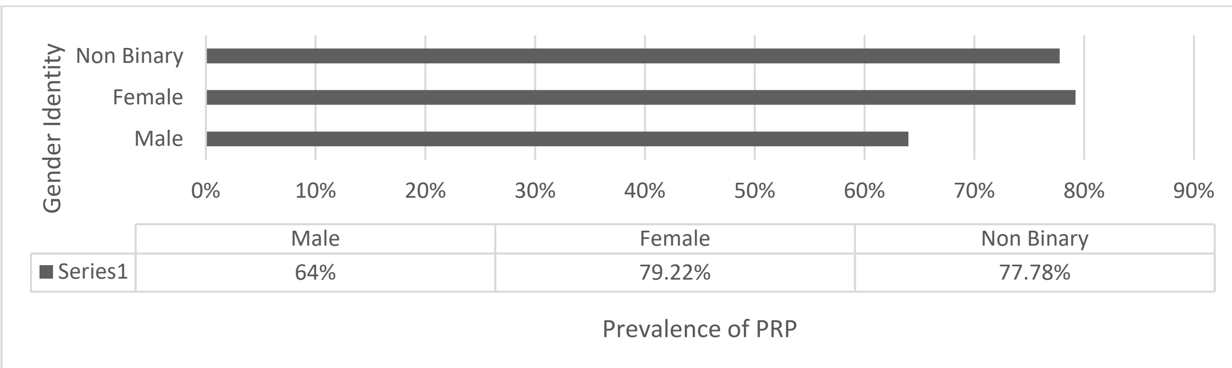


Figure 3.11 Prevalence of lifetime playing-related pain by gender identity.

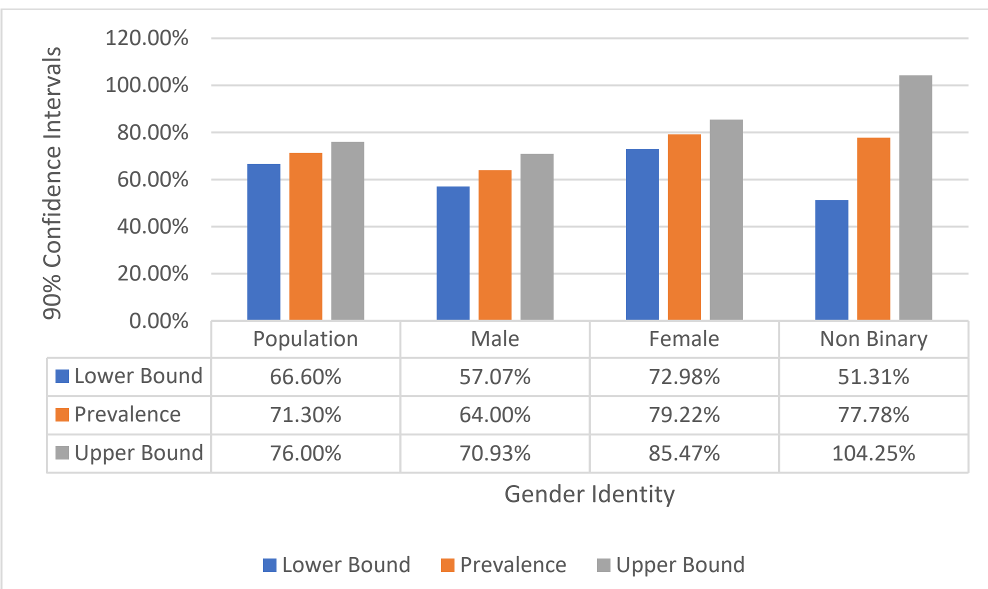
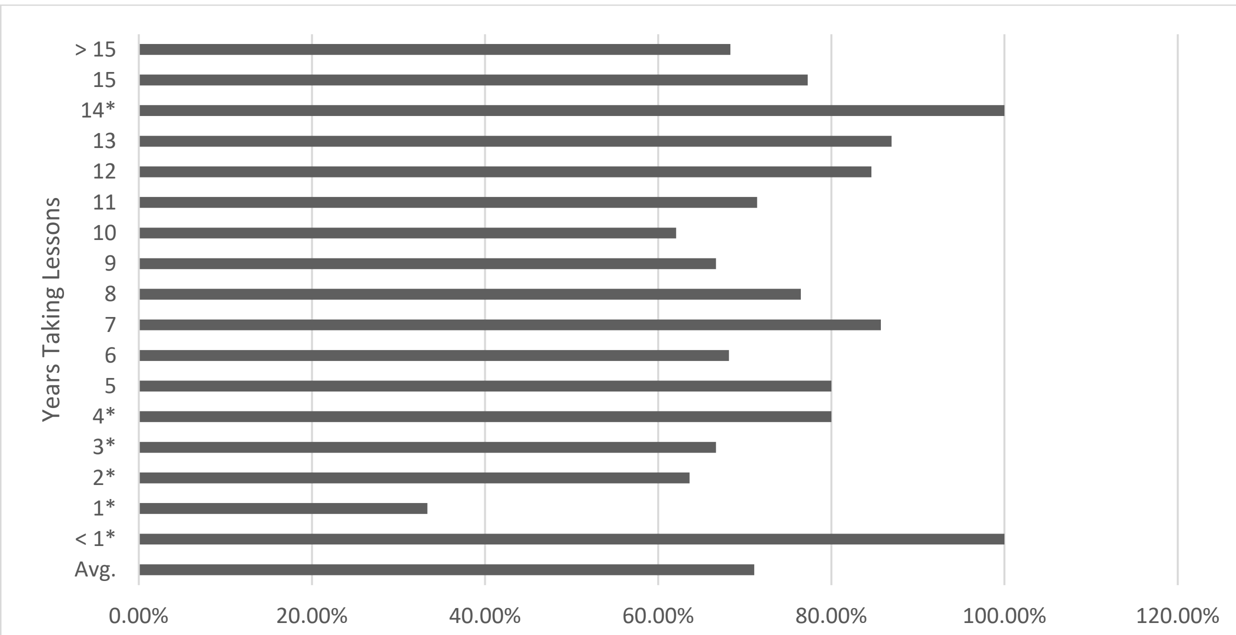


Figure 3.12 Ninety percent confidence intervals of lifetime playing-related pain by gender identity.

91 In bibliography, see studies by Kjelland, Philipson, Price, and Rumsey.

Q3 Is there a relation between number of years taking horn lessons and prevalence of lifetime, recent, or current PRP?

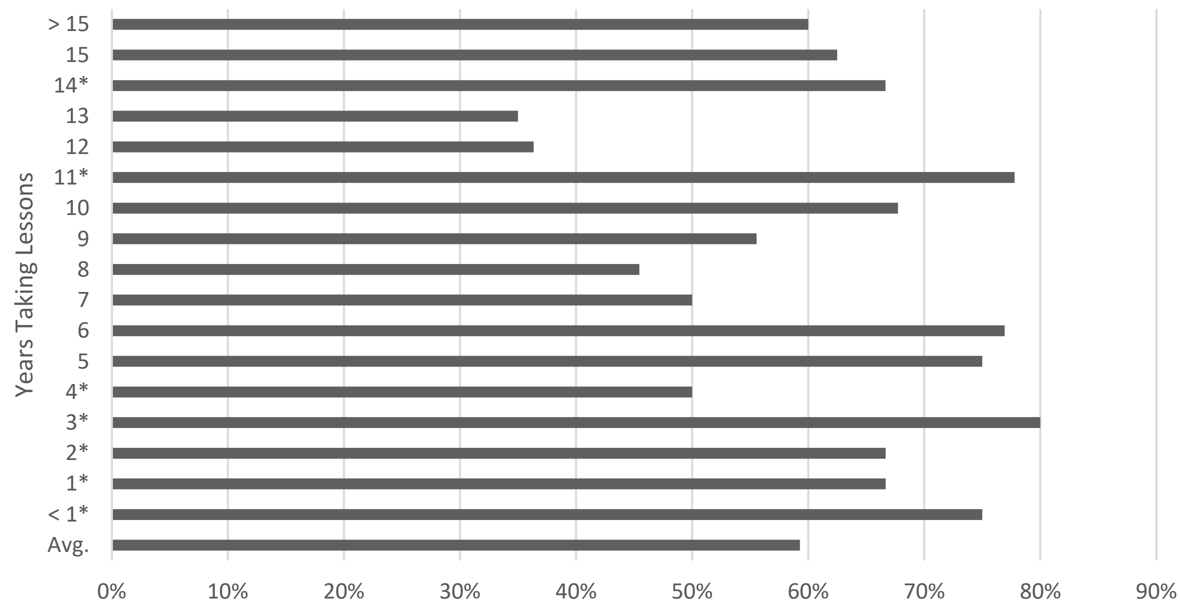
The prevalence of respondents reported experiencing PRP throughout their lifetime was 71.09%. Figure 3.13 shows lifetime prevalence rates of PRP by number of years taking lessons. The number of years taking lessons has no relation with lifetime PRP levels. Sample sizes were too small to establish statistical significance for any category with 90% confidence intervals.



	Avg.	< 1*	1*	2*	3*	4*	5	6	7	8	9	10	11	12	13	14*	15	> 15
Series1	71.09	100%	33.33	63.63	66.67	80%	80%	68.18	85.71	76.47	66.67	62.07	71.43	84.62	86.96	100%	77.27	68.33

Figure 3.13 Prevalence of lifetime playing-related pain by years taking lessons.
Note: * indicates a sample size of less than 15.

The prevalence rate of respondents with lifetime PRP reported recent PRP was 59.29%. Figure 3.14 breaks down the prevalence rate of recent PRP by number of years taking horn lessons; more education is not related to lower levels of recent PRP, suggesting that most teachers do not establish habits that help students develop injury-preventative body use. Sample sizes were too small to establish statistical significance for any category with 90% confidence intervals.

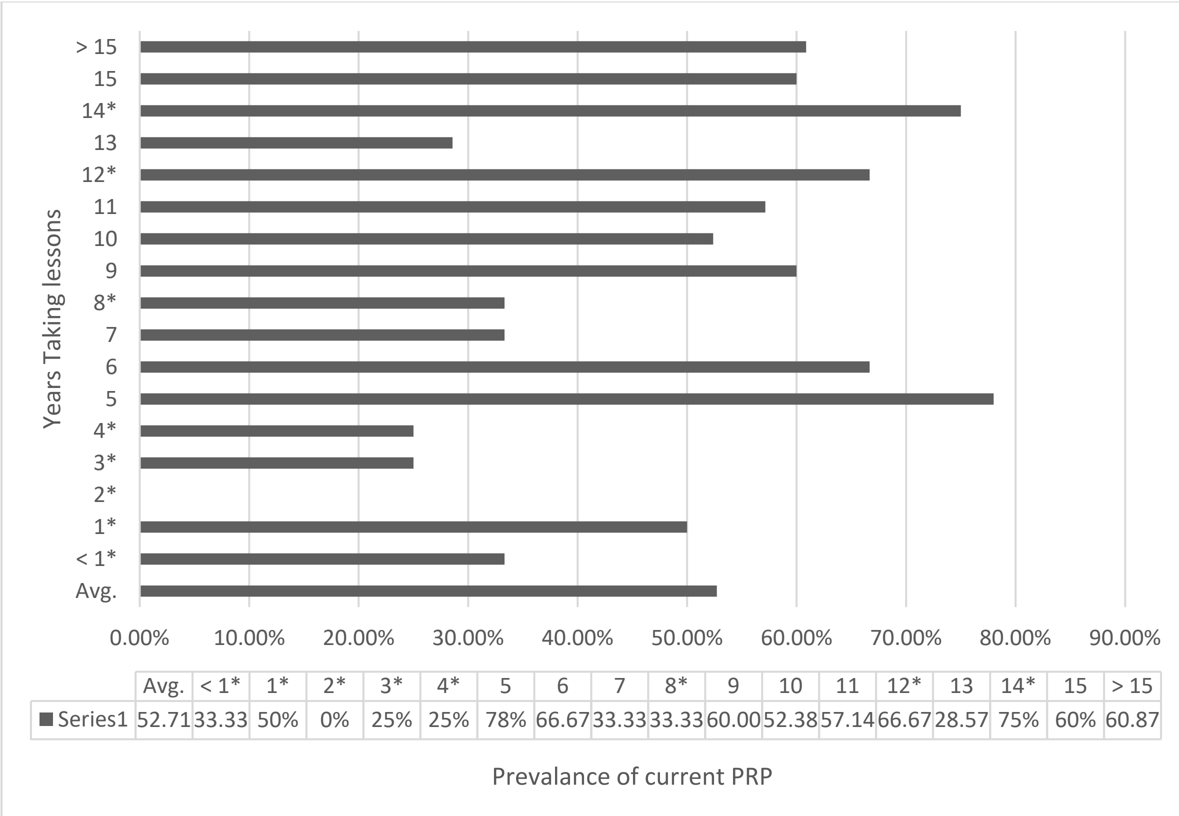


	Avg.	< 1*	1*	2*	3*	4*	5	6	7	8	9	10	11*	12	13	14*	15	> 15
Series1	59%	75%	66.67	66.67	80%	50%	75%	76.92	50%	45.45	55.56	67.74	77.78	36.35	35%	66.66	62.50	60%

Prevalence of Recent PRP

Figure 3.14 Prevalence of recent playing-related pain (within the last year) in a population with a lifetime history of playing-related pain by years taking lessons.
Note: * indicates a sample size of less than 10.

Of the respondents with recent PRP, 52.71% reported current PRP. Figure 3.15 breaks down this population by the number of years taking lessons; again, more years taking lessons is not associated with lower levels of current PRP. This suggests that more education does not adequately help people establish body use that prevent PRP or help decrease symptoms. All categories overlapped at 90% confidence intervals, no category had significantly different prevalence.

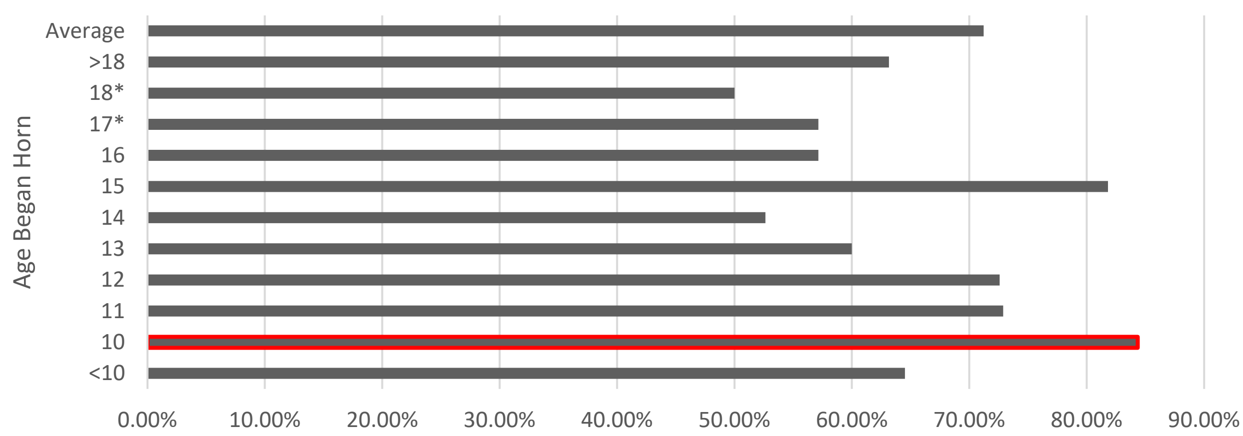


	Avg.	< 1*	1*	2*	3*	4*	5	6	7	8*	9	10	11	12*	13	14*	15	> 15
Series1	52.71	33.33	50%	0%	25%	25%	78%	66.67	33.33	33.33	60.00	52.38	57.14	66.67	28.57	75%	60%	60.87

Figure 3.15 Prevalence of current playing-related pain (within the last week) in a population with history of recent playing-related pain by years taking lessons.
Note: * indicates a sample size of 5 or less.

Q4 Is there a relation between the age respondents started the horn and prevalence of lifetime PRP?

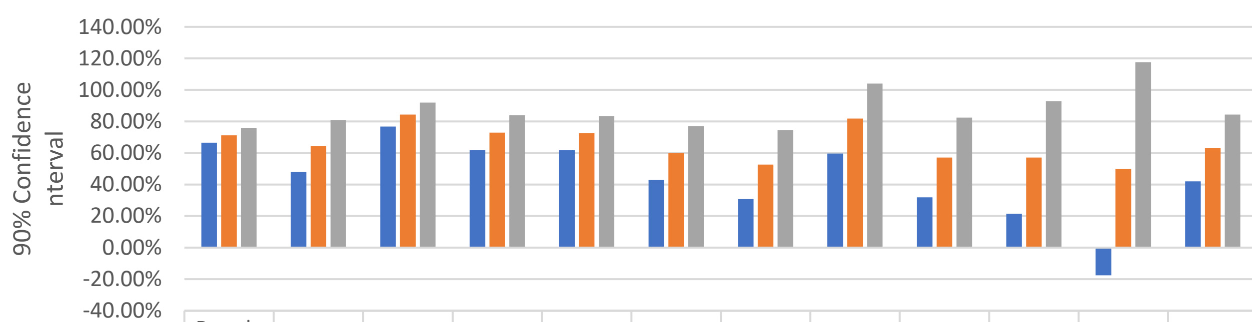
Figure 3.16 shows lifetime prevalence rates of PRP broken down by the age hornists started the instrument; the population had an average rate of 71.09%. Figure 3.17 shows the 90% confidence intervals of lifetime PRP by the age respondents started the horn. Starting the horn at the age of 10 has significantly higher prevalence of lifetime PRP than the average population; starting the horn in teenage years or later may help prevent the development of PRP. Many elementary-aged students are too small to hold full-size horn easily, and the physical compensations they necessarily adopt at an early age to hold up the instrument become habitual unless corrected by a teacher once they have grown.



	<10	10	11	12	13	14	15	16	17*	18*	>18	Average
Series1	64.52%	84.34%	72.88%	72.58%	60%	52.63%	81.81%	57.14%	57.14%	50%	63.16%	71.22%

Prevalence of Lifetime PRP

Figure 3.16 Prevalence of lifetime playing-related pain by age began the horn.
Note: red border shows significantly difference from the average population at $p < .10$, and * indicates a sample size of less than 10.



	Popula tion	<10	10	11	12	13	14	15	16	17	18	>18
Lower Bound	66.51%	48.10%	76.72%	61.83%	61.76%	42.92%	30.75%	59.61%	31.88%	21.42%	-17.53%	42.02%
Prevalence	71.22%	64.52%	84.34%	72.88%	72.58%	60.00%	52.63%	81.82%	57.14%	57.14%	50.00%	63.16%
Upper Bound	75.93%	80.93%	91.96%	83.94%	83.40%	77.08%	74.51%	104.03%	82.40%	92.87%	117.53%	84.29%

Age Began Horn

Lower Bound Prevalence Upper Bound

Figure 3.17 Ninety percent confidence intervals of lifetime prevalence of playing-related pain by respondents' age began the horn.

Q5 Is there a relation between the number of years playing the horn and prevalence of lifetime PRP?

Figure 3.18 shows the numbers of respondents with and without PRP by of years playing the horn. There is a pattern similar to the data of hornist age; more respondents reported PRP approximately when most hornists are in college or at the beginning of their careers, and the lowest rate is for the longest-playing respondents, likely because most players suffering chronic PRP do not make it to 40 years of playing.

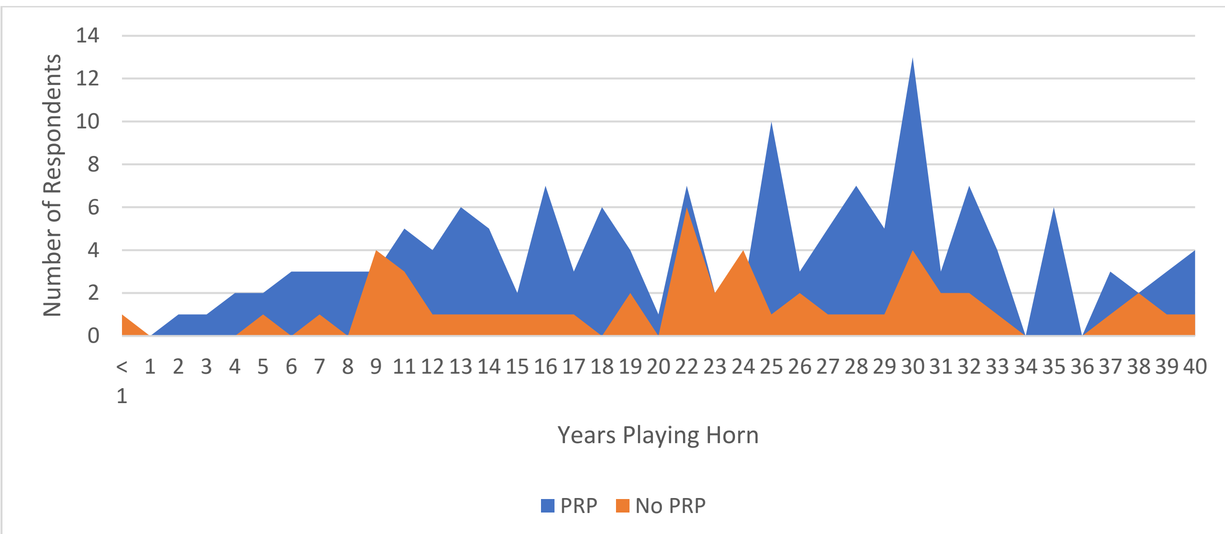
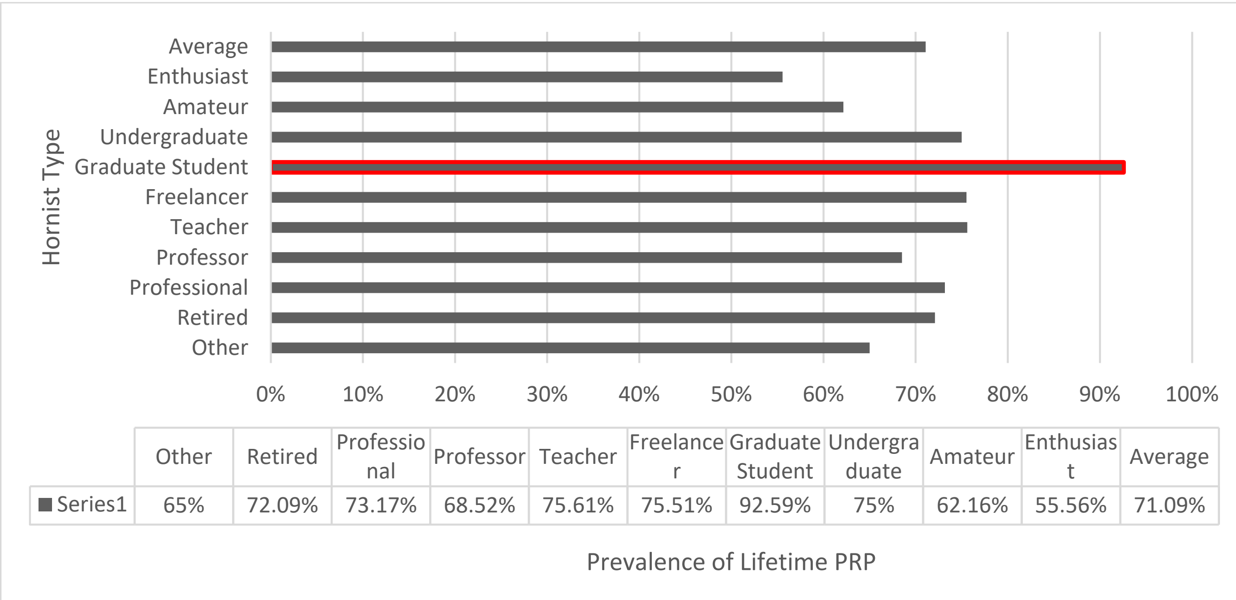


Figure 3.18 Number of respondents with and without of lifetime playing-related pain by years playing the horn.

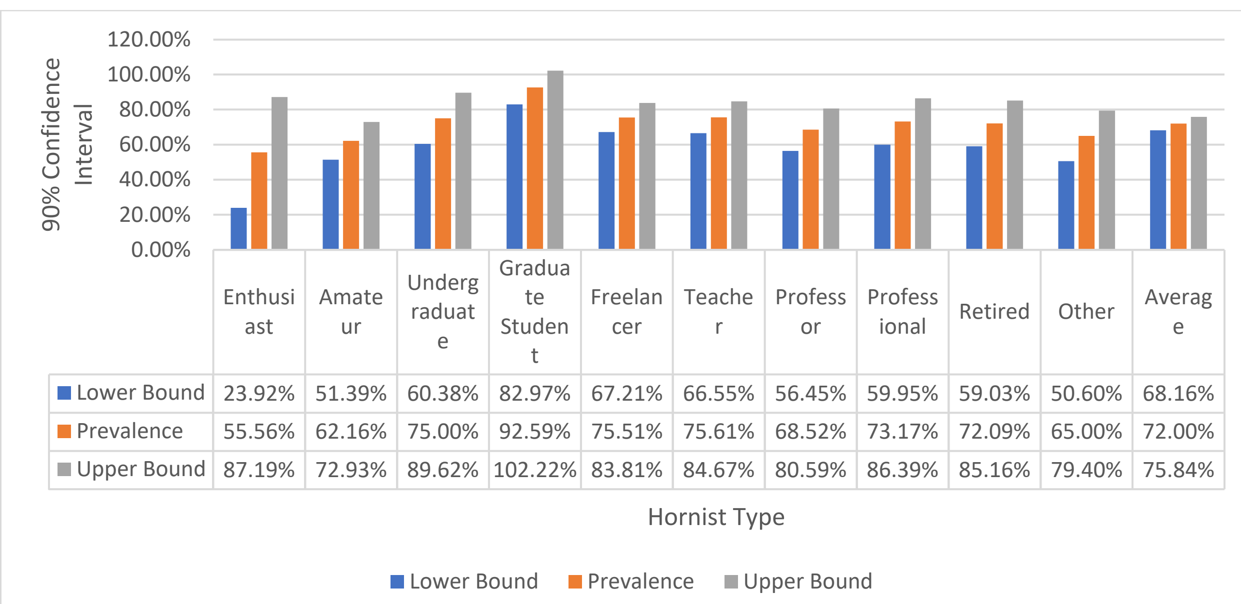
Q6 Is there a relation between musician class (undergraduate student, freelancer, professional, etc.) and prevalence of lifetime, recent, or current PRP?

Figure 3.19 breaks down the prevalence of lifetime PRP by type of horn player. Figure 3.20 shows 90% confidence intervals for all categories of hornist type. Graduate students showed a significantly higher prevalence rate of lifetime PRP than the average population, professors, and amateurs. Respondents were able to select multiple responses. An enthusiast is defined as a player who enjoys the horn but does not play it regularly; while an amateur is defined as someone who regularly plays the horn but who is rarely paid to do so. A freelancer is defined as a player who is paid to perform with multiple ensembles; while a professional is someone who performs fulltime with primarily 1 ensemble. The teacher category includes respondents who teach private lessons and/or public school. Enthusiasts and amateur hornists, who do not face the financial pressure to continue playing while in pain, report lower rates of lifetime PRP.



	Other	Retired	Professional	Professor	Teacher	Freelancer	Graduate Student	Undergraduate	Amateur	Enthusiast	Average
Series1	65%	72.09%	73.17%	68.52%	75.61%	75.51%	92.59%	75%	62.16%	55.56%	71.09%

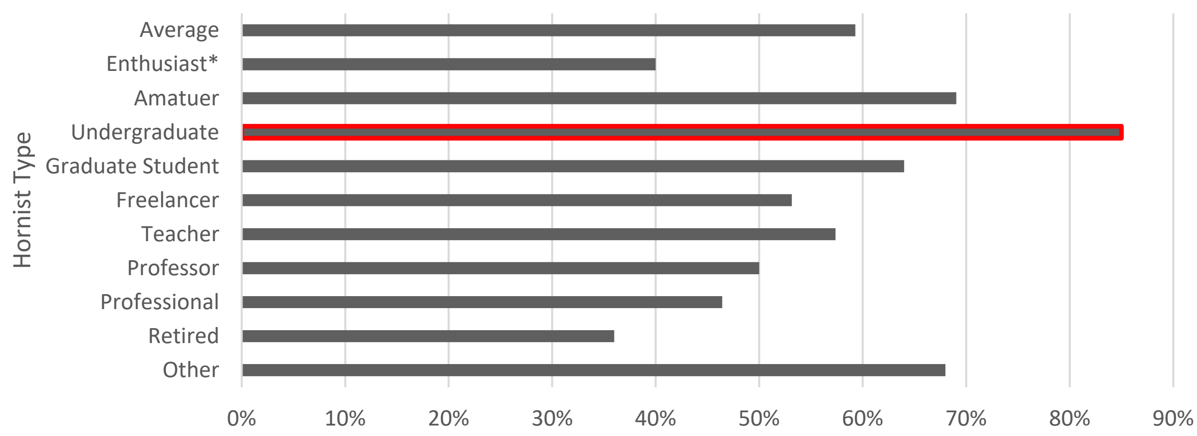
Figure 3.19 Prevalence of lifetime playing-related pain by hornist type.
Note: red border shows significantly difference from the average population at $p < .10$.



	Enthusiast	Amateur	Undergraduate	Graduate Student	Freelancer	Teacher	Professor	Professional	Retired	Other	Average
Lower Bound	23.92%	51.39%	60.38%	82.97%	67.21%	66.55%	56.45%	59.95%	59.03%	50.60%	68.16%
Prevalence	55.56%	62.16%	75.00%	92.59%	75.51%	75.61%	68.52%	73.17%	72.09%	65.00%	72.00%
Upper Bound	87.19%	72.93%	89.62%	102.22%	83.81%	84.67%	80.59%	86.39%	85.16%	79.40%	75.84%

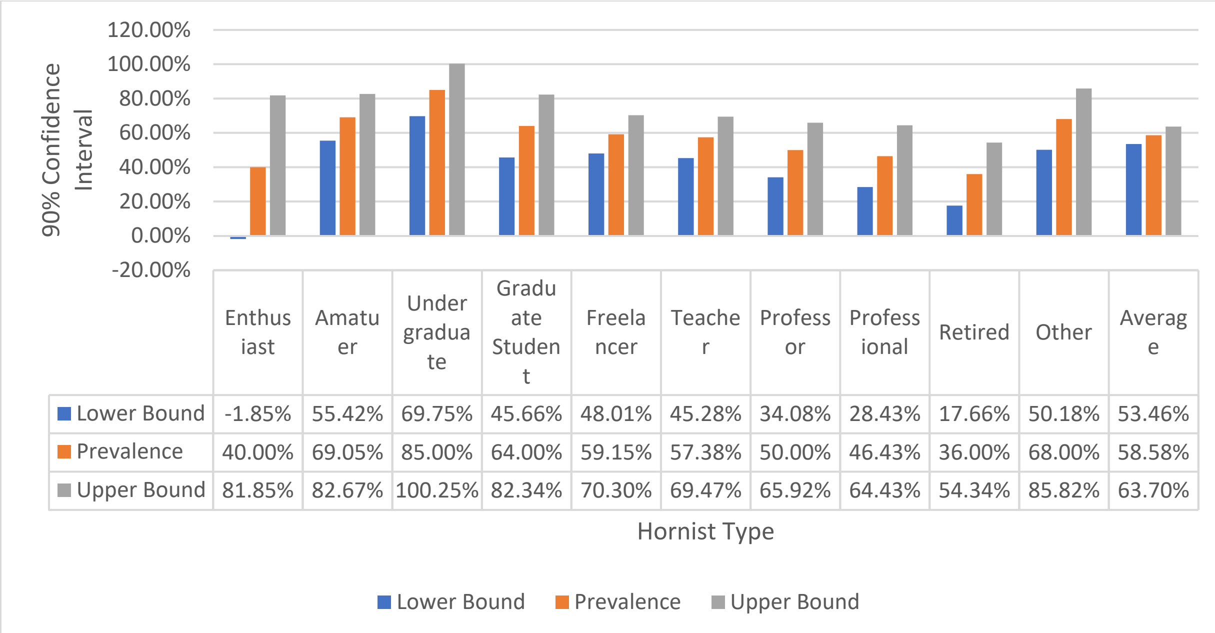
Figure 3.20 Ninety percent confidence intervals of lifetime playing-related pain by horn player type.

Figure 3.21 shows hornists with a lifetime history of PRP who reported recent PRP broken down by hornist type. Figure 3.22 shows 90% confidence intervals recent PRP by hornist type. Undergraduate students had significantly higher recent PRP prevalence than the average population, teachers, professors, professionals, and retired hornists. This suggests that undergraduate students are either less able to access coping strategies to relieve their PRP and/or are experiencing their first instance of PRP. Professionals, college professors and freelancers who may have more experience managing PRP are likely better able to tailor their playing schedule to avoid overuse injuries than college students with less experience, knowledge of the literature, and ability to reduce their playing obligations. Additionally, retired hornists had significantly lower prevalence rates than amateurs.



	Other	Retired	Professional	Professor	Teacher	Freelancer	Graduate Student	Undergraduate	Amatuer	Enthusiast*	Average
Series1	68%	36%	46.43%	50%	57.38%	53.16%	64%	85%	69.05%	40%	59.29%

Figure 3.21 Prevalence of recent playing-related pain in a population with a lifetime history of playing-related pain by hornist type.
Note: red border shows significantly difference from the average population at $p < .10$, and * indicates a sample size less than 10.



	Enthusiast	Amatuer	Undergraduate	Graduate Student	Freelancer	Teacher	Professor	Professional	Retired	Other	Average
Lower Bound	-1.85%	55.42%	69.75%	45.66%	48.01%	45.28%	34.08%	28.43%	17.66%	50.18%	53.46%
Prevalence	40.00%	69.05%	85.00%	64.00%	59.15%	57.38%	50.00%	46.43%	36.00%	68.00%	58.58%
Upper Bound	81.85%	82.67%	100.25%	82.34%	70.30%	69.47%	65.92%	64.43%	54.34%	85.82%	63.70%

Figure 3.22 90% confidence intervals and averages of recent playing-related pain in a population with a lifetime history of playing-related pain by hornist type.

Figure 3.23 shows the prevalence rates of hornists with a history of recent PRP reporting current PRP (within the last week) broken down by hornist type. Figure 3.24 shows 90% confidence intervals for prevalence of current PRP in a population with recent PRP by hornist type; all intervals overlap, so no category is significantly different. The average prevalence rate for this population is 50%; graduate students, freelancers, and retired hornists reported pain at a higher prevalence rate than the average. Overall, university students, with increased playing responsibilities and fewer coping mechanisms, are populations that may be more likely to have a history of PRP and be coping with current PRP.

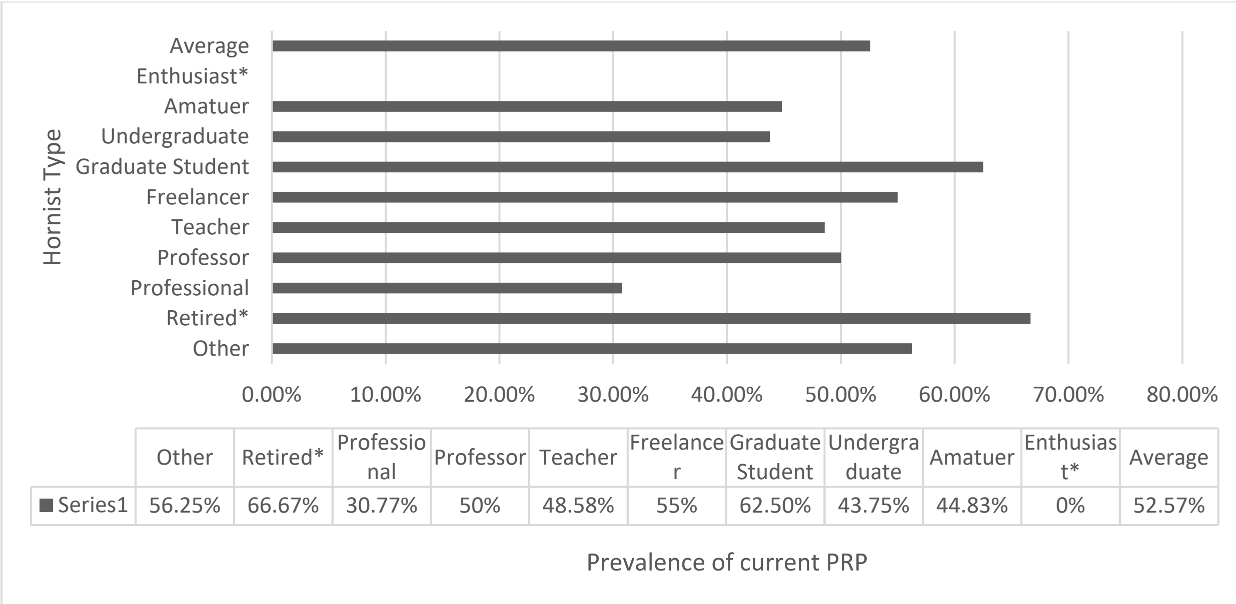


Figure 3.23 Prevalence of current playing-related pain in a population with a lifetime history of playing-related pain by horn player type.
Note: * indicates a sample size less than 10.

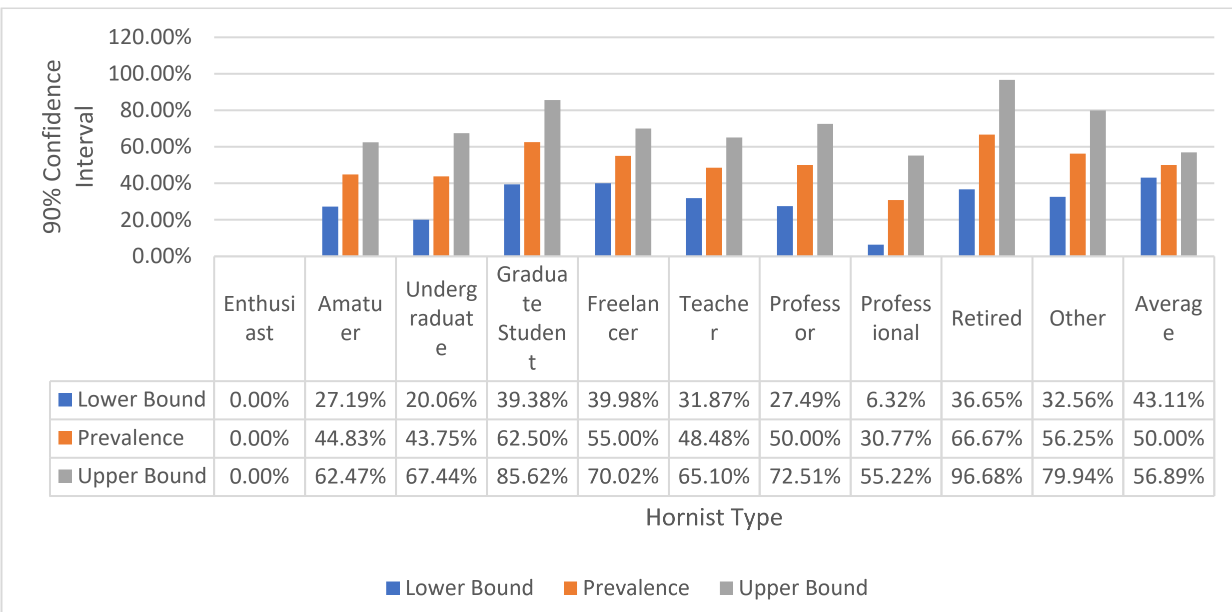


Figure 3.24 Ninety percent confidence intervals and averages of current playing-related pain in a population with a recent history of playing-related pain by horn player type.

Q7 Is there a relation between specializing in primarily high horn, low horn, or mixed and prevalence of lifetime PRP?

Respondents were asked to select the primary parts that they perform on and were allowed to make multiple choices. Principal and third were always considered high horn, second and fourth always low; assistant/utility was considered either high or low. Respondents deemed high horn players only selected principal, third, assistant/utility, or some combination thereof. Respondents deemed as low horn players only selected second, fourth, assistant/utility, or some combination thereof. Respondents who selected only assistant/utility were considered high hornists. Respondents who selected second or fourth in combination with principal and/or third were considered mixed players.

Figure 3.25 shows the prevalence of lifetime PRP broken down by high/low/mixed specialties. Figure 3.26 shows 90% confidence intervals of prevalence of lifetime PRP by high/low/mixed specialties. All the confidence intervals overlap, so at 90% confidence level, there is not statistically significant difference between any of the categories. When compared to the population average of 71.39%, mixed playing shows a higher prevalence of lifetime PRP, specializing in high playing shows a lower prevalence of lifetime PRP than the average, and specializing in low playing shows an approximately average prevalence of lifetime PRP.

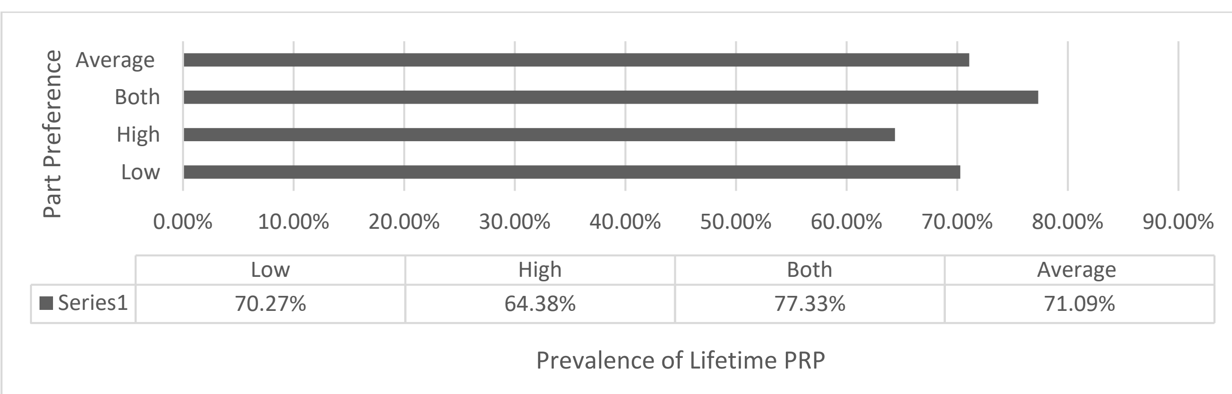


Figure 3.25 Prevalence of lifetime playing-related pain in hornists specializing in low, high, or mixed parts.

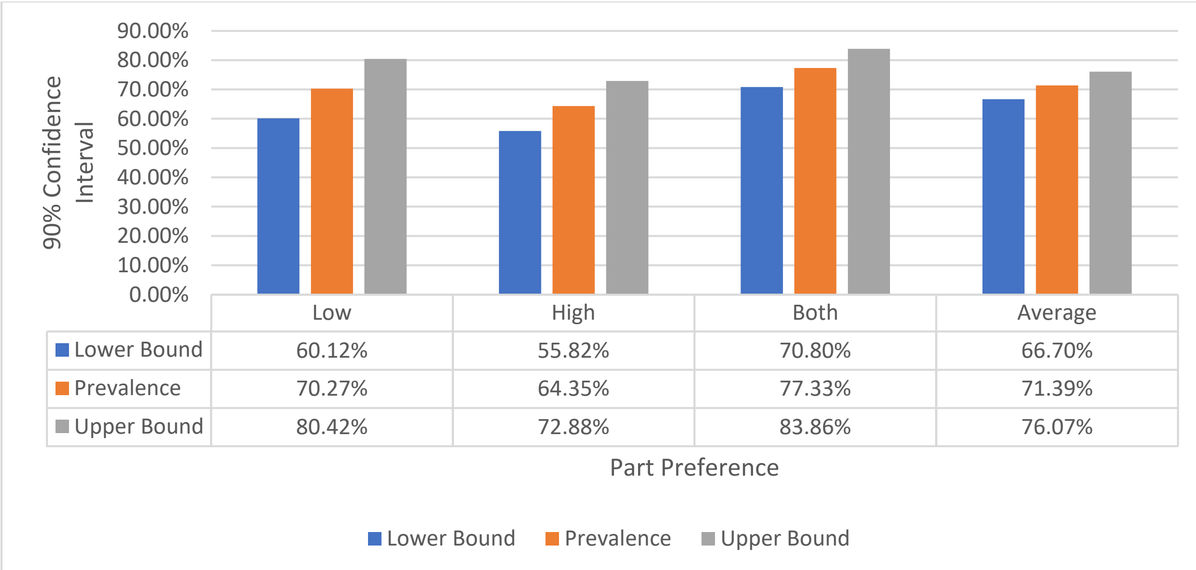
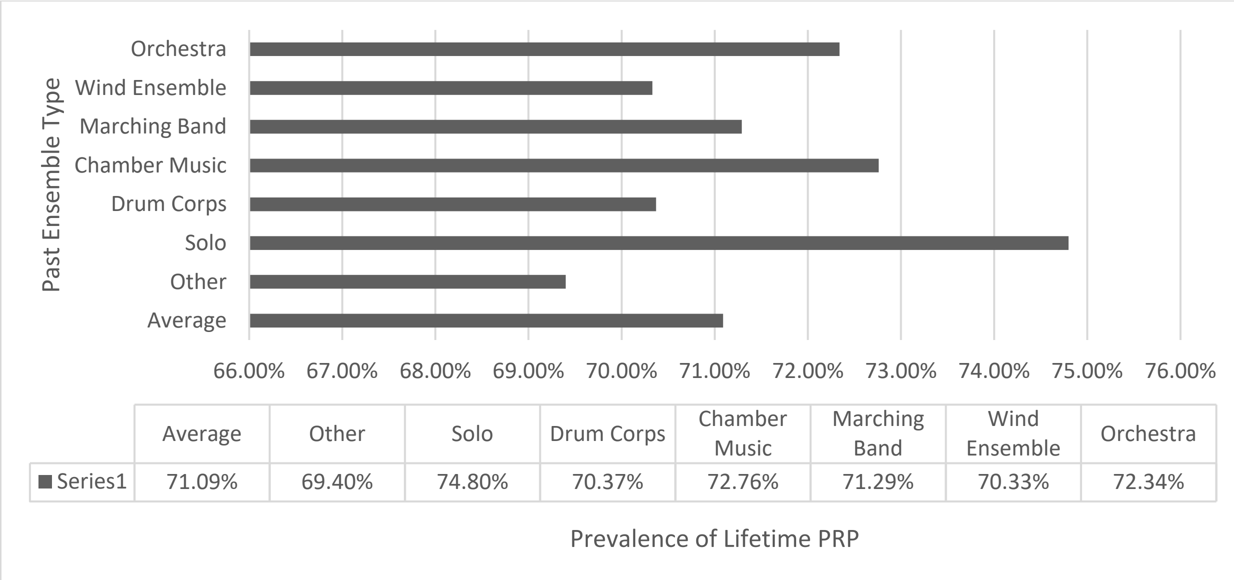


Figure 3.26 Ninety percent confidence intervals of prevalence of lifetime playing-related pain in hornists specializing in low, high, or mixed parts.

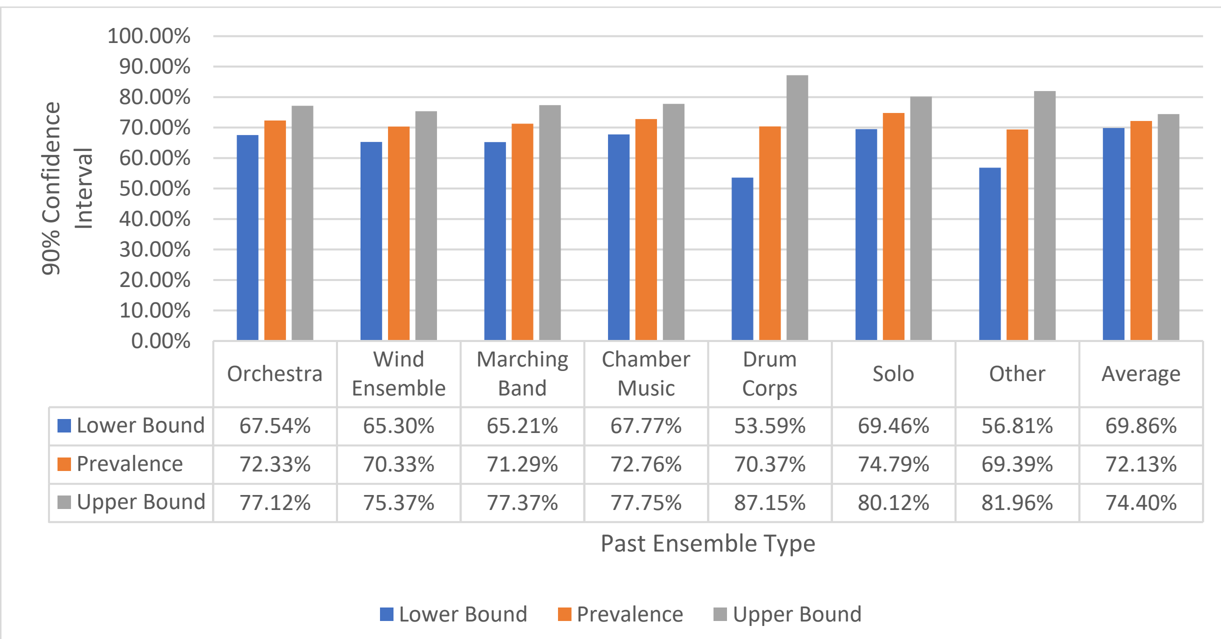
Q8 Is there a relation between a history of playing in a certain type of ensemble (i.e., marching band or orchestra) and prevalence of lifetime PRP?

Figure 3.27 shows the prevalence of lifetime PRP broken down by experience playing in various ensembles. Figure 3.28 shows 90% confidence intervals of prevalence of lifetime PRP broken down by experience playing in various ensembles. When compared to the mean value of 72.13%, all ensemble experience was within 3 percentage points; all confidence intervals overlapped, so none were significantly different. Many of the categories represented a large majority of respondents: over 80% of respondents indicated that they had a history of playing in an orchestra, wind ensemble, or chamber ensemble, while between 50 and 60% of respondents had a history of performing in marching band or solos. Only 7.6% of respondents had a history of playing in drum corps.



	Average	Other	Solo	Drum Corps	Chamber Music	Marching Band	Wind Ensemble	Orchestra
Series1	71.09%	69.40%	74.80%	70.37%	72.76%	71.29%	70.33%	72.34%

Figure 3.27 Prevalence of lifetime playing-related pain with history of various ensemble playing.



	Orchestra	Wind Ensemble	Marching Band	Chamber Music	Drum Corps	Solo	Other	Average
Lower Bound	67.54%	65.30%	65.21%	67.77%	53.59%	69.46%	56.81%	69.86%
Prevalence	72.33%	70.33%	71.29%	72.76%	70.37%	74.79%	69.39%	72.13%
Upper Bound	77.12%	75.37%	77.37%	77.75%	87.15%	80.12%	81.96%	74.40%

Figure 3.28 Ninety percent confidence intervals of prevalence of lifetime playing-related pain with history of various ensemble playing.

Q9 Is there a relation between currently playing in certain ensembles (i.e., marching band or orchestra) and prevalence of current or recent PRP?

Figure 3.29 shows recent prevalence of PRP among hornists with a lifetime history of PRP broken down by current ensemble type. The average prevalence rate was 59.69%. Figure 3.30 shows the 90% confidence intervals of prevalence of recent PRP in horn players with a lifetime history of PRP by current ensemble type. All the intervals overlap, so no category is significantly different at a 90% confidence level.

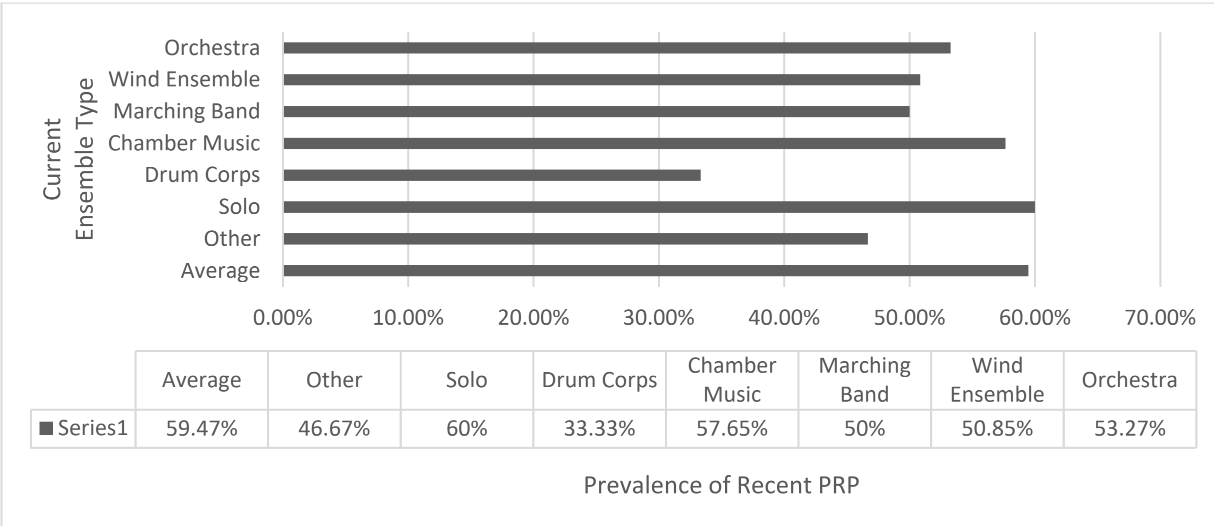


Figure 3.29 Prevalence of recent (within the last year) playing-related pain in horn players with a lifetime history of playing-related pain by current ensemble type.

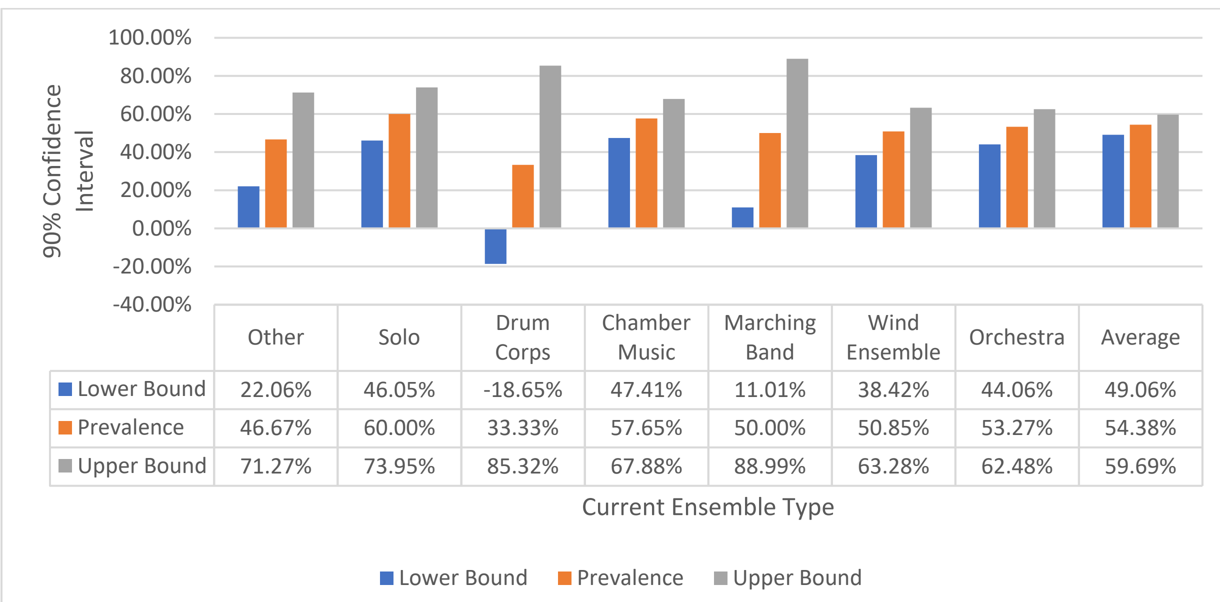
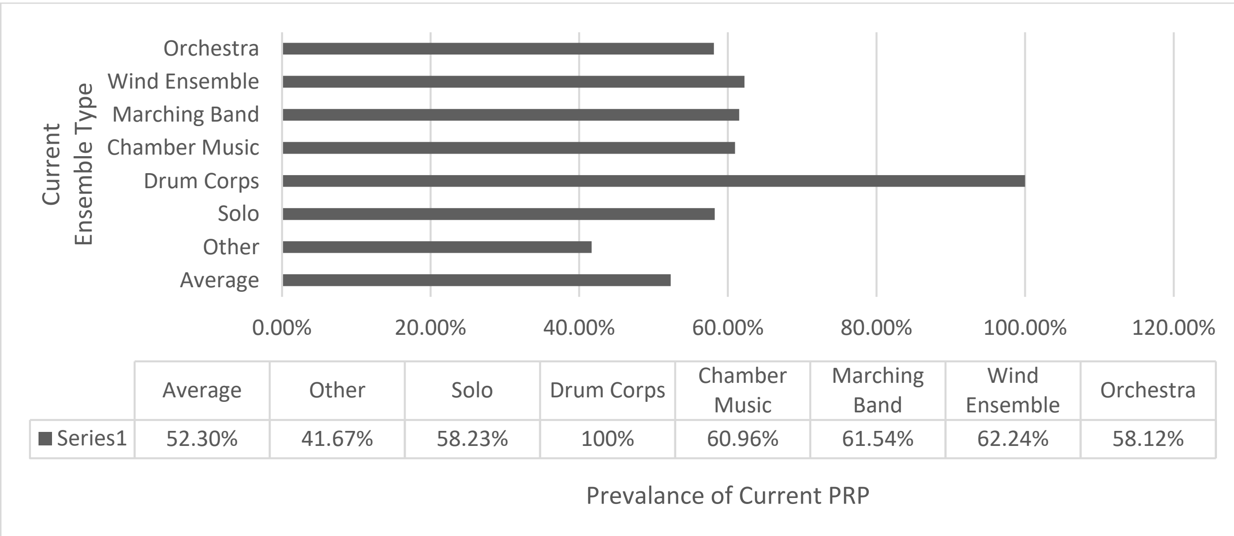


Figure 3.30 Ninety percent confidence intervals of prevalence of recent (within the last year) playing-related pain in horn players with a lifetime history of playing-related pain by current ensemble type.

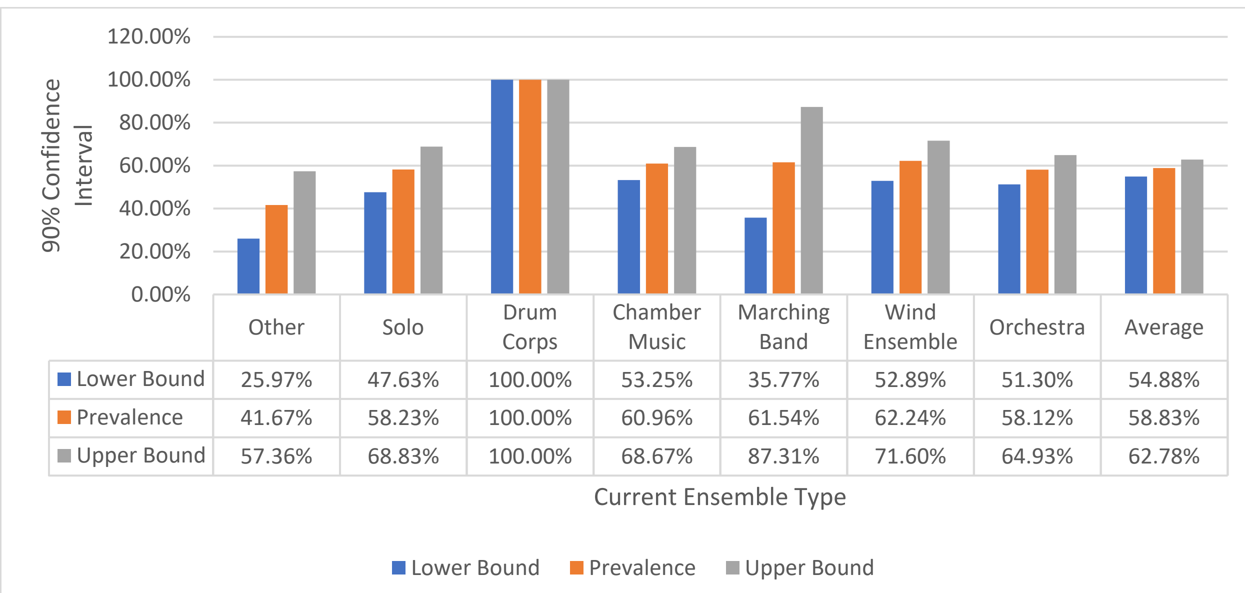
Figure 3.31 shows current prevalence of PRP among hornists with a recent history of PRP broken down by current ensemble type. The overall average was 54.88%. Figure 3.32

shows 90% confidence intervals of prevalence of current PRP of horn players with a recent history of PRP by ensemble type. With the exception drum corps members, which had a sample size of 1, all the confidence intervals overlap, so none were significantly different.



	Average	Other	Solo	Drum Corps	Chamber Music	Marching Band	Wind Ensemble	Orchestra
Series1	52.30%	41.67%	58.23%	100%	60.96%	61.54%	62.24%	58.12%

Figure 3.31 Prevalence of current (within the last week) playing-related pain of horn players with a recent history of playing-related pain by ensemble type.

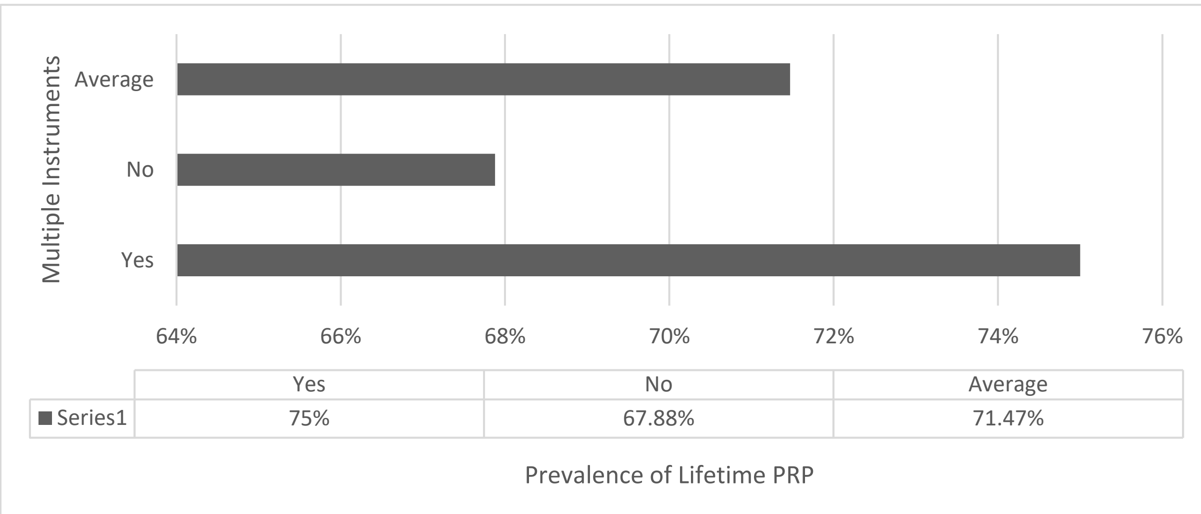


	Other	Solo	Drum Corps	Chamber Music	Marching Band	Wind Ensemble	Orchestra	Average
Lower Bound	25.97%	47.63%	100.00%	53.25%	35.77%	52.89%	51.30%	54.88%
Prevalence	41.67%	58.23%	100.00%	60.96%	61.54%	62.24%	58.12%	58.83%
Upper Bound	57.36%	68.83%	100.00%	68.67%	87.31%	71.60%	64.93%	62.78%

Figure 3.32 Ninety percent confidence intervals of prevalence of current (within the last week) playing-related pain of horn players with a recent history of playing-related pain by ensemble type.

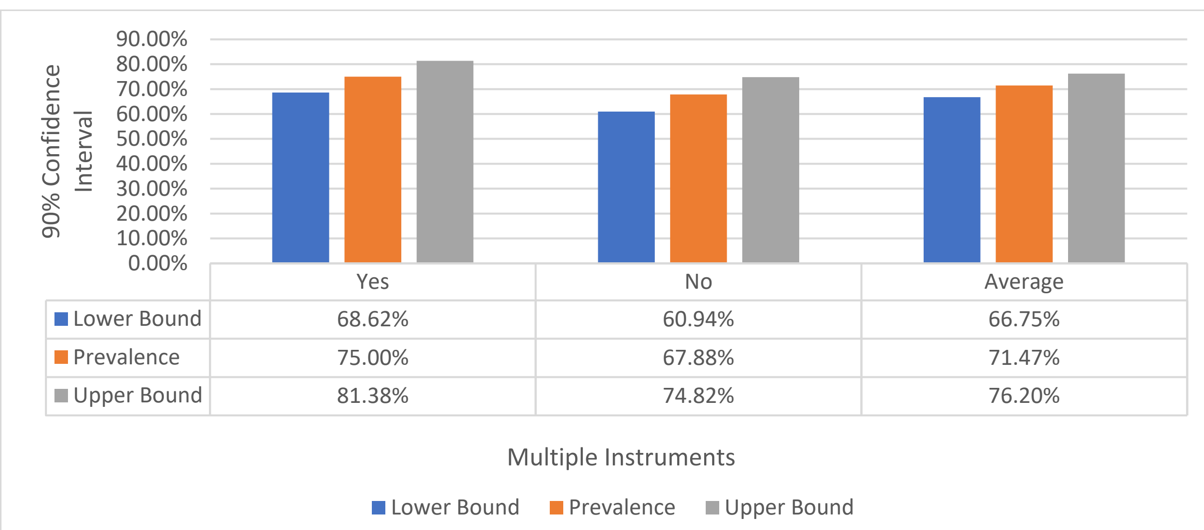
Q10 Is there a relation between playing multiple instruments and lifetime prevalence of PRP?

Figure 3.33 shows the prevalence rate of lifetime PRP for hornists who only played the horn and those who reported playing other instruments. Figure 3.34 shows 90% confidence intervals for rates of lifetime PRP broken down by respondents who only played the horn and those who played other instruments; 90% confidence intervals all overlapped, so neither is statistically significantly different.



	Yes	No	Average
Series1	75%	67.88%	71.47%

Figure 3.33 Prevalence of lifetime playing-related pain by respondents who reported playing instruments other than horn.



	Yes	No	Average
Lower Bound	68.62%	60.94%	66.75%
Prevalence	75.00%	67.88%	71.47%
Upper Bound	81.38%	74.82%	76.20%

Figure 3.34 Ninety percent confidence intervals for lifetime playing-related pain by respondents who reported playing instruments other than horn.

Q11 Is there a relation between typical number of hours playing the horn per week and prevalence of current or recent PRP?

Figure 3.35 shows the prevalence of recent PRP in respondents with lifetime PRP broken down by typical number of hours playing the horn per week. Figure 3.36 shows 90% confidence intervals for the prevalence of recent PRP in respondents with lifetime PRP by typical number of hours playing the horn per week. The mean PRP prevalence was 59.47%. Playing less than 5 hours per week showed a statistically significant lower PRP prevalence rate of 32.14% at a 90% confidence interval.

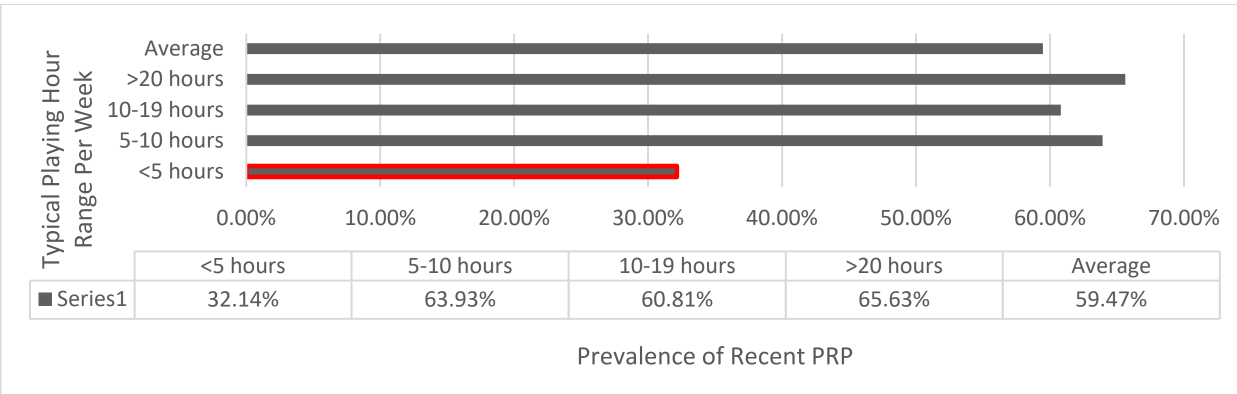


Figure 3.35 Prevalence of recent playing-related pain (within a year) in respondents with a lifetime history of playing-related pain by typical number of hours playing the horn per week. *Note*: red border shows significantly difference from the average population at $p < .10$.

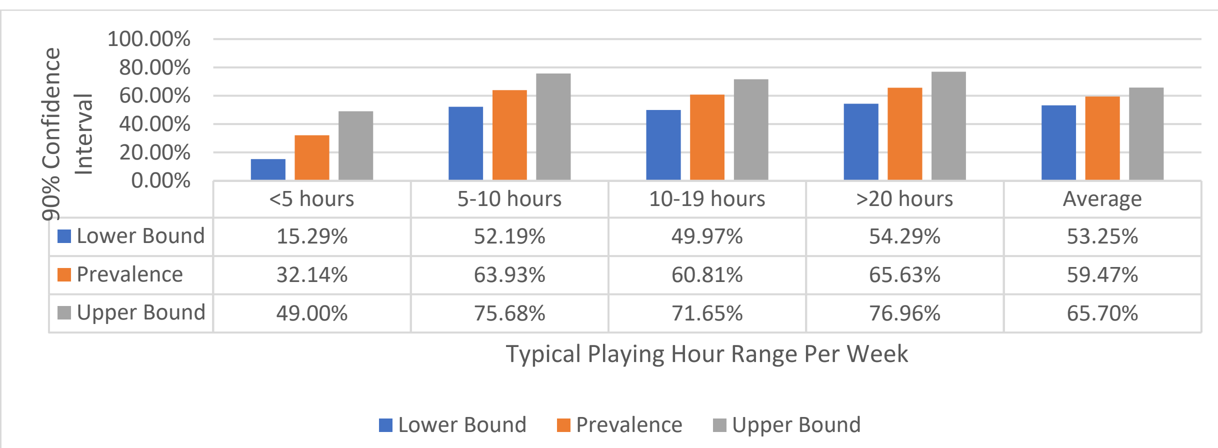
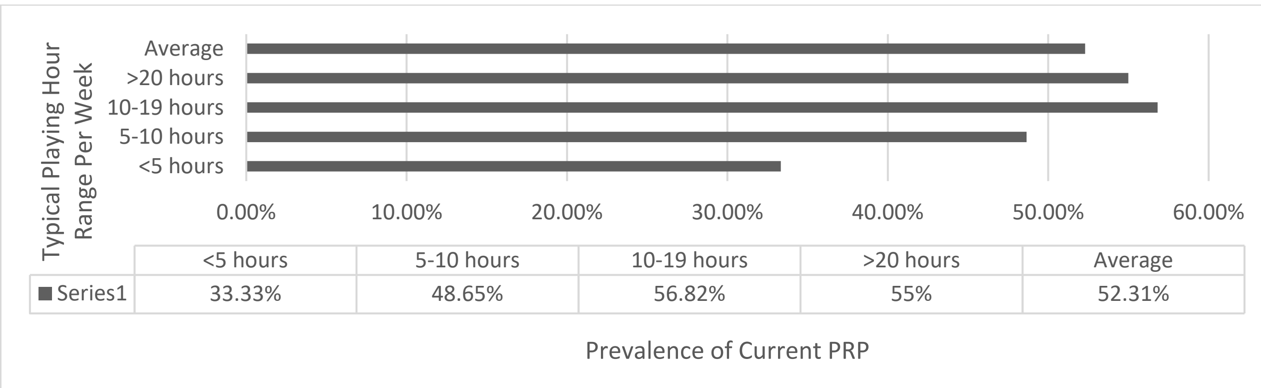


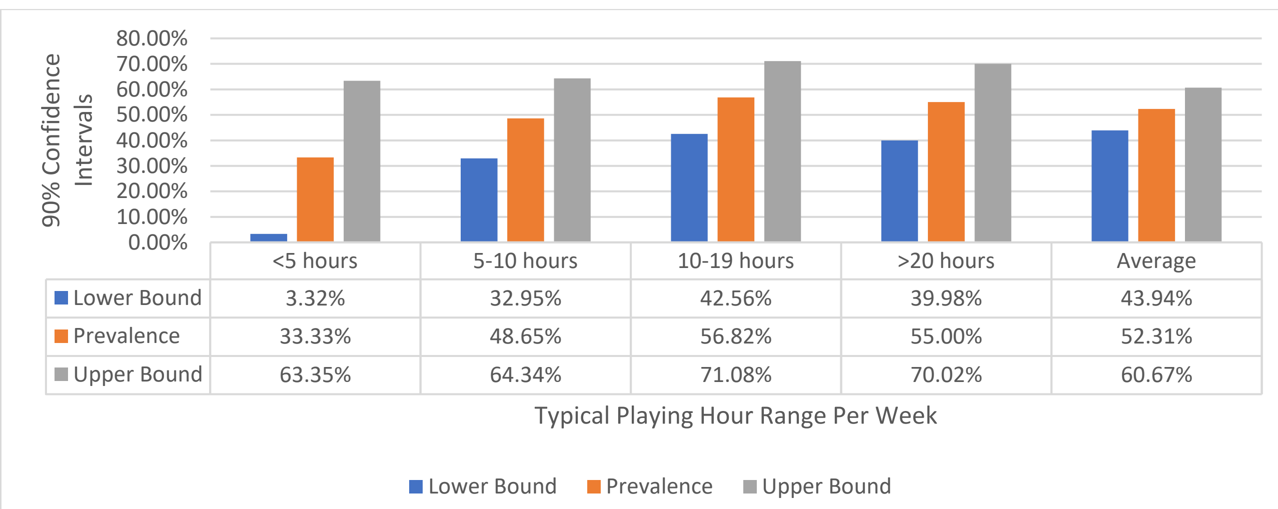
Figure 3.36 Ninety percent confidence intervals for prevalence of recent playing-related pain (within a year) in respondents with a lifetime history of playing-related pain by typical number of hours playing the horn per week.

Figure 3.37 shows the prevalence of current PRP in respondents with recent PRP broken down by typical number of hours playing the horn per week. The mean PRP prevalence was 52.31%. Figure 3.38 shows 90% confidence intervals for the prevalence of current PRP in respondents with a recent history of PRP broken down by typical number of hours playing the horn per week. All categories’ confidence intervals overlap, so none are significantly different. The sample size for playing less than 5 hours per week was too small to show a statistical significance, but at 33.33%, is similar to the statistically significant prevalence of recent PRP.



	<5 hours	5-10 hours	10-19 hours	>20 hours	Average
Series1	33.33%	48.65%	56.82%	55%	52.31%

Figure 3.37 Prevalence of current playing-related pain (within a week) in respondents with a recent history of playing-related pain by typical number of hours playing the horn per week.



	<5 hours	5-10 hours	10-19 hours	>20 hours	Average
Lower Bound	3.32%	32.95%	42.56%	39.98%	43.94%
Prevalence	33.33%	48.65%	56.82%	55.00%	52.31%
Upper Bound	63.35%	64.34%	71.08%	70.02%	60.67%

Figure 3.38 Ninety percent confidence intervals of prevalence of current playing-related pain (within a week) in respondents with a recent history of playing-related pain by typical number of hours playing the horn per week.

Q12 Is there a relation between typical number of hours sitting in a week and prevalence of current or recent PRP?

Figure 3.39 shows the prevalence of recent PRP in respondents with lifetime PRP by reported typical number of hours sitting each week. Figure 3.40 shows 90% confidence intervals for the prevalence of recent PRP in respondents with lifetime PRP by reported typical number of hours sitting each week. All categories overlapped at a 90% confidence interval, so although sitting less than 4 hours per week has a much lower prevalence rate, the sample size was too small to establish significance at 90% confidence.

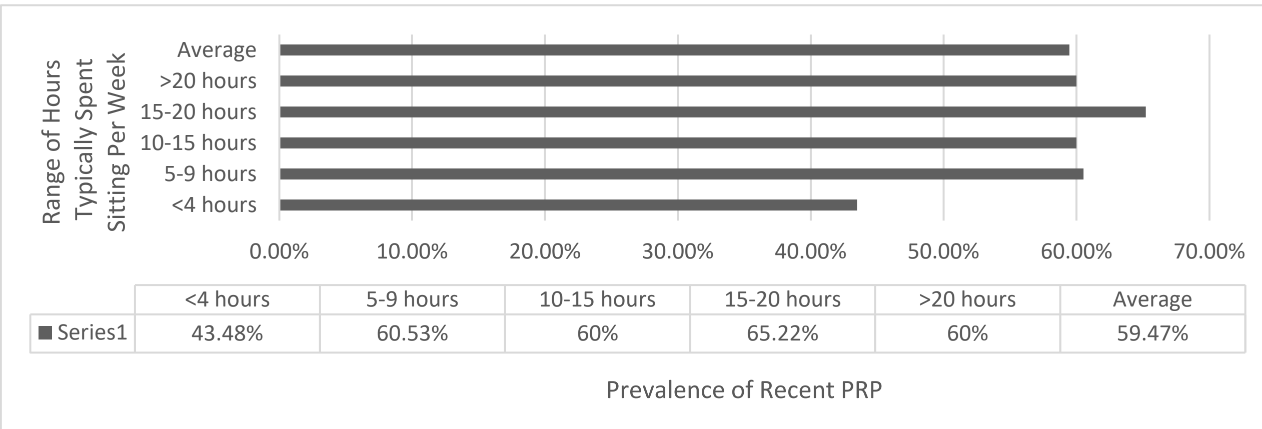


Figure 3.39 Prevalence of recent playing-related pain in respondents with lifetime playing-related pain by reported typical number of hours sitting each week.

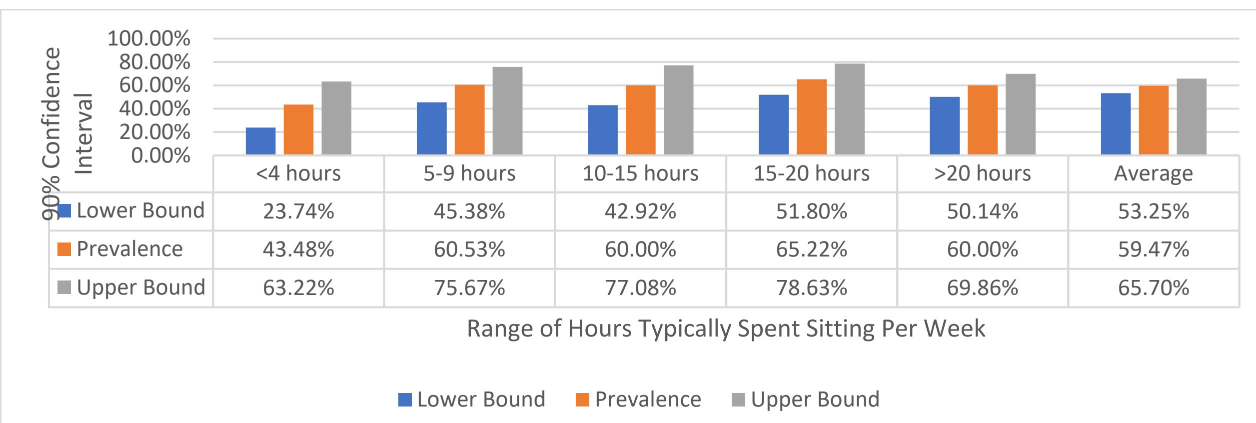
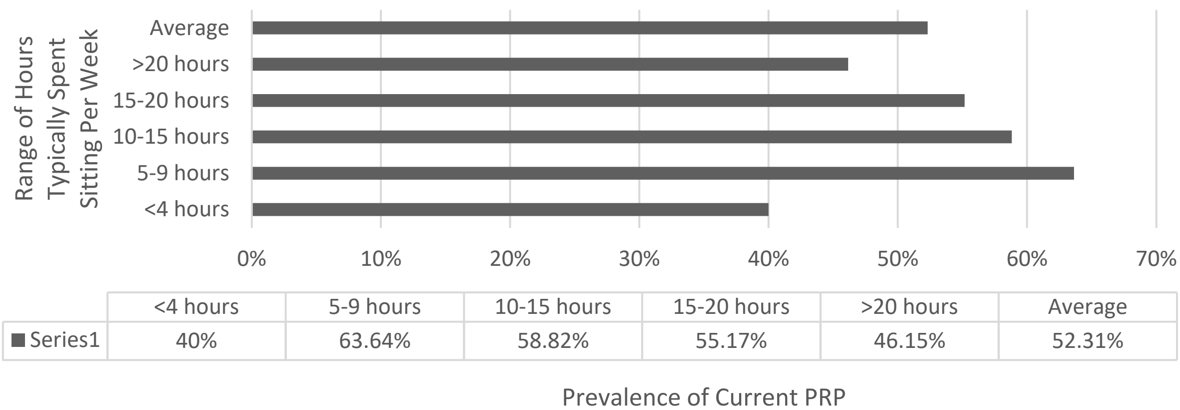


Figure 3.40 Ninety percent confidence intervals for prevalence of recent playing-related pain in respondents with lifetime playing-related pain by reported typical number of hours sitting each week.

Figure 3.41 shows the prevalence of current PRP in respondents with recent PRP by reported average number of hours sitting each week. There is no relation with the average number of hours spent sitting per week and current prevalence of PRP, sample sizes were too small to establish significance for any category.



	<4 hours	5-9 hours	10-15 hours	15-20 hours	>20 hours	Average
Series1	40%	63.64%	58.82%	55.17%	46.15%	52.31%

Figure 3.41 Prevalence of recent playing-related pain in respondents with a history of lifetime playing-related pain by reported average number of hours sitting each week.

Q13 Is practicing the horn sitting, standing, or both a risk or protective factor for lifetime prevalence of PRP?

Figure 3.42 shows the prevalence rate of lifetime PRP by typical practice position. Figure 3.43 shows 90% confidence intervals for the prevalence rate of lifetime PRP by typical practicing position. Significance could not be established at a 90% confidence interval for any category because of small sample sizes; standing all the time has a much lower prevalence rate than the average of 71.3% but only consisted of a sample size of 7 as most hornists practice seated unless they are preparing a solo.

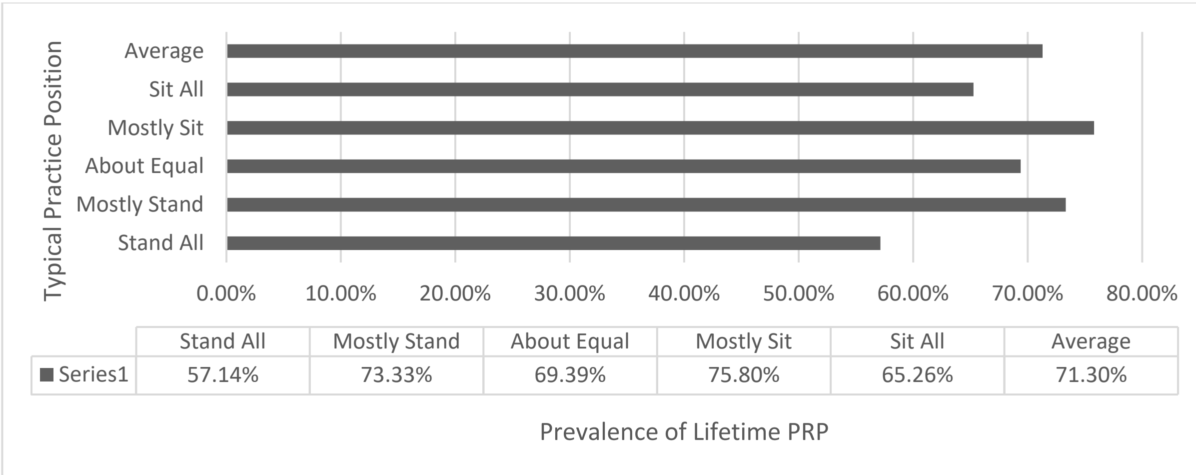


Figure 3.42 Prevalence rates of lifetime playing-related pain by typical practicing position.

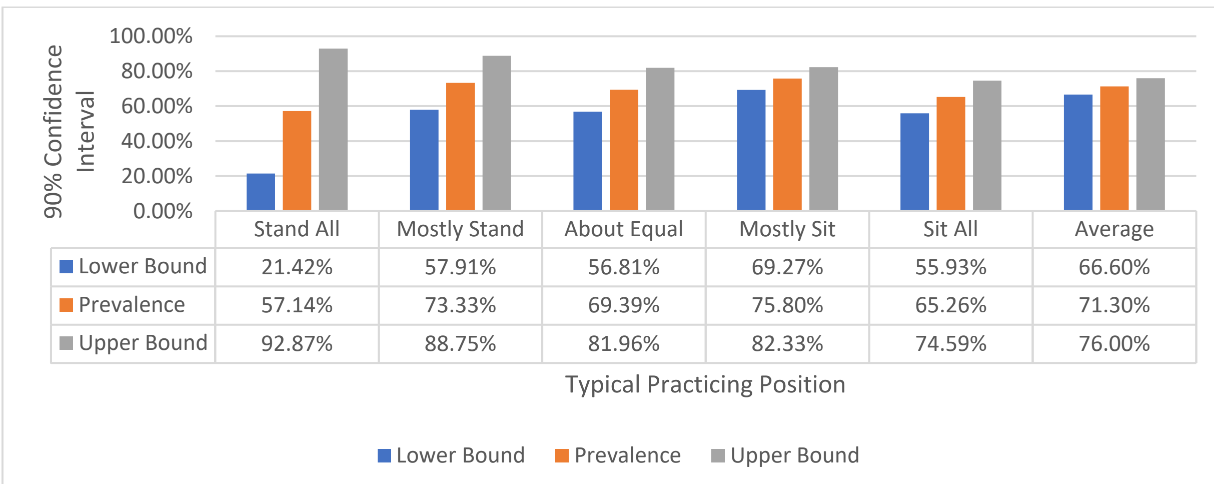


Figure 3.43 Ninety percent confidence intervals for prevalence rate of lifetime playing-related pain by typical practicing position.

Q14 Is performing the horn sitting, standing, or both a risk or protective factor for lifetime prevalence of PRP?

Figure 3.44 shows the prevalence rate of lifetime PRP by typical performing position. Figure 3.45 shows 90% confidence intervals for the prevalence rate of lifetime PRP by typical performing position. Significance could not be established at a 90% confidence interval for any category because of small sample sizes; however, standing all the time and sitting all the time had much lower prevalence rates than the average of 71.3%

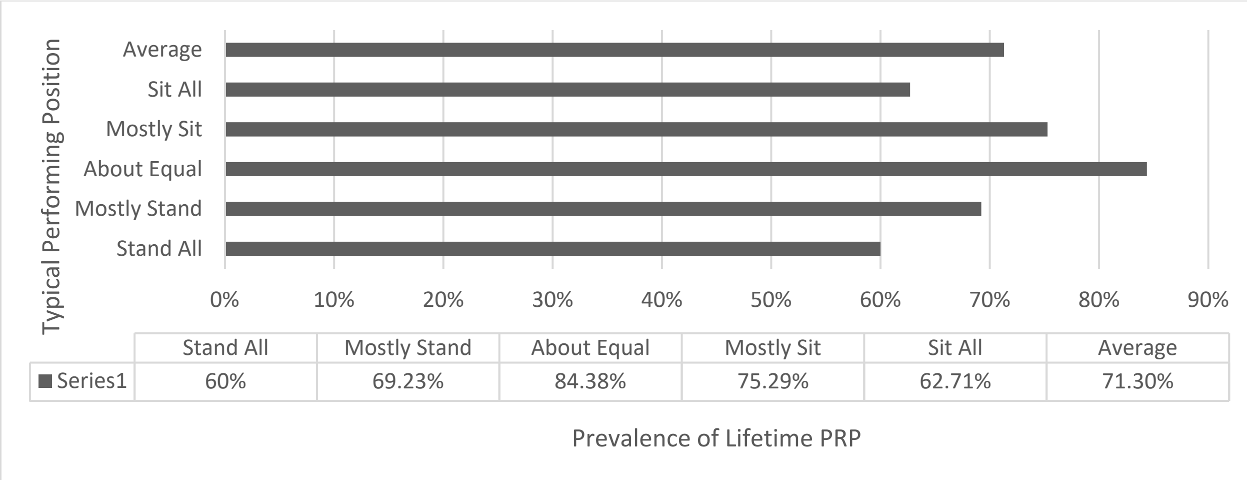


Figure 3.44 Prevalence rate of lifetime playing-related pain by typical performing position.

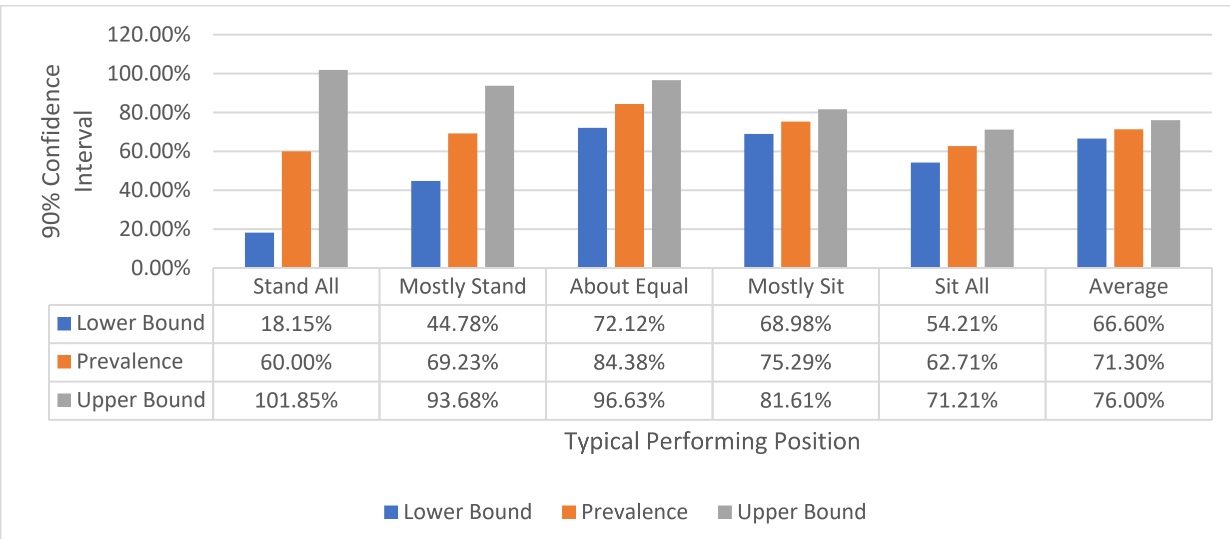
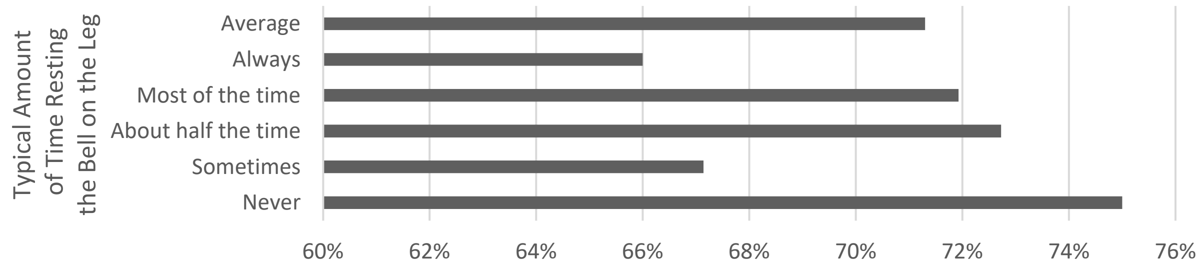


Figure 3.45 Ninety percent confidence intervals for prevalence of lifetime playing-related pain by typical performing position.

Q15 Is resting the horn on the leg when playing a risk or protective factor for lifetime prevalence of PRP?

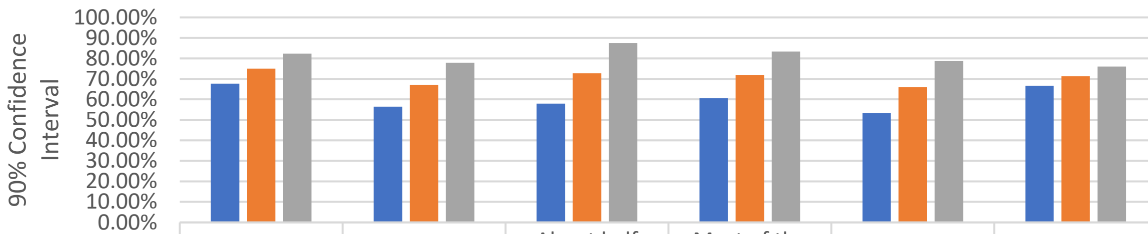
Figure 3.46 shows the prevalence rate of lifetime PRP by amount of time typically spent resting the bell of the horn on the leg. Figure 3.47 shows 90 % confidence intervals for the prevalence rate of lifetime PRP by amount of time typically spent resting the bell of the horn on the leg. Significance could not be established for any category at a 90% confidence interval, so no risk or protective factors could be determined.



	Never	Sometimes	About half the time	Most of the time	Always	Average
Series1	75%	67.14%	72.73%	71.93%	66%	71.30%

Prevalence of Lifetime PRP

Figure 3.46 Prevalence of lifetime playing-related pain by typical amount of time resting the bell on the leg.



	Never	Sometimes	About half the time	Most of the time	Always	Average
Lower Bound	67.69%	56.42%	57.92%	60.56%	53.20%	66.60%
Prevalence	75.00%	67.14%	72.73%	71.93%	66.00%	71.30%
Upper Bound	82.31%	77.87%	87.54%	83.30%	78.80%	76.00%

Typical Amount of Time Resting the Bell on the Leg

Lower Bound Prevalence Upper Bound

Figure 3.47 Ninety percent confidence intervals for prevalence of lifetime playing-related pain by typical amount of time resting the bell on the leg.

Q16 How do horn teachers currently describe good posture or body use to their students?

Players who indicated that teaching horn was a primary part of their careers were asked "Please describe how you teach students to hold their instrument. What do you look to correct?" Below are some of the responses (edited for clarity).

Right hand shaped like a hand shake. Curled left hand fingers. Gentle angle with the horn across the body so the bell doesn't point straight into the leg. Lead pipe should come straight to face which steers things like bell being on or off leg.

The main focus is to create a relatively natural posture that allows one to play this awkwardly shaped instrument in the most relaxed way possible. Each student is different and their height, strength, flexibility and size of instrument can be important factors to take into account.

Start with good posture, spine aligned, windpipe straight, bring horn to you not the other way around. Horn should be balanced between both hands to allow for natural movement and being able to play for long periods of time. No bell on knee!

Left arm not elevated as a chicken wing, both elbows essentially pointed downwards; shoulders not too tilted (especially not hunching left shoulder), right hand in bell with fingers and thumb together very slightly bent; weight of horn on right hand first knuckle/finger and base of thumb; the bulk of the weight should be on the right hand so the left is free and calm for operating valves. Almost to the point you could imagine (only imagine) balancing the horn on the right hand.

I try to ensure that they are aware of their skeletal alignment, and are using their muscles as efficiently as possible (i.e., not contorted). If they have their arms akimbo, or are arching their back, or have some type of postural habit that will lead to more tension and strain on their bodies, I try to correct that.

I teach students to balance the weight of the horn across the top of their right hand. I also highly encourage the use of an installed duck foot flipper for ergonomic support of the horn on the left hand. I find that this helps negate unwanted tension on that side. On or off the leg is fine so long as right-hand position is correct and bell placement is away from the abdomen.

Knees below sit bones, sitting upright but neutrally-not overly "straight", I advocate for bell off the leg unless students have preexisting issues or pain, I also advocate for a duck's foot and no pinky ring on their horn, straight right hand where horn sits on top of hand/index, neutral straight neck/head, looking for students who lean forward and or tilting.

We must first look at our posture without the horn: gentle S-curve of the back, sitting bones planted in the chair, the base of the back of the head back, shoulders down. I then incorporate the horn by making sure "the horn comes to you; you do not change the aforementioned posture to fit the horn". Elbows down and close to the body. This would be for both on- and off-the-leg playing.

I want them to be balanced in their chair and find a balanced way to support the horn, with the lead pipe at a slightly downward angle. I often recommend a hand strap for smaller students in order to prevent posture abnormalities from trying to shift the weight of the horn to accommodate their smaller hands. Head and neck should be in alignment -- I coach them to "bring the horn to you, not the other way around."

I make sure that the body is balanced first and the neck stays as neutral as possible. Then I encourage my students to bring the horn to their lips without twisting the torso or bending their neck. This is an effort to offset the unbalanced load that the horn places on the body. Usually, this results in playing off the leg.

"Bring the horn to you", imagine a rope through your spine out the top of your head pulling you to the ceiling, bell off the leg, horn loop for hand where possible, support to hold up horn where needed/possible.

Comfortably upright posture; bring the horn to you; lead pipe angled down roughly 45 degrees; feet on the floor; [bell] on or off the leg is fine, provided your torso is upright and forward; can move leg to accommodate bell or use a foot pedal to facilitate playing on the leg.

I get them to stand or sit with good posture, bring the horn up with both arms equal and central (mouthpipe is now too much to their left) then turn their head slightly to the left and allow the right shoulder to go back a small amount. No exaggerated asymmetry. Then bring the horn to the head, not the head to the horn.

Establishing good posture is an important first step for many horn teachers; there are a lot of similarities between teachers' descriptions of how they teach posture. There are also some teachers that directly contradict each other. Many teachers recommended a "natural" position; what precisely is meant by "natural" position is sometimes unclear. Another common theme is setting a balanced posture first and then bringing the horn to the face rather than adjusting the body to fit the horn. Right-hand position and holding the bell on or off of the leg are also common themes.

Q17 What are the most common locations and intensities of pain reported by hornists suffering PRP during their lifetime?

Two hundred twenty-four participants with PRP identified the anatomical locations of their pain from an anatomical map.[92] Figure 3.48 shows the prevalence rates of lifetime PRP by

[92] See question 18 in survey in Appendix A to view an image of the anatomical map

anatomical location. Areas of particular concern are concentrated along the left upper extremity/neck/back, the lips/jaw, and the lower back.

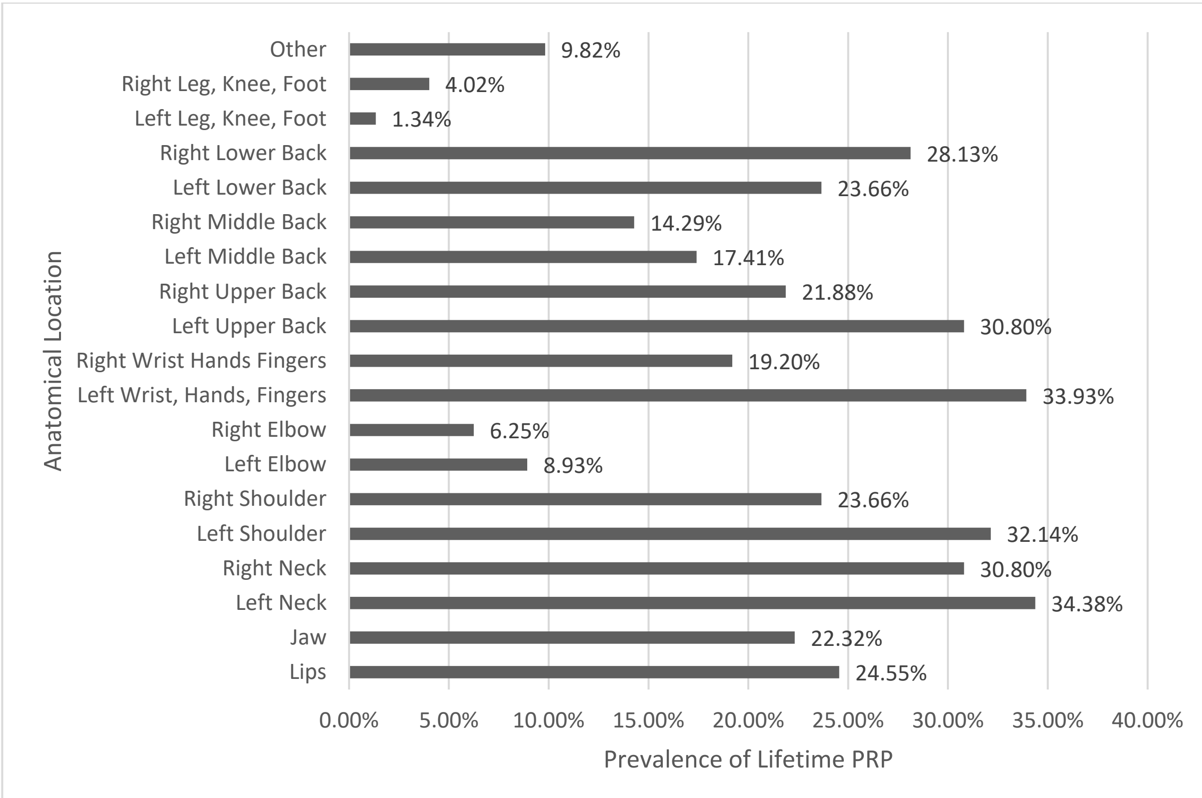


Figure 3.48 Prevalence rates of lifetime playing-related pain by anatomical location.

Table 3.1 shows the average reported intensities of lifetime pain broken down by anatomical site. Respondents were asked to report the highest intensity of their pain during their lifetime on a scale of 1 to 5, 1 being mild and 5 being excruciating. Some of the locations cited by individuals in the “other” section included abdomen, hips, sternum, front of neck tendons, and ears. Table 3.1 also includes the standard error; several anatomical sites received quite small sample sizes, and as the sample size decreases, the data becomes less reliable. Higher standard errors (anything above .2), indicate the likelihood that the average pain intensity truly reflects the intensity felt in the population is less certain.

Table 3.1 Average Intensities of Lifetime Playing-Related Pain by Anatomical Site

Sites	Average intensity	Standard error
Lips	3.11	.137537
Jaw	3.04	.152735
Left Neck	3.1	.124217
Right Neck	3.17	.12159
Left Shoulder	3.22	.126101
Right Shoulder	3.21	.15247
Left Elbow	3.05	.228079
Right Elbow	2.79	.30735
Left Wrist, Hands, Fingers	2.91	.115855
Right Wrist Hands Fingers	2.85	.150974
Left Upper Back	2.91	.111959
Right Upper Back	2.88	.128571
Left Middle Back	2.92	.160128
Right Middle Back	3.09	.160867
Left Lower Back	3.57	.131866
Right Lower Back	3.59	.125988
Left Leg, Knee, Foot	3.67	.271355
Right Leg, Knee, Foot	2.78	.343333
Other	2.91	.255841

Q18 What are the most common locations and intensities of pain reported by hornists suffering recent (in the last year) PRP?

One hundred twenty-eight respondents with recent PRP identified the anatomical locations of their pain from an anatomical map.[93] Figure 3.49 shows the prevalence rates of recent PRP by anatomical location. Areas of particular concern are concentrated along the left upper extremity/neck/back, the lips/jaw, and the lower back.

[93] See question 18 in survey in Appendix A to view an image of the anatomical map

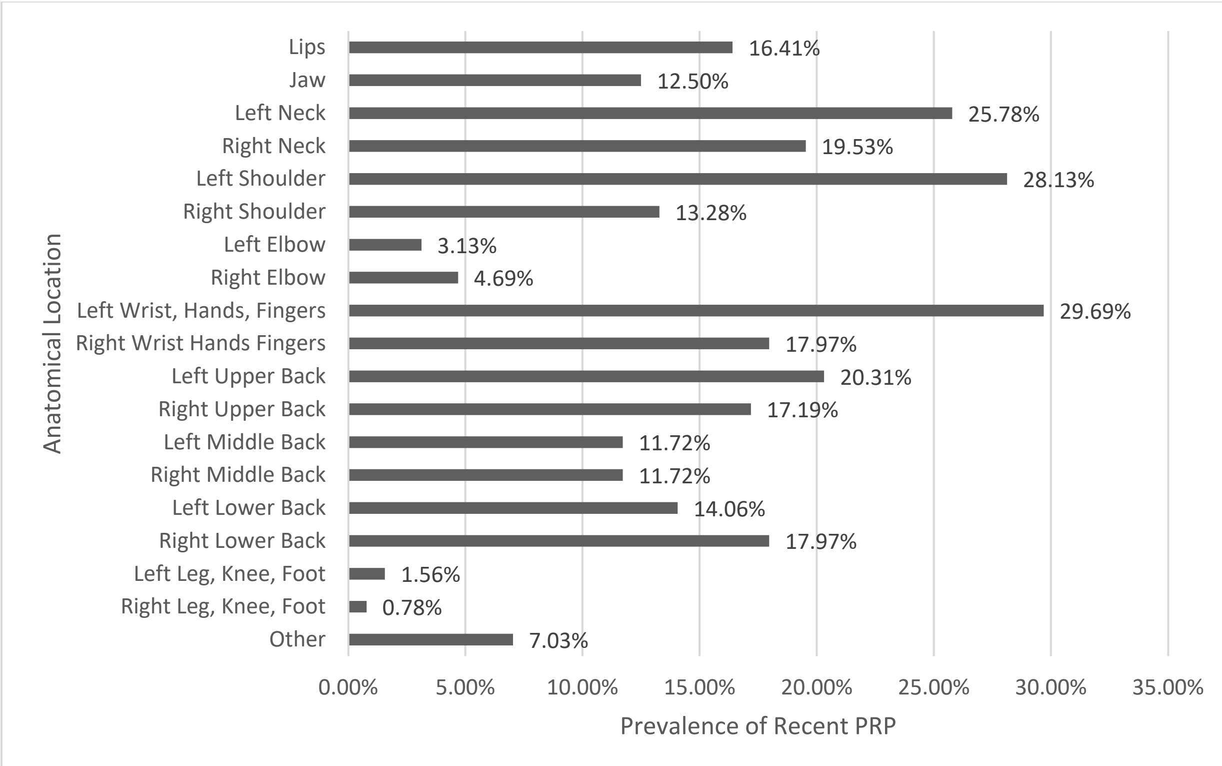


Figure 3.49 Prevalence rates of recent (within past year) playing-related pain in a population with a history of lifetime playing-related pain by anatomical location.

Table 3.2 shows the average reported intensities of recent pain broken down by anatomical site. For each selected site, respondents were asked to report the highest intensity of their pain during the last year on a scale of 1 to 5, 1 being mild and 5 being excruciating. Some of the locations cited by individuals in the "other" section included abdomen and teeth/gums. Table 3.2 also includes the standard error; several anatomical sites received quite small sample sizes, and as the sample size decreases, the data becomes less reliable. A standard error of 0 indicates that only 1 pain intensity was selected and represents a sample size of 1 or 2.

Table 3.2 Average Intensities of Recent Playing-Related Pain by Anatomical Site

Sites	Average intensity	Standard error
Lips	2.71	.202943
Jaw	3.06	.1875
Left Neck	3.15	.20193
Right Neck	3.12	.19
Left Shoulder	3.25	.176667
Right Shoulder	3.29	.232834
Left Elbow	2.5	.25
Right Elbow	3.17	.436826
Left Wrist, Hands, Fingers	2.87	.144377
Right Wrist Hands Fingers	2.74	.224764
Left Upper Back	3.04	.196004
Right Upper Back	3.05	.172582
Left Middle Back	3.2	.302093
Right Middle Back	3.47	.227215
Left Lower Back	3.33	.176777
Right Lower Back	3.48	.148045
Left Leg, Knee, Foot	5	0
Right Leg, Knee, Foot	2	0
Other	3.11	.29

Q19 What are the most common locations and intensities of pain reported by hornists suffering current (in the last week) PRP?

Sixty-eight respondents with current PRP identified the anatomical locations of their pain from an anatomical map.[94] Figure 3.50 shows the prevalence rates of current PRP by anatomical location. Areas of particular concern are concentrated along the left upper extremity/neck/back, the lips/jaw, and the lower back.

[94] See question 18 in survey in Appendix A to view an image of the anatomical map

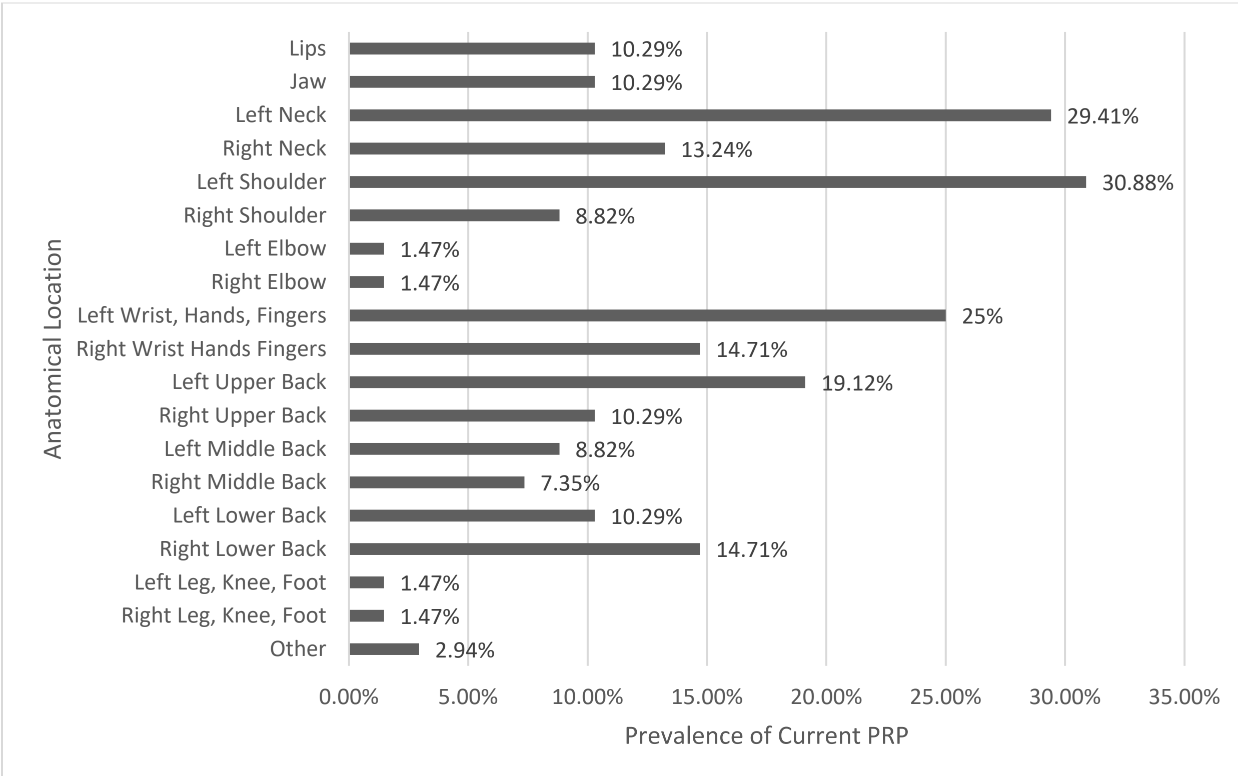


Figure 3.50 Prevalence rates of current (within last week) playing-related pain in a population with a history of recent playing-related pain by anatomical location.

Table 3.3 shows the average reported intensities of current pain broken down by anatomical site. For each selected site, respondents were asked to report the highest intensity of their pain during the last week on a scale of 1 to 5, 1 being mild and 5 being excruciating. Table 3.3 also includes the standard error; several anatomical sites received quite small sample sizes. Higher standard errors (anything above .2) indicate less reliable data. A standard error of 0 indicates that only 1 pain intensity was selected and represents a sample size of 1 or 2.

Table 3.3 Average Intensities of Current Playing-Related Pain by Anatomical Site

Sites	Average intensity	Standard error
Lips	2.29	.389303
Jaw	2.71	.264575
Left Neck	2.5	.239259
Right Neck	2.11	.29
Left Shoulder	2.71	.202943
Right Shoulder	2	.334764
Right Elbow	3	0
Left Wrist, Hands, Fingers	2.59	.23526
Right Wrist Hands Fingers	2.11	.18025
Left Upper Back	2.85	.263483
Right Upper Back	2.71	.332609
Left Middle Back	2.5	.457238
Right Middle Back	3	.281745
Left Lower Back	2.57	.185203
Right Lower Back	2.9	.297254
Left Leg, Knee, Foot	5	0
Right Leg, Knee, Foot	2	0
Other	4	0

Q20 Are there age ranges when hornists suffering PRP are most likely to first experience symptoms?

One hundred ninety-eight respondents suffering from lifetime PRP indicated their symptoms began before age 51 and had an average onset age of 27.92 years. Figure 3.51 graphs the number of respondents for each age with and without lifetime PRP; ages over 50 were grouped together in the survey and had a prevalence rate of 66.15%; this accounts for the spike at the end of the graph. There is a grouping of onset in young adults between the ages of 16 and 22, roughly corresponding to college students. This reflects the tendency of undergraduate and graduate students to report the highest prevalence levels of current and recent PRP as reported in question 6. However, while young adults seem to be at the greatest risk, it is also clear that respondents reported developing first-time symptoms at every age.

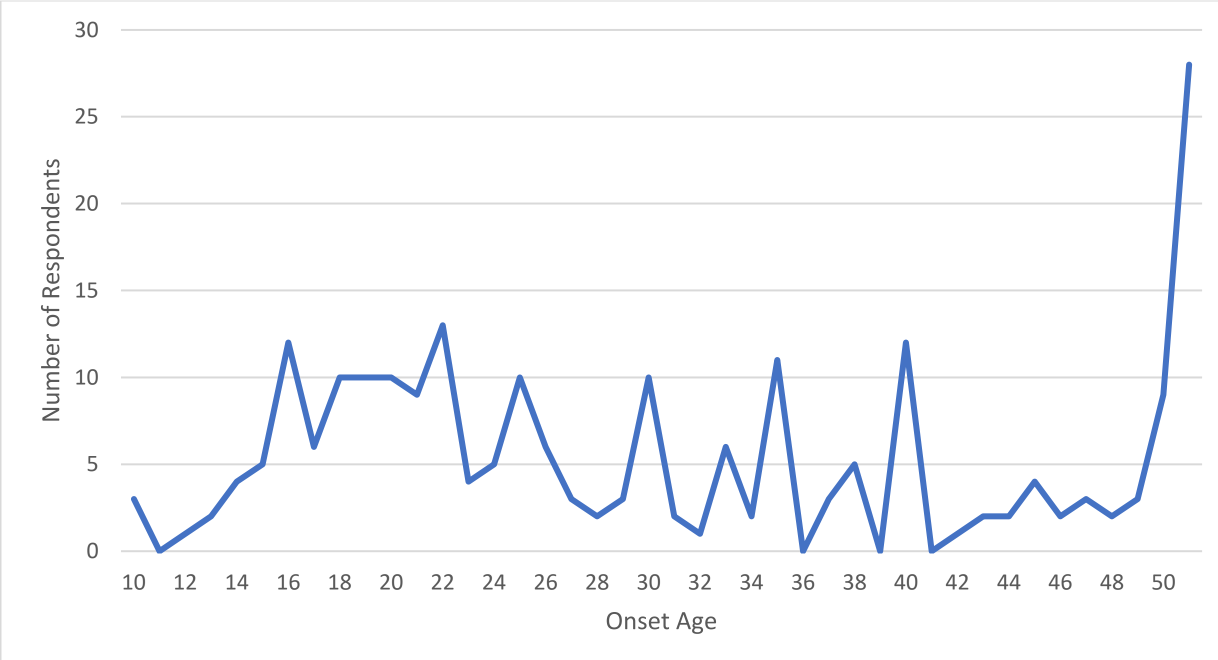


Figure 3.51 Onset age of playing-related pain.

Q21 What is the prevalence rate of receiving a satisfactory diagnosis for hornists suffering from PRP?

Of 224 responses to the question: "Have you received a satisfactory diagnosis to determine the cause or physical dysfunction that has affected your horn playing?" 53.23% responded yes, and 47.77% responded no. Arthritis, temporomandibular joint disorders (TMJ), carpal tunnel syndrome, scoliosis, pinched nerves, tendonitis, focal dystonia, and a variety of overuse and postural injuries were cited as some of the satisfactory diagnoses by respondents.

Q22 What professionals do hornists suffering from PRP consult for their conditions?

Figure 3.52 shows who respondents they have consulted about their PRP. Respondents were able to give multiple responses, so the rate of respondents who did not consult anyone was 13.83%, which is an improvement over the approximately 30% of college students and faculty with PRP who did not consult anyone reported by Stanek[95] in 2017.

[95] Stanek et al., 24.

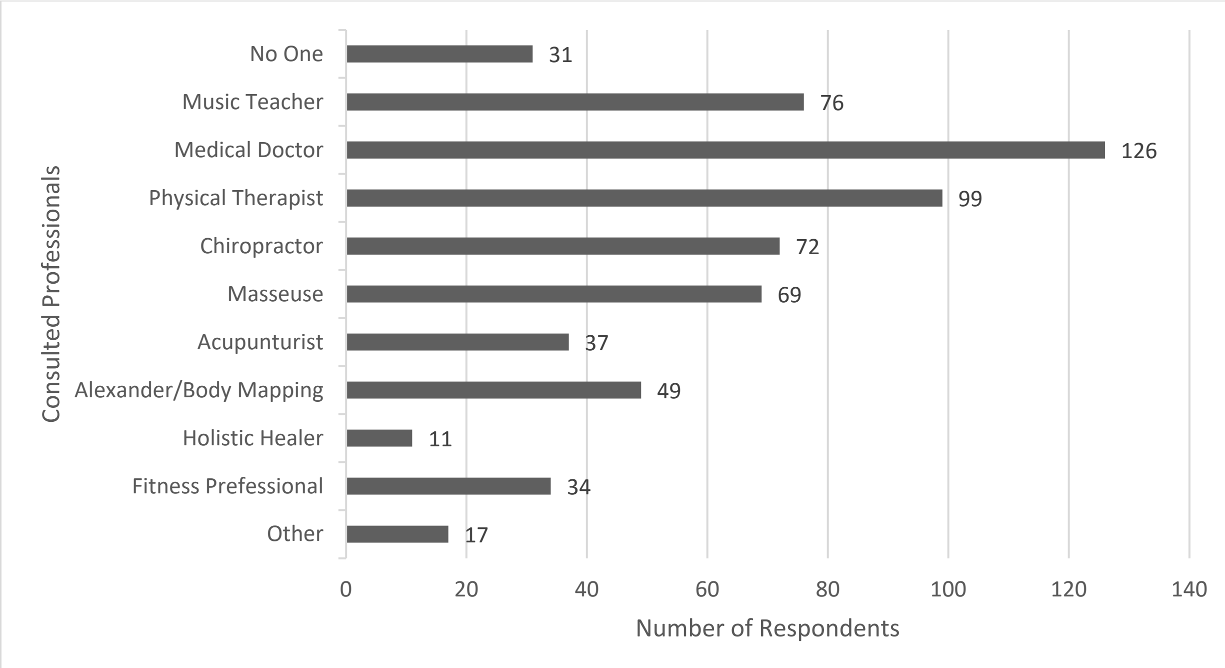


Figure 3.52 Number of responses to “Who Have you Consulted About Your Pain or Physical Dysfunction?”

Q23 What are the experiences of receiving care for PRP?

Respondents were asked to describe how hepful people who they consulted for their PRP were are relieving their conditions. Selected responses are reprinted below; they have been edited for clarity and to remove information that could personally identify a respondent.

> Not helpful, too early to fully diagnose/do anything, does not understand what is required for my instrument.
>
> Strengthening exercises (during undergrad) were helpful to some extent; massage, chiropractic provided temporary relief.
>
> Good for temporary relief, but most was them teaching me how to maintain and live with the problem, not necessarily getting rid of it since that isn’t possible. Ex: needing to stretch and do certain exercises to lessen the pain.
>
> Chiropractic very helpful, physical therapy helpful, holistic healer not helpful.
>
> Not very helpful – as an adult I was clinically recommended to decrease playing.
> Very helpful. My pain is almost completely gone after a month of therapy and exercise.

Chiropractor was excellent in keeping back pain and sciatica at bay. I also consulted a neurologist to make sure my back wasn't causing neuropathy, as I was also having numb toes (I ended up having tarsal tunnel syndrome, not caused by horn playing). After a few years my back pain went away and now I am fine. I play with no discomfort/pain.

Exceptionally helpful: my dentist had asked if I had any new pain playing Horn. I said yes, he then noted that my rear teeth (my right side) had stopped meeting. He then went forward with a referral to my orthodontist.

Music teacher was slightly helpful by constantly monitoring my posture. Physical therapist helped more, he had me bring in my horn and show him how I sit when I play, then made adjustments. Acupuncturist was most helpful, she relieved the pain completely, but I did not continue treatments.

I just have to plan for some "not so good days"

Very. My doctor is the world's leading research scientist for musician's focal dystonia.

They tried, but told me it would never heal.

The body mapping and alexander technique teachers were very helpful. Doing a general yoga and meditation practice helped me a lot, even when I was doing it without teachers. I found the physical therapist to also be very helpful in teaching me exercises to do to address specific concerns. The chiropractor was great because he also did massage, but the actual chiropractic work I am not sure was very helpful. My music teachers were generally not able to help because it was not their specialty, but their emotional support was very helpful after previous teachers who partially contributed to the injuries.

My horn teacher was the most helpful in finding the cause of the pain. The others could help treat the symptoms or helped my overall posture, but since the pain was from holding my horn, it took another small woman who played horn to help me do it correctly.

Therapy has been the most helpful resource, specifically Graston and an individualized home stretch/lifting program. Chiropractic adjustments have helped when pain is unbearable.

Not helpful at all. They say that if it hurts, to not do it.

What I think helped me the most is many hours of training with Alexander technique. I think also that I had more problems when I was resting the horn on my leg because I am quite tall and this gave me a weird posture. Now I do not have pain anymore since I adapted my posture.

Horn professor completely dismissed complaints, medical doctor prescribed braces, suggested surgery.

Few people were helpful, actually. Took a combination of physical therapy and electrostimulation to finally manage the symptoms.

The massage therapist treated my left shoulder, arm and hand, providing temporary relief. The physiotherapist had me bring in the Horn to show him exactly how I hold it, and then taught me very useful, specific exercises to strengthen my left arm. These have successfully resolved my issues for the most part. I resume the exercises whenever needed.

The doctor told me that as long as I continue playing Horn and golf, I will continue to have discomfort in my right tricep and elbows. I have had this for more than 2 years, and it is very mild now. I now play on a lighter Horn made by Finke, and use a strap which helps even out the weight of the Horn. I have also tried the Ergo Brass, but didn’t get used to it.

Music Teachers - helped with advice on recovering from overuse injury and re-thinking my approach to playing the horn. Medical Professional - gave specific diagnosis of micro-trauma overuse injury, advised extensive rest period. Chiropractor/Acupuncture/Massage - helped treat pain and general tightness. Also consulted an Ayurvedic professional - mixed feelings on the results

So far, I have not found a long-term solution to the pain I experience. Chiropractic adjustments and massage are the most beneficial, but provide only temporary relief.

Alexander practitioner has been the most beneficial. Regular strength training, stretching, and cardio help as well.

Acupuncturist was extremely helpful at the outset, PT was extremely helpful over the long term. Medical doctor was unhelpful. Chiro and massage are helpful, but don’t make dramatic changes.

I don't go to a chiropractor regularly, but when I do, adjustments help put my spine back into place, at least for a little while. The most effective treatment I've had featured the use of microcurrent therapy (TENS - Transcutaneous Electrical Nerve Stimulation, basically acupuncture + a very mild electrical current), which really helped loosen my tight muscles, albeit temporarily. I studied Alexander Technique briefly in college, but found it more useful for general activity (e.g., walking, sitting, carrying heavy objects, etc.) than for horn playing.

Alexander technique and yoga have been very helpful for pain management, and strengthening. I did a round of physical therapy in grad school, and am currently doing a second round, and both have been very helpful.

This is a nerve issue in the maxillary area that was caused by a teacher changing a setting by force. The mouthpiece was driven into my face so hard by the professor that the

> phrase "you'll never forget where that goes" was used and this started a decade long cycle of nerve and jaw related issues. I was diagnosed with what the problem could be, and did not receive further help in healing. I did use a personal trainer to teach me how to engage my core differently and fix my posture, in hopes of re-learning to loosen up my shoulders/neck/jaw while playing and recovering from this phase in my life. This has been helpful, on top of changing the setting back on my own terms.
>
> I now use a brace for my thumb and temporarily an ergobrass support. It is difficult to find someone who can help because they often don't understand that not playing is not an option.
>
> Nothing worked permanently except stopping playing

Limitations

This study had several limitations. Because amateur players, retired hornists, public school teaching hornists, and other types of horn players are often underrepresented or entirely absent from similar surveys, the goal of the various distribution methods of the survey was to reach as wide a variety of hornists as possible. Due to the method of distribution, it is impossible to calculate a response rate, so this survey may report inflated prevalence of PRP due to volunteer bias. Hornists who have suffered from PRP may be more likely to respond to this survey due to the experience of dealing with an injury than a hornist who has not. Although reported prevalence rates are possibly higher than what truly exists in the population, PRP among musicians is a well-established problem, and understanding the trends within the hornist population is relevant and important.

In the interest of LGBTQIA+ inclusivity, respondents were asked to report their gender identity, rather than their biological sex assignment at birth, so it is possible that some biological sex assignments do not match the gender that was reported. Any data that compares gender could include data of respondents assigned to another sex at birth. Respondents were also given the option to select “non-binary/third gender/other or prefer not to respond.” Data from these categories were not included in anything that compares male and female gender.

To ensure consistent understanding of the questions in a survey by respondents, some surveys are verified for reliability by surveying a small group several weeks apart and comparing data for consistency before distributing to the wider population. The survey was not verified before distribution.

Although this survey was completed by 340 respondents, the sample size was too small to determine statistical significance for most of the trends seen between subsets of the populations, such as age groups. The response pool likely needed to increase about tenfold to produce results with better statistical confidences. The active horn-playing community is small enough that reaching that many hornists would be quite challenging.

Future studies would ideally find a method of wider distribution that could calculate a response rate, include data from juveniles under 18, increase the sample size to about 3,000, distribute a verified survey, and include a question about sex assigned at birth rather than only gender identity.

Conclusion

The PRMDs in Horn Players Health Survey showed with statistical significance at a 90% confidence rate ($p < .10$) that respondents who began the horn at the age of 10 had a higher prevalence rate of playing-related pain (PRP) than the average population, graduate students reported higher a prevalence rate of lifetime PRP than the average population, undergraduate students reported a higher prevalence rate of recent (within the last year) PRP than the average population, and playing the horn less than 5 hours a week was associated with lower recent prevalence of PRP than the average population. Women reported higher significantly higher PRP levels than men, similar to previous studies.[96]

[96] Stanek et al., 23.

Older respondents who had been playing the horn longer reported a lower lifetime prevalence rate of PRP, likely because chronic sufferers of PRP drop out of the horn playing population as they age. More years taking horn lessons, was not a protective factor for developing lifetime, recent, or current PRP. Beginning the horn as a teenager or later is likely a protective factor for developing PRP. Undergraduate and graduate students were the most likely to report lifetime, recent, and current PRP, freelancers also had higher-than-average rates of PRP. Practicing or performing seated versus standing did not have a protective effect for developing PRP. Resting the bell on the leg while seated may have a protective effect for developing PRP.

There were no risk or protective trends associated with different types of ensemble playing or history of different types of ensemble playing. Playing multiple instruments may be a risk factor in developing PRP. Sitting for less than 5 hours a week may be a protective factor for developing PRP, however the sample size that sat less than 5 hours a week was very small.

Similar to Chesky et al.,[97] PRP was primarily located along the left upper extremity (neck to fingers), lips and jaw, and both sides of the low back. Pain intensities of the low back were higher than upper extremity pain levels. Onset ages for lifetime PRP tended to be around college in the late teens and early twenties or later in life in the forties; however, developing PRP can occur at any age.

About 50% of respondents suffering from PRP reported receiving a satisfactory diagnosis of the cause of pain that allowed them to manage their symptoms and learn to play with the condition. Many musicians still face difficulty with medical professionals adequately understanding their predicament and taking their complaints seriously. The stigma around injury

---

[97] Chesky et al., 98.

in the musician community is lessening; fewer respondents reported consulting no one for help than in previous studies.[98]

Although the sample sizes were often too small to produce statistically significant results, the data from the Playing-Related Postural Disorders in Horn Players Health Survey mirrors many trends previously seen in other studies. It is impossible to capture the unique situations of every individual in survey data; this survey gives a clearer, more detailed picture of what injuries horn playing populations face than previous research has produced

[98]In bibliography, see studies by Kjelland, Philipson, Price, Rumsey, and Stanek.

CHAPTER IV

STUDY TWO: SURFACE ELECTROMYOGRAPHY OF THE LOW BACK IN HORN PLAYERS

Contribution of Authors and Co-Authors

Manuscript in Chapter IV

Author: Daniel Nebel

Contributions: Conceived the study topic, developed, and implemented the study design. Generated and analyzed data. Wrote first draft of the manuscript.

Co-Author: Dr. Sara Winges

Contributions: Helped conceive study topic, design, and implementation. Generated raw EMG data, guided data and statistical analysis, and provided feedback on drafts of the manuscript.

Co-Author: Dr. Melissa Malde

Contributions: Provided feedback on study design, Body Mapping and Alexander Technique terminology, and drafts of manuscript.

Co-Author: Dr. Gary Heise

Contributions: Provided feedback on study design and drafts of manuscript.

Co-Author: Dr. Jon Adler

Contributions: Provided feedback on study design and drafts of manuscript.

Co-Author: Dr. Reiner Krämer

Contributions: Provided feedback on study design and drafts of manuscript.

Co-Author: Dr. Robert Fant

Contributions: Generated tone quality data.

Co-Author: Dr. Randall Faust

Contributions: Generated tone quality data.

Co-Author Jeffrey Fowler

Contributions: Generated tone quality data.

Co-Author: Susan McCullough

Contributions: Generated tone quality data.

Co-Author: Dr. Jeb Wallace

Contributions: Generated tone quality data.

Abstract

Potentially debilitating performance-related pain (PRP) is common among professional and aspiring instrumentalists, can lead to significant loss of income, and sometimes end a career. Postural misalignments that lead to PRP can develop early in students' training and is often successfully addressed by a music teacher recommending a change in technique. The nature of a musician's PRP is dependent on how the instrument is held; however, there has never been an in-depth study of PRP in hornists. This study seeks to identify a common pattern of imbalances through an electromyography and posture study that compares participants' natural body positions with the use of an ERGObrass™ aid and Alexandrian-Based Instructions and their effects on postural alignment, muscle activity, and players' tone quality.

Literature Review of Electromyography Studies in Musicians

Surface electromyography (sEMG) is the non-invasive application of electrodes to the skin in order to measure neural signals in the muscle tissue below the skin; it is a somewhat less accurate method than needle electromyography (nEMG), which places the electrode sensors directly in the muscle tissue. Due to its non-invasive nature, sEMG has been the preferred method of measuring muscle activity in musician wellness studies. In 2000, James M. Kjelland reviewed 15 years of musician-specific electromyography (EMG) studies; he divided the studies into 6 categories: validation of EMG for specific research applications, observations with EMG, using EMG to establish norms for comparison, EMG as a diagnostic tool, using EMG to compare or validate methodologies and playing techniques, and EMG as part of biofeedback training.[99]

Lennert Philipson, Rolf Sörbye, Pål Larsson, and Stojan Kaladjev describe an EMG study of upper extremity muscles of 9 professional violinists.[100] At the time of the study, 5 of the subjects reported upper-extremity pain that prevented them from performing. At rest, EMG patterns and levels were equivalent between all 9 subjects, but while playing, the violinists experiencing pain demonstrated 2-5% higher activation levels in the left and right trapezius, right deltoid, and right bicep – the right arm is the bow arm and is more dynamically active in playing violin. Researchers also tested playing in various postural configurations: standing tense, standing relaxed, seated tense, and seated relaxed. They also recorded activity not playing, playing a détaché stroke, and playing a martellé stroke. Various strokes and postural positions did not reveal significant changes in EMG patterns in the muscles that were tested (bilaterally trapezius, biceps, triceps, and deltoids). Philipson et al demonstrated that higher muscle activations are associated with PRP; this suggests that finding a way to reduce these higher activations may also result in a reduction of pain. However, it should be noted that although self-reported pain is associated with higher muscle activations, this association is by no means a definitive diagnosis of the cause of the participants' pain.

[99] Kjelland, 115-118.
[100] Philipson et al., 79-82.

Kevin Price and Alan Watson describe an EMG study of brass players to determine the effectiveness of the ERGObrass™ (EB) system at reducing muscle tension.[101] The product is designed to transfer the weight of the instrument through a peg to the ground, chair, or belt (see figure 1.8).

Price and Watson recorded sEMG bilaterally on the sternocleidomastoid, trapezius, anterior and posterior deltoids, clavicular pectoralis, and biceps. All subjects demonstrated significantly less muscle activation in most muscles when using the EB support except for the sternocleidomastoid, which in brass playing, is activated mostly with inhalation rather than by supporting the instrument. The typical reduction in muscle activation when using the EB was 15-30%; 1 subject demonstrated 70% reduction.

As suggested by the manufacturer of the EB system, the subjects, were given 8 weeks to adjust to using an EB support system and fine-tune the device to comfortably fit their bodies and instruments prior to the sEMG study. It is not clear the percentage of playing time the subjects used the device during the 8 weeks prior to the study. If participants made a complete switch for 8 weeks, as recommended by the manufacturer, changes in habits and muscle activation would likely occur as the body becomes more reliant on the EB, and this could result in higher sEMG readings without the EB than in a subject who had not become reliant on the EB.

One of the few musician-based EMG study that examined lower-back muscles was conducted by Alessandro Russo, Alejandra Arancets-Garza, Samuel D'Emanuele, Francesca Serafino, and Roberto Merletti with 9 violinists in 2019 to compare erector spinae activation when using a "standard" (but backless, which is not standard) orchestral chair with and ergonomic chair that had lumbar support and encouraged less hip flexion, which has been shown

---

[101] Price and Watson, 183-190.

to put less strain on the lower back.[102] Eight of 9 subjects in this study were female, and 8 of 9 subjects were between 15 and 22 years of age, so the sample population is not representative of all violinists. None of the subjects had a history of PRP. Subjects played 2 Kreutzer studies for 2 hours straight; every 5 minutes they switched to play 20 seconds of a Rode study while EMG readings were recorded. The long duration was meant to induce fatigue in the postural muscles and mimic the repetitive task of playing violin that is common in orchestral rehearsals and practice sessions. Tests on the 2 different chairs occurred a week apart and subjects were instructed not to perform strenuous activities on the days prior to the test. The testing protocol of playing approximately 5 minutes of the same music constantly for 2 hours straight seems mind-numbingly boring – a situation that most musicians hopefully do not often experience.

The sEMG used in this study consisted of 2 arrays of 128 electrodes arranged in 16 rows of 8 columns placed bilaterally on the erector spinae in the low back. They recorded patterns of burst-like signals that have been observed in similar postural muscle studies with sEMG arrays in 8 of the 9 subjects. The ergonomic chair had an average of 40.1% lower muscle activation levels as well as a significantly smaller region of activity in the lower back. The authors concluded that despite 2 hours of continuous playing, the muscles did not reach a fatigue level, which is unsurprising considering that erector spinae muscles constantly work to keep one upright throughout the day and musicians regularly participate in rehearsals and practice sessions that last similar durations. They concluded that "the perception of fatigue does not seem to have an electrophysiological counterpart."[103]

Dr. Lazaro reviewed 75 needle EMG (nEMG) and peripheral nerve conduction case studies of patients with low back pain from his practice who did not have underlying health

---

[102] Russo et al., 205-214.
[103] Ibid., 212.

conditions, such as diabetes, that would affect an nEMG study.[104] The nEMG tests were normal for these patients and were not helpful in diagnosing the radiculopathy, plexopathy, or myopathy that were diagnosed through patient history and other imaging techniques. Needle EMG is more accurate than sEMG at determining how motor units fire, so nEMG is more useful in a clinical setting focused on specific motor units. However, Lazaro questions the usefulness of nEMG and peripheral nerve conduction tests in diagnosing the cause of low back pain and suggests that a normal test cannot be used to eliminate structural problems, such as a herniated disc, as a possible diagnosis. Lazaro explains that EMG tests can only measure and detect problems with the efferent motor nerves; efferent nerves do not relay sensory pain signals, so nEMG can only indirectly diagnose a cause of pain if it involves a motor nerve unit in some way. This concept must be kept in mind when designing any EMG study.

Research Questions

Q24 Compared to neutral positions without the horn, how does playing the horn increase postural misalignments?

Q25 Does using an ERGObrass™ (EB) system or receiving Alexandrian-based instructions (ABI) on how to hold the horn help bring the body into better alignment compared to participants' natural posture with the horn?

Q26 Do misalignments associated with playing the horn occur with asymmetrical increases in muscle activity between the left and right sides of the body?

Q27 Do misalignments and increased asymmetrical muscle activation when playing the horn have any relation to lifetime, recent, or current playing-related pain (PRP)?

Q28 Confirming Watson and Price's study,[105] does the use of an ERGObrass™ (EB) system help reduced muscle activity in the deltoids compared to participants' natural posture (NP) with the horn?

Q29 Does the use of an ERGObrass™ (EB) system help reduce muscle activity in the lumbar erector spinae (LES) compared to participants' natural posture (NP) with the horn?

---

[104] Lazaro.

[105] Price and Watson, 183-190.

Q30 Do Alexandrian-based instructions (ABI) on how to hold the horn help reduce muscle activity in the deltoids and lumbar erector spinae (LES) compared to participants' natural posture with the horn?

Q31 Keeping changes in muscle activity, alignment, and tone quality in mind, is using an ERGObrass^{TM} (EB) system or receiving Alexandrian-based instructions (ABI) a better intervention?

General Methodology

The Surface Electromyography (EMG) of the Low Back in Horn Players study was approved by the Institutional Review Board at the University of Northern Colorado (Protocol Number: 2104025563, see Appendix F.) Ten participants, both professional and student hornists from Colorado, were recruited for the study at the University of Northern Colorado Biomechanics Laboratory. After completing the Playing-Related Musculoskeletal Disorders in Horn Players Survey (see Chapter III.), participants provided written consent to participate in the study. Reflective markers were placed bilaterally on the acromion processes of the shoulders, the spinous process of the C7 vertebrae, and in a triangle on the waistband at the sacrum to record movement and body positions. Surface electromyography electrodes were placed bilaterally over the posterior and anterior deltoids and lumbar erector spinae (LES) muscles.

The anterior deltoids (ADs) are on the front part of the shoulder and primarily lift the arm forward; the posterior deltoids (PDs) are on the back part of the shoulder and lift the upper arm backwards.[106] They are considered antagonistic muscles, performing opposite movements, but can both be engaged with isometric contraction when stabilizing the shoulder joint. The erector spinae muscles run in strips bilaterally along the entire spine on the back.[107] This study investigates the erector spinae in the lumbar region, between the pelvis and the ribs. In addition to stabilizing the spine, the erector spinae's primary role is to keep the torso upright; when

[106]Clark et al., 638-639.
[107] Ibid., 634.

activated the lumbar erector spinae (LES) increase lordosis (the natural concave curve of the lower back) which occurs when the pelvis is rotated anteriorly but the torso remains upright.

Movement and muscle activity were recorded simultaneously with a Delsys Trigno EMG system and a Vicon Giganet running Vicon Nexus 2.12.1 software. At the beginning of data collection, 5-second calibration trials were taken of participants both standing and seated without their instruments. Then the participants were instructed to perform a 1-octave C major scale up and down in half notes (metronome at 80 beats per minute) while in 6 different situations; 5 iterative trials were taken of each situation for a total of 32 trials (including calibration). The 6 different situations were: seated in natural posture (NP), standing in NP, seated using an ERGObrass™ (EB) support, standing using an EB support, seated with Alexandrian-based instructions (ABI), and standing with ABI (see Appendix B to read the instructions). Instructions were drawn from the practice of Alexander Technique (AT) and were not identical between participants; they were chosen based on misalignments observed by the researcher. Instructions for most participants did not progress beyond the basic seated and standing posture instructions.

For the calibration trials participants were told to adopt the stance or seated position they would normally use during rests in a performance. Although the data in the calibration trials may suggest potential asymmetrical postures that likely exist in participants' daily lives, the calibration trials are considered participants' neutral position because inexact placement of reflective markers may be the source of measured asymmetrical postures in calibration trials. All data are reported as changes from this neutral position. To ensure the data captured participants performing on their instrument, recordings commenced after participants began to play. Participants were encouraged to move and relax between trials and to strive to play their most beautiful C Major scales in order to simulate a more natural and realistic playing experience.

In order to control for order bias, participants progressed through the 6 playing situations in the different orders. Odd numbered participants started seated and then alternated between seated and standing trials; even numbered participants started standing and then alternated with seated trials. All participants began with their NP (seated and standing); Participants 1-5 then used an EB (seated and standing) before receiving ABI, while Participants 6-10 received ABI prior to using an EB. The data collection process was audio-recorded for comparison of tone quality.

Finally, researchers recorded the self-reported height of the participants; previous experience, with AT, Body Mapping (a more musician-specific approach to AT), and using an EB. All seated trials occurred on a backless bench that was 18 inches high. Although backless seats are not standardly used by musicians, a backless seat was necessary for the visibility of the reflective markers placed on the lower back.

Electromyography Analysis

Electromyography (EMG) readings were recorded at 2000 Hz. Data from seconds 0-5 were extracted for calibration trials and seconds 1-16 was extracted for all other trials. Data for each trial were detrended by calculating the average and subtracting the average from each point, thus making the average for each trial 0. Data were then rectified by taking the absolute value of each point, so all negative numbers became positive. Then data were amplified by multiplying all numbers by 1,000 so that the differences between numbers are simpler to detect. Then the mean was taken to determine the average level of muscle activity for each muscle throughout the trial (muscle activity averages are shown in Appendix D).

Averages of the 5 trials in each of the 6 situations were taken for each muscle; NP trial averages were then compared to calibration trials and shown as a percentage of change; muscle activity in calibration trials was considered the participants' neutral activity level. Then EB and ABI trial averages were compared to NP averages and shown as a percentage of change. Bilateral changes of muscle activity were compared to determine if asymmetrical loading of the body occurred and look for trends between participants.

For each muscle in both seated and standing positions repeated measures ANOVAs were performed using SPSS software to compare the effect of the different situations on average muscle activity levels at a 95% confidence level ($p < .05$).

Reflective Marker Data Analysis Methods

Data matching the timeframes of the electromyography data (seconds 0-5 for calibration trials and seconds 1-16 for other trials) were selected. Trial number 7STI4 (see table C.1 in Appendix C for trial number labeling key), participant 7's 4th standing trial with ABI, was the exception; due to missing data for the reflective marker on the left sacrum caused by clothing obscuring the reflective marker, the final 15 seconds of time, which had the greatest number of data points, were selected instead.

An X,Y,Z coordinate was recorded in every frame for each reflective marker; the coordinates from the selected frames were averaged and distances and angles were calculated from the average coordinates. (See tables C.2 and C.3 in Appendix C).

Shoulder to Hip Twisting

To measure shoulder to hip twisting, slopes between the reflective markers on the left and right sacrum and between the markers on the left and right shoulders were calculated in the X,Y-plane, using the formula:

Let X_1, Y_1 = position coordinates of right sacrum/shoulder
Let X_2, Y_2 = position coordinates of left shoulder/sacrum
$(Y_1-Y_2)/(X_1-X_2)$

The angle (tanΘ) between the slope of the sacrum and slope of the shoulders was calculated using the formula:

Let M_1 = slope of shoulders,
Let M_2 = slope of sacrum:
$\tan\Theta = (M_1 - M_2)/(1 + M_1 M_2)$.

tanΘ was converted to angle degrees using the formula: $\tan^{-1}(\tan\Theta)$. Because the participants were facing the y axis, a negative angle indicates a twist of the shoulder to the right in relation to the hips. A positive angle indicates a twist of the shoulders to the left in relation to the hips. The larger the angle, the more the participant is twisted.

For example, the X,Y points are shown in table 4.1 for trial 3STCal (participant 3's standing calibration trial) and the slopes are graphed in figure 4.1 with calculations following.

Table 4.1 X,Y points (mm) for Trial 3STCal

R. Sacrum X	R. Sacrum Y	L. Sacrum X	L. Sacrum Y
722.287	-93.582	725.052	-161.407
R. Shoulder X	**R. Shoulder Y**	**L. Shoulder X**	**L. Shoulder Y**
585.759	42.942	613.625	-345.611

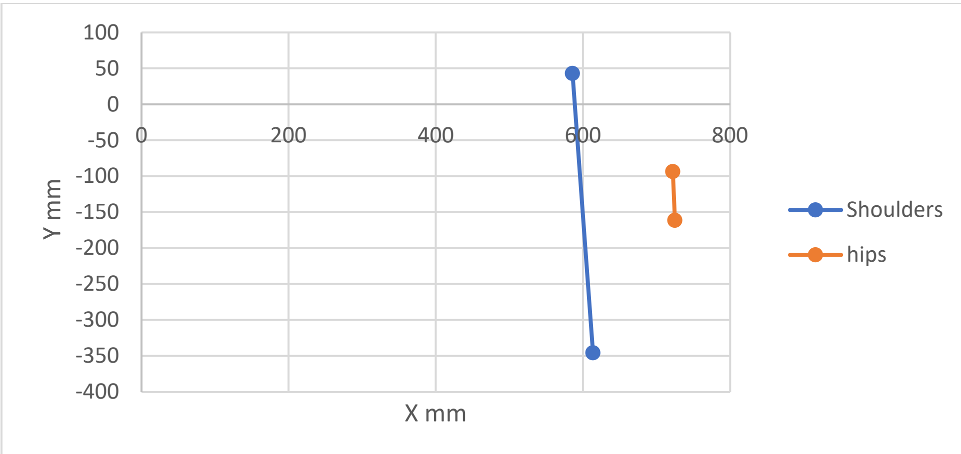


Figure 4.1 Graph of hip and shoulder slopes for trial 3STCal.
The participant is facing the Y axis.
To calculate the slope of the hips: (-93.582-(-161.407) / (722.287-725.052) = -24.523
To calculate the slope of the shoulders: (42.942-(-345.611)) / (585.759-613.625) = -13.944
To calculate tanϴ: (-24.523 - (-13.944)) / (1+((-24.523) - (-13.9435)) = 0.030850331
To calculate the angle: $\tan^{-1}(0.030850331) = 1.767593787°$

The degrees of twisting were calculated for all trials, except participant 2's standing trials, where insufficient reflective marker data were recorded. For every participant, the angles of twisting of the 5 trials within each of the 6 situations were averaged. The difference in degrees of shoulder to hip angles from neutral was calculated by subtracting the calibration trials from the average of participants' seated and standing trials in NP, with an EB, and with ABI. A repeated measures ANOVA was performed using SPSS software to compare the effect of the different situations on the average change in angle degree of shoulder to hip twisting from Cal at a 95% confidence level ($p < .05$).

Distances between Points

For all trials, distances using the X,Y,Z-coordinates were calculated in millimeters between the C7 marker (referred to as middle shoulder) and middle sacrum, the right shoulder and right sacrum, the left shoulder and left sacrum, and the left and right shoulder using the formula:

Let $P_1 = (X_1, Y_1, Z_1)$
Let $P_2 = (X_2, Y_2, Z_2)$
distance between P_1 and $P_2 = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2}$

The calculated distances for the 5 trials in each situation were averaged and then compared to distances in the calibration trials. Percentages of change of length from the calibration to NP, using an EB, and after receiving ABI were calculated. AT generally encourages a lengthening and widening of the body; the goal of the ABI is to crystalize these principals into a method to teach hornists how to use their bodies with more ease and poise, so more shortening from neutral calibration trials is considered less successful body use. Asymmetrical shortening or shortening on one side while simultaneously lengthening on the other side is considered an increase in postural distortion due to either torso twisting or dipping of the shoulder.

A participant who exhibited an approximately equal amount of shortening between the shoulders and hips in all 3 distances likely shows increased anterior pelvic tilt. A repeated measures ANOVA was performed using SPSS software to compare the effect of the different situations on the average lengths between C7 vertebrae and center of the sacrum (M to M), right shoulder, and right sacrum (R to R), left shoulder and left sacrum (L to L), and between the shoulders (S to S) at a 95% confidence level ($p < .05$).

Participant Demographics

Ten participants completed the Playing-Related Pain in Horn Players Survey prior to recording sEMG and positional data. Table 4.2-4.7 show demographic information of the participants.

Table 4.2 Participant Basic Demographic Information

Participant	Self-reported height (in.)	Age range	Sex	Years playing horn	Years of lessons
1	70	55 - 64	Female	40+	15+
2	64	35 - 44	Female	32	14
3	67	18 - 24	Female	10	3
4	67	18 - 24	Female	11	4
5	69	18 - 24	Male	8	7
6	63	25 - 34	Female	15	9
7	63.5	25 - 34	Female	6	6
8	69	25 - 34	Female	22	12
9	71	25 - 34	Female	17	11
10	67	18 - 24	Female	3	<1

Table 4.3 Participant Musician Demographic Information

Participant	Musician class	Primary part(s)	Current ensembles	Previous ensembles
1	Freelancer, Professor, Retired	1, 4	Orchestra, Chamber Music	Orchestra, Wind Ensemble, Chamber Music, Solo
2	Freelancer	1, 2, 3, 4, Asst./Utility	Orchestra, Chamber Music	Orchestra, Wind Ensemble, Marching Band, Chamber Music, Solo
3	Undergraduate Student	2, 3	Orchestra, Chamber Music, Solo	Orchestra, Wind Ensemble, Marching Band, Chamber Music, Solo
4	Graduate Student	1, 2, 3, 4	Orchestra, Wind Ensemble, Chamber Music, Solo	Orchestra, Wind Ensemble, Marching Band, Chamber Music, Drum Corps, Solo
5	Undergraduate Student	2, 3, 4, Asst./Utility	Orchestra, Wind Ensemble, Marching Band, Solo	Orchestra, Wind Ensemble, Marching Band, Chamber Music, Solo
6	Freelancer	1, 3, Asst./Utility	Orchestra, Chamber Music, Drum Corps	Orchestra, Wind Ensemble, Marching Band, Chamber Music, Solo
7	Graduate Student	1, 2, 3, 4	Orchestra, Wind Ensemble, Chamber Music, Solo	Orchestra, Wind Ensemble, Chamber Music, Solo
8	Graduate Student	1, 2, 4	Orchestra, Wind Ensemble, Chamber Music	Orchestra, Wind Ensemble, Marching Band, Chamber Music, Solo
9	Graduate Student, Teacher	1, 2, 3, 4, Asst./Utility	Orchestra, Wind Ensemble, Chamber Music	Orchestra, Wind Ensemble, Marching Band, Chamber Music, Solo
10	Undergraduate Student	2	Wind Ensemble, Marching Band, Solo	Wind Ensemble, Marching Band

Table 4.4 Participant Practicing Habit Information

Participant	Hours playing horn/week	Hours sitting/week	Practice sit vs. stand	Perform sit vs. stand	Bell on leg
1	10-19	<4	Sit all	Mostly sit	Always
2	20+	15-20	Mostly sit	Mostly sit	Never
3	10-19	20+	Mostly stand	Mostly sit	Never
4	10-19	5-9	About equal	Mostly stand	About half
5	10-19	10-15	Mostly sit	Mostly sit	Never
6	5-9	20+	Mostly sit	Mostly sit	Never
7	20+	15-20	Mostly sit	Mostly sit	Never
8	<5	<4	Mostly sit	Mostly sit	Mostly
9	20+	20+	Mostly sit	Mostly sit	Sometimes
10	5-9	10-15	Mostly sit	Mostly sit	Sometimes

Table 4.5 Participant Lifetime Playing-Related Pain

Participant	Lifetime PRP	Suspect PRP caused by horn	Known cause	Does horn playing worsen pain?	Onset age
1	No	...	...	...	...
2	Yes	Yes	TMJ	Probably not	18
3	Yes	Maybe	...	Definitely yes	17
4	Yes	Yes	mellophone in drum corps	Definitely yes	19
5	Yes	No	...	Probably not	18
6	Yes	Yes	car accident	Definitely yes	21
7	Yes	Yes	Ganglion cyst in each wrist	Probably yes	23
8	Yes	No	...	Probably yes	24
9	Yes	No	...	Definitely yes	14
10	Yes	Yes	...	Definitely yes	15

Table 4.6 Participant Pain Locations and Intensities

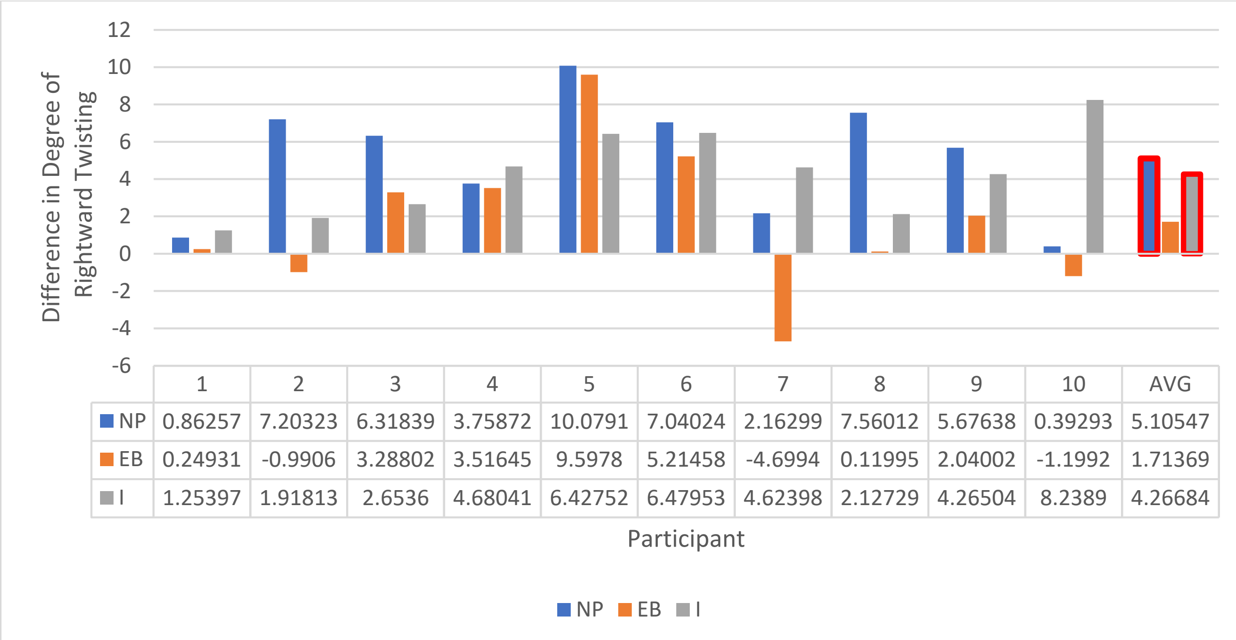
Participant	Lifetime pain locations and intensities	Recent pain locations and intensities	Current pain locations and intensities
1	None	...	...
2	excruciating jaw, very painful bilateral neck, and very painful bilateral shoulder	...	...
3	very painful jaw, painful bilateral neck, uncomfortable left shoulder, very painful right shoulder pain, uncomfortable right upper back, and painful right middle back	painful jaw, uncomfortable left hand/wrist/fingers, uncomfortable right upper back, and painful right middle back	uncomfortable left hand/wrist/fingers, painful right upper back, and painful right middle back
4	very painful left neck, very painful left shoulder, painful left hand/wrist/fingers, very painful left upper back, very painful left middle back, and painful bilateral lower back	very painful left neck, very painful left shoulder, uncomfortable left hand/wrist/fingers, very painful left upper back, painful left middle back, and painful bilateral lower back	painful left neck, very painful left shoulder, painful left upper back, uncomfortable left middle back, and uncomfortable bilateral lower back
5	uncomfortable left neck, uncomfortable right hand/wrist/fingers, and painful right upper back	painful right upper back	uncomfortable right upper back
6	excruciating bilateral neck, excruciating bilateral shoulder, very painful left hand/wrist/fingers, excruciating left upper back, very painful left lower back, and excruciating right lower back	recent PRP of excruciating bilateral neck, excruciating bilateral shoulder, painful left hand/wrist/fingers, excruciating left upper back, and very painful bilateral lower back	very painful left neck, very painful left shoulder, very painful left upper back, and very painful right lower back
7	uncomfortable jaw, uncomfortable left hand/wrist/fingers, and painful right hand/wrist/fingers	uncomfortable left hand/wrist/fingers, and painful right hand/wrist/fingers	uncomfortable right hand/wrist/fingers
8	painful lip, and very painful bilateral lower back	...	...
9	excruciating lip, very painful jaw, excruciating left neck, painful right neck, excruciating left shoulder, very painful right shoulder, excruciating left hand/wrist/fingers, very painful right hand/wrist/fingers, excruciating left upper back, very painful right upper back, and very painful bilateral middle back	excruciating left neck, excruciating left shoulder, and very painful left hand/wrist/fingers	painful left neck and painful left shoulder
10	very painful right middle back and very painful right side	...	...

Table 4.7 Participant Experience with ERGObrass^{TM} (EB), Alexander Technique (AT), and Body Mapping (BM)

Participant	Experience with EB	Experience with AT/BM
1	None	Group AT class
2	None	Limited
3	None	Limited
4	None	None
5	None	None
6	Used regularly sitting	BM course, and AT masterclass
7	None	Limited private AT lessons
8	None, used plexiglass bell prop	BM course
9	Regularly for past 6 weeks	BM course, AT class, private AT lessons
10	None	None

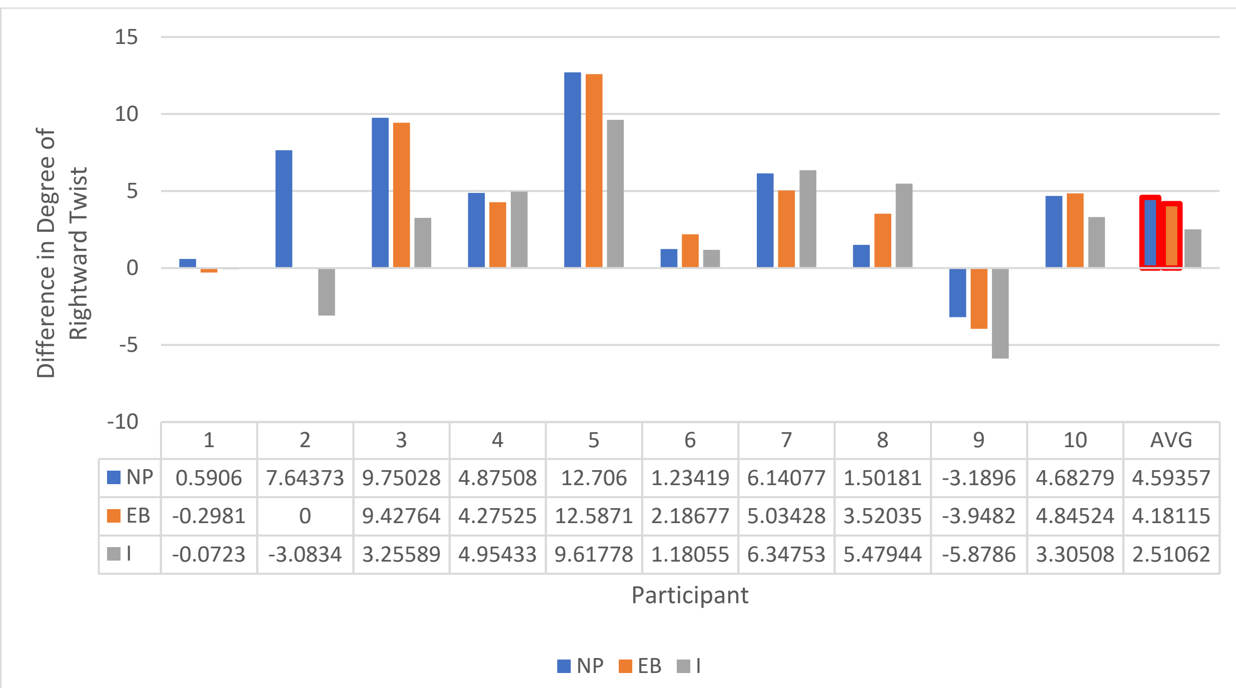
Reflective Marker Results

Figures 4.2 and 4.3 compare the change in degree of twisting of the shoulders in relation to the hips from the calibration trials without the horn to the average of participants' trials with natural posture (NP), using the ERGObrass^{TM} (EB), and after receiving Alexandrian-based instructions (ABI). A positive number indicates an increase in twist to the right; a negative number indicates an increase of twist to the left.



	1	2	3	4	5	6	7	8	9	10	AVG
NP	0.86257	7.20323	6.31839	3.75872	10.0791	7.04024	2.16299	7.56012	5.67638	0.39293	5.10547
EB	0.24931	-0.9906	3.28802	3.51645	9.5978	5.21458	-4.6994	0.11995	2.04002	-1.1992	1.71369
I	1.25397	1.91813	2.6536	4.68041	6.42752	6.47953	4.62398	2.12729	4.26504	8.2389	4.26684

Figure 4.2 Comparison of angle changes between Natural Position (NP), ERGObrass™ (EB), and Alexandrian-Based Instructions (I) of seated shoulder to hip twists compared to neutral. *Note*: red border indicates $p < .05$.



	1	2	3	4	5	6	7	8	9	10	AVG
NP	0.5906	7.64373	9.75028	4.87508	12.706	1.23419	6.14077	1.50181	-3.1896	4.68279	4.59357
EB	-0.2981	0	9.42764	4.27525	12.5871	2.18677	5.03428	3.52035	-3.9482	4.84524	4.18115
I	-0.0723	-3.0834	3.25589	4.95433	9.61778	1.18055	6.34753	5.47944	-5.8786	3.30508	2.51062

Figure 4.3 Comparison of angle changes between Natural Position (NP), ERGObrass™ (EB), and Alexandrian-Based Instructions (I) of standing shoulder to hip twists compared to neutral. *Note*: red border indicates $p < .05$.

Compared to calibration trials, all participants in NP increased twisting to the right except for Participant 9 while standing. Both the use of the EB system and receiving ABI shows an average reduction of twisting to the right compared to NP; most participants reduced their rightward twisting with both interventions; ABI was slightly more effective at reducing rightward twisting than EB.

Figures 4.4-4.7 show the percentages of change in average length for distances between the C7 vertebrae and middle of the sacrum (M to M), left shoulder and left sacrum (L to L), right shoulder and right sacrum (R to R), and left and right shoulders (S to S) between calibration (Cal) trials without the horn to participants' natural postures (NP). A negative number indicates a shortening in the distance between the points. A change of 1% is approximately 5 millimeters. A red border around an average indicates an association with a significant p-value. All participants showed a shortening from the right shoulder to right sacrum when playing the horn. When shortening along the right side is less than shortening along the left or lengthening occurs along the left side with shortening on the right, an increase in rightward twist of the shoulders and/or a dip of the right shoulder is likely occurring.

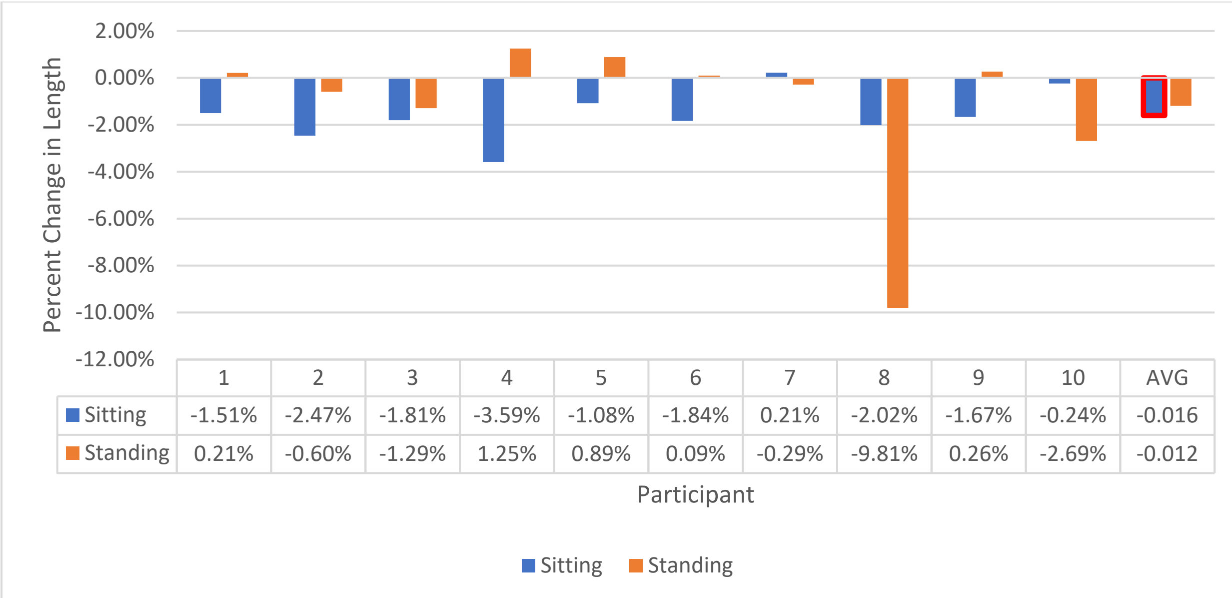


Figure 4.4 Percentage of change in lengths between C7 and middle sacrum from Calibration to Natural Position.
Note: red border indicates $p < .05$.

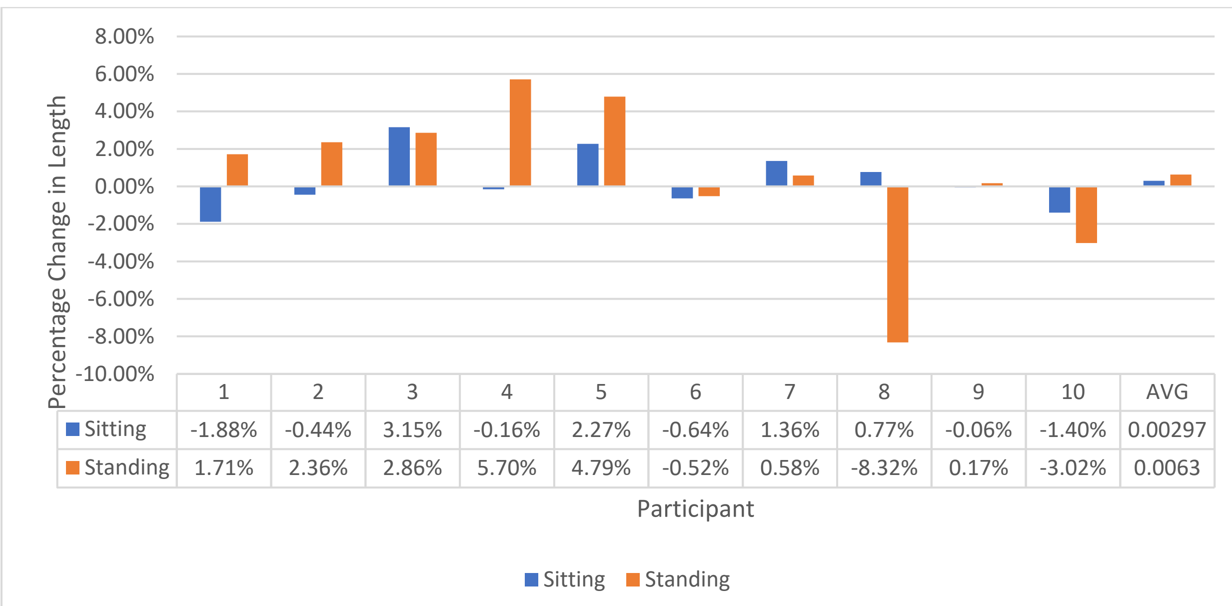
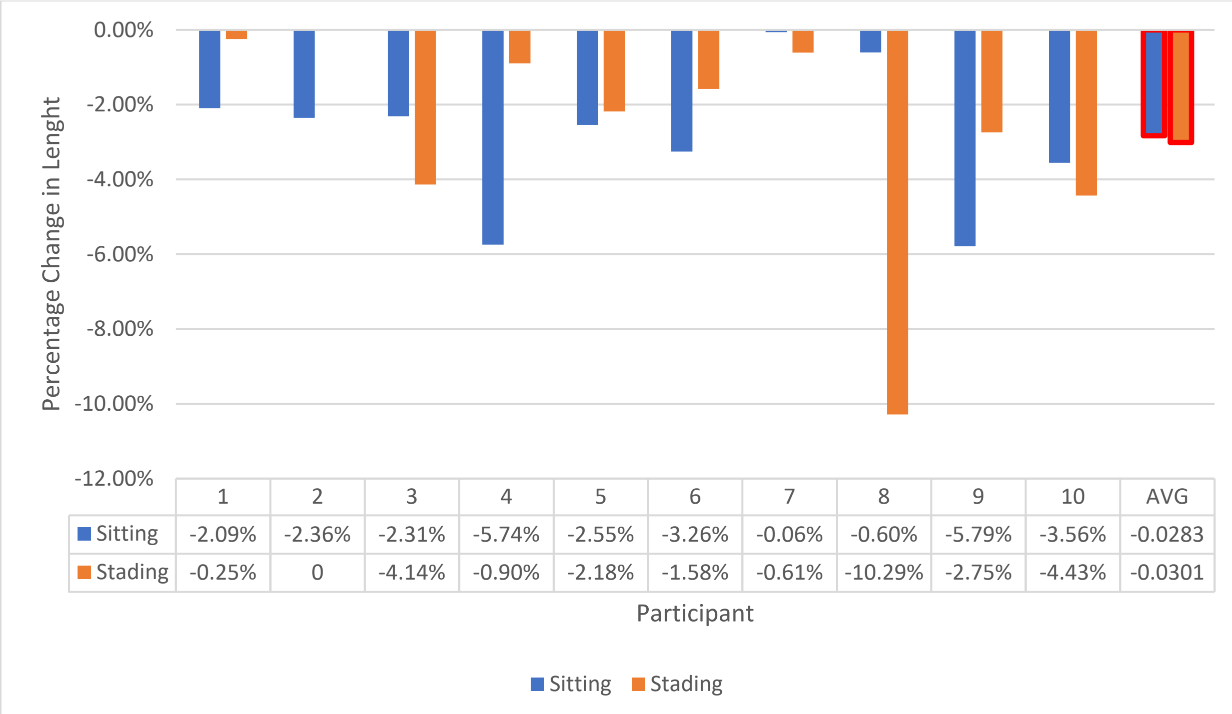
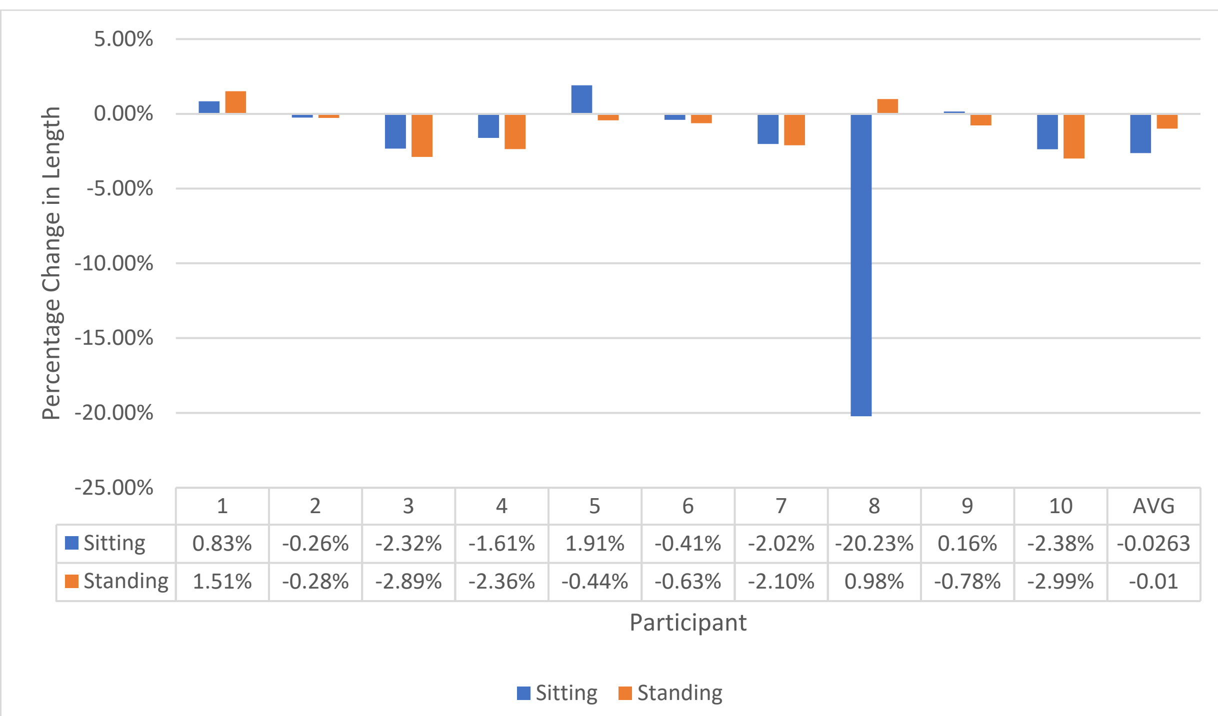


Figure 4.5 Percentage of change in left side lengths from Calibration to Natural Position
Note: * Participant 2 Standing data shows the distance from left shoulder to middle sacrum due to missing left sacrum data points.



	1	2	3	4	5	6	7	8	9	10	AVG
Sitting	-2.09%	-2.36%	-2.31%	-5.74%	-2.55%	-3.26%	-0.06%	-0.60%	-5.79%	-3.56%	-0.0283
Stading	-0.25%	0	-4.14%	-0.90%	-2.18%	-1.58%	-0.61%	-10.29%	-2.75%	-4.43%	-0.0301

Figure 4.6 Percentage of change in right side length from Calibration to Natural Position
Note: * Participant 2 standing data shows the distance from right shoulder to middle sacrum due to missing right sacrum data points. Red border indicates $p < .05$.



	1	2	3	4	5	6	7	8	9	10	AVG
Sitting	0.83%	-0.26%	-2.32%	-1.61%	1.91%	-0.41%	-2.02%	-20.23%	0.16%	-2.38%	-0.0263
Standing	1.51%	-0.28%	-2.89%	-2.36%	-0.44%	-0.63%	-2.10%	0.98%	-0.78%	-2.99%	-0.01

Figure 4.7 Percentage of change in length between the shoulders from Calibration to Natural Position.

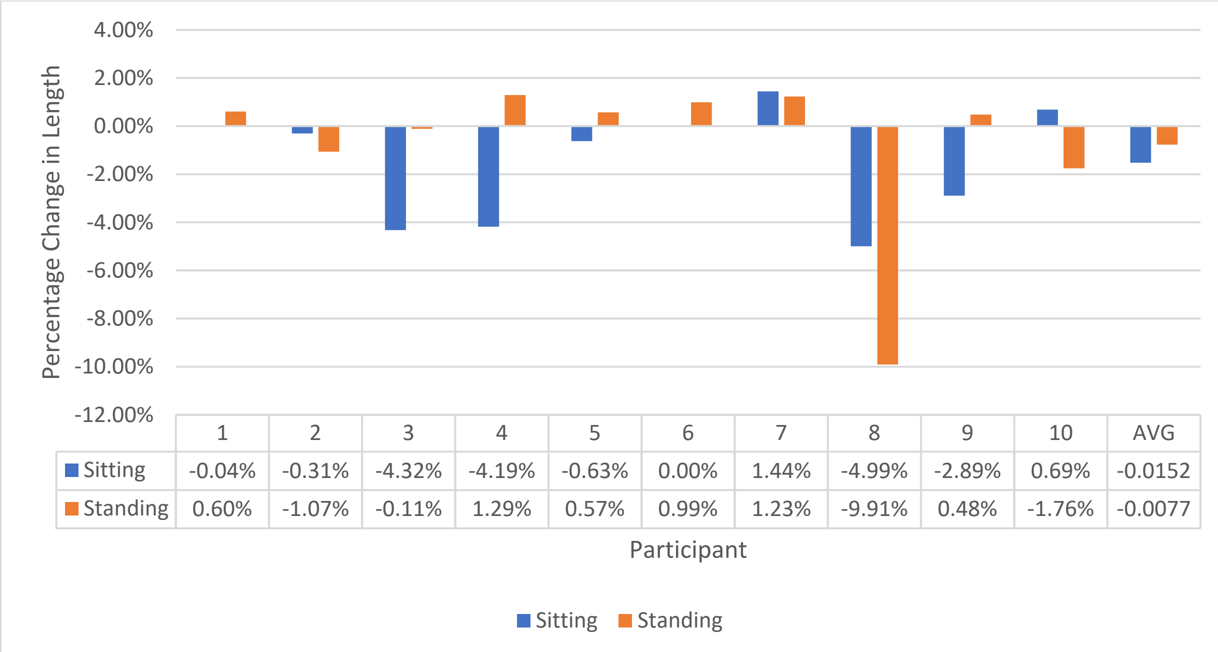
Research Question Results

Q24 Compared to neutral positions without the horn, how does playing the horn increase postural misalignments?

As seen in figures 4.2 and 4.3, when adopting their natural positions, most participants showed an increase in twisting of the shoulders to the right. Participants twisted an average of 4.85° more to the right when playing their instrument. As seen in figures 4.4-4.7, most participants experienced more shortening along the right side than the left. Most participants also experienced some narrowing of the shoulders, and shortening along the spine from the sacrum to the C7 vertebrae. Playing the horn generally increases horn players' tendency to twist to the right, narrow the shoulders, and increase lordosis in the lumbar region.

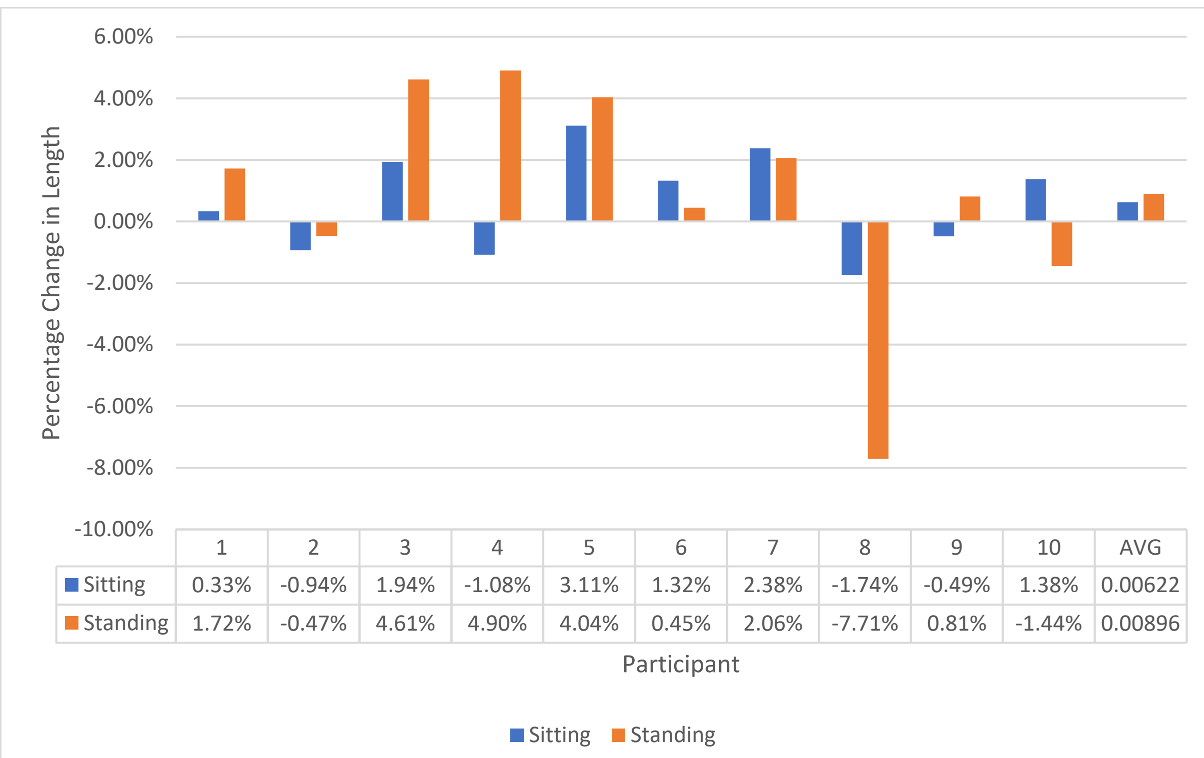
Changes in Length with an ERGObrass™

Figures 4.8-4.11 show the percentage of change in average length for distances between the C7 vertebrae and middle of the sacrum (M to M), left shoulder and left sacrum (L to L), right shoulder and right sacrum (R to R), and left and right shoulder (S to S) between calibration (Cal) trials without the horn to trials using an ERGObrass™ (EB). In all participants except for Participant 7, more shortening or less lengthening was recorded on the right side of the body than the left; the tendency to shorten more on the right than the left continues with the EB, although the tendency is less pronounced than when participants were in their NP. Less narrowing between the shoulders from calibration than NP was observed with the EB.



	1	2	3	4	5	6	7	8	9	10	AVG
Sitting	-0.04%	-0.31%	-4.32%	-4.19%	-0.63%	0.00%	1.44%	-4.99%	-2.89%	0.69%	-0.0152
Standing	0.60%	-1.07%	-0.11%	1.29%	0.57%	0.99%	1.23%	-9.91%	0.48%	-1.76%	-0.0077

Figure 4.8 Percentage of change in length between C7 vertebrae and middle sacrum from Calibration to ERGObrass™.



	1	2	3	4	5	6	7	8	9	10	AVG
Sitting	0.33%	-0.94%	1.94%	-1.08%	3.11%	1.32%	2.38%	-1.74%	-0.49%	1.38%	0.00622
Standing	1.72%	-0.47%	4.61%	4.90%	4.04%	0.45%	2.06%	-7.71%	0.81%	-1.44%	0.00896

Figure 4.9 Percentage of change in length on left side from Calibration to ERGObrass™. *Note*: * Participant 2 standing data shows the distance from left and shoulder to middle sacrum due to missing left sacrum data points.

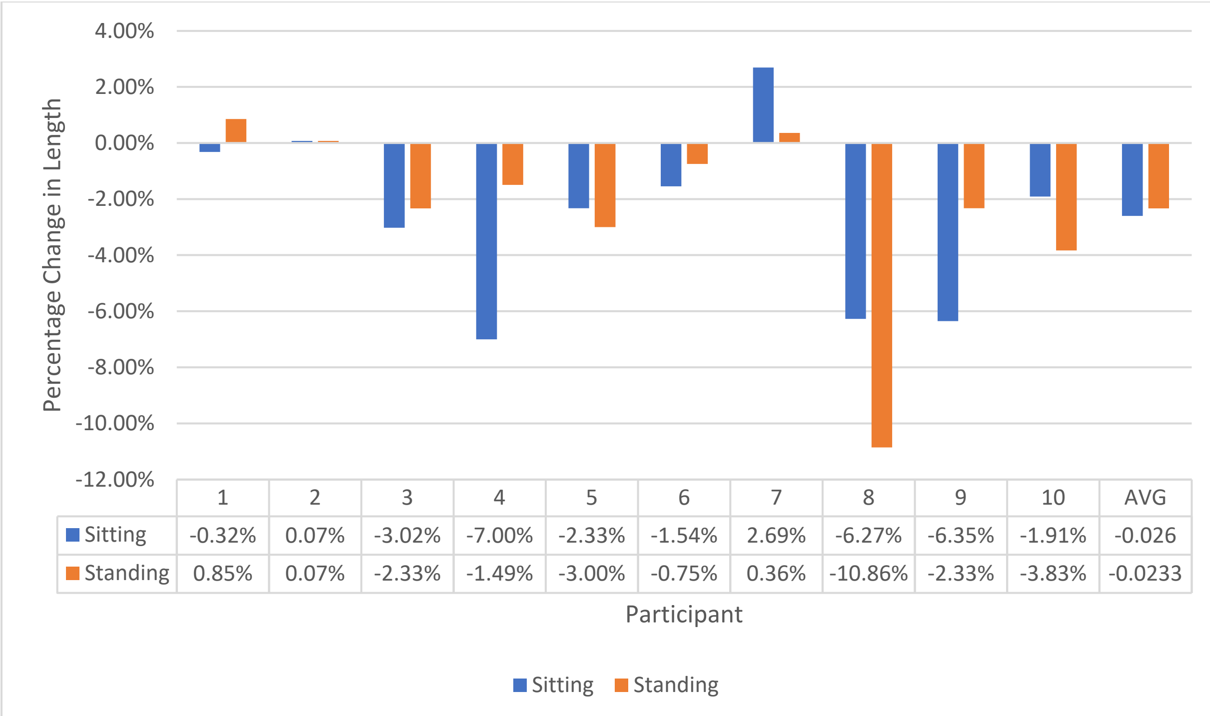


Figure 4.10 Percentage of change in length on right side from Calibration to ERGObrass^{TM}.
Note: * Participant 2 standing data shows the distance from right shoulder to middle sacrum due to missing right sacrum data points.

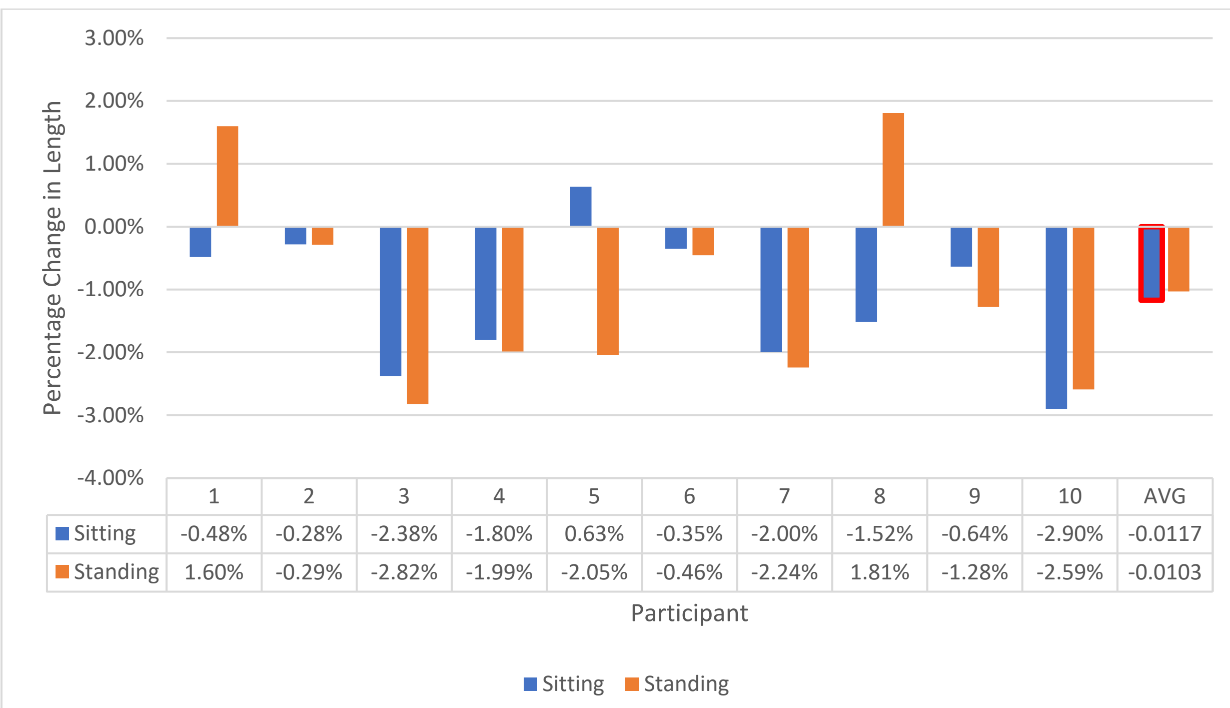
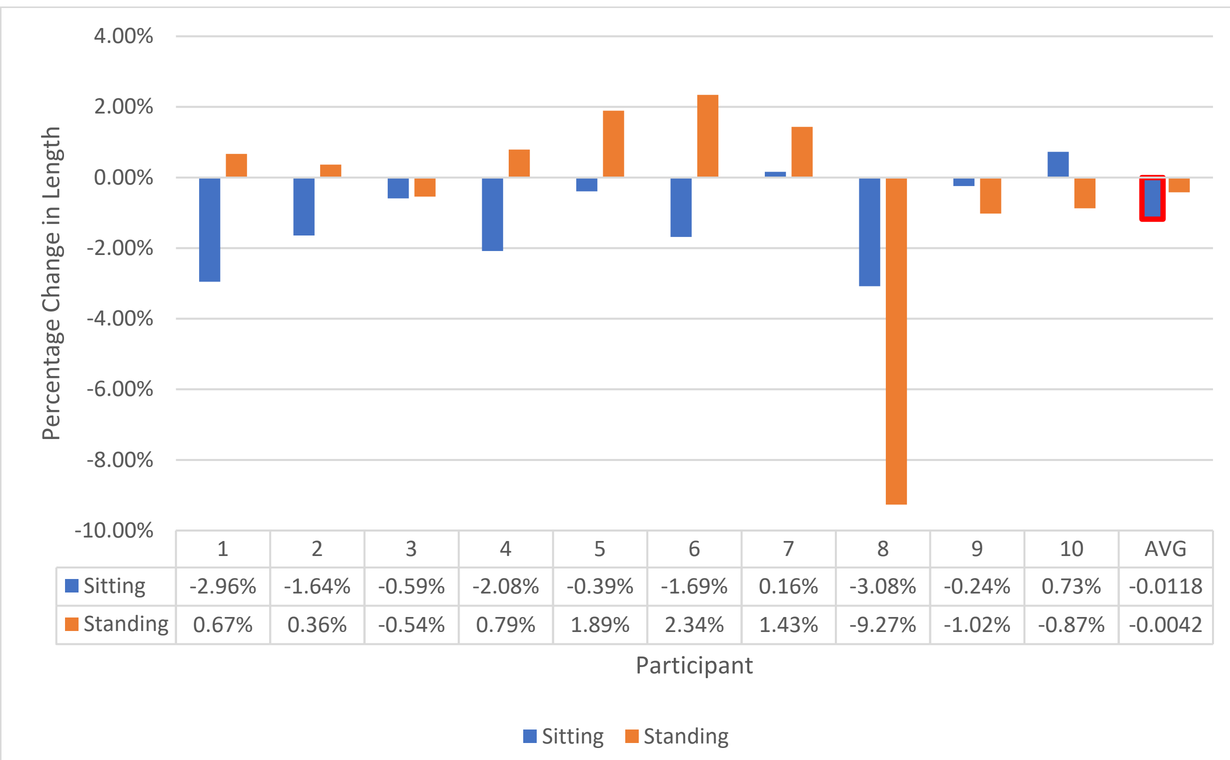


Figure 4.11 Percentage of change in length between shoulders from Calibration to ERGObrass^{TM}.
Note: red border indicates $p < .05$.

Changes in Length with Alexandrian-Based Instructions

Figures 4.12-4.15 show the percentage of change in average length for distances between the C7 vertebrae and middle of the sacrum (M to M), left shoulder and left sacrum (L to L), right shoulder and right sacrum (R to R), and left and right shoulder (S to S) between calibration trials without the horn to trials following instructions.

Again, almost all participants showed more shortening or less lengthening on the right side compared to the left. This trend was smaller with ABI than with EB or in NP. With ABI, participants showed a greater tendency to narrow the shoulders than when using EB.



	1	2	3	4	5	6	7	8	9	10	AVG
Sitting	-2.96%	-1.64%	-0.59%	-2.08%	-0.39%	-1.69%	0.16%	-3.08%	-0.24%	0.73%	-0.0118
Standing	0.67%	0.36%	-0.54%	0.79%	1.89%	2.34%	1.43%	-9.27%	-1.02%	-0.87%	-0.0042

Figure 4.12 Percentage of change in length between C7 vertebrae and middle sacrum from Calibration to Alexandrian-Based Instructions.
Note: red border indicates $p < .05$.

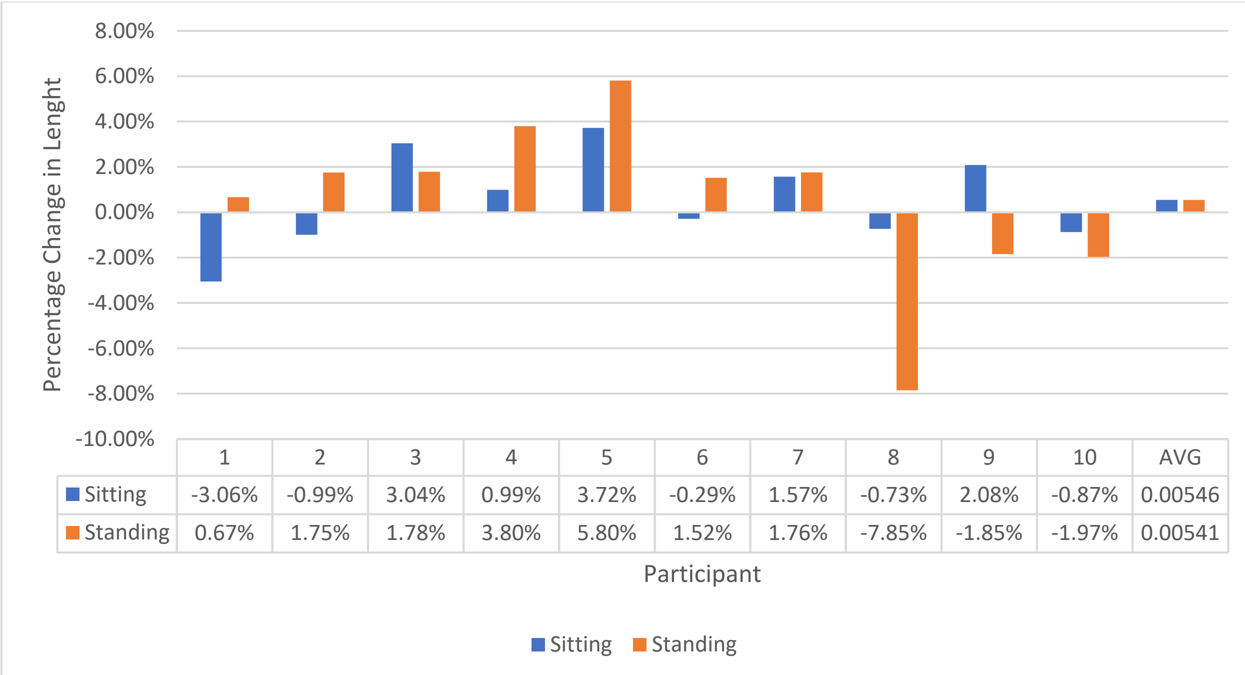


Figure 4.13 Percentage of change in length on left side from Calibration to Alexandrian-Based Instructions.
Note: * Participant 2 standing data shows the distance from left shoulder to middle sacrum due to missing left sacrum data points.

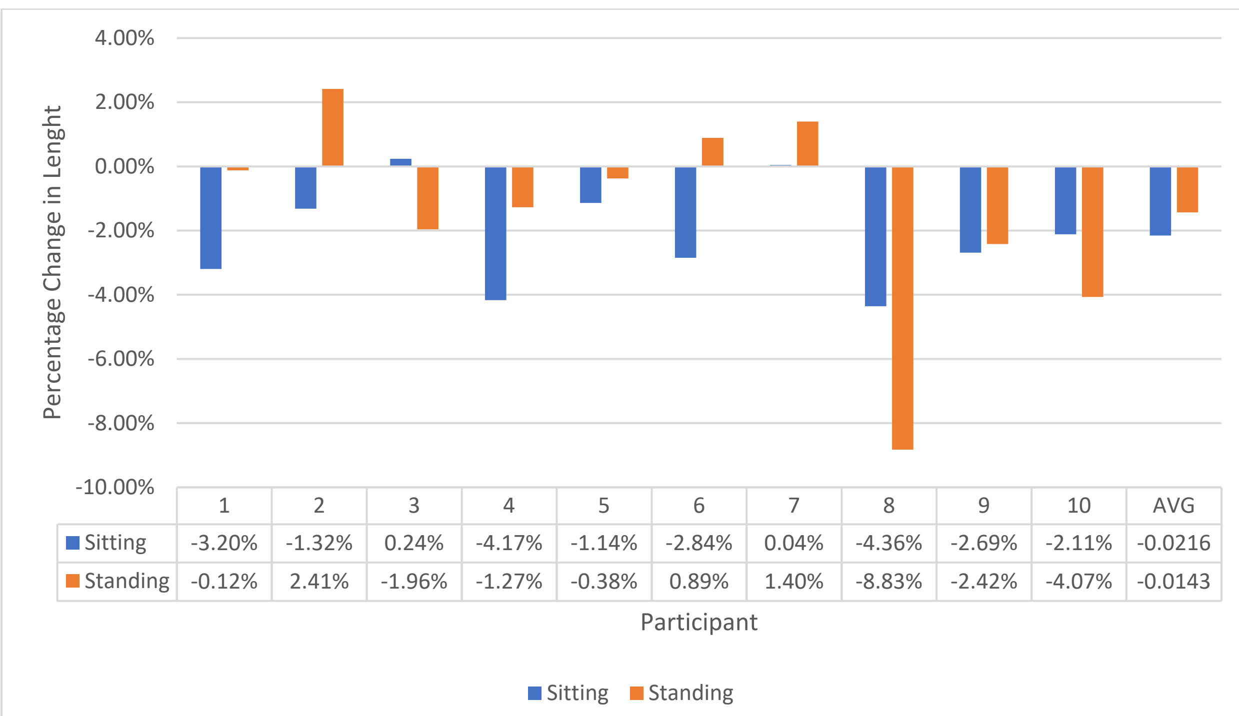
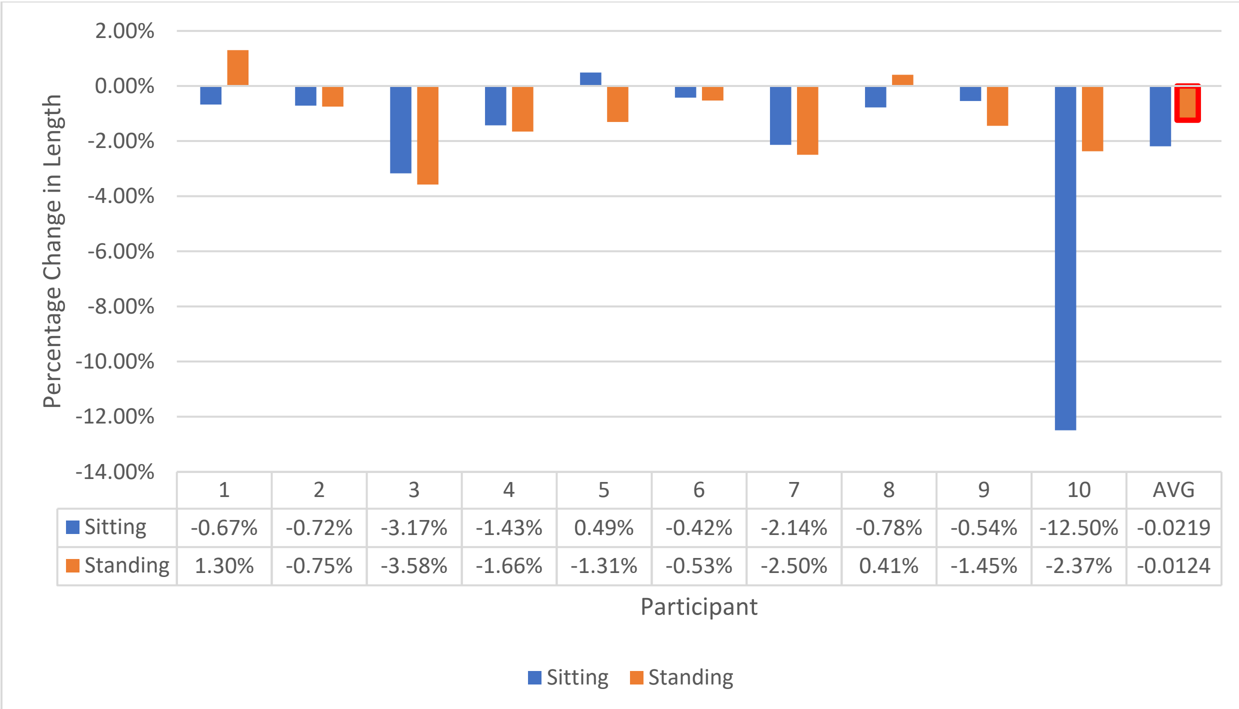


Figure 4.14 Percentage of change in length on right side from Calibration to Alexandrian-Based Instructions.
Note: * Participant 2 standing data shows the distance from right shoulder to middle sacrum due to missing right sacrum data points.



	1	2	3	4	5	6	7	8	9	10	AVG
Sitting	-0.67%	-0.72%	-3.17%	-1.43%	0.49%	-0.42%	-2.14%	-0.78%	-0.54%	-12.50%	-0.0219
Standing	1.30%	-0.75%	-3.58%	-1.66%	-1.31%	-0.53%	-2.50%	0.41%	-1.45%	-2.37%	-0.0124

Figure 4.15 Percentage of change in length between shoulders from Calibration to Alexandrian-Based Instructions.
Note: red border indicates $p < .05$.

Research Question Results

Q25 Does using an ERGObrass™ (EB) system or receiving Alexandrian-based instructions (ABI) on how to hold the horn help bring the body into better alignment compared to participants' natural posture with the horn?

For the 10 participants, using the EB compared to NP, on average, reduced twisting to the right by 2° and reduced the difference of length change between left and right side by 0.4%. Receiving ABI compared to NP, on average, reduced twisting to the right by 1.5° and reduced the difference of change of lengths between left and right side by 1.3%. These tendencies are not universally true for the participants. Using the EB, the average reduction in shoulder narrowing was 0.72%, and the average reduction in spine shortening was 0.33%. Receiving ABI, the average reduction in shoulder narrowing was 0.1%, and the average reduction in spine shortening was 0.68%. Better alignment occurred with both interventions.

Distances and Angles Statistical Analysis

Table 4.8 shows the f-values for repeated measures ANOVA tests performed for the averages of each of the measured angles and distances; table 4.8 also shows the and p-values of each f-value, which indicates the reliability of the overall ANOVA analysis. Tables 4.9 and 4.10 show paired p-values for the different situations generated by the repeated measures ANOVAs that were performed to compare the effect of the different situations on the Hip to Sacrum angle (H to S) and average lengths between C7 vertebrae and center of the sacrum (M to M), right shoulder and right sacrum (R to R), left shoulder and left sacrum (L to L), and between the shoulders (S to S) at a 95% confidence level. This indicates that average percentages of change in length/angle associated with the pairs with significant p-values (labeled with *) are also significant and are outlined in red in figures 4.2 to 4.15.

Table 4.8 ANOVA-RM F-values and Significance for Angles and Distances

Measurement	F value	P Value
Seated H to S Angle	26.032	<.001 *
Seated M to M	6.616	.019 *
Seated L to L	0.335	.801
Seated R to R	9.738	.007 *
Seated S to S	0.551	.442
Standing H to S Angle	1.706	.264
Standing M to M	2.037	.197
Standing L to L	0.172	.912
Standing R to R	5.789	.026 *
Standing S to S	3.06	.101 *

* $p < .05$.

Table 4.9 P-Values from ANOVA-RM Pairs Seated

Situation pair	H to S angle	M to M	L to L	R to R	S to S
Cal, EB	.205	.071	.297	.029	.01 *
Cal, ABI	<.001 *	.021 *	.442	.002	.09
Cal, NP	<.001 *	<.001 *	.539	<.001 *	.231
EB, ABI	.073	.661	.937	.558	.317
EB, NP	.006 *	.898	.626	.852	.465
ABI, NP	.53	.275	.561	.357	.814

* $p < .05$.

Table 4.10 P-Values from ANOVA-RM Pairs Standing

Situation pair	H to S angle	M to M	L to L	R to R	S to S
Cal, EB	.033 *	.472	.576	.7	.069
Cal, ABI	.066	.647	.75	.205	.019 *
Cal, NP	.031 *	.298	.714	.024 *	.063
EB, ABI	.244	.27	.574	.045 *	.337
EB, NP	.831	.087	.639	.152	.787
ABI, NP	.274	.047 *	.829	.005 *	.181

* $p < .05$.

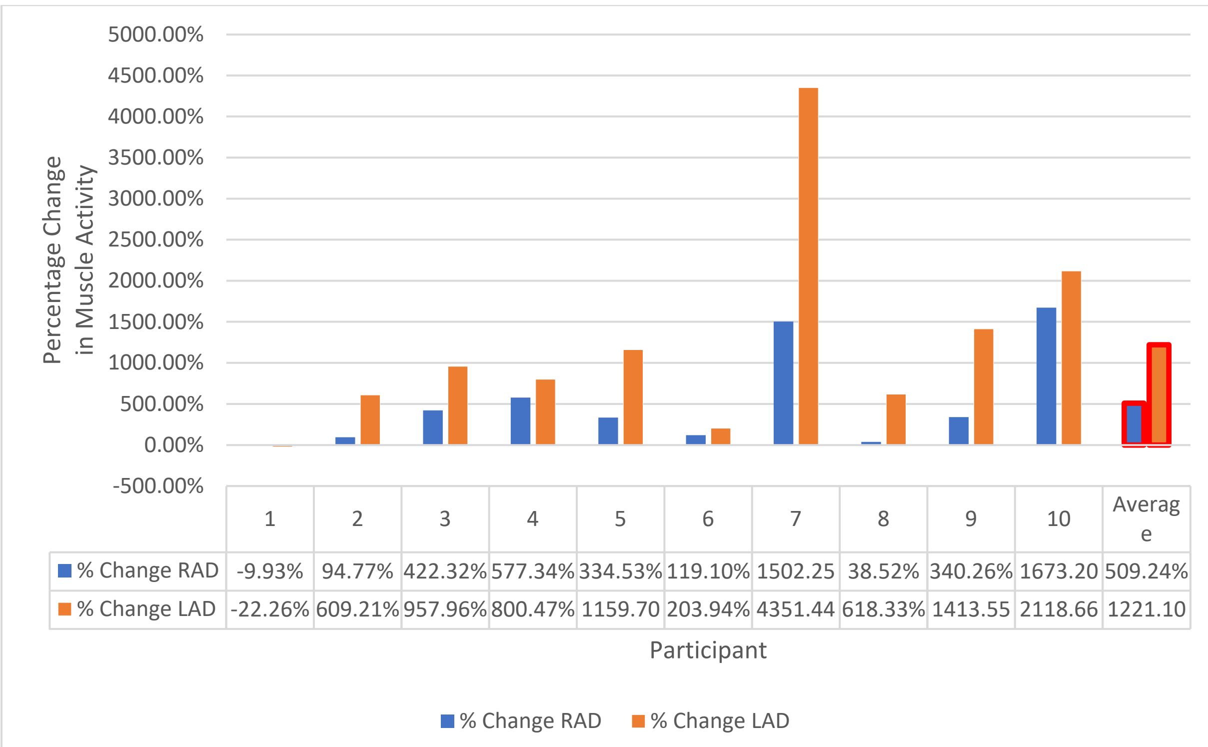
Electromyography Results

Table 4.11 shows the muscle labeling key for all electromyography data; muscle abbreviations are also found in the List of Abbreviations.

Table 4.11 Muscle Labeling Key

Abbreviation	Muscle name
RAD	Right Anterior Deltoid
LAD	Left Anterior Deltoid
RPD	Right Posterior Deltoid
LPD	Left Posterior Deltoid
RLES	Right Lumbar Erector Spinae
LLES	Left Lumbar Erector Spinae

Figures 4.16-4.18 show the percentage of change of each participant's muscle activity in their natural seated position while playing the horn from the seated calibration (Cal) trial without the horn. With the exception of Participant 1, most muscles demonstrated, as expected, substantial increases in activity when playing the horn, especially in the anterior deltoids, particularly on the left side. Overall, there was an average of 355.02% increase in muscle activity across all muscles and participants.



	1	2	3	4	5	6	7	8	9	10	Average
% Change RAD	-9.93%	94.77%	422.32%	577.34%	334.53%	119.10%	1502.25	38.52%	340.26%	1673.20	509.24%
% Change LAD	-22.26%	609.21%	957.96%	800.47%	1159.70	203.94%	4351.44	618.33%	1413.55	2118.66	1221.10

Figure 4.16 Percentage of change in Left Anterior Deltoid (LAD) and Right Anterior Deltoid (RAD) activity from seated Calibration to Natural Position.
Note: red border indicates $p < .05$.

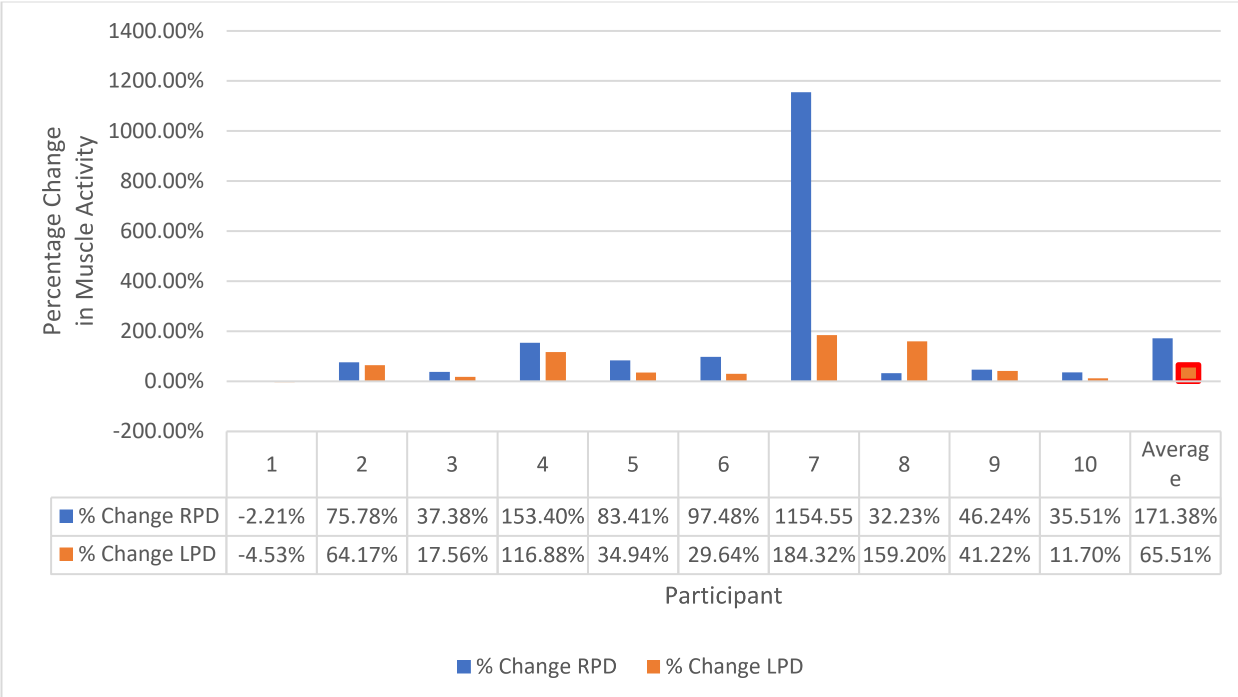


Figure 4.17 Percentage of change in Right Posterior Deltoid (RPD) and Left Posterior Deltoid (LPD) activity from seated Calibration to Natural Position.
Note: red border indicates $p < .05$.

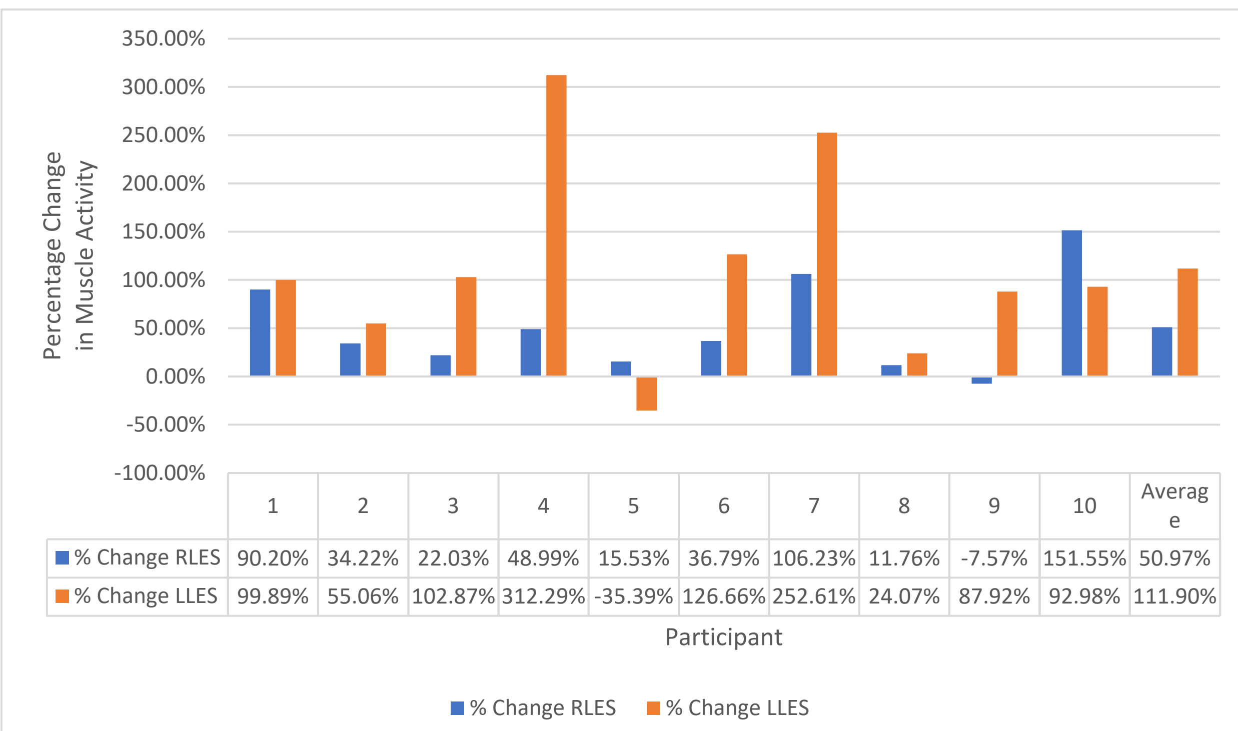
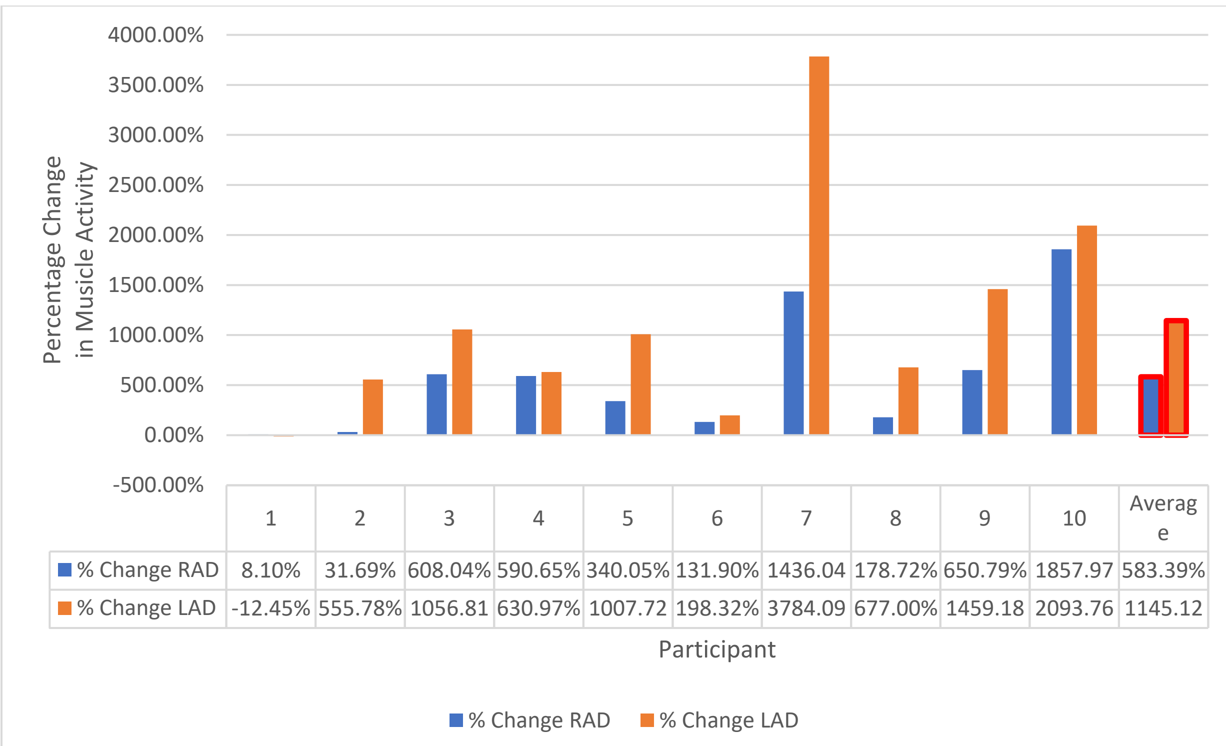


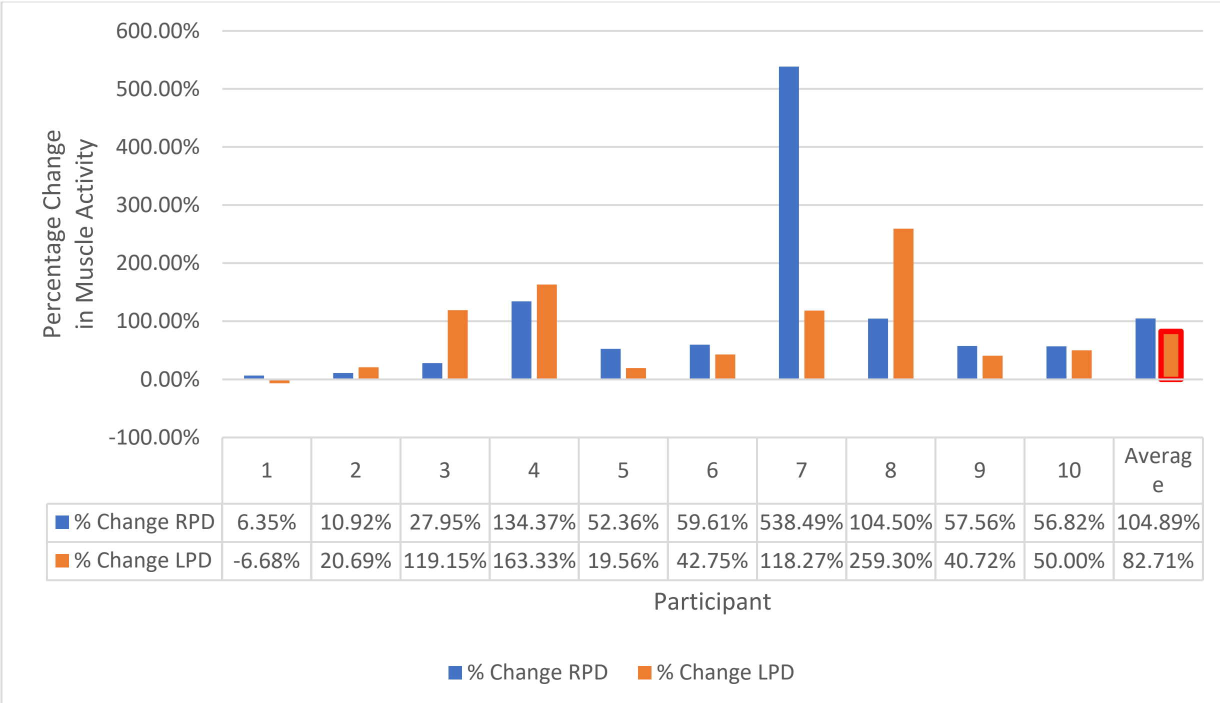
Figure 4.18 Percentage of change in Right Lumbar Erector Spinae (RLES) and Left Lumbar Erector Spinae (LLES) activity from seated Calibration to Natural Position.

Figures 4.19-4.21 show the percentage of change of each participant's muscle activity in their standing NP while playing the horn from the standing Cal without the horn. Most muscles demonstrated a substantial increase in activity when playing the horn, especially in the anterior deltoids, particularly on the left side. Interestingly, Participant 1 demonstrated remarkably small increases in muscle activity and some decreases. Overall, there was an average of 351.51% increase in muscle activity across all muscles and participants.



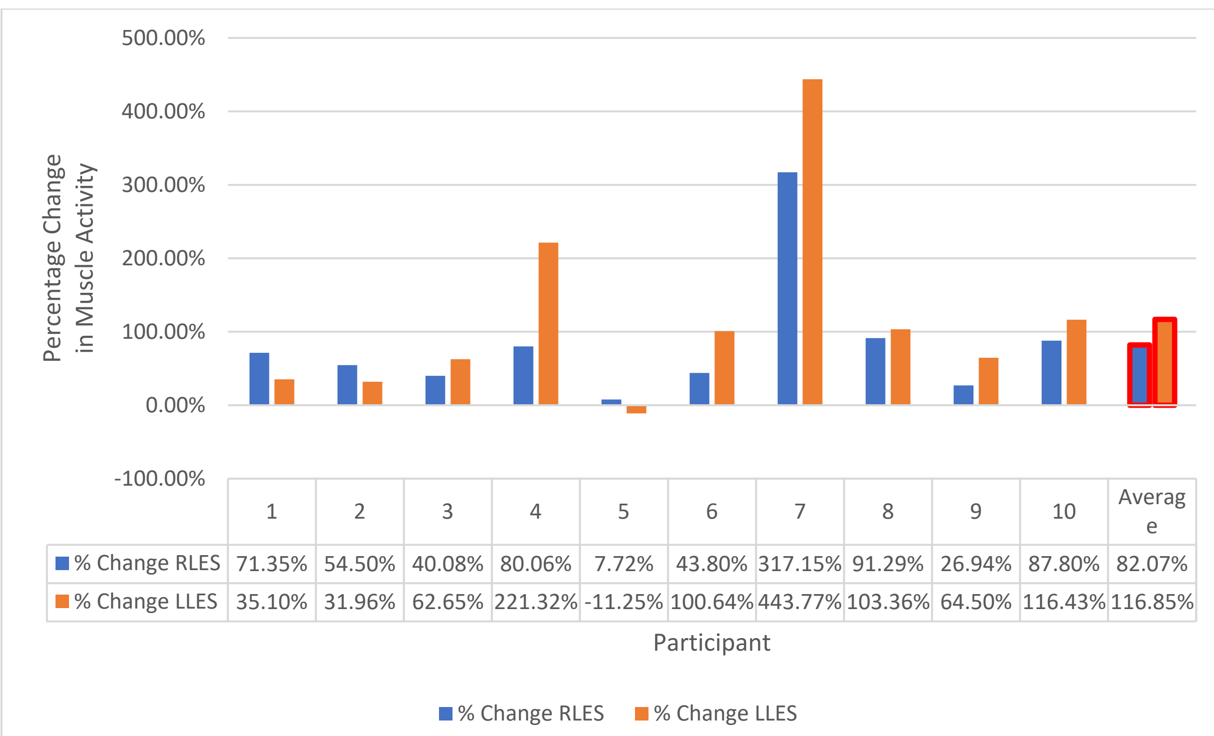
	1	2	3	4	5	6	7	8	9	10	Average
% Change RAD	8.10%	31.69%	608.04%	590.65%	340.05%	131.90%	1436.04	178.72%	650.79%	1857.97	583.39%
% Change LAD	-12.45%	555.78%	1056.81	630.97%	1007.72	198.32%	3784.09	677.00%	1459.18	2093.76	1145.12

Figure 4.19 Percentage of change in Right Anterior Deltoid (RAD) and Left Anterior Deltoid (LAD) activity from standing Calibration to Natural Position.
Note: red border indicates $p < .05$.



	1	2	3	4	5	6	7	8	9	10	Average
% Change RPD	6.35%	10.92%	27.95%	134.37%	52.36%	59.61%	538.49%	104.50%	57.56%	56.82%	104.89%
% Change LPD	-6.68%	20.69%	119.15%	163.33%	19.56%	42.75%	118.27%	259.30%	40.72%	50.00%	82.71%

Figure 4.20 Percentage of change in Right Posterior Deltoid (RPD) and Left Posterior Deltoid (LPD) activity from standing Calibration to Natural Position.
Note: red border indicates $p < .05$.



	1	2	3	4	5	6	7	8	9	10	Average
% Change RLES	71.35%	54.50%	40.08%	80.06%	7.72%	43.80%	317.15%	91.29%	26.94%	87.80%	82.07%
% Change LLES	35.10%	31.96%	62.65%	221.32%	-11.25%	100.64%	443.77%	103.36%	64.50%	116.43%	116.85%

Figure 4.21 Percentage of change in Right Lumbar Erector Spinae (RLES) and Left Lumbar Erector Spinae (LLES) activity from standing Calibration to Natural Position.

Note: red border indicates $p < .05$.

Research Questions Results

Q26 Do misalignments associated with playing the horn occur with asymmetrical increases in muscle activity between the left and right sides of the body?

Figures 4.16-4.21 show differences in increases in muscle activity between muscles on the left and right side of the body in NP from Cal. Increases were greater mostly on the left side of the body. While seated in NP, every participant had greater increases in muscle activity in the left anterior deltoid (LAD) compared to the right anterior deltoid (RAD), except for Participant 1 who had reduced muscle activity in both shoulders while playing; Participant 1 had less reduction in muscle activity in the RAD compare to the LAD. Eight of 10 participants had greater increases of muscle activity in the left lumbar erector spinae (LLES) over the right lumber erector spinae (RLES), and 8 of 10 had greater increases of muscle activity in the right posterior deltoid (RPD) over the left posterior deltoid (LPD). As seen in figures 4.2 and 4.3, all participants showed an increase of the rightward twisting angle. As seen in figures 4.4-4.7, all participants experienced a shortening of the distance between the right shoulder and right sacrum. Seven of 10 participants narrowed the shoulders and 9 of 10 participants decreased the distance along the middle of the back. Three of the participants had decreases in all measured distances. Playing the horn while seated compared to neutral posture increased misalignments and increased muscle activity more in the LAD, LLES, and RPD than their bilateral pair.

While standing going from the Cal to NP, 9 of 10 participants had greater increases in muscle activity in the LAD than the RAD; 7 of 10 participants had greater increases of muscle activity in their LLES than their RLES; and 6 of 10 participants had greater increases of muscle activity in the RPD over their LPD. As seen in figures 4.2 and 4.3, 9 of 10 participants increased the angle of shoulder to hip twist to the right. As seen in figure 4.6, all participants had a decrease of distance between the right shoulder and right sacrum; figure 4.5 indicates 7 of 10 participants increased the distance from left shoulder to left sacrum; and figure 4.7 indicates 8 of 10 narrowed the distance between the shoulders. Playing the horn while standing increased misalignments, primarily with a twist to the right, and increased the muscle activity in the LAD, LLES, and RPD over their bilateral pair.

Q27 Do misalignments and increased asymmetrical muscle activation when playing the horn have any relation to lifetime, recent, or current PRP?

Question 27 is a bit more challenging to answer because only Participant 1 did not report a lifetime history of PRP. Participant 1's muscle activity data were rather anomalous: as seen in figures 4.16 and 4.17, in NP compared to Cal while seated, they had decreases in muscle activity in all measured shoulder muscles, and, as seen in figures 4.19 and 4.20 while standing had decreases in muscle activity in the left shoulder and very modest increases in the right shoulder. Both standing and seated, increases in muscle activity in the LES (figures 4.18 and 4.21) were average to the group, but were not particularly asymmetrical. While standing Participant 1 had the smallest increase in rightward twisting (see figures 4.2 and 4.3) and while seated had the second smallest increase in rightward twisting. While seated, they had shortening along the left, middle, and right back, but at 2% or less. While standing they showed the smallest amount of shortening on the right side and lengthening in all other distances. Participant 1's anomalous data suggests that having no history of lifetime PRP is associated with lower levels of asymmetrical muscle activity and better NP alignment when playing the horn. However, generalizing that statement based on only one participant is not ideal.

All participants who reported a recent history of PRP also reported a current history of PRP. Participants 1, 2, 8, and 10 did not report a recent history of PRP. However, although

Participant 8 did not report a recent history of PRP through the survey, they did verbally report visiting urgent care for low back pain within the past week, so for this discussion, they were included as having recent PRP.

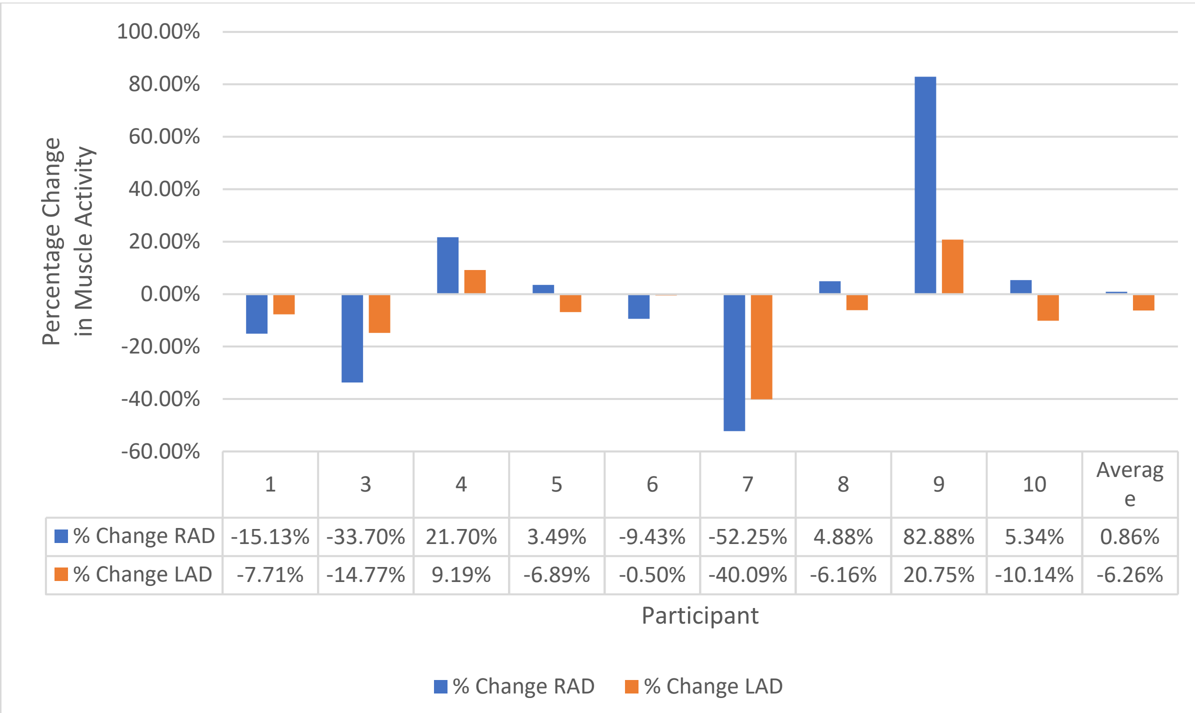
As seen in figures 4.16 and 4.19, Participant 2 had large increases in LAD activity over RAD activity, although there was a similarly large increase in LAD over RAD in most participants. Otherwise, muscle activity increases were low and fairly balanced from left to right. Standing distance data suggests better alignment (see figures 4.4-4.9) than other participants, seated misalignments were about the same at other participants. They showed one of the highest increases in rightward twisting (see figures 4.2 and 4.3) for both seated and standing.

Participant 10 was the least experienced horn players and had large bilateral increases in anterior deltoid activity between 1673% and 2093% as seen in figures 4.16 and 4.19. LES activity (figures 4.18 and 4.21) also had fairly large increases between 87% and 151%.

Compensations with increased asymmetrical muscle activations from past injuries seem to become habitual and remain as the primary movement pattern, even after recovery. There is no discernible difference between misalignment patterns and muscle activations in participants with lifetime PRP but no recent PRP and participants experiencing current PRP.

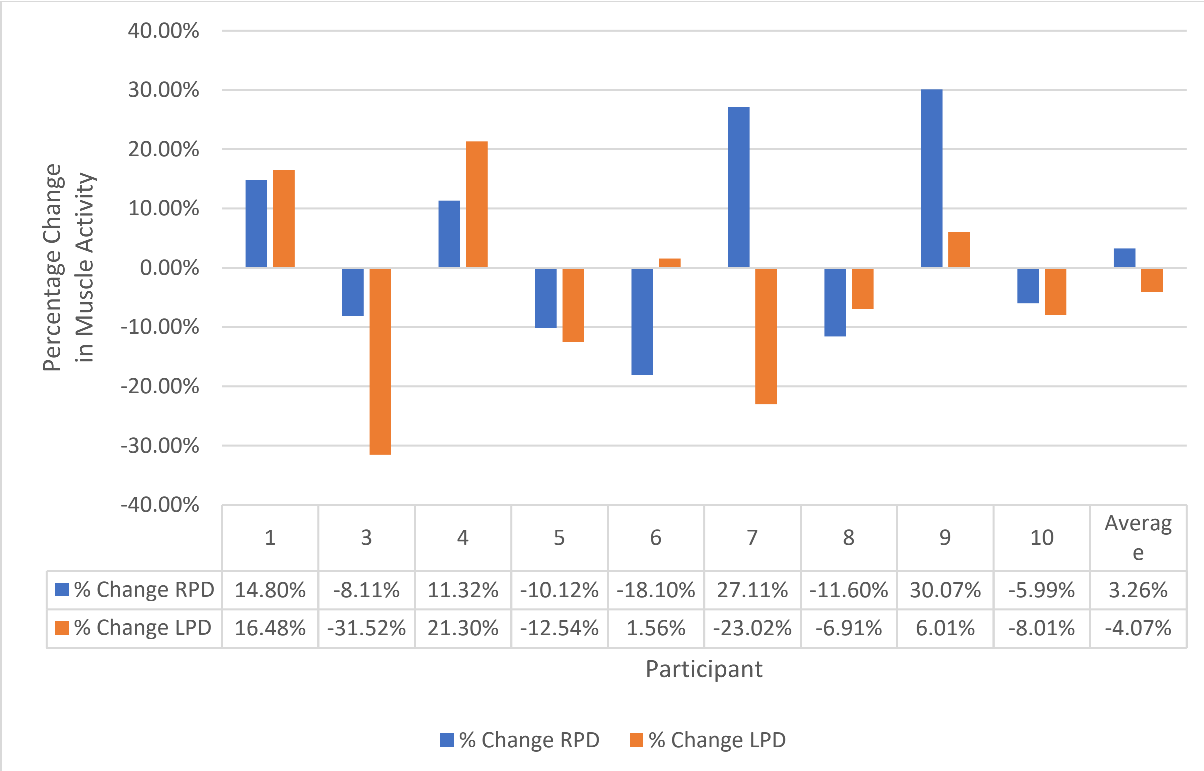
Electromyography Results with ERGObrass™

Figures 4.22-4.24 show the percentage of change of each participant's muscle activity using an EB while seated from seated NP. Many muscles demonstrated decreases in activity of up to 99%, particularly on the left side of the body. The EB did not interface well with Participant 2's horn; Participant 2 reported that the horn felt like it was constantly tipping, and this discomfort manifested in a 435.96% increase in the muscle activity of Participant 2's RAD. Because the EB was not functioning as intended, Participant 2's data were eliminated in this section; muscle activity decreased on average 4.93%. when participants used the EB while seated. Participant 4, who also reported feeling uncomfortable with the system, and Participant 9 had increases in muscle activity in all muscles when using the EB. Interestingly Participant 9, who had a current history of PRP, had been using an EB while in recovery for the previous 6 weeks but consistently experienced increases in muscle activity with the EB compared to NP.



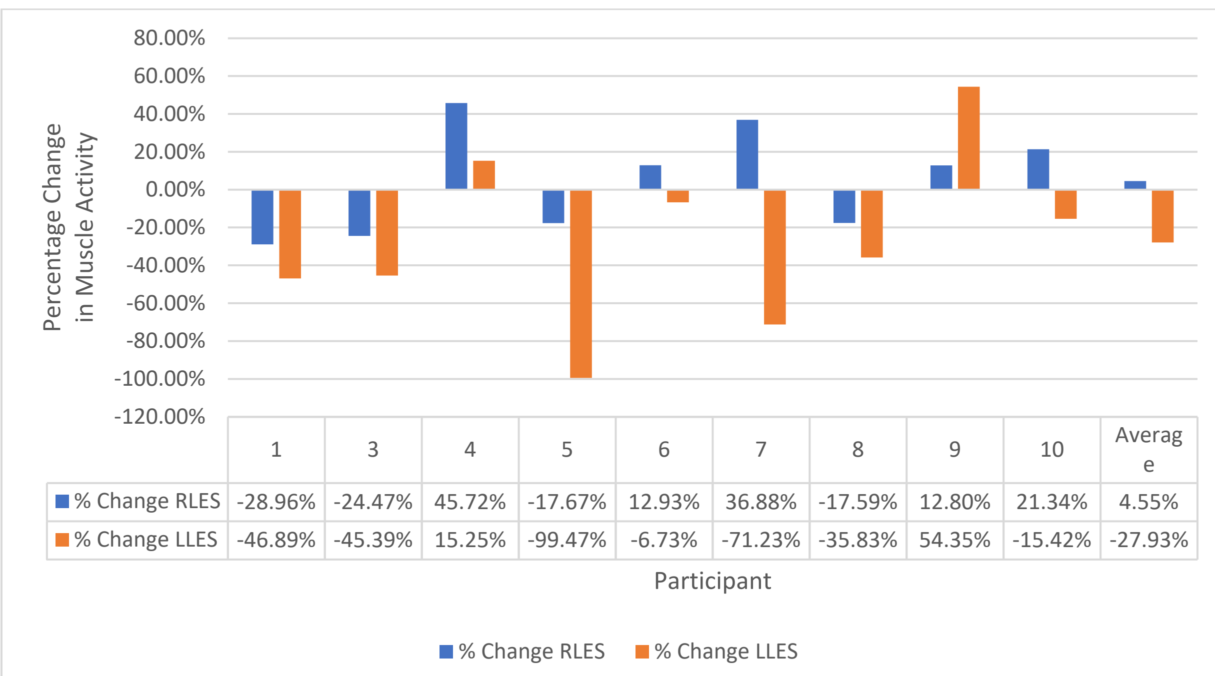
	1	3	4	5	6	7	8	9	10	Average
% Change RAD	-15.13%	-33.70%	21.70%	3.49%	-9.43%	-52.25%	4.88%	82.88%	5.34%	0.86%
% Change LAD	-7.71%	-14.77%	9.19%	-6.89%	-0.50%	-40.09%	-6.16%	20.75%	-10.14%	-6.26%

Figure 4.22 Percentage of change of Right Anterior Deltoid (RAD) and Left Anterior Deltoid (LAD) activity using ERGObrass^{TM} from seated Natural Position.



	1	3	4	5	6	7	8	9	10	Average
% Change RPD	14.80%	-8.11%	11.32%	-10.12%	-18.10%	27.11%	-11.60%	30.07%	-5.99%	3.26%
% Change LPD	16.48%	-31.52%	21.30%	-12.54%	1.56%	-23.02%	-6.91%	6.01%	-8.01%	-4.07%

Figure 4.23 Percentage of change of Right Posterior Deltoid (RPD) and Left Posterior Deltoid (LPD) activity using ERGObrass^{TM} from seated Natural Position.



	1	3	4	5	6	7	8	9	10	Average
% Change RLES	-28.96%	-24.47%	45.72%	-17.67%	12.93%	36.88%	-17.59%	12.80%	21.34%	4.55%
% Change LLES	-46.89%	-45.39%	15.25%	-99.47%	-6.73%	-71.23%	-35.83%	54.35%	-15.42%	-27.93%

Figure 4.24 Percentage of change of Right Lumbar Erector Spinae (RLES) and Left Lumbar Erector Spinae (LLES) activity using ERGObrass^{TM} from seated Natural Position.

Figures 4.25-4.27 shows the percentage of change of each participant's muscle activity using an EB while standing from their standing NP. Many muscles demonstrated decreases in activity of up to 60%. Participants 1, 3, 8, and 10, none of which had previous experience using an EB, were able to reduce muscle activity in all muscles using the EB. Because the EB did not interface well with Participant 2's horn, they experienced a 365.52% increase in RAD activity, and their data were eliminated from this section. Using the EB while standing had an overall average 14.62% decrease in muscle activity compared to NP.

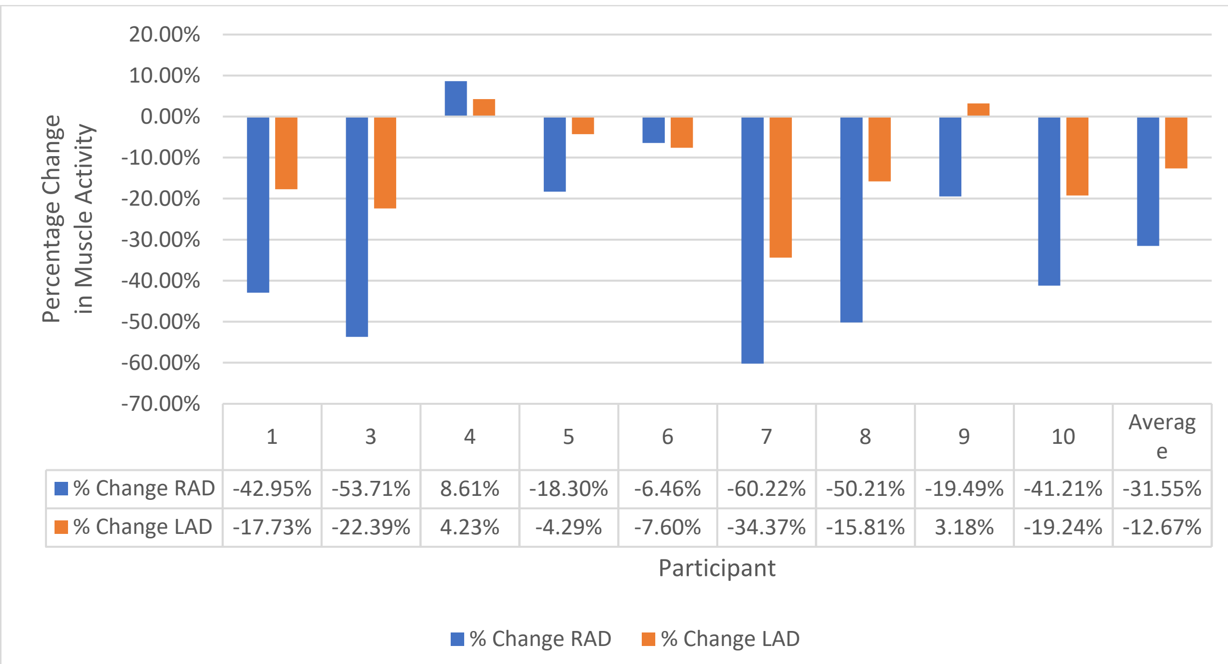


Figure 4.25 Percentage of change of Right Anterior Deltoid (RAD) and Left Anterior Deltoid (LAD) activity using ERGObrass^{TM} from standing Natural Position.

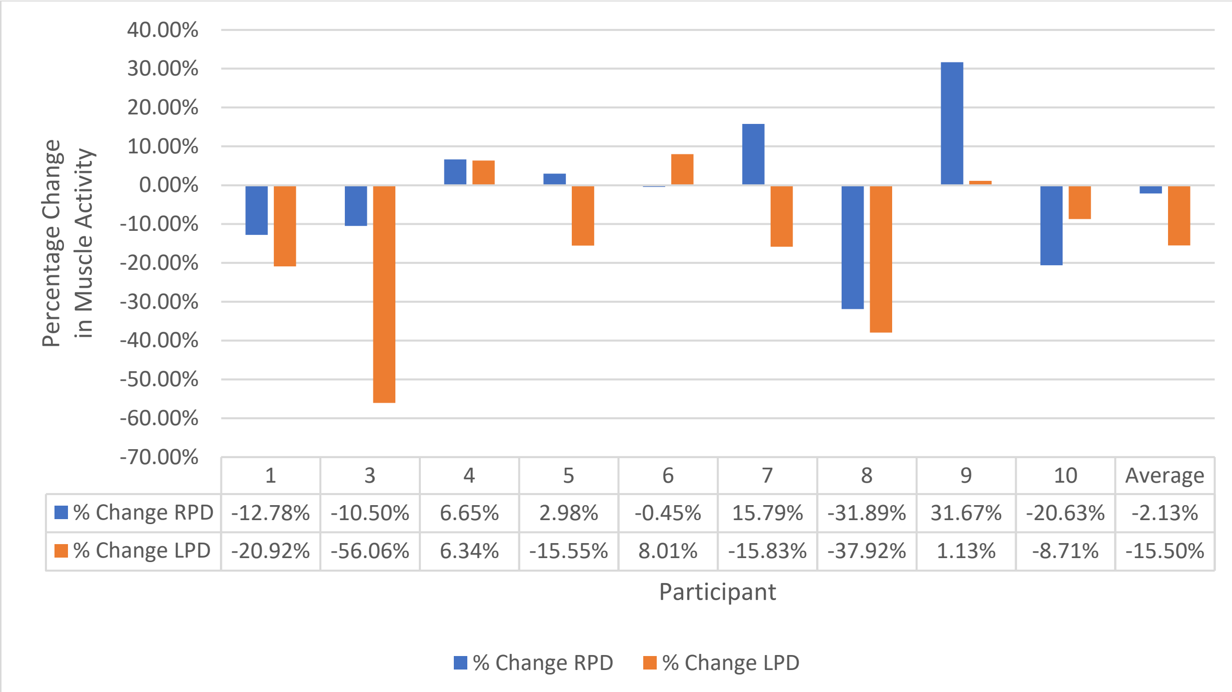


Figure 4.26 Percentage of change of Right Posterior Deltoid (RPD) and Left Posterior Deltoid (LPD) activity using ERGObrass^{TM} from standing Natural Position.

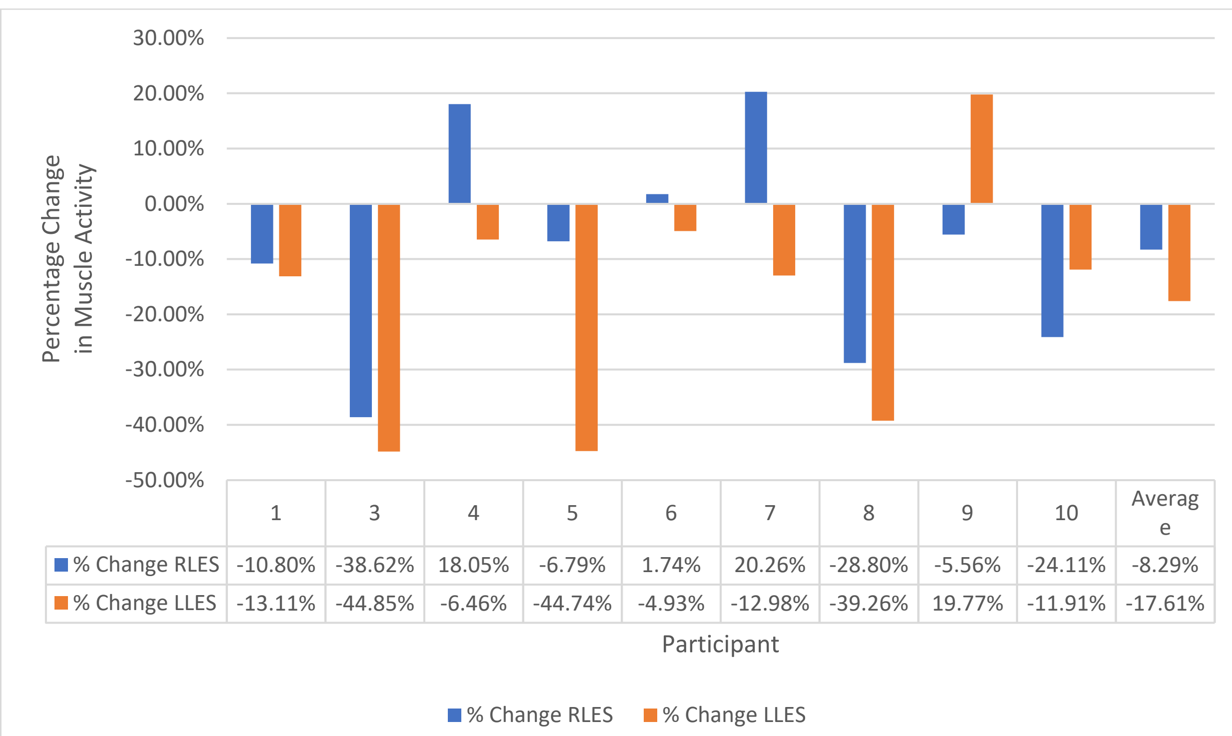


Figure 4.27 Percentage of change of Right Lumbar Erector Spinae (RLES) and Left Lumbar Erector Spinae (LLES) activity using ERGObrass^{TM} from standing Natural Position.

Research Questions Results

Q28 Confirming Watson and Price's study,[108] does the use of an ERGObrass™ (EB) system help reduced muscle activity in the deltoids compared to participants' natural posture (NP) with the horn?

As seen in figures 4.22-4.26, using the EB usually reduced shoulder muscle activity. While seated using the EB, participants had an average increase in muscle activity of 0.87% for RADs and 3.26% for RPDs compared to NP. Participants had an average decrease of muscle activity of 6.26% for LADs and 4.07% for LPDs. Participants 4 and 9 had increases in muscle activity in all measured muscles; only about half of participants had reductions in muscle activity for any given muscle.

While standing using the EB, RADs reduced activity by an average of 31.55% compared to NP. RPDs had an average reduction of 2.13%; LADs had an average reduction of 12.67%; and LPDs had an average reduction of 15.55%. Participant 4 had increases in muscle activity in all the measured shoulder muscles; the greatest reduction was Participant 7's 60% reduction in their RAD.

While standing, using the EB consistently reduced muscle activity in most participants' shoulder muscles. While seated, the most common way the system is used, the EB did not consistently reduce muscle activity in participants' shoulder muscles. The EB seems to have a modest effect for the left shoulder, which is the more commonly injured upper extremity in horn players, while on average it did not reduce muscle activity in the right shoulder. Watson and Price's study is partially confirmed.

Q29 Does the use of an ERGObrass™ (EB) system help reduce muscle activity in the lumbar erector spinae (LES) compared to participants' natural posture (NP) with the horn?

---

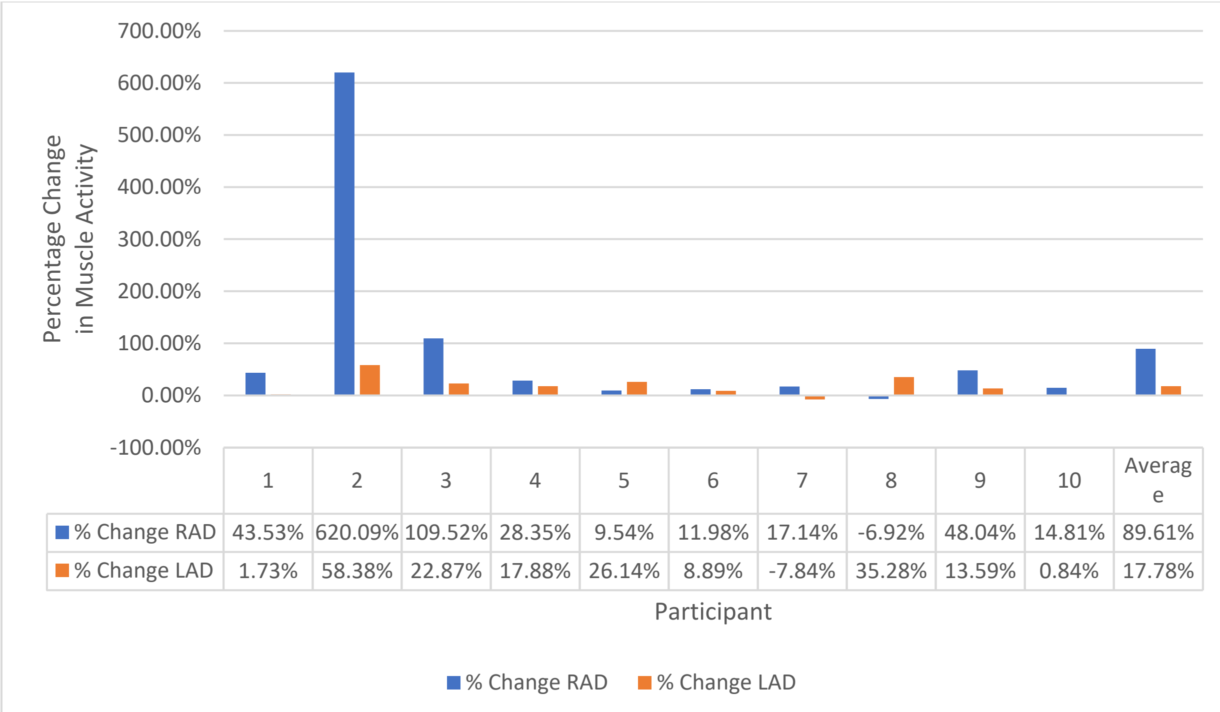
[108] Watson and Price, 183-190.

As seen in figures 4.22-4.25, LESs had reductions in activity while using the EB standing; reductions in the LESs are less consistent when seated. While seated using the EB, participants had an average reduction of 27.95% in LLES activity with 8 of 9 participants having reductions. Participants had an average increase of 4.55% of RLES activity with only 4 participants experiencing reductions of muscle activity.

While standing using the EB, participants had an average reduction of 17.61% LLES activity and an average of 8.29% reduction of RLES muscle activity. Eight of 9 participants had reductions on the left and 6 of 9 participants had reductions on the right. The EB seems to be effective at reducing erector spinae muscle activity on the left side of the body, both seated and standing, but not on the right side.

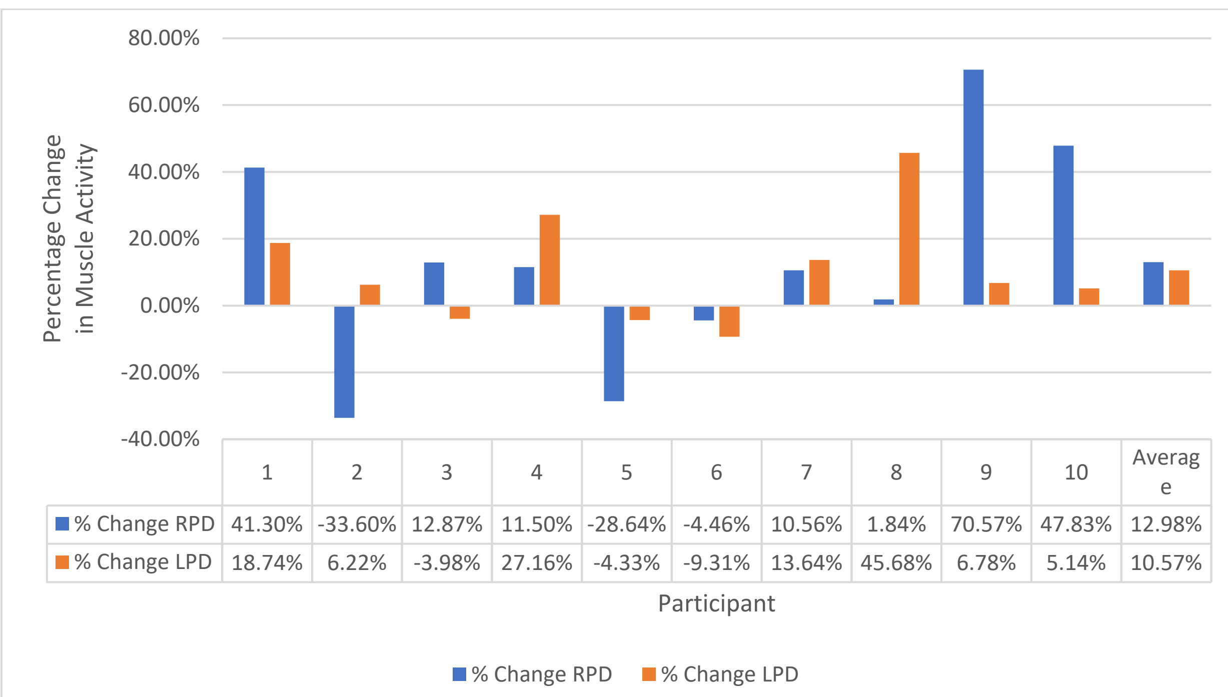
Electromyography Results with Alexandrian-Based Instructions

Figure 4.28-4.30 show the percentage of change of each participant's muscle activity with ABI while seated from their NP. LES muscles demonstrated decreases in activity of up to 47% in most participants while many participants had an increase in deltoid muscle activity; Participant 2 had a 620% increase in activity in the right anterior deltoid. The instructions were primarily focused on establishing spinal alignment and eliminating lower back tension, which occurred in 8 of 10 participants. Participant 9, who had a current PRP, experienced increases in all muscle activity. Overall, there was an average of 16.28% increase in muscle activity across all muscles and participants.



	1	2	3	4	5	6	7	8	9	10	Average
% Change RAD	43.53%	620.09%	109.52%	28.35%	9.54%	11.98%	17.14%	-6.92%	48.04%	14.81%	89.61%
% Change LAD	1.73%	58.38%	22.87%	17.88%	26.14%	8.89%	-7.84%	35.28%	13.59%	0.84%	17.78%

Figure 4.28 Percentage of change of Right Anterior Deltoid (RAD) and Left Anterior Deltoid (LAD) activity with Alexandrian-Based Instructions from seated Natural Position.



	1	2	3	4	5	6	7	8	9	10	Average
% Change RPD	41.30%	-33.60%	12.87%	11.50%	-28.64%	-4.46%	10.56%	1.84%	70.57%	47.83%	12.98%
% Change LPD	18.74%	6.22%	-3.98%	27.16%	-4.33%	-9.31%	13.64%	45.68%	6.78%	5.14%	10.57%

Figure 4.29 Percentage of change of Right Posterior Deltoid (RPD) and Left Posterior Deltoid (LPD) activity with Alexandrian-Based Instructions from seated Natural Position.

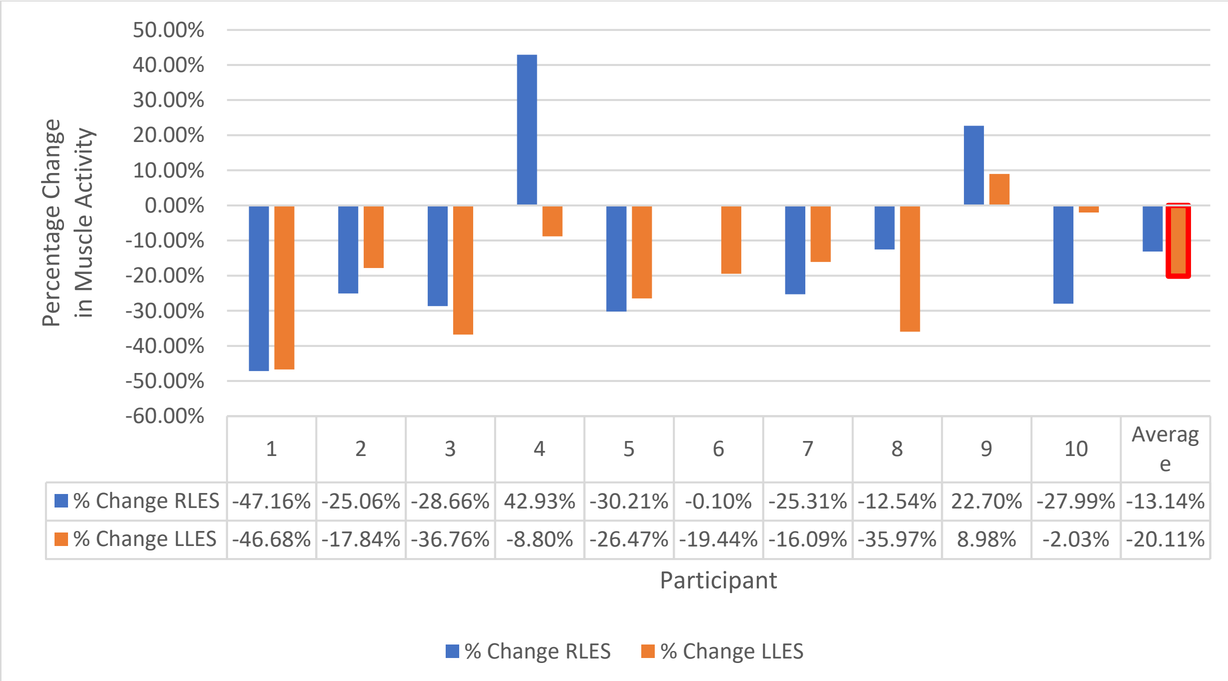


Figure 4.30 Percentage of change of Right Lumbar Erector Spinae (RLES) and Left Lumbar Erector Spinae (LLES) activity with Alexandrian-Based Instructions from seated Natural Position.
Note: red border indicates $p < .05$.

Figures 4.31-4.33 show the percentage of change of each participant's muscle activity with ABI while standing from NP; results are mixed with no obvious patterns. The instructions had average decreases in erector spinae muscles, particularly on the right side, and generally increased activity in the left anterior deltoid. Participants 1 and 6 had increases across all muscles, and Participant 2, again, had a large increase in RAD activity. Overall, there was an average of 9.62% increase in muscle activity across all muscles and participants.

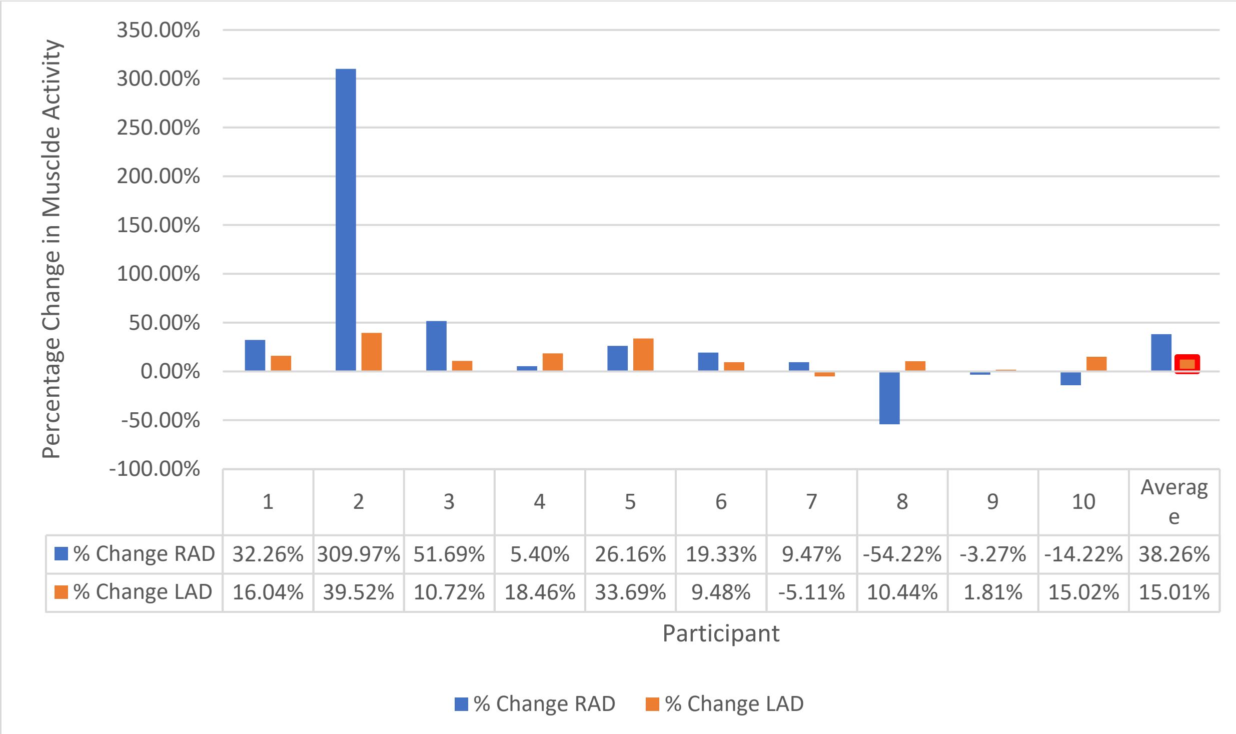


Figure 4.31 Percentage of change Right Anterior Deltoid (RAD) and Left Anterior Deltoid (LAD) activity with Alexandrian-Based Instructions from standing Natural Position.
Note: red border indicates $p < .05$.

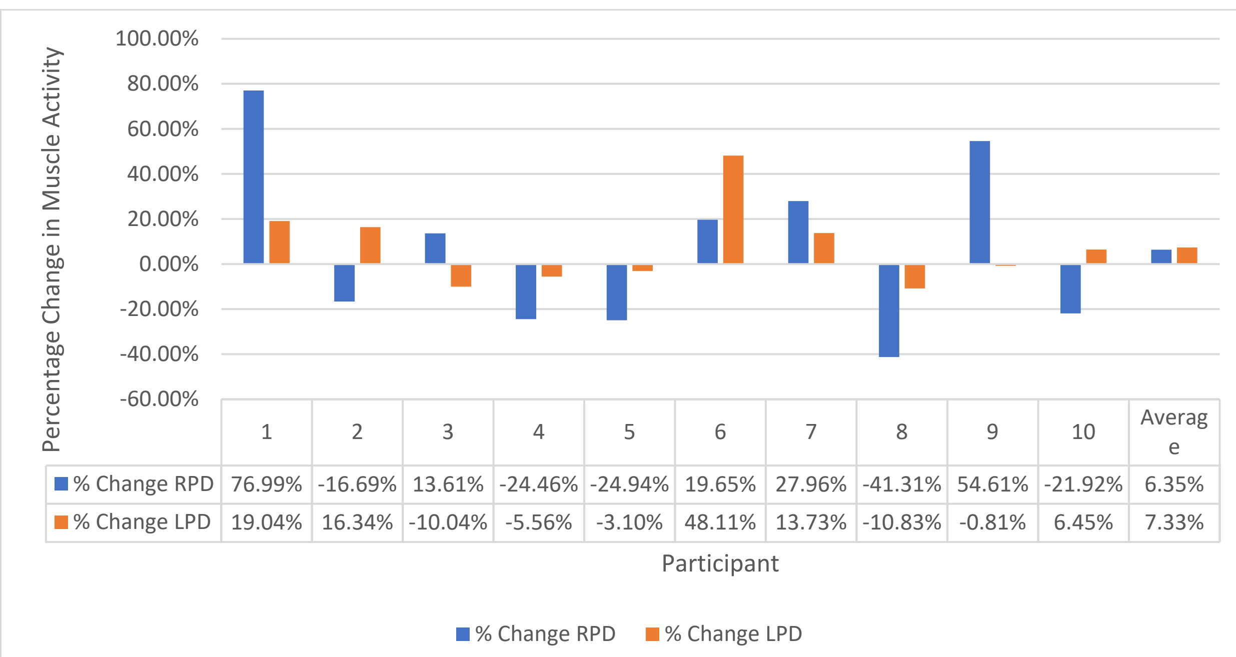


Figure 4.32 Percentage of change in Right Posterior Deltoid (RPD) and Left Posterior Deltoid (LPD) activity with Alexandrian-Based Instructions from standing Natural Position.

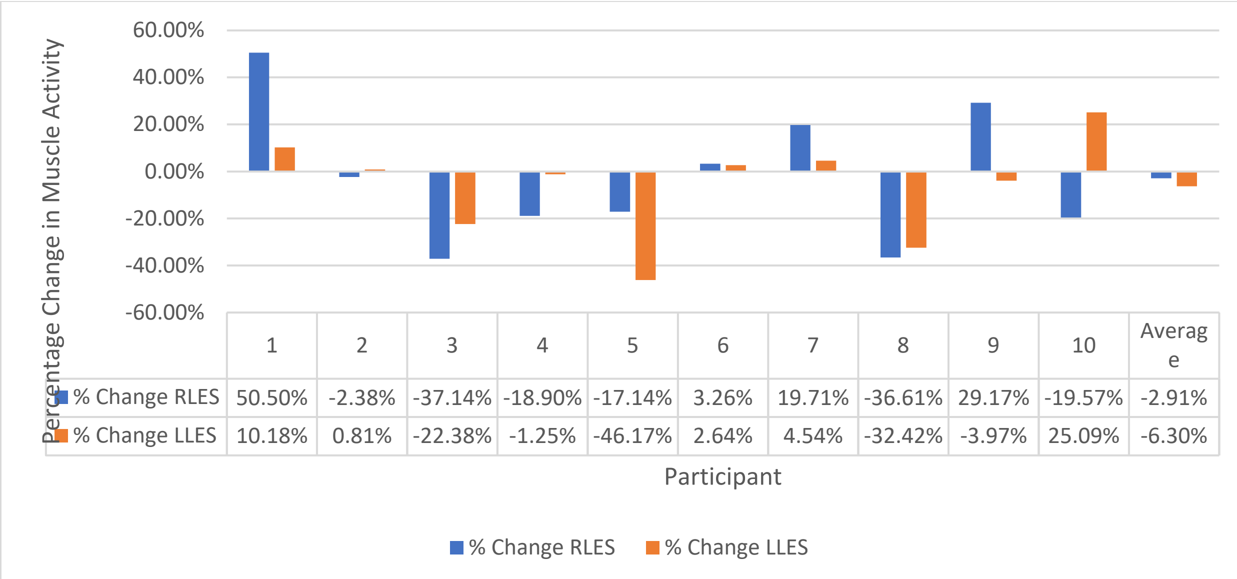


Figure 4.33 Percentage of change in Right Lumbar Erector Spinae (RLES) and Left Lumbar Erector Spinae (LLES) activity with Alexandrian-Based Instructions from standing Natural Position.

Research Question Results

Q30 Do Alexandrian-based instructions (ABI) on how to hold the horn help reduce muscle activity in the deltoids and lumbar erector spinae (LES) compared to participants' natural posture (NP) with the horn?

As seen in figures 4.28-4.30, it is apparent that while seated, ABI reduced muscle activity in the RLES by an average of 13.14% and LLES by an average of 21.00%. As seen in figures 4.30 and 4.33, it is apparent that while standing, ABI reduced RLES activity by an average of 2.91% and LLES activity by an average of 6.3%, although only half of participants had reductions in muscle activity in the lower back while standing compared to 8 participants who had reductions while seated. As seen in figures 4.28-4.32, participants receiving ABI experienced an average increase in all deltoid activity, seated and standing, ranging between 6.35% and 89.61%. It should be noted that the goal of the ABI was better alignment rather than a reduction in muscle activity. Although ABI were marginally successful at reducing LES muscle activity, overall, there was no consistent pattern to suggest it is a successful intervention for reducing muscle activation in most players.

Electromyography Statistical Analysis

Tables 4.12 and 4.13 show the f-values and p-values of the f-value for repeated measures ANOVA tests performed for each of the averaged muscle activity levels. Tables 4.12 and 4.13 show paired p-values for the different situations generated by the repeated measures ANOVAs that were performed to compare the effect of the different situations on the muscle activity at a 95% confidence level. This indicates that average percentages of change in muscle activity associated with the pairs with significant p-values (labelled with *) are also significant and are outlined in red in the figures 4.16-4.33.

Table 4.12 ANOVA-RM F-values and Significance Seated Electromyography

Muscle	F value	P value
RAD	4.052	.058
RPD	11.311	.004 *
RLES	2.718	.125
LAD	7.98	.012 *
LPD	3.006	.104
LLES	5.585	.028 *

* $p < .05$.

Table 4.13 ANOVA-RM F-values and Significance Standing Electromyography

Muscle	F value	P value
RAD	6.564	.019 *
RPD	2.318	.162
RLES	5.712	.027
LAD	12.096	.004 *
LPD	7.143	.016 *
LLES	3.228	.091

* $p < .05$.

Table 4.14 P-Values from ANOVA-RM Pairs Seated

Situation pair	RAD	RPD	RLES	LAD	LPD	LLES
Cal, NP	.014 *	.146	.013 *	.02 *	.008 *	.22
Cal, EB	.007 *	.185	.025 *	.008 *	.015 *	.785
Cal, IN	.003 *	.129	.074	.007 *	.011 *	.727
NP, EB	.588	.381	.571	.298	.445	.158
NP, IN	.053	.198	.145	.076	.07	.013 *
EB, IN	.07	.894	.044 *	.03 *	.052	.349

* $p < .05$.

Table 4.15 P-Values from ANOVA-RM Pairs Standing

Situation pair	RAD	RPD	RLES	LAD	LPD	LLES
Cal, NP	.007 *	.117	.007 *	.012 *	.01 *	.04 *
Cal, EB	.013 *	.168	.053	.012 *	.065	.308
Cal, IN	.001 *	.147	.04 *	.003 *	<.001 *	.219
NP, EB	.281	.724	.516	.093	.088	.075
NP, IN	.162	.168	.998	.022 *	.371	.362
EB, IN	.031 *	.368	.579	.006 *	.019 *	.1

* $p < .05$.

Audio Methodology and Analysis

Audio recordings of all the trials were created and labeled. Five professional hornists rated the tone quality of each trial on a scale of 1 to 10, 1 being poor and 10 being excellent. Judges were instructed to score each participant in one sitting because comparisons between trials of the same participant were the relevant data. Judges were instructed to go with their gut reactions; they were told that several different situations that were being compared but were not given details about those situations. In order to minimize trends due to playing order bias, trials were listened to by the judges in the same order for each participant, which was not the same order as they were performed. The 25 scores for of the 6 situations for each participant were averaged; ABI and EB trials were then compared to NP trials and shown as a percentage of change. Finally, the 250 scores for each situation across all participants were averaged, and ABI and EB trials were then compared to NP averages and shown as a percentage of change. A repeated measures ANOVA was performed using SPSS software to compare the effect of the different situations on tone quality at a 95% confidence level ($p < .05$).

Audio Results

Figures 4.34 and 4.35 show the percentage of change of tone quality scores from natural posture (NP) to ERGObrass™ (EB) and Alexandrian-based instructions (ABI) interventions for each participant. Changes in tone quality with ABI were mostly improvements (17 of 20 trials) with statistically significant average increases of 12.1% while seated and 10.48% while standing. Changes in tone quality using an EB were more mixed (14 of 20 trials improved); seated with EB had an average of 9.4% tone quality improvement; standing with EB had an average of 4.78% tone quality improvement. ABI were often a better intervention than EB for tone quality.

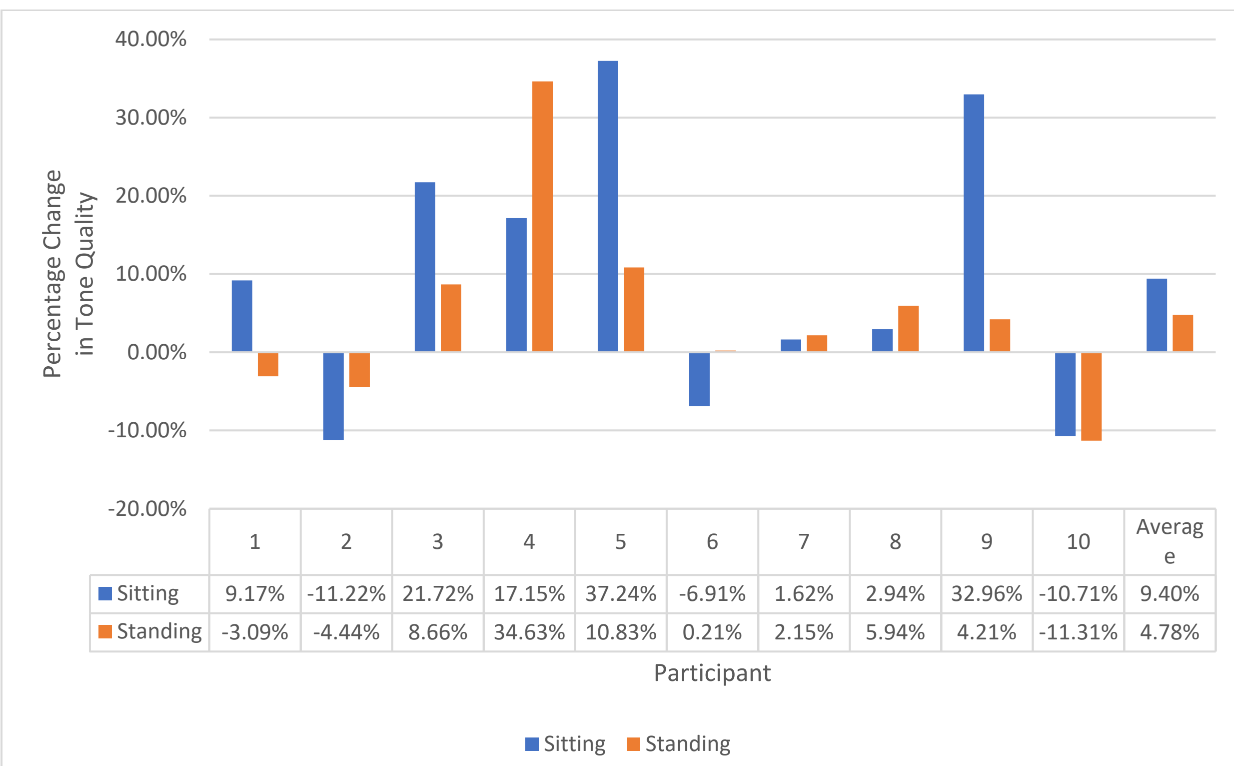


Figure 4.34 Percentage of change in tone quality from Natural Position to ERGObrass™.

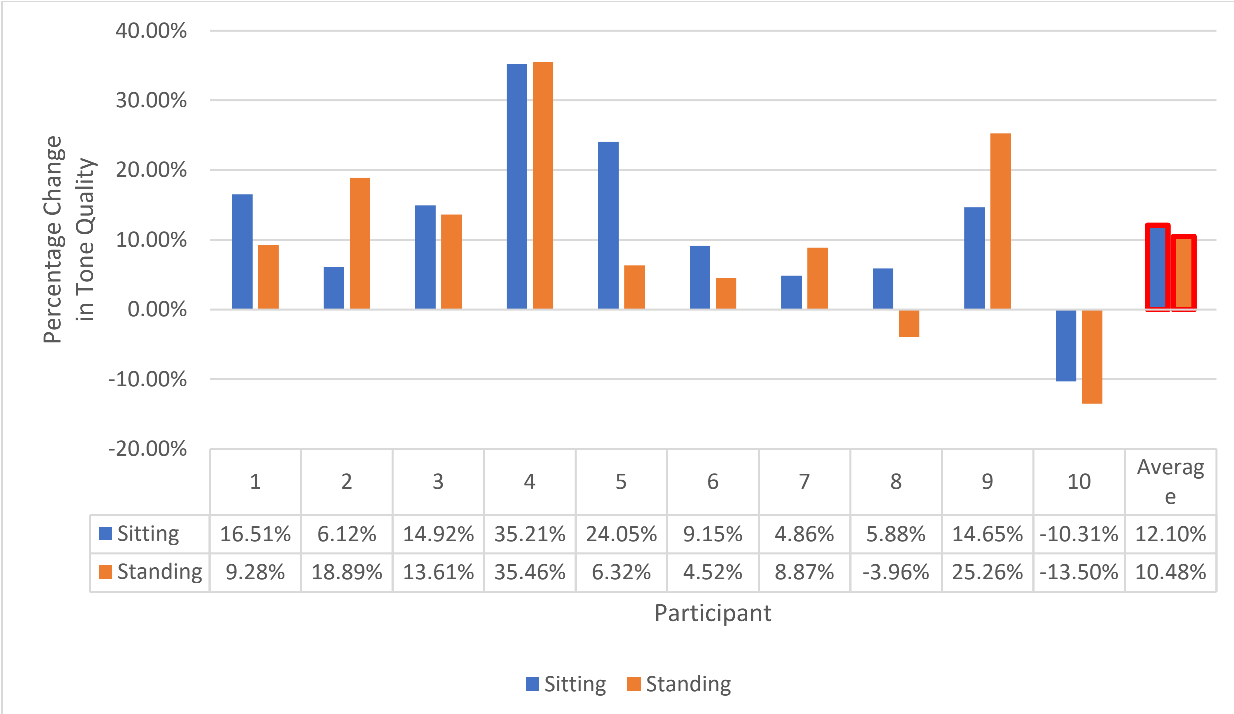


Figure 4.35 Percentage of change in tone quality from Natural Position to Alexandrian-Based Instructions.
Note: red border indicates $p < .05$.

Tone Quality Statistical Analysis

Table 4.16 shows the f-values and p-values of the f-value for repeated measures ANOVA tests performed for changes in standing and seated tone quality. Table 4.17 show paired p-values for the different situations generated by the repeated measures ANOVAs that were performed to compare the effect of the different situations on tone quality at a 95% confidence level ($p < .05$). This indicates that average percentages of tone quality associated with the pairs with significant p-values (labelled with *) are also significant and are outlined in red in figure 4.35.

Table 4.16 ANOVA-RM F-values and Significance for Tone Quality

Stance	F-value	P-value
Standing	3.421	.084
Seated	6.173	.024 *

* $p < .05$.

Table 4.17 P-Values from ANOVA-RM Pairs Tone Quality

Situation pair	P-value
Standing NP, EB	.329
Standing NP, ABI	.024 *
Standing EB, ABI	.082
Seated NP, EB	.318
Seated NP, ABI	.007 *
Seated EB, ABI	.182

* $p < .05$.

Research Question Results

Q31 Keeping changes in muscle activity, alignment, and tone quality in mind, is using an ERGObrass™ (EB) system or receiving Alexandrian-based instructions (ABI) a better intervention?

See Appendix E for tables combining electromyography, positional, and audio data for each participant. Table 4.18 shows which intervention: ABI or EB had a better effect for each participant. Improvements in tone quality, better alignment, and reductions in muscle activity were considered for each participant to determine what was a better intervention. In many individuals, both interventions were effective. No participant experienced an improvement in tone quality accompanied by better alignment in all measurements and reduced muscle activity for all muscles. Overall, using an EB was slightly more effective than ABI.

Table 4.18 Superior interventions for each participant

Participant	Seated	Standing
1	EB	EB
2	ABI	ABI
3	EB	ABI
4	ABI	ABI
5	EB	EB
6	ABI	EB
7	EB	EB
8	EB	EB
9	EB	ABI
10	EB	EB

Limitations

With a complex study, there are many limitations. The participant pool was 90% biologically female and 80% were between the ages of 18 and 34. Ninety percent of participants reported a lifetime PRP and 60% reported current PRP. The participant pool was not an ideal representation of the population of horn players.

With the data collection protocol, participants were asked to play a one-octave C major scale with a metronome 32 times to control for timing of recordings, and consistency of actions. However, repetitively playing a C Major scale is musically unstimulating and not representative of what a hornist does in everyday life while performing and practicing. Additionally, having electrodes and reflective markers attached while performing could cause overall increased muscle tension compared to normal playing because of the unfamiliarity of the situation.

This study reports the acute effects of using an EB system; the manufacturer suggests a 6-week adjustment period to the product, so greater improvements in tone quality, body alignment, and reductions in muscle activity may be detected after a longer adjustment period. Studying the acute effects of the EB was a more practical protocol because only 1 EB system was required, the equipment did not need to be distributed prior to the study, it was simpler to determine how much time participants had spent using the EB, and participant recruitment was easier because they were not being asked to use an EB for 6 weeks prior to data collection.

There is no objective standard for good tone quality; although 5 professionals judged the audio recordings, other professional judges could have produced quite different results. The audio data could suffer from two types of order bias; as a participant progressed through the data collection, fatigue from playing could set in and negatively affect tone quality scores if they were recorded towards the end of the session. Natural postures were always recorded prior to EB and ABI. Although recordings were made in an order that hopefully reduced order bias, all judges listened to trials in the same order. With 320 renditions of C Major scales, order bias from listening is possible.

Participant 10 had decreases in tone quality in all 4 categories; Participant 10 was the most inexperienced participant in the study with only 3 years playing the horn and less than a year taking lessons. This suggests that Participant 10 either fatigued during the data collection process or that introducing detailed postural instructions or novel equipment to beginning horn students may be a less effective strategy than waiting until students gain more experience and are more comfortable with basic horn proficiencies.

Equipment malfunctions are another potential source of error; there were a few instances with Participant 2 and 7 when clothing obscured reflective markers on the sacrum and data analysis protocols had to be modified or data were too unreliable to report.

Although the goal of the EB and ABI interventions has been to search for reduced muscle activations and more symmetrical body positioning respectively, this assumes that those conditions are individually better for players. EMG measures efferent neural signals: the brain telling muscle fibers when to contract and by how much. Pain is a mechanism of afferent neural signals, so while it is often true that increased muscle activation is associated with increased pain, it is impossible to determine a cause-and-effect relationship. Underactive muscle activation can be just as detrimental to playing the horn as overactive muscles, so an increase in muscle activity is not necessarily unfavorable. There were instances in the data where muscle activation increased, posture distortions improved, and tone quality did as well.

The assumption that symmetry is ideal for playing the horn is also not necessarily the only postural option for easeful playing that prevents and alleviates PRP. Twisting is not a detrimental posture, most human muscles contribute to some twisting actions; some degree of rightward twist while playing the horn is inevitable due to its asymmetrical shape. Statically twisting to the right for long periods may require the individual to strengthen and mobilize muscles that twist to the left in order to have a more balanced body.

Conclusion

The Surface Electromyography (EMG) of the Low Back in Horn Players study showed that compared to neutral positions (Cal) without the horn while seated and standing, playing the horn increases misalignments, usually by increasing torso twisting to the right accompanied by lengthening along the left side of the torso, shortening along the right side of the torso, and narrowing between the shoulders (Q24). Participants experiencing both interventions of using of an ERGObrass^{TM} (EB) system and receiving Alexandrian-based instructions (ABI) experienced better alignment compared to participants' natural position (NP) with the horn (Q25). The EB especially reduced the tendency to twist the shoulders to the right and allowed the majority of participants to increase lengthening along the spine. ABI resulted in an almost-universal tendency of participants to narrow the distance between the shoulders, most likely because instructions focused on changes in spinal alignment rather than shoulder alignment. ABI were associated with reductions in other misalignments, such as rightward twisting and shortening along the spine compared to participants' NP.

Increases in misalignments with playing the horn are accompanied by asymmetrical increases in muscle tension; left anterior deltoids (LADs), left lumbar erector spinae (LLESs), and right posterior deltoids (RPDs) usually showed greater increases in muscle activity as participants held the horn and increased twisting to the right (Q26). Although the limited subject pool prevented a stronger assertion, a lifetime history without playing-related pain (PRP) is likely related to better alignments and less asymmetrical muscle activation when playing the horn (Q27): Participant 1, the only participant without a lifetime history of PRP, had anomalous muscle activity and reflective marker data that suggest this is the case. Participants with a lifetime history of PRP but not recent PRP demonstrated misalignments and asymmetrical increases in muscle activity similar to participants with recent or current PRP.

While standing, the use of EB partially confirmed Watson and Price's study[109] with modest reductions of muscle activity in the deltoids (Q28). While seated, participants also had a modest reduction in muscle activity in the left deltoids, however, they did not see reductions in right deltoid muscle activity. Watson and Price's study was partially confirmed. The use of an EB system was associated with reduced muscle activity in the LLES compared to participants' NP. It did not result in reduced muscle activity in the RLES, but the left lower back has a greater prevalence of pain and higher increases in muscle action, so using an EB is likely an effective intervention in reducing back pain, especially if it occurs on the left side (Q29). ABI were not associated with reductions in muscle activity in the deltoids and lumbar erector spinae (LES)

---

[109] Price and Watson, 183-190.

compared to participants' NPs (Q30). There was a modest reduction for muscles on the left side of the body associated with ABI.

Tone quality scores improved more consistently with both seated and standing ABI and with statistically significant averages than with an EB, however, using an EB was also an effective intervention for improving tone quality for most participants (Q31). The EB had better results at reducing muscle activation, and both interventions were about equally effective at improving alignment.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The PRMDs in Horn Players Health (PRMDHPH) Survey revealed some new information and confirmed the findings of similar studies. The PRMDHPH Survey revealed similar trends in anatomical locations of pain reported by Chesky et al.[110] Lifetime rates of playing-related pain (PRP) were 71% and lifetime rates of PRMD (PRP possibly caused by playing the instrument) were 55%. Most respondents suffering from PRP indicated that playing the horn made their pain worse.

Areas of concern included the left upper extremity from the neck to the fingers, the low back, and the embouchure (lips and/or jaw). Low back pain was less prevalent but had higher intensities than pain in the upper extremity. Women tend to suffer from PRP at higher rates than men; differences in stature and hypermobility are likely the cause of this trend. Factory-made horns designed for smaller hand spans or with more adjustability for the left-hand fit could help reduce this trend.

Older hornists who have played the horn longer reported lower lifetime rates of PRP; this is likely more due to attrition: chronically injured players leave the career so older hornists appear to have lower risk for PRP. Adding injury to the already stressful and financially marginal lifestyles of most professional musicians is often, understandably, a deciding factor for moving on to an alternative career. Interestingly, more years of lessons did not provide any protective factor of developing PRP, nor did it seem to help musicians cope with recent or current PRP. The

[110] Chesky et al., 96.

likeliest age for PRP do develop was between 16 and 25, college students, both graduates and undergraduates, consistently reported the highest levels of current, recent, and lifetime PRP. This suggests that college may be one of the best times to educate aspiring musician about playing loads and optimal body positions in order to prevent the development of more severe PRP.

Respondents who started the horn at the age of 10 had a significantly higher risk of developing PRP than respondents who started later. Often young beginners play on equipment too large and heavy for them to easily handle. The postural compensations they employ to play a cumbersome instrument remain with them, even after they have grown. Electromyography data supports this idea; hornists with a lifetime history of PRP showed patterns of muscle activation similar to hornists suffering current PRP, while the hornist without lifetime PRP showed less muscle activation in the shoulders when playing the horn than without holding it.

More widespread availability of ¾-sized horns for beginning band programs or beginning horns that incorporate the ERGObrass™ (EB) mechanism or something similar into their design, like cellos have endpins, could be of great benefit to starting beginners off with less risk of developing PRP. Currently there is some stigma around using an EB in the horn community, and it is usually only used by injured players in recovery. More well-known professional players are using the EB regularly in public and reducing this stigma, but more needs to be done to normalize musicians taking positive action to improve their body positions with tools like the EB.

Quality teaching of healthful posture of beginners could help young beginners to avoid developing pain, and switching hornists to the instrument in middle school after they have learned basic music skills on another instrument may decrease the likelihood of developing PRP. Hornists who played the instrument for 5 hours or less a week were significantly less likely to report PRP, so instilling basic good posture at a young age is more important than working on highly detailed postural habits while a student is still struggling to execute basics (such as correct pitches and fingerings).

Electromyography consistently showed much greater increases in muscle activation in the left anterior deltoid (LAD), left lumbar erector spinae (LLES), and right posterior deltoid (RPD) than their bilateral pair. Reflective marker data revealed that playing the horn, due to its unbalanced shape often caused a twist towards the right, narrowing of the shoulders, and a reduction of length between the right shoulder and right hip. Both interventions of the EB and ABI helped to improve alignment, reduce muscle activation, and usually improved tone quality. EB was somewhat more successful with muscle activation reduction, and ABI were more successful with improving spinal alignment. A combination of individualized postural instructions and using an EB may yield the best results.

Many participants experienced improved tone quality scores with both the EB and ABI compared to NP. However, ABI improvements were more consistent and statistically significant. Although breathing was never directly addressed in the instructions, several of the participants reported that with the instructions they felt improvements in and more awareness of their breathing. This suggests that teachers may hear more improvements in students' tone by focusing on body position than by working on breathing exercises.

Checkpoints for Teaching Optimal Posture

These checkpoints are based on both the background research and original research presented here. They are similar to the instructions reproduced in Appendix B, but are also based on the analysis of the resulting data. They are meant as a concise tool that could be used by a teacher to help optimize a student's body positions while playing the horn.

1. Establish neutral spine with natural S curve when viewed from side, symmetrical when viewed from the front with shoulders of equal height, both seated and standing.

2. Balance the spine vertically as a unit over arches of the feet when standing or over the sitting bones when seated. Common misalignments are thrusting the hips forward when standing or overarching the lower back and balancing on the back of the thighs rather than the sitting bones when seated.

3. Balance the head on top of the neck. It should be equally as easy to nod the head yes as shake the head no. A useful way to find a balanced head is to sing and move the chin forward and backwards and listen for the position that creates the most resonance.

4. Once a neutral spine balance has been established, bring the horn to you; avoid bringing the face to the horn. Resting the horn on the leg is fine if a balanced spine can be maintained.

5. Balance the majority of the weight of the horn on the index finger and thumb of the right hand; maintain a neutral wrist position (no flexion, extension, or radial/ulnar deviation).

6. Keep the left-hand fingers bent and use the tips of the fingers at the end of the levers. Avoid using the pinkie hook and keep the wrist straight. It may be necessary to use a hand strap or duck's foot in order to cease using the pinkie hook.

7. To promote breadth, allow the elbows to spread down and away from each other. Allow for some space between the arms and ribcage.

8. When standing maintain an active stance by keeping the knees and hips flexible and unlocked. Adopt a mini-lunge with the left foot forward of the right; the right foot can point out to the right up to 45 degrees.

9. A torso twist to the right is likely, avoid letting the right shoulder collapse down towards the left hip by finding length along the spine as it twists up to the right.

See figures 5.1 and 5.2 for photographic examples of ideal posture incorporating the above checkpoints.

Figure 5.1 Seated playing position.

Figure 5.2 Standing playing position.

Final Conclusions

Musicians seeking out help for their playing-related pain (PRP) is improving; the PRMDs in Horn Players Survey reported respondents consulted with medical doctors and physical therapists than any other category, and only 13% of respondents did not seek help from anyone, lower than the rate reported by Stanek et al in 2017.[111] Still, about half of musicians do not receive a satisfactory diagnosis/management plan for their PRP.

Unfortunately, many musicians experiencing playing-related injuries do not have a positive recovery experience. Injuries that impact a musician's ability to perform are often stressful enough without the additional concerns related to finances, status in the musician community, and frustrations accessing quality care that most musicians currently face. There are a variety of institutional steps that could be taken to reduce the impact injuries have on musicians, the most important of which involves education. All music educators from pre-Kindergarten through university professors should have better knowledge of the body and the potential medical problems related to playing an instrument or singing. Teachers must educate their students about playing loads and safe strategies to rebuild after time off. Teachers need to empower students to say "no" when they are being overworked.

At a minimum, music educators should be able to refer students to helpful medical practitioners to address the issues. Medical practitioners often do not understand the highly complex physical interactions between a musician and their instrument, and will be more helpful in treating them when they collaborate with their patients to address the root cause of their pain, not just treat symptoms. One retired medical professional who is an amateur hornist commented to the researcher that they did not see how musculoskeletal disorders were relevant to horn playing and questioned the usefulness of PRMDs in Horn Players Health Survey.

[111] Stanek et al., 17.

Educational institutions and employers should implement policies and strategies that do not threaten a musician's ability to earn a living or a student's ability to complete a degree when they are dealing with an injury. Governments should be responsible in ensuring that these practices are common across the industry. Any poll would reveal that practically every musician is acquainted with at least one individual who no longer plays music due to a playing-related injury. If a musician does not personally suffer an injury at some point in their career, it is inevitable that they will teach or work with someone who is dealing with one. There are many financial, social, and psychological stressors that exacerbate the physical injuries musicians suffer and ultimately cause many injured musicians to leave the field. Many of these injuries are ignorantly self-inflicted through poor body use and could be prevented or reduced by more attentive and informed music teachers. This document is meant as a resource for horn players and teachers to help prevent and alleviate playing-related pain in horn players through better use of the body.

BIBLIOGRAPHY

Ackermann, Bronwen, Tim Driscoll, and Dianna T. Kenny. "Musculoskeletal Pain and Injury in Professional Orchestral Musicians in Australia." *Medical Problems of Performing Artists*, December 2012, 181-187.

Ajidahun, Adedayo Tunde and Julie Phillips. "Prevalence of Musculoskeletal Disorders Among Instrumental Musicians at a Center for Performing Arts in South Africa." *Medical Problems of Performing Artists*, June 2013, 96-99.

de Alcantara, Pedro. *Indirect Procedures: A Musician's Guide to the Alexander Technique*. Oxford: Oxford University Press, 1997.

Anderson, Lotte Nygaard, Stephanie Mann, Birgit Juul-Kristensen, and Karen Søgaard. "Comparing the Impact of Specific Strength Training vs General Fitness on Professional Symphony Orchestra Musicians: A Feasibility Study." *Medical Problems of Performing Artists*, June 2012, 94-100.

Anderson, Lotte Nygaard, Kirsten Kaya Roessler, and Henning Eichberg. "Pain Among Professional Orchestral Musicians: A Case Study in Body Culture and Health Psychology." *Medical Problems of Performing Artists*, September 2013, 124-130.

Baadjou, Vera A.E., Jeanine A.M.C.F. Verbunt, Marjon D.F. Eijsden-Besseling, Stephanie M.D. Huysmans, and Rob J.M. Smeets. "The Musician as (In)Active Athlete? Exploring the Association Between Physical Activity and Musculoskeletal Complaints in Music Students." *Medical Problems of Performing Artists*, December 2015, 231-237.

Basmajian, J.V. *Muscles Alive: Their Functions Revealed by Electromyography*. 4th ed. Baltimore, MD: The Williams and Wilkins Company, 1978.

Batson, Glenna. "Conscious Use of the Human Body in Movement: The Peripheral Neuroanatomic Basis of the Alexander Technique." *Medical Problems of Performing Artists*. March 1996, 3-11.

Bejjani, Fadi Joseph. "Musculoskeletal Occupational Disorders." In *Medical Problems of the Instrumentalist Musician*, 219-244. Edited by Raoul Tubiana and Peter C. Amadio. London: Martin Dunitz, 2000.

Berque, Patrice, Heather Gray, and Angus McFayden. "Playing-Related Musculoskeletal Problems Among Professional Orchestra Musicians in Scotland: A Prevalence Study Using a Validated Instrument, The Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM)." *Medical Problems of Performing Artists*, June 2016, 78-86.

Bilger, Angela Cordell. "A Conversation with Jennifer Montone: Jaw and Back Injuries." *The Horn Call*, February 2020, 42-44.

Bilger, Angela Cordell. "Musician's Well: Stories of Musicians and Their Recoveries." *https://www.musicianswell.com/stories* 2022; accessed 27 April 2022.

Brandfonbrener, Alice G. "Epidemiology and Risk Factors" In *Medical Problems of the Instrumentalist Musician*, 171-194. Edited by Raoul Tubiana and Peter C. Amadio. London: Martin Dunitz, 2000.

Brandfonbrener, Alice G. "History of Playing-Related Pain in 330 University Freshman Music Students." *Medical Problems of Performing Artists*, March 2009, 30-36.

Cacciatore, Timothy, Omar S. Mian, Amy Peters, and Brian L. Day. "Neuro-mechanical interference of posture on movement: evidence from Alexander technique teachers rising from a chair." *Neurophysiology of American Physiological Society*, May 2014.

Cailliet, Rene. "Abnormalities of the Sitting Postures of Musicians." *Medical Problems of Performing Artists*, December 1990, 131-135.

Caldron, Paul H., Leonard H. Calabrese, John D. Clough, Richard J. Lederman, George Williams, and Judith Leatherman. "A Survey of Musculoskeletal Problems Encountered in High-Level Musicians." *Medical Problems of Performing Artists*, December 1986, 136-139.

Cavalcanti Garcia, M.A. and T.M. Vieira, "Surface electromyography: Why, when and how to use it," *Medicina del Deporte* 4/1 (2011), 17-28.

Chan, Clifford, Tim Driscoll, and Bronwen J. Ackermann. "Effect of a Musicians' Exercise Intervention on Performance-Related Musculoskeletal Disorders." *Medical Problems of Performing Artists*, December 2014, 181-188.

Chesky, Kris, Karendra Devroop, and James Ford, III. "Medical Problems of Brass Instrumentalists: Prevalence Rates for Trumpet, Trombone, French Horn, and Low Brass." *Medical Problems of Performing Artists*, June 2002, 93-98.

Clark, Michael A., Scott C. Lucett, Erin McGill, Ian Montel, and Brian Sutton. *NASM Essentials of Personal Fitness Training*, 6th edition. Burlington, MA: Jones and Bartlett Learning, 2018.

Conable, Barbara. *What Every Musician Needs to Know About the Body: The Practical Application of Body Mapping to Music Making*. Portland, OR: Andover Press, 2000.

Cram, Jeffrey R., Glenn S. Kasman, and Jonathan Holtz. *Introduction to Surface Electromyography*. Gaithersburg, MD: Aspen Publishers, 1998.

Davies, Janet and Sandra Mangion. "Predictors of Pain and Other Musculoskeletal Symptoms among Professional Instrumental Musicians: Elucidating Specific Effects." *Medical Problems of Performing Artists*, December 2002, 155-168.

Deane, Richard. *The Efficient Approach: Accelerated Development for the Horn*. Atlanta, GA: Atlanta Brass Society Press, 2009.

Dimon, Theodore and G. David Brown. *Anatomy in Action: The Dynamic Muscular Systems that Create and Sustain the Moving Body*. Berkeley, CA: North Atlantic Books, 2015.

Dommerholt, Jan. "Posture." In *Medical Problems of the Instrumentalist Musician*, 399-420. Edited by Raoul Tubiana and Peter C. Amadio. London: Martin Dunitz, 2000.

Eijsdden-Besseling, M.D.F, M. Kujers, B. Kap, H. Stam, and E. Terpstra-Lindman, "Differences in Posture and Postural Disorders Between Music and Medical Students," *Medical Problems of Performing Artists*, September 1993, 110-114.

Ericson, John. "Horn Matters: Got Dimes?" *https://www.hornmatters.com/2009/09/got-dimes/* 2009; accessed 1 April 2023.

Farkas, Philip. *The Art of French Horn Playing*. Secaucus NJ: Summy-Birchard, 1956.

Felman, Adam. "What's to Know About Flat Feet?" *https://www.medicalnewstoday.com/articles/168608* 27 July 2018; accessed 7 April 2020.

Fishbein, Martin, Susan E. Middlestadt, Victor Ottati, Susan Straus, and Alan Ellis. "Medical Problems Among ICSOM Musicians: Overview of a National Survey." *Medical Problems of Performing Artists*, March 1988, 1-8.

Fotiadis, Dimosthenis G., Eleni G. Fotiadou, Dimitrios G. Kokaridas, and Argyrios C. Mylonas. "Prevalence of Musculoskeletal Disorders in Professional Symphony Orchestra Musicians in Greece: A Pilot Study Concerning Age, Gender, and Instrument-Specific Results." *Medical Problems of Performing Artists*, June 2013, 91-95.

de Greef, Mathieu, Ruud van Wijck, Koop Reynders, Joost Taussaint, and Rike Hessling. "Impact of Groningen Exercise Therapy for Symphony Orchestra Musicians Program on Perceived Physical Competence and Playing-Related Musculoskeletal Disorders of Professional Musicians." *Medical Problems of Performing Artists*, December 2003, 156-160.

Green, Jennifer A., Philippe Chamagne, and Raoul Tubiana. "Prevention." In *Medical Problems of the Instrumentalist Musician*, 531-557. Edited by Raoul Tubiana and Peter C. Amadio. London: Martin Dunitz, 2000.

Horvath, Janet. *Playing (Less) Hurt: An Injury Prevention Guide for Musicians*. Milwaukee, WI: Hal Leonard Corporation, 2000.

Iltis, Peter. "The Physiology of Breathing: Setting the Record Straight." *The Horn Call*, February 2013, 35-38.

James, Ian. "Survey of Orchestras." In *Medical Problems of the Instrumentalist Musician*, 195-202. Edited by Raoul Tubiana and Peter C. Amadio. London: Martin Dunitz, 2000.

Jaret, Peter. "Fainting and Loss of Consciousness." *Health Day*, 1 January 2020, *https://consumer.healthday.com/encyclopedia/first-aid-and-emergencies-20/emergencies and-first-aid-news-227/fainting-and-loss-of-consciousness-644511.html* (accessed 7 April 2020).

Kaneko, Yumi, Sergio Lianza, and William J. Dawson. "Pain as an Incapacitating Factor in Symphony Orchestra Musicians in São Palo, Brazil." *Medical Problems of Performing Artists*, December 2005, 168-174.

Kasman, Glenn S., Jeffrey R. Cram, and Steven L. Wolf. *Clinical Applications in Surface Electromyography: Chronic Musculoskeletal Pain*. Gaithersburg, MD: Aspen Publishers, 1998.

Kjelland, James M. "Application of Electromyography and Electromyographic Biofeedback in Music Performance Research: A Review of Literature since 1985." *Medical Problems of Performing Artists*, September 2000, 115-118.

Kleinman, Judith and Peter Buckoke. *The Alexander Technique for Musicians*. London: Bloomsbury Methuen Drama, 2013.

Krebs, Claudia, Joanne Weinberg, Elizabeth Akesson, and Esma Dilli. *Neuroscience* [2012], 2nd edition, Philadelphia: Wolters Klewer, 2018.

Lazaro, R.P., "Electromyography in musculoskeletal pain: A reappraisal and practical considerations," *Surgical Neurology International* 6:143 (2015).

Little, Paul, George Lewith, Fran Webley, Maggie Evans, Angela Beattie, Karen Middleton, Jane Barnett, Kathleen Ballard, Frances Oxford, Peter Smith, Lucy Yardley, Sandra Hollinghurst, and Debbie Sharp. "Randomised controlled trial of Alexander Techniques Lessons, Exercise, and Massage (ATEAM) for Chronic and Recurrent Back Pain," *BMJ (bmj.com)* May 26, 2008. 1-8.

Meinke, William B., "A Proposed Standardized Medical History and Physical Form for Musicians," *Medical Problems of Performing Artists*, December 1995, 137-139.

McGill, Stuart. *Low Back Disorders: Evidence-Based Prevention and Rehabilitation*. Champaign, IL: Human Kinetics, 2002.

Nakamura, Masaya, Yuji Nishiwaki, Takahiro Ushida, and Yoshiaki Toyama. "Prevalence and Characteristics of Chronic Musculoskeletal Pain in Japan." *Journal of Orthopedic Science*, July 2011, 424-432.

Nawrocka, Agniezka, Wladyslaw Mynarski, Aneta Powershka-Didkowska, Malgorzata Grabara, and Wieslaw Garbaciak. "Musculoskeletal Pain Among Polish Music School Students." *Medical Problems of Performing Artists*, June 2014, 64-69.

Newmark, Jonathan, and Michael S. Weinstein. "A Proposed Standard Music Medicine History and Physical Examination Form," *Medical Problems of Performing Artists*, December 1995, 134-136.

Ohlendorf, Daniela, Charlotte Doerry, Vanessa Fisch, Sebastian Schamberger, Christina Erbe, Eileen M. Wanke, and David A. Groneberg. "Standard Reference Values of the Postural Control in Healthy Young Female Adults in Germany: an Observational Study." *BMJ Open*, 15 May 2019, 1-6.

Paull, Barbara and Christina Harrison. *The Athletic Musician: A Guide to Playing Without Pain*. Lanham, MD: Scarecrow Press, 1997.

Parry, Christopher Wynn. "Clinical approaches" In *Medical Problems of the Instrumentalist Musician*, 203-218. Edited by Raoul Tubiana and Peter C. Amadio. London: Martin Dunitz, 2000.

Pearson, Bruce. *Best in Class: Comprehensive Band Method, Book 1 French Horn*. San Diego, CA: Kjos West, 1982.

Pherigo, Johnny L. "What Every Musician Needs to Know about the Body – An Introduction to Body Mapping." *The Horn Call*, October 2014, 90-93.

Pherigo, Johnny L. "What Every Musician Needs to Know about the Body II – Achieving Whole-Body Balance." *The Horn Call*, February 2015, 97-101.

Pherigo, Johnny. "Body Mapping III: Mastering the Exhale." *The Horn Call*, February 2016, 52 55 and 77 and 85.

Philipson, Lennart, Rolf Sörbye, Pål Larsson, and Stojan Kaladjev. "Muscular Load Levels in Performing Musicians as Monitored by Quantitative Electromyography." *Medical Problems of Performing Artists*, June 1990, 79-82.

Pihalaja, Pasi. "A Device for Holding the Horn." *The Horn Call*, May 2008, 85-87.

Porterfield, James A. and Carl DeRosa. *Mechanical Low Back Pain: Perspectives in Functional Anatomy*. 2nd ed. Philadelphia, PA: W.B. Saunders Company, 1998.

Price, Kevin and Alan H.D. Watson. "Effect of Using Ergobrass Ergonomic Supports on Postural Muscles in Trumpet, Trombone, and French Horn Players." *Medical Problems of Performing Artists*, September 2018, 183-190.

Ramella, M., F. Fronte, and R.M. Converti. "Postural Disorders in Conservatory Students: The Diesis Project." *Medical Problems of Performing Artists*, March 2014, 19-22.

Rider, Wendell. *Real World Horn Playing*. San Jose, CA: Wendell Rider Publications, 2006.

Rieband, Irena Marie. "The Pursuit of Confidence in Horn Playing: From Dis-ease to Ease, Sound Technique and Healthy Musicianship." M.A. Dissertation, Academy of Music Gdansk, 2008.

Rosenthal, Philip. M.D. "Back Pain Facts and Fallacies: A Response to William Scharnberg," *The Horn Call*, November 1999, 81-82.

Russo, Alessandro, Alejandra Arancets-Garza, Samuel D'Emanuele, Francesca Serafino, and Roberto Merletti. "HDsEMG Activity of the Lumbar Erector Spinae of Violin Players: Comparison of Two Chairs." *Medical Problems of Performing Artists*, December 2019, 205-214.

Soar, Tim and Aron Cserveny. "The Monkey," In *Defining the Alexander Technique*, (London: Self Published at the-alexander-technique.org.uk, 2010), Chapter 16.

Scharnberg, William. "Relieving Back Pain," *The Horn Call*, May 1999, 57-58.

Smith, David W.E. "Medical Problems of Orchestral Musicians According to Age and Stage of Career." *Medical Problems of Performing Artists*, December 1992, 132-134.

Smith, Nicholas. *Don't Miss! Ideas, concepts, and exercises designed to increase accuracy on an inaccurate instrument*. Wichita, KS: Hornsmith Publishing, 2010.

Stanek, Jeremey L., Kevin D. Komes, and Fred A. Murdock. "A Cross-Sectional Study of Pain Among U.S. College Music Students and Faculty." *Medical Problems of Performing Artists*, March 2017, 20-26.

Titley, Nick A. "Heels and Your Posture." *National Posture Institute Online*, May 2015, *https://www.npionline.org/articles/heels-and-your-posture.htm* (accessed 7 April 2020).

Vining, David. *Notes of Hope: Stories by Musicians Coping with Injuries*. Flagstaff, AZ: Mountain Peak Music, 2014.

Wallace, Eric, Derek Klinge, and Kris Chesky. "Musculoskeletal Pain in Trombonists: Results from the UNT Trombone Health Survey." *Medical Problems of Performing Artists*, June 2016, 87-95.

Watson, Alan H.D., *The Biology of Musical Performance and Performance-related Injury*. Scarecrow Press: Lanham, MD. 2009.

Wilson, Frank R., "Glenn Gould's Hand." In *Medical Problems of the Instrumentalist Musician*, 379-398, Edited by Raoul Tubiana and Peter C. Amadio. London: Martin Dunitz, 2000.

Yeung, Ella, Winnie Chan, Florence Pan, Phoebe Sau, Maggie Tsui, Belinda Yun and Christine Zaza. "A Survey of Playing-related Musculoskeletal Problems among Professional Orchestra Musicians in Hong Kong." *Medical Problems of Performing Artists*, March 1999, 43-47.

Zaza, Helen. *Musicians' Playing-Related Musculoskeletal Disorders: An Examination of Physical, Psychological, and Behavioural Factors*. Ph.D. Dissertation, University of Waterloo, 1995.

Zetterberg, Carl, Helena Backlund, Jenny Karlsson, Helen Werner, and Lars Olson. "Musculoskeletal Problems among Male and Female Music Students," *Medical Problems of Performing Artists*, December 1998, 160-166

APPENDIX A

PLAYING-RELATED MUSCULOSKELETAL DISORDERS IN HORN PLAYERS SURVEY

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH

Please take the time to read through this statement and decide whether you would like to participate in this research study.

Title Playing-Related Postural Disorders in Horn Players Health Survey
Principal Investigator Daniel Nebel, School of Music, DM candidate.
Research Advisor Dr. Sara Winges, Ph. D., Asst. Professor School of Sport and Exercise Science

Purpose and Description The horn weighs approximately six pounds and is held in front of the body for long periods of time. The shape of the instrument loads the body unequally and may result in muscle imbalances that can lead to potentially debilitating pain.

The specific aim of this study is to determine the prevalence, location, and intensities of playing-related musculoskeletal disorders in horn players and look for correlations with demographics within the horn playing population, including gender, education level, age, type of playing, and years playing the instrument.

Confidentiality Your responses are confidential; you will be asked to provide your initials and birth year to create a unique identifier in order to ensure duplicate surveys are not received. In any public report, we will not include any information that will make it possible to identify you. Research records will be kept on a password-protected device; only the researchers will have access to the records.

Voluntary Participation

Please understand that your participation is voluntary. You may decide not to participate in this study and if you begin participation you may decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Your completion of the research procedures indicates your consent.

Disclosing career-impacting injuries can understandably be difficult, if you are unable to be completely truthful with your responses, please do not complete this survey.

- Yes, take this survey
- No, do not take this survey

1. To prevent duplicate responses and ensure your confidentiality, please type your initials and the year you were born to create a unique identifier. (ex: JJL1963)

2. What is your age?

- Under 18
- 18 - 24
- 25 - 34
- 35 - 44
- 45 - 54
- 55 - 64
- 65 - 74
- 75 - 84
- 85 or older

3. What is your gender?

- Male
- Female
- Non-binary / third gender
- Prefer not to say

4. How long have you played horn?

- less than 1 year
- 1 year
- Yearly responses up to 40
- more than 40 years

5. How many years of horn lessons have you taken?

- none
- less than 1 year
- 1 year
- yearly responses up to 15
- more than 15 years

6. At what age did you begin to play the horn?

- younger than 10 years old
- 10 years old
- yearly responses up to 18
- older than 18 years old

7. How would you describe yourself as a hornist? (check all that apply)

- Enthusiast - I have fun with the horn but do not play it regularly.
- Amateur - I regularly play the horn but am rarely paid to perform.
- Undergraduate College Student

- o Graduate College Student
- o Freelancer - Horn performance is a main source of income for me from multiple ensembles (additional non-music income may supplement your earnings).
- o Teacher - private lessons and/or public school
- o College Professor
- o Professional - I perform full time primarily with one ensemble.
- o Retired
- o Other (please specify) ____

8. (If teacher or college professor selected) Please describe how you teach students to hold their instrument. What do you look to correct?

9. What part(s) do you primarily play? (check all that apply)

- o Principal
- o Second
- o Third
- o Fourth
- o Assistant/Utility

10. What types of ensemble playing do you currently do? (check all that apply)

- o Orchestra
- o Wind Ensemble
- o Marching Band
- o Chamber Music
- o Drum Corps
- o Solo
- o Other (please specify) ____

11. What types of ensemble playing have you previously done? (check all that apply)

- o Orchestra
- o Wind Ensemble
- o Marching Band
- o Chamber Music
- o Drum Corps
- o Solo
- o Other (please specify) ____

12. Do you play any other instruments?

- o No
- o Yes (please specify) ____

13. How much do you generally play horn (practice, performance, and rehearsals) in a usual week?

- Less than 5 hours
- 5-9 hours
- 10-19 hours
- 20 hours or more

14. How much time do you usually spend sitting (in the car, at a desk, on public transportation, etc.) each week?

- None
- 4 hours or less
- 5-9 hours
- 10-15 hours
- 15-20 hours
- more than 20 hours

15. When practicing, how much do you sit and stand?

- Stand all of the time
- Mostly stand
- About equal amounts
- Mostly sit
- Sit all of the time

16. When performing, how much do you sit and stand?

- Stand all of the time
- Mostly stand
- About equal amounts
- Mostly sit
- Sit all of the time

17. When sitting, how much do you rest your bell on the leg?

- Never
- Sometimes
- About half of the time
- Most of the time
- All of the time

18. In your lifetime, have you experienced significant pain that made playing your instrument more difficult or uncomfortable?

- Yes
- No

If No is selected, survey ends.

19. Is your pain caused by something other than horn playing (i.e., car accident)?

- Yes (what is the cause?) ____
- Maybe (what do you suspect may be the cause?) __________________________
- No

20. Does horn playing make your pain worse?

- Definitely yes
- Probably yes
- Might or might not
- Probably not
- Definitely not

21. At what age did first experience this pain or discomfort?

- 10
- Yearly responses up to 50
- older than 50

22. Have you received a satisfactory diagnosis to determine the cause of the pain or physical dysfunction that has affected your horn playing?

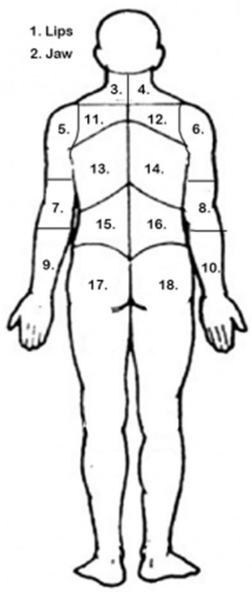
- Yes (if willing, please specify) ____
- No

23. Who have you consulted about your pain or physical dysfunction? (check all that apply)

- No One
- Music Teacher
- Medical Doctor
- Physical Therapist
- Chiropractor
- Masseuse
- Acupuncturist
- Alexander Teacher/Feldenkrais Teacher/Body Mapping Instructor
- Holistic Healer
- Fitness Professional (Personal Trainer, Yoga Instructor, Pilates Instructor, or similar)
- Other (please specify) ____

24. Please describe how helpful the person(s) you consulted was in relieving your pain/discomfort.

26. *Please identify locations where you have experienced significant pain or physical dysfunction that made playing your instrument more difficult or uncomfortable* *<u>in your lifetime</u>*.



(check all that apply)

- o Lips
- o Jaw
- o Left Side Neck
- o Right Side Neck
- o Left Shoulder
- o Right Shoulder
- o Left Elbow
- o Right Elbow
- o Left Hand, Wrist, or Fingers
- o Right Hand, Wrist or Fingers
- o Left Upper Back
- o Right Upper Back
- o Left Middle Back
- o Right Middle Back
- o Left Lower Back
- o Right Lower Back
- o Left Leg, Knee, or Foot
- o Right Leg, Knee, or Foot
- o Other (please specify) ____

27-45 are displayed only when correlating answer above is selected

27. What is your highest intensity of Lip Pain <u>in your lifetime</u>?

- o Mild
- o Uncomfortable

- Painful
- Very Painful
- Excruciating

28. What is your highest intensity of Jaw Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

29. What is your highest intensity of Left Side Neck Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

30. What is your highest intensity of Right Side Neck Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

31. What is your highest intensity of Left Shoulder Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

32. What is your highest intensity of Right Shoulder Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

33. What is your highest intensity of Left Elbow Pain in your lifetime?

- Mild
- Uncomfortable

- Painful
- Very Painful
- Excruciating

34. What is your highest intensity of Right Elbow Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

35. What is the highest intensity of Left Hand, Wrist, or Fingers Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

36. What is the highest intensity of Right Hand, Wrist, or Fingers Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

37. What is the highest intensity of Left Upper Back Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

38. What is the highest intensity of Right Upper Back Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

39. What is the highest intensity of Left Middle Back Pain in your lifetime?

- Mild
- Uncomfortable

- Painful
- Very Painful
- Excruciating

40. What is the highest intensity of Right Middle Back Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

41. What is the highest intensity of Left Lower Back Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

42. What is the highest intensity of Right Lower Back Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

43. What is the highest intensity of Left Leg, Knee, or Foot Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

44. What is the highest intensity of Right Leg, Knee, or Foot Pain in your lifetime?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

45. What is the highest intensity of Other Location Pain in your lifetime?

- Mild
- Uncomfortable
- Painful

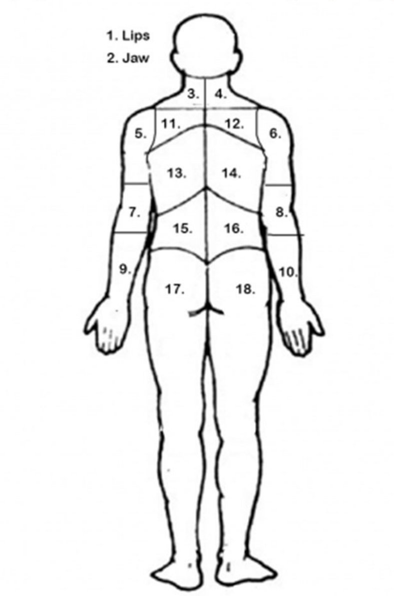
- o Very Painful
- o Excruciating

46. In the <u>last year</u>, have you experienced significant pain that made playing your instrument more difficult or uncomfortable?

- o Yes
- o No

If no is selected skip to end of survey

47. *Please identify locations where you have experienced significant pain or physical dysfunction that made playing your instrument more difficult or uncomfortable in the last year.*



(check all that apply)

- o Lips
- o Jaw
- o Left Side Neck
- o Right Side Neck
- o Left Shoulder
- o Right Shoulder
- o Left Elbow
- o Right Elbow
- o Left Hand, Wrist, or Fingers
- o Right Hand, Wrist or Fingers
- o Left Upper Back
- o Right Upper Back
- o Left Middle Back
- o Right Middle Back

- Left Lower Back
- Right Lower Back
- Left Leg, Knee, or Foot
- Right Leg, Knee, or Foot
- Other (please specify) ____

48-66 are displayed only when correlating answer above is selected

48. What is your highest intensity of Lip Pain <u>in the last year</u>?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

49. What is your highest intensity of Jaw Pain <u>in the last year</u>?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

50. What is your highest intensity of Left Side Neck Pain <u>in the last year</u>?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

51. What is your highest intensity of Right Side Neck Pain <u>in the last year</u>?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

52. What is your highest intensity of Left Shoulder Pain <u>in the last year</u>?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

53. What is your highest intensity of Right Shoulder Pain <u>in the last year</u>?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

54. What is your highest intensity of Left Elbow Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

55. What is your highest intensity of Right Elbow Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

56. What is the highest intensity of Left Hand, Wrist, of Finger Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

57. What is the highest intensity of Right Hand, Wrist, of Finger Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

58. What is the highest intensity of Left Upper Back Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

59. What is the highest intensity of Right Upper Back Pain in the last year?

- Mild

- Uncomfortable
- Painful
- Very Painful
- Excruciating

60. What is the highest intensity of Left Middle Back Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

61. What is the highest intensity of Right Middle Back Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

62. What is the highest intensity of Left Lower Back Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

63. What is the highest intensity of Right Lower Back Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

64. What is the highest intensity of Left Leg, Knee, or Foot Pain in the last year?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

65. What is the highest intensity of Right Leg, Knee, or Foot Pain in the last year?

- Mild
- Uncomfortable

- Painful
- Very Painful
- Excruciating

66. What is the highest intensity of Other Location Pain in the last year?

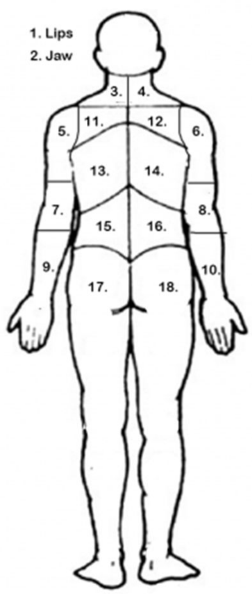
- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

67. In the last week, have you experienced significant pain that made playing your instrument more difficult or uncomfortable?

- Yes
- No

If no, skip to end of survey.

68. *Please identify locations where you have experienced significant pain or physical dysfunction that made playing your instrument more difficult or uncomfortable in the last week.*



(check all that apply)

- Lips
- Jaw
- Left Side Neck
- Right Side Neck
- Left Shoulder
- Right Shoulder
- Left Elbow

- Right Elbow
- Left Hand, Wrist, or Fingers
- Right Hand, Wrist or Fingers
- Left Upper Back
- Right Upper Back
- Left Middle Back
- Right Middle Back
- Left Lower Back
- Right Lower Back
- Left Leg, Knee, or Foot
- Right Leg, Knee, or Foot
- Other (please specify) ____

Q69-87 are displayed only when correlating answer above is selected

69. What is the highest intensity of Lip Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

70. What is the highest intensity of Jaw Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

71. What is the highest intensity of Left Side Neck Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

72. What is the highest intensity of Right Side Neck Pain in the last week?)

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

73. What is the highest intensity of Left Shoulder Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

74. What is the highest intensity of Right Shoulder Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

75. What is the highest intensity of Left Elbow Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

76. What is the highest intensity of Right Elbow Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

77. What is the highest intensity of Left Hand, Wrist, or Fingers Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

78. What is the highest intensity of Right Hand, Wrist, or Fingers Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

79. What is the highest intensity of Left Upper Back Pain in the last week?

- Mild

- o Uncomfortable
- o Painful
- o Very Painful
- o Excruciating

80. What is the highest intensity of Right Upper Back Pain in the last week?

- o Mild
- o Uncomfortable
- o Painful
- o Very Painful
- o Excruciating

81. What is the highest intensity of Left Middle Back Pain in the last week?

- o Mild
- o Uncomfortable
- o Painful
- o Very Painful
- o Excruciating

82. What is the highest intensity of Right Middle Back Pain in the last week?

- o Mild
- o Uncomfortable
- o Painful
- o Very Painful
- o Excruciating

83. What is the highest intensity of Left Lower Back Pain in the last week?

- o Mild
- o Uncomfortable
- o Painful
- o Very Painful
- o Excruciating

84. What is the highest intensity of Right Lower Back Pain in the last week?

- o Mild
- o Uncomfortable
- o Painful
- o Very Painful
- o Excruciating

85. What is the intensity of Left Leg, Knee, or Foot Pain in the last week?

- o Mild
- o Uncomfortable

- Painful
- Very Painful
- Excruciating

86. What is the intensity of Right Leg, Knee, or Foot Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

87. What is the intensity of Other Location Pain in the last week?

- Mild
- Uncomfortable
- Painful
- Very Painful
- Excruciating

APPENDIX B

VERBAL INSTRUCTIONS GUIDELINES FOR SURFACE ELECTROMYOGRAPHY STUDY

As these instructions were given, the researcher was physically demonstrating the positions so that participants had a visual representation. The goal was to first ensure the spine, especially in the lumbar region remained closer to neutral. Participants were first given basic position instructions, such as: “take a staggered stance with your left foot forward of you right. Release your hips and knees, as if you were about to catch a ball.” If the participant’s posture was close to the basic positions, further instructions based on observations were also given.

Basic Sitting Position

1. Place your feet flat on the floor and wide enough to create a tripod effect between your feet and your seat.

2. Balance on your sitting bones. Have participants find and identify their sitting bones by sitting on their hands or by rocking the pelvis forward and back. If they are on balanced on the back of the thighs, have them tuck the pelvis a bit and release the lower back. If they are on the tailbone have them sit more forward.

3. Balance the head on top of the spine by locating the joint under the ears and nodding the head yes to find the balance point. Then demonstrate singing to find the best head position for resonance and have them try it.

4. Once you have found this balanced position bring your horn up to your face; avoid bringing your face to your horn.

5. Help adjust right and left-hand positions to play with the horn off of the leg if players are not used to doing so already.

Basic Standing Position

1. Stand with your feet flat on the floor parallel to each other, adopt a slightly staggered stance with your left foot forward of your right.

2. Release your knees and hips by pretending you are about to catch a ball, or by pretending to be a monkey.[112]

[112] The Monkey is an Alexander Technique position of mechanical advantage. Chapter 16 of Tim Soar’s 2010 publication *Defining the Alexander Technique* explains it in detail and can be accessed at the-alexander-technique.org.uk

3. Balance the head on top of the spine by locating the joint under the ears and nodding the head yes to find the balance point. Then demonstrate singing to find the best head position for resonance and have them try it.

4. Once you have found this balanced position bring your horn up to your face; avoid bringing your face to your horn.

5. Help adjust right and left-hand positions to play standing if players are not used to doing so already.

If a player is already set up in the above positions, the following guidelines will be addressed

1. Ensure the left wrist is straight and the fingers are all curved and close together (avoid using the pinkie hook, a strap or duck foot on the horn might be necessary to make that happen)

2. Balance the weight of the horn primarily on the right thumb and proximal knuckle of the right hand. The right wrist should also be neutral or slightly flexed.

3. Allow the elbows to float down and away from each other, creating more space under the armpits for expansion of the ribs when inhaling.

4. Allow the front side of the body to be equally as wide as the back side of the body by letting your collarbone curve back to meet your shoulder blade.

5. Draw diagonals across the back between the right hip and left shoulder and between the left hip and right shoulder. Allow equal lengthening along both diagonals (there is a tendency to allow the right shoulder/left hip diagonal to shorten because of how the horn is held.

6. Draw diagonals across the front of the torso between the right hip and left shoulder and between the left hip and right shoulder. Allow equal lengthening along both diagonals.

APPENDIX C

AVERAGE X, Y, Z COORDINATES OF REFLECTIVE MARKERS FOR ALL TRIALS

During data collection, 5 trials each in 6 different postural scenarios plus 2 calibration trials were recorded for a total of 32 trials for each participant. Trials were labeled with the scheme: participant number; SI for sitting or ST for standing; N, I, or E: N for natural posture, E for using an ERGObrass™ support, I for specific postural instructions[113] drawn from the principles of Alexander Technique and Body Mapping; and a trial number 1 through 5. For example, 3STE2, is the participant 3's second standing trial using the ERGObrass™ support. Calibration trials end with Cal.

Table C.1 Trial Labeling Key

Participant number	Position	Situation	Situation trial number
1-10	SI = Sitting ST = Standing	Cal = Calibration E = ERGObrass I = Instructions N = Natural Posture	1-5

Table C.2 Average X, Y, Z Coordinates of Reflective Markers on Sacrum

Trial	Sacrum middle			Sacrum right			Sacrum left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
1SICal	1414.027	-41.751	572.795	1413.45	21.57	624.423	1395.421	-82.378	627.758
1SIE1	1415.376	-51.782	571.591	1410.442	9.963	624.536	1397.459	-93.992	625.986
1SIE2	1415.551	-51.790	571.279	1410.667	9.943	624.33	1397.497	-93.913	625.804
1SIE3	1415.563	-51.903	571.351	1410.641	9.783	624.433	1397.523	-94.161	625.747
1SIE4	1415.365	-51.832	571.399	1410.38	9.897	624.435	1397.138	-94.023	625.803
1SIE5	1414.302	-51.748	573.094	1408.666	9.996	626.348	1396.065	-93.975	627.674
1SII1	1379.606	-40.145	569.389	1371.442	20.831	620.469	1366.465	-82.493	622.47
1SII2	1379.979	-40.474	568.514	1372.39	20.254	620.096	1367.354	-82.997	621.677
1SII3	1380.502	-39.413	569.295	1372.573	21.093	620.974	1368.197	-82.169	622.785
1SII4	1380.395	-39.436	569.739	1372.147	21.163	621.338	1367.592	-82.146	623.113
1SII5	1380.169	-39.941	569.521	1372.16	20.644	621.21	1367.633	-82.599	622.431
1SIN1	1405.761	-50.243	571.948	1402.017	11.645	623.185	1389.438	-91.296	625.584

[113] See Appendix B for a script of the verbal instructions used during data collection.

Table C.2 Continued

Trial	Sacrum middle			Sacrum right			Sacrum left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
1SIN2	1404.766	-43.682	577.585	1398.735	18.859	628.485	1387.552	-84.359	632.256
1SIN3	1407.189	-44.275	574.713	1401.26	17.993	625.941	1390.458	-85.118	629.438
1SIN4	1406.492	-44.658	575.643	1400.335	17.443	627.263	1389.673	-85.749	630.364
1SIN5	1407.349	-45.061	574.284	1401.213	16.83	625.884	1390.825	-86.304	628.805
1STCal	1058.798	2.476	993.387	1062.766	64.143	1018.421	1037.94	-39.777	1027.937
1STE1	904.142	-21.709	1000.75	903.792	38.61	1027.534	884.958	-66.547	1030.967
1STE2	915.299	4.701	1001.427	907.209	64.685	1028.722	901.215	-41.923	1031.531
1STE3	905.444	-12.165	1002.927	902.43	47.786	1029.425	889.27	-58.218	1031.5
1STE4	910.308	-12.652	1005.337	905.559	47.713	1032.037	893.456	-58.551	1035.085
1STE5	909.115	-10.373	1000.636	903.388	49.604	1027.526	894.462	-56.858	1030.225
1STI1	1042.019	15.6123	990.952	1037.821	77.651	1017.454	1025.152	-28.163	1026.838
1STI2	1048.467	-1.934	990.167	1047.908	59.912	1017.201	1030.793	-45.447	1024.443
1STI3	1046.846	23.658	977.671	1045.851	84.383	1006.194	1031.086	-21.527	1011.664
1STI4	1035.957	19.256	978.573	1037.717	81.122	1006.533	1016.682	-23.491	1014.699
1STI5	1047.567	30.313	981.432	1048.729	91.435	1011.549	1029.225	-13.911	1015.823
1STN1	1086.449	-18.932	985.09	1083.834	41.382	1014.433	1069.591	-64.4	1018.617
1STN2	1084.754	-4.65	995.706	1078.04	55.761	1023.699	1068.784	-50.749	1028.341
1STN3	1081.877	-13.923	997.037	1075.89	46.168	1023.74	1066.195	-60.309	1027.793
1STN4	1083.055	-4.619	999.595	1078.243	55.562	1026.318	1066.051	-50.724	1030.092
1STN5	1074.336	-6.829	997.061	1070.86	53.382	1023.735	1057.124	-52.722	1027.451
2SICal	1141.889	35.105	560.239	1141.323	61.4	600.033	1133.337	4.273	598.575
2SIE1	1159.95	-93.417	562.532	1157.46	-68.534	607.85	1145.921	-124.016	605.333
2SIE2	1159.597	-93.303	562.776	1156.905	-68.415	608.162	1145.606	-123.817	605.628
2SIE3	1162.54	-93.067	559.343	1160.332	-68.373	604.858	1149.357	-123.765	602.206
2SIE4	1161.047	-92.475	561.022	1158.602	-67.398	606.408	1147.626	-122.864	603.933
2SIE5	1159.474	-92.136	562.85	1156.647	-67.045	608.199	1145.698	-122.394	605.697
2SII1	1158.566	-32.964	553.972	1155.22	-7.739	598.603	1148.591	-64.292	596.624
2SII2	1155.763	-33.843	555.331	1151.958	-8.731	600.309	1145.938	-65.199	598.291
2SII3	1157.009	-34.11	553.941	1154.144	-8.9	598.921	1147.047	-65.346	597.059
2SII4	1152.88	-33.28	558.592	1149.451	-8.1696	603.51	1142.418	-64.876	601.084
2SII5	1154.031	-33.494	557.334	1150.491	-8.2787	602.225	1143.625	-64.927	600.086

Table C.2 Continued

Trial	**Sacrum middle**		**Sacrum right**		**Sacrum left**				
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
2SIN1	1121.38	-118.297	572.877	1121.654	-91.431	613.283	1102.479	-145.636	612.013
2SIN2	1123.876	-117.952	570.435	1124.472	-90.975	610.889	1105.692	-145.289	609.676
2SIN3	1122.388	-118.349	571.667	1122.946	-91.427	612.065	1103.829	-145.527	610.95
2SIN4	1123.791	-118.263	570.34	1124.703	-91.144	610.698	1105.59	-145.188	609.851
2SIN5	1123.495	-117.79	570.635	1124.26	-90.644	611.053	1105.315	-144.764	610.137
2STCal [a]	912.1842	19.818	995.288	900.833	47.031	1019.362	897.649	-12.034	1018.168
2STE1[a]	844.0416	-203.795	985.671	...	...	...	...	...	...
2STE2 [a]	841.4799	-205.556	986.174	...	...	...	...	...	...
2STE3 [a]	841.9557	-219.611	985.923	...	...	...	...	...	...
2STE4 [a]	842.9477	-224.157	984.74	...	...	...	...	...	...
2STE5 [a]	843.8595	-230.597	984.054	832.423	-201.084	1008.651	...	...	...
2STI1 [a]	775.004	-49.338	976.253	774.77	-20.353	1004.139	753.475	-79.941	1002.307
2STI2 [a]	744.2122	-60.566	974.174	742.695	-30.938	1002.639	721.505	-86.835	1001.125
2STI3 [a]	724.7389	-65.068	972.026	722.866	-37.217	1000.618	700.309	-91.827	999.909
2STI4 [a]	738.9696	-40.839	978.033	734.907	-12.162	1006.998	712.973	-67.143	1006.018
2STI5 [a]	727.0903	-41.433	974.086	723.213	-13.112	1003.674	700.915	-67.827	1001.772
2STN1 [a]	841.1923	-176.196	985.886	840.041	-146.735	1012.04	817.557	-201.278	1009.294
2STN2 [a]	838.8658	-168.739	986.603	836.32	-139.159	1012.832	814.911	-192.923	1010.559
2STN3 [a]	833.961	-171.084	987.433	831.224	-141.331	1013.565	805.326	-195.208	1011.873
2STN4 [a]	835.320	-174.148	989.141	832.549	-144.361	1015.231	809.148	-197.246	1013.428
2STN5 [a]	831.579	-178.24	988.519	828.923	-148.457	1014.485	807.732	-200.934	1012.176
3SICal	1135.378	-44.306	664.626	1136.319	-8.203	622.012	1138.428	-76.836	623.879
3SIE1	1063.409	148.196	675.276	1070.115	184.183	634.59	1071.667	115.683	634.637
3SIE2	1073.092	148.605	667.802	1078.131	185.272	626.972	1080.612	116.734	626.642
3SIE3	1077.486	147.814	665.855	1082.438	184.253	624.697	1084.013	115.681	624.637
3SIE4	1082.96	147.532	663.06	1087.144	184.323	622.063	1089.165	115.824	621.689
3SIE5	1066.894	147.928	667.337	1071.983	184.435	626.321	1074.361	115.747	626.398
3SII1	1155.965	86.017	640.217	1154.717	122.478	597.831	1158.069	53.33	599.387
3SII2	1149.75	86.783	643.214	1149.692	123.011	600.936	1153.191	53.937	602.509
3SII3	1153.526	86.785	641.082	1152.69	123.215	598.737	1156.087	53.983	600.298
3SII4	1153.305	86.345	641.093	1152.45	122.86	598.847	1156.065	53.786	600.371
3SII5	1146.956	88.622	645.031	1146.696	125.28	602.702	1151.133	56.298	604.13

Table C.2 Continued

Trial	**Sacrum middle**			**Sacrum right**		**Sacrum left**			
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
3SIN1	1106.935	79.740	665.764	1108.788	116.31	623.458	1111.299	47.594	624.648
3SIN2	1105.854	81.082	666.166	1107.961	117.231	623.741	1110.619	48.619	625.146
3SIN3	1100.45	78.165	657.072	1101.543	114.732	615.227	1103.388	46.018	615.703
3SIN4	1100.514	78.304	656.551	1101.488	114.494	614.672	1103.365	45.814	615.308
3SIN5	1088.27	80.235	662.695	1090.718	116.55	620.737	1093.284	47.963	621.668
3STCal	715.061	-129.299	1034.586	722.287	-93.582	991.806	725.052	-161.407	991.741
3STE1	773.319	-78.107	1021.229	779.835	-41.129	978.511	781.12	-109.957	977.203
3STE2	763.489	-66.262	1020.181	769.015	-28.913	977.89	772.081	-97.687	976.374
3STE3	757.871	-58.662	1019.052	759.915	-21.286	976.485	768.639	-89.614	975.173
3STE4	768.496	-72.619	1017.383	770.703	-35.783	974.346	779.808	-104.052	974.369
3STE5	764.671	-70.043	1017.418	766.691	-33.431	974.427	776.422	-101.578	974.878
3STI1	496.123	-304.209	1011.846	508.174	-269.162	968.976	500.279	-337.721	967.14
3STI2	498.97	-343.671	1013.778	511.053	-309.584	970.738	503.553	-378.241	969.43
3STI3	486.509	-355.751	996.836	501.667	-329.248	972.554	491.488	-397.663	972.138
3STI4	495.367	-382.78	1013.204	508.88	-350.215	969.368	496.78	-418.098	969.464
3STI5	498.48	-386.193	1016.152	517.996	-355.409	972.598	494.901	-420.534	972.158
3STN1	529.479	-148.219	1023.831	536.405	-112.981	978.15	533.332	-181.166	978.519
3STN2	546.003	-135.596	1019.471	548.772	-99.923	973.505	550.904	-168.045	973.454
3STN3	532.107	-131.823	1022.194	538.227	-96.614	976.114	534.921	-164.57	976.557
3STN4	524.322	-110.628	1021.387	527.463	-75.292	975.46	529.562	-143.256	976.6
3STN5	512.839	-111.931	1019.705	519.485	-76.846	973.865	514.45	-144.645	974.451
4SICal	1175.822	3.436	589.395	1176.045	27.442	621.101	1173.152	-30.802	614.37
4SIE1	1141.718	-8.734	606.439	1137.16	15.791	637.494	1132.527	-42.635	629.221
4SIE2	1136.992	-8.340	609.962	1131.791	16.375	641.067	1127.815	-42.291	633.147
4SIE3	1135.257	-8.735	610.749	1129.891	15.908	641.939	1125.847	-42.757	633.751
4SIE4	1132.118	-9.68	611.897	1126.644	14.857	643.003	1122.451	-43.633	634.599
4SIE5	1129.876	-10.472	612.364	1124.503	13.993	643.311	1120.134	-44.457	634.913
4SII1	1139.45	23.662	587.172	1139.352	48.002	615.91	1135.239	-10.269	609.029
4SII2	1135.635	23.748	589.392	1135.266	48.053	618.496	1131.215	-10.254	611.502
4SII3	1136.767	23.403	588.53	1136.607	47.674	617.49	1132.32	-10.571	610.464
4SII4	1135.667	23.507	588.836	1135.519	47.794	617.721	1131.065	-10.424	610.755

Table C.2 Continued

Trial	Sacrum middle		Sacrum right			Sacrum left			
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
4SII5	1134.114	22.799	589.853	1133.915	47.18	618.797	1129.134	-11.021	611.856
4SIN1	1123.386	19.366	606.63	1119.906	43.738	636.211	1115.712	-14.397	628.817
4SIN2	1124.755	19.327	605.142	1121.982	43.692	634.577	1117.643	-14.469	627.197
4SIN3	1121.655	17.686	606.588	1118.977	42.14	636.053	1113.56	-15.939	628.578
4SIN4	1125.586	15.478	602.695	1123.766	40.012	631.471	1117.391	-17.981	624.394
4SIN5	1119.993	15.714	606.741	1117.772	40.127	636.457	1111.497	-17.841	629.041
4STCal	892.729	15.054	1020.238	888.373	40.765	1049.936	878.962	-17.941	1041.729
4STE1	846.05	-91.778	1000.263	847.52	-67.698	1031.444	833.319	-124.401	1022.602
4STE2	831.618	-94.969	1001.941	832.573	-70.864	1033.104	819.098	-127.869	1023.951
4STE3	829.015	-99.738	1000.403	830.779	-75.694	1031.513	815.941	-132.225	1022.636
4STE4	822.914	-119.475	1001.987	824.272	-95.228	1033.043	809.432	-151.868	1024.088
4STE5	813.792	-93.715	1000.779	814.904	-69.893	1032.107	800.792	-126.609	1022.348
4STI1	843.228	14.961	1005.049	842.145	40.285	1035.832	828.868	-17.247	1027.988
4STI2	838.42	18.297	997.524	838.099	43.406	1028.399	826.499	-14.423	1021.079
4STI3	825.589	16.426	997.444	826.116	41.634	1028.042	813.001	-15.761	1021.028
4STI4	835.885	22.709	994.25	835.254	47.551	1025.532	824.261	-10.573	1017.212
4STI5	835.872	16.696	991.576	836.031	41.671	1022.639	825.685	-16.34	1015.365
4STN1	900.166	-34.77	1005.69	900.058	-9.881	1035.464	887.991	-67.192	1027.521
4STN2	892.719	-39.942	1007.499	891.732	-15.343	1037.509	881.75	-73.002	1028.821
4STN3	895.45	-12.791	1009.317	893.197	11.817	1039.258	884.916	-46.075	1030.448
4STN4	886.465	-28.015	1008.841	884.729	-3.706	1038.917	876.079	-61.431	1029.692
4STN5	888.071	-10.68	1007.291	886.66	13.609	1037.307	877.582	-43.994	1028.053
5SICal	1178.981	3.822	531.949	1180.308	41.363	567.267	1175.919	-33.875	561.147
5SIE1	1162.063	26.422	549.391	1161.75	61.628	584.647	1155.308	-12.153	577.159
5SIE2	1163.562	26.148	548.008	1163.449	61.274	583.349	1157.065	-12.466	575.952
5SIE3	1163.619	27.08	548.656	1163.354	62.189	583.964	1157.036	-11.44	576.723
5SIE4	1164.739	26.969	547.398	1164.657	62.101	582.69	1158.257	-11.522	575.492
5SIE5	1163.936	26.988	548.714	1163.436	62.032	584.284	1157.362	-11.621	576.744
5SII1	1167.937	-2.221	525.985	1169.353	33.675	561.04	1166.067	-40.858	555.22
5SII2	1182.372	-7.097	527.207	1183.975	28.599	562.337	1180.164	-45.178	556.517

Table C.2 Continued

Trial	Sacrum middle			Sacrum right			Sacrum left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
5SII3	1188.187	-5.415	523.434	1190.369	30.182	558.711	1187.231	-43.42	552.939
5SII4	1198.067	-3.417	522.321	1200.483	32.004	557.561	1197.055	-41.339	552.011
5SII5	1200.355	-3.439	519.555	1203.421	32.067	554.884	1199.992	-41.352	549.143
5SIN1	1165.857	-41.402	539.4	1167.365	-5.449	573.738	1162.162	-79.421	568.585
5SIN2	1168.53	-36.18	544.16	1168.545	-0.198	578.051	1163.973	-73.869	573.289
5SIN3	1171.013	-36.195	541.174	1171.295	-0.345	575.251	1167.145	-73.995	570.197
5SIN4	1173.103	-36.424	539.233	1174.291	-0.461	573.254	1169.242	-74.091	568.606
5SIN5	1175.952	-36.815	535.989	1177.797	-1.033	570.134	1172.774	-74.764	565.35
5STCal	792.024	-82.467	947.949	789.33	-44.991	974.639	774.996	-119.278	971.315
5STE1	839.401	-67.325	939.804	836.165	-27.883	969.696	818.048	-100.937	966.55
5STE2	813.386	-61.284	938.732	809.791	-22.24	968.829	792.394	-95.207	965.072
5STE3	816.938	-55.732	938.014	813.379	-16.466	967.877	796.297	-89.436	965.018
5STE4	794.141	-49.899	936.52	790.699	-10.736	966.434	773.659	-83.689	963.457
5STE5	781.937	-46.659	935.395	777.249	-7.68	965.223	762.377	-81.185	961.968
5STI1	805.202	-41.996	925.116	799.889	-2.91	955.281	788.751	-76.301	953.808
5STI2	822.316	-57.47	919.704	818.731	-18.546	950.008	805.934	-91.531	948.664
5STI3	816.192	-49.833	921.664	812.386	-11.062	952.19	799.557	-83.961	950.487
5STI4	813.78	-57.583	922.147	810.205	-18.299	951.975	795.997	-91.036	951.109
5STI5	825.215	-60.718	920.573	822.074	-21.919	951.172	807.454	-94.799	948.786
5STN1	779.587	-130.906	937.204	780.956	-91.848	966.149	754.972	-161.957	963.477
5STN2	766.971	-120.54	938.08	768.259	-81.37	966.775	742.029	-151.203	964.586
5STN3	759.597	-107.664	936.875	759.87	-68.399	965.628	736.128	-138.917	963.71
5STN4	753.323	-113.438	936.824	753.119	-74.325	965.914	729.906	-145.171	963.091
5STN5	755.627	-95.466	937.282	753.596	-56.589	966.915	733.785	-128.419	963.327
6SICal	1220.132	-225.123	553.082	1217.188	-167.738	599.78	1212.226	-257.256	611.422
6SIE1	1207.217	-163.442	565.413	1198.636	-106.277	611.962	1191.093	-195.481	622.828
6SIE2	1207.22	-163.334	565.08	1198.736	-106.15	611.596	1191.286	-195.298	622.48
6SIE3	1223.676	-164.431	544.577	1219.821	-107.348	591.699	1214.274	-196.849	602.418
6SIE4	1221.43	-164.295	547.372	1216.757	-107.291	594.45	1210.836	-196.69	605.269
6SIE5	1219.757	-164.174	549.438	1214.542	-107.198	596.416	1208.529	-196.538	607.307

Table C.2 Continued

Trial	Sacrum middle			Sacrum right			Sacrum left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
6SII1	1188.678	-151.407	542.899	1186.415	-93.456	589.149	1185.278	-183.41	598.782
6SII2	1189.438	-151.639	541.874	1187.673	-93.902	588.101	1186.283	-183.788	597.76
6SII3	1188.393	-151.844	542.934	1186.233	-94.158	589.091	1184.473	-183.945	598.811
6SII4	1189.039	-151.753	542.363	1187.011	-94.032	588.577	1185.493	-183.836	598.328
6SII5	1189.785	-151.793	541.477	1188.092	-93.97	587.705	1186.648	-183.859	597.5
6SIN1	1190.414	-88.376	566.782	1180.808	-30.506	610.795	1177.602	-119.995	623.09
6SIN2	1191.858	-88.755	564.833	1182.798	-30.947	608.845	1179.175	-120.272	621.4
6SIN3	1192.061	-88.53	564.718	1182.838	-30.541	608.783	1179.591	-119.925	621.265
6SIN4	1193.974	-88.419	561.968	1185.452	-30.407	606.217	1182.466	-119.735	618.724
6SIN5	1193.214	-88.892	562.164	1184.81	-30.968	606.408	1181.689	-120.34	618.914
6STCal	941.52	-218.448	927.752	919.375	-162.127	964.274	911.56	-252.047	969.765
6STE1	841.415	-185.622	926.082	834.615	-125.557	963.031	805.27	-211.461	968.913
6STE2	834.149	-190.871	922.639	827.863	-131.095	960.388	798.823	-217.047	965.977
6STE3	832.333	-203.576	924.958	828.266	-143.393	962.232	795.511	-228.037	967.634
6STE4	828.657	-207.435	924.405	824.413	-147.303	961.708	792.027	-232.107	966.98
6STE5	825.379	-208.914	925.367	820.926	-148.632	962.463	788.7	-233.537	967.635
6STI1	810.003	-190.8	900.277	803.791	-131.823	939.914	780.084	-219.164	946.257
6STI2	804.794	-189.638	897.602	798.599	-130.789	937.279	775.571	-218.353	943.384
6STI3	808.088	-191.953	892.838	802.808	-133.278	932.854	779.217	-220.698	939.222
6STI4	805.263	-188.662	896.504	799.302	-129.717	936.22	775.952	-217.187	942.406
6STI5	808.510	-191.927	898.91	802.653	-133.163	938.996	778.888	-220.523	944.573
6STN1	911.028	-192.224	929.787	909.7	-132.578	968.204	871.848	-214.761	972.597
6STN2	915.316	-192.904	928.904	910.566	-133.136	967.223	877.846	-217.657	971.67
6STN3	914.18	-190.262	927.649	909.479	-130.493	965.933	876.93	-215.047	970.51
6STN4	909.566	-195.464	928.159	904.555	-135.441	966.171	872.155	-220.202	971.15
6STN5	912.229	-181.931	928.651	906.153	-121.867	966.353	875.096	-207.054	971.494
7SICal	1311.668	-38.114	543.441	1319.916	-0.846	567.934	1304.485	-61.99	582.107
7SIE1	1291.864	-162.392	530.54	1309.317	-129.899	557.38	1275.944	-183.565	567.547
7SIE2	1294.718	-164.322	526.766	1312.818	-132.118	553.554	1279.697	-185.722	563.96
7SIE3	1293.332	-163.787	528.187	1310.952	-131.357	554.989	1277.668	-185.218	565.221
7SIE4	1291.676	-162.68	530.078	1309.143	-130.087	556.704	1275.748	-183.893	567.231
7SIE5	1292.905	-163.135	528.726	1310.25	-130.525	555.435	1277.488	-184.632	565.779

Table C.2 Continued

Trial	Sacrum middle			Sacrum right			Sacrum left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
7SII1	1303.364	-185.464	534.536	1319.474	-151.317	559.774	1289.562	-207.382	571.609
7SII2	1301.322	-184.694	536.299	1317.911	-150.977	560.695	1286.97	-205.851	574.086
7SII3	1312.334	-179.113	531.555	1327.179	-144.249	556.575	1300.427	-201.634	569.198
7SII4	1312.242	-179.958	530.871	1327.641	-144.958	555.668	1300.639	-202.284	568.408
7SII5	1308.522	-181.706	530.892	1324.76	-146.829	556.043	1296.463	-203.914	567.626
7SIN1	1324.242	-60.896	540.675	1337.244	-24.404	564.356	1311.63	-82.043	578.802
7SIN2	1323.055	-60.508	541.573	1336.507	-24.108	565.231	1310.21	-81.534	579.839
7SIN3	1324.294	-60.544	540.378	1337.796	-24.098	564.14	1311.945	-81.7	578.394
7SIN4	1325.188	-60.736	539.493	1338.309	-24.261	562.932	1312.94	-81.848	577.685
7SIN5	1324.891	-61.528	538.94	1338.148	-25.099	562.595	1312.657	-82.736	576.937
7STCal	996.6347	-20.023	908.59	1005.294	19.838	930.283	971.226	-35.763	941.404
7STE1	943.287	-83.97	898.935	954.082	-46.185	923.93	915.437	-98.979	929.648
7STE2	913.722	-102.702	905.083	924.548	-64.443	930.002	884.88	-116.669	935.378
7STE3	927.042	-108.844	902.961	940.952	-71.904	927.935	897.484	-122.028	933.655
7STE4	941.822	-88.769	897.01	954.718	-52.004	922.018	913.254	-103.201	927.882
7STE5	928.032	-99.398	902.014	942.769	-63.814	927.535	901.699	-115.072	933.725
7STI1	945.208	-147.019	895.031	959.444	-110.464	918.367	920.08	-162.961	924.604
7STI2	937.061	-148.57	899.486	949.378	-110.859	923.358	911.059	-164.392	929.338
7STI3	911.655	-143.998	889.096	926.685	-107.691	913.697	885.645	-158.461	919.421
7STI4 [b]	930.747	-136.12	888.163	944.659	-99.619	912.924	908.612	-152.28	916.934
7STI5	973.301	-108.956	895.89	984.838	-71.343	920.305	949.52	-127.055	927.761
7STN1	782.261	-183.15	902.268	794.488	-146.21	925.745	757.016	-199.437	933.207
7STN2	771.605	-193.41	906.393	784.682	-156.806	930.107	746.458	-209.66	937.174
7STN3	806.352	-215.858	904.186	817.199	-178.679	925.339	781.842	-233.763	932.971
7STN4	816.65	-209.972	905.702	830.756	-173.56	928.098	790.601	-225.212	936.232
7STN5	849.108	-202.071	904.44	864.798	-166.654	927.093	822.41	-216.606	934.484
8SICal	1438.833	50.098	566.651	1430.951	79.688	617.214	1439.919	17.048	610.001
8SIE1	1329.277	104.49	549.74	1328.965	137.12	592.981	1328.197	69.537	588.1
8SIE2	1329.945	104.41	548.91	1329.808	137.077	592.023	1328.853	69.488	587.218
8SIE3	1319.628	105.894	557.115	1316.443	138.777	599.329	1315.779	71.002	595.08
8SIE4	1325.117	105.165	551.672	1322.416	138.727	592.187	1321.004	70.473	588.55
8SIE5	1319.174	103.197	555.926	1315.56	136.673	596.405	1313.809	68.381	592.642

Table C.2 Continued

Trial	Sacrum middle			Sacrum right			Sacrum left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
8SII1	1399.6	199.592	533.573	1397.62	232.895	577.564	1401.686	165.433	570.555
8SII2	1395.955	198.796	537.821	1393.138	232.213	581.764	1396.591	164.773	575.1
8SII3	1399.525	197.705	533.196	1398.245	230.93	577.199	1401.429	163.492	570.443
8SII4	1406.64	198.429	523.356	1407.302	232.309	566.393	1410.252	164.543	559.817
8SII5	1402.608	198.095	528.275	1402.355	231.568	571.666	1405.296	163.969	565.372
8SIN1	1402.054	248.49	546.376	1404.094	276.187	597.799	1393.876	213.614	589.843
8SIN2	1397.032	250.399	551.937	1397.771	278.264	603.744	1388.749	215.676	595.802
8SIN3	1400.737	249.908	547.588	1402.045	277.893	598.941	1392.621	215.099	590.983
8SIN4	1401.956	246.69	543.102	1409.745	275.697	591.968	1394.606	213.033	588.099
8SIN5	1392.65	247.039	553.368	1397.094	275.903	602.543	1382.632	213.452	598.15
8STCal	1136.764	26.199	972.008	1121.126	61.298	1006.577	1125.665	-7.906	1001.253
8STE1	1037.375	46.908	966.648	1024.58	82.238	1001.466	1024.219	13.023	996.917
8STE2	1002.911	40.874	966.056	992.554	77.255	1000.389	986.655	8.244	995.681
8STE3	1022.064	33.209	963.885	1012.191	68.712	999.046	1007.168	-0.222	994.538
8STE4	1009.604	42.622	969.427	998.265	78.791	1004.408	993.686	9.8	998.568
8STE5	1006.501	20.02	965.497	997.394	56.898	1001.264	990.135	-11.806	996.559
8STI1	904.862	135.459	956.004	889.407	169.516	992.514	895.952	100.979	990.439
8STI2	896.238	130.786	957.392	879.223	165.004	992.182	888.084	96.336	990.535
8STI3	884.589	149.891	953.964	866.0	184.345	988.303	877.16	115.917	985.964
8STI4	893.057	129.271	960.881	875.734	163.901	994.349	882.839	94.962	992.547
8STI5	905.737	133.957	955.765	888.304	167.87	990.067	898.002	99.296	987.871
8STN1	1137.098	42.23	964.15	1126.48	77.319	1001.346	1121.87	8.6547	997.315
8STN2	1134.477	41.306	963.845	1124.328	76.597	1000.835	1118.628	7.978	996.88
8STN3	1135.148	99.477	962.22	1121.454	133.901	998.771	1123.044	65.032	995.241
8STN4	1125.796	77.066	956.197	1118.084	113.714	993.041	1108.806	45.64	987.815
8STN5	1122.188	62.38	957.977	1115.184	99.29	994.227	1103.719	31.435	988.867
9SICal	1369.036	-53.888	597.158	1362.895	-8.022	634.99	1356.732	-81.67	643.877
9SIE1	1304.426	-40.521	611.494	1296.252	3.577	649.708	1287.08	-70.196	653.405
9SIE2	1303.359	-40.249	612.721	1294.707	4.048	650.748	1285.642	-69.705	654.736
9SIE3	1304.649	-40.656	611.297	1296.285	3.45	649.436	1287.162	-70.262	653.271
9SIE4	1304.52	-40.807	611.025	1296.166	3.111	649.254	1287.191	-70.502	652.938

Table C.2 Continued

Trial	Sacrum middle			Sacrum right			Sacrum left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
9SIE5	1299.698	-38.613	614.536	1289.932	5.377	652.615	1281.931	-68.52	656.164
9SII1	1367.38	-9.601	597.793	1360.609	35.66	635.44	1353.67	-37.425	643.964
9SII2	1363.83	-9.523	600.508	1356.464	35.448	638.119	1349.691	-37.342	646.461
9SII3	1380.207	-5.685	589.768	1375.104	39.31	627.508	1368.8	-33.518	636.143
9SII4	1381.625	-6.361	588.944	1376.523	38.613	626.808	1370.423	-34.474	635.271
9SII5	1377.267	-9.311	592.871	1371.015	35.088	631.102	1364.861	-37.836	638.814
9SIN1	1353.739	-70.079	605.067	1346.693	-23.401	642.467	1336.522	-96.8	651.083
9SIN2	1356.959	-68.33	602.522	1349.039	-21.67	639.68	1340.085	-95.594	648.478
9SIN3	1347.032	-66.321	608.123	1337.797	-19.93	645.042	1329.981	-93.735	653.422
9SIN4	1353.127	-67.363	603.202	1344.875	-21.339	640.649	1337.389	-95.221	648.739
9SIN5	1351.213	-66.944	604.13	1343.045	-20.684	641.225	1335.177	-94.345	649.832
9STCal	1050.763	-39.47	1088.146	1038.929	6.876	1123.363	1029.328	-68.853	1131.635
9STE1	1101.96	-54.218	1079.324	1090.798	-8.296	1116.907	1083.105	-85.005	1120.47
9STE2	1106.594	-46.127	1078.745	1094.419	-0.726	1116.753	1088.369	-77.482	1119.729
9STE3	1072.877	-28.782	1078.777	1060.854	16.55	1116.767	1054.97	-60.431	1119.801
9STE4	1079.198	-6.103	1077.18	1066.373	38.549	1115.822	1061.753	-38.419	1117.77
9STE5	1073.854	-19.088	1077.616	1061.764	26.089	1115.681	1056.843	-50.951	1118.778
9STI1	904.307	-73.294	1092.868	895.796	-25.324	1129.051	879.829	-100.928	1135.429
9STI2	896.832	-70.256	1095.607	886.728	-22.03	1131.13	871.461	-97.881	1137.539
9STI3	906.939	-76.687	1098.729	897.732	-27.74	1133.594	879.435	-102.916	1140.227
9STI4	920.511	-65.06	1092.465	912.686	-17.083	1128.665	895.554	-92.287	1135.186
9STI5	912.231	-72.779	1093.451	904.824	-24.757	1129.735	886.419	-99.658	1135.77
9STN1	967.776	-66.501	1086.194	955.082	-20.994	1121.958	948.377	-97.696	1129.795
9STN2	980.385	-81.925	1086.81	970.173	-35.453	1122.329	959.02	-111.768	1130.607
9STN3	982.442	-75.153	1084.699	968.83	-29.762	1120.489	964.266	-106.563	1128.483
9STN4	981.203	-70.893	1084.66	969.113	-24.883	1120.126	961.914	-101.526	1128.512
9STN5	983.959	-64.946	1083.088	969.059	-20.071	1119.243	966.798	-97.047	1126.656
10SICal	1338.24	3.889	591.663	1319.251	45.487	620.264	1322.613	-35.419	628.221
10SIE1	1344.498	-13.785	569.974	1326.659	34.242	608.384	1326.899	-44.817	612.991
10SIE2	1343.961	-13.79	570.256	1326.241	34.108	608.687	1326.1	-44.894	613.172
10SIE3	1343.587	-13.773	570.896	1325.354	34.185	609.052	1325.318	-44.805	613.65

Table C.2 Continued

Trial	**Sacrum middle**			**Sacrum right**			**Sacrum left**		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
10SIE4	1343.061	-13.784	571.456	1324.332	34.295	609.707	1324.482	-44.816	614.256
10SIE5	1343.27	-13.768	571.2159	1324.908	34.248	609.367	1324.873	-44.758	613.917
10SII1	1348.79	-11.75	565.656	1337.224	37.795	604.81	1331.377	-40.532	609.363
10SII2	1347.564	-11.598	566.579	1335.347	37.903	605.569	1329.675	-40.43	610.163
10SII3	1348.286	-11.559	565.742	1336.48	38.079	604.842	1330.53	-40.206	609.129
10SII4	1347.325	-11.353	566.413	1335.167	38.381	605.4456	1329.05	-39.837	609.754
10SII5	1347.457	-12.932	567.69	1335.363	35.732	607.038	1328.536	-42.374	611.405
10SIN1	1359.846	0.497	574.425	1345.063	49.267	611.897	1341.576	-29.619	616.775
10SIN2	1358.805	0.382	574.785	1343.376	49.152	612.207	1340.206	-29.743	617.048
10SIN3	1358.059	0.179	574.888	1342.485	48.935	612.293	1339.386	-29.954	617.144
10SIN4	1358.917	0.554	573.904	1343.488	49.513	611.336	1340.483	-29.281	616.23
10SIN5	1360.055	-1.133	573.276	1345.482	47.722	610.856	1341.531	-30.812	615.863
10STCal	822.451	-45.669	1029.871	807.449	-5.184	1048.349	796.875	-82.828	1057.694
10STE1	841.836	-169.804	1018.72	826.534	-119.419	1043.638	815.894	-195.148	1049.046
10STE2	830.203	-182.81	1017.64	817.953	-131.706	1043.46	803.12	-206.944	1048.597
10STE3	823.157	-168.721	1017.604	807.726	-117.941	1041.929	797.716	-193.774	1048.32
10STE4	830.289	-161.56	1016.964	815.486	-110.631	1041.509	805.026	-186.397	1047.711
10STE5	824.934	-175.407	1016.96	811.392	-124.316	1041.494	799.087	-199.78	1047.55
10STI1	546.614	-23.003	1015.093	529.803	26.895	1041.557	521.688	-49.263	1047.456
10STI2	543.553	-27.869	1009.815	527.167	21.866	1036.427	519.556	-54.349	1042.645
10STI3	539.297	-32.772	1016.138	525.065	17.865	1042.036	512.965	-57.686	1048.431
10STI4	525.784	-48.969	1016.749	513.781	2.17	1042.413	498.86	-72.979	1049.09
10STI5	535.057	-45.665	1014.342	523.181	5.312	1039.753	508.532	-69.628	1046.709
10STN1	834.503	-100.958	1021.454	816.796	-52.974	1044.467	810.217	-128.83	1050.593
10STN2	843.592	-92.423	1020.198	826.098	-43.999	1043.556	819.252	-119.78	1049.854
10STN3	833.544	-102.821	1021.127	814.214	-55.08	1042.925	809.558	-130.99	1049.449
10STN4	830.87	-91.961	1020.775	809.895	-44.714	1041.268	807.762	-120.851	1048.194
10STN5	828.73	-98.928	1022.166	809.332	-50.92	1042.419	804.1	-126.872	1049.293

Note: [a] missing all significant portions of data points for Left Sacrum and Right Sacrum.

[b] missing significant data points for Left Sacrum: final 15 seconds used instead of seconds 1-16.

Table C.3 Average X, Y, Z Coordinates for Reflective Markers on Shoulders

Trial	Shoulders middle			Shoulders right			Shoulders left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
1SICal	1275.914	31.594	1100.098	1211.301	206.17	1026.531	1171.766	-119.104	1068.262
1SIE1	1266.613	-7.499	1098.767	1196.077	166.423	1029.684	1167.538	-159.8	1060.577
1SIE2	1267.597	-7.2	1098.468	1194.201	166.31	1029.376	1168.602	-159.981	1061.411
1SIE3	1263.551	-9.982	1098.677	1190.188	163.134	1029.858	1166.544	-162.583	1061.321
1SIE4	1263.733	-7.706	1098.289	1191.978	165.285	1027.389	1166.597	-160.88	1060.629
1SIE5	1261.049	-4.568	1098.842	1187.929	168.212	1027.782	1163.3	-157.792	1063.571
1SII1	1260.931	10.582	1089.013	1181.165	179.045	1020.756	1168.146	-146.613	1055.872
1SII2	1267.42	2.453	1088.78	1183.382	170.099	1024.736	1177.166	-155.124	1058.024
1SII3	1269.591	-0.78	1088.977	1182.227	167.267	1026.089	1178.087	-160.17	1056.734
1SII4	1266.668	-1.564	1089.587	1180.712	165.041	1026.631	1177.145	-162.257	1055.705
1SII5	1267.254	1.009	1088.835	1180.338	166.535	1026.065	1180.384	-160.21	1056.821
1SIN1	1278.562	16.091	1094.88	1208.088	191.055	1022.056	1171.26	-139.149	1057.212
1SIN2	1269.068	23.954	1096.879	1194.445	195.7	1020.239	1166.698	-133.194	1063.303
1SIN3	1272.163	23.505	1095.358	1197.368	193.142	1016.828	1175.128	-135.661	1062.119
1SIN4	1267.855	16.381	1095.989	1190.395	186.117	1019.443	1171.519	-142.966	1061.674
1SIN5	1274.471	10.615	1096.029	1192.937	180.26	1022.478	1180.208	-150.666	1060.757
1STCal	1040.5	34.663	1478.041	984.262	216.899	1431.853	930.837	-106.514	1453.484
1STE1	861.496	11.731	1487.265	790.787	190.919	1437.143	751.909	-139.545	1457.21
1STE2	863.22	31.788	1488.572	769.368	198.811	1442.414	776.384	-132.685	1457.549
1STE3	860.808	17.548	1487.669	781.777	191.068	1437.328	763.464	-140.908	1456.927
1STE4	859.377	19.96	1489.393	772.829	191.415	1438.618	764.943	-141.938	1458.244
1STE5	863.931	19.502	1486.918	771.473	190.223	1433.968	771.65	-145.603	1454.558
1STI1	1005.642	45.819	1478.5	924.781	221.452	1427.331	906.758	-109.977	1448.575
1STI2	1023.554	26.956	1476.218	943.197	203.812	1429.137	921.271	-127.367	1447.879
1STI3	1047.013	45.558	1463.416	967.458	224.048	1417.744	940.059	-106.003	1442.017
1STI4	1013.581	43.216	1469.863	945.166	226.9	1420.992	900.452	-103.342	1437.877
1STI5	1030.532	52.149	1471.184	955.436	232.962	1425.734	921.498	-97.9144	1444.105
1STN1	1066.262	0.44	1476.453	986.538	177.986	1431.414	963.421	-155.43	1448.527
1STN2	1055.065	21.423	1482.949	967.729	195.606	1433.952	956.683	-137.89	1456.817
1STN3	1053.307	7.172	1480.852	965.699	180.972	1433.745	956.508	-151.926	1454.379
1STN4	1050.834	17.241	1482.715	967.24	193.372	1435.099	949.028	-138.051	1457.538

Table C.3 Continued

Trial	Shoulders middle		Shoulders right		Shoulders left				
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
1STN5	1049.953	15.536	1480.445	968.581	192.895	1434.059	946.484	-137.359	1457.752
2SICal	1089.302	59.204	1084.926	1022.308	251.345	1022.15	968.333	-124.985	1041.458
2SIE1	1106.702	-77.32	1086.144	1048.673	118.175	1034.65	976.891	-254.599	1040.191
2SIE2	1106.131	-80.754	1086.452	1051.94	115.714	1033.186	975.175	-256.122	1040.587
2SIE3	1113.176	-76.13	1084.855	1048.837	117.99	1031.769	988.198	-257.142	1039.116
2SIE4	1112.799	-70.868	1084.169	1049.843	125.11	1032.132	979.726	-247.315	1044.101
2SIE5	1111.202	-70.696	1084.433	1047.64	124.562	1033.91	978.365	-248.299	1043.452
2SII1	1135.886	-19.444	1074.233	1061.637	173.172	1026.023	1005.608	-200.722	1038.488
2SII2	1133.638	-20.821	1072.766	1055.526	170.668	1024.367	1004.315	-203.054	1040.015
2SII3	1136.22	-22.494	1072.195	1066.71	172.362	1022.248	998.2427	-198.944	1041.045
2SII4	1121.302	-19.115	1076.988	1046.644	173.857	1028.147	989.31	-199.133	1042.367
2SII5	1127.291	-18.61	1075.056	1053.754	175.236	1026.506	994.572	-198.013	1041.624
2SIN1	1087.197	-106.107	1083.676	1076.129	97.819	1035.584	914.696	-245.366	1046.011
2SIN2	1085.646	-97.513	1084.123	1073.881	106.264	1032.361	911.616	-236.519	1047.407
2SIN3	1083.718	-97.588	1084.544	1077.956	106.513	1031.686	905.395	-231.583	1047.746
2SIN4	1087.442	-93.474	1084.172	1082.645	110.354	1030.06	907.125	-225.834	1050.483
2SIN5	1084.55	-90.954	1084.558	1082.515	112.906	1029.31	901.804	-220.384	1050.521
2STCal [a]	875.415	31.68	1462.897	812.868	221.996	1405.783	770.304	-156.156	1419.96
2STE1 [a]	816.026	-188.763	1448.713	757.761	2.565	1397.618	695.531	-371.52	1409.242
2STE2 [a]	812.527	-189.63	1449.367	758.296	3.321	1396.302	689.259	-369.438	1408.255
2STE3 [a]	812.78	-203.552	1448.933	760.835	-7.677	1395.273	682.394	-379.027	1406.853
2STE4 [a]	814.913	-210.123	1447.767	760.705	-13.598	1395.563	681.995	-385.162	1405.848
2STE5 [a]	817.079	-216.729	1447.277	768.14	-18.026	1395.7	677.175	-386.987	1407.245
2STI1 [a]	765.788	-33.305	1446.951	738.812	170.627	1399.213	603.086	-181.081	1415.818
2STI2 [a]	727.719	-43.667	1446.747	697.751	160.871	1400.96	565.44	-191.94	1415.116
2STI3 [a]	712.858	-47.658	1443.574	688.546	157.926	1397.292	546.684	-192.125	1408.869
2STI4 [a]	721.115	-20.129	1446.314	695.972	183.764	1397.369	554.411	-166.956	1413.204
2STI5 [a]	714.169	-27.772	1442.953	693.256	176.198	1397.587	549.038	-174.045	1406.507
2STN1 [a]	819.613	-165.409	1451.782	840.388	34.931	1400.327	632.983	-282.493	1417.166
2STN2 [a]	813.298	-159.69	1453.133	832.027	41.944	1401.702	626.239	-276.703	1416.756

Table C.3 Continued

Trial	Shoulders middle		Shoulders right		Shoulders left				
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
2STN3 [a]	805.744	-158.616	1454.361	823.464	43.968	1401.829	617.51	-274.573	1417.919
2STN4 [a]	804.151	-164.296	1453.45	829.507	36.816	1400.757	611.499	-273.894	1417.806
2STN5 [a]	803.21	-169.296	1452.354	830.318	31.736	1398.459	607.856	-275.781	1417.017
3SICal	1079.503	-47.992	1103.335	988.187	138.194	1040.965	984.603	-249.545	1028.677
3SIE1	1031.906	129.441	1092.026	948.871	318.647	1049.313	930.405	-58.552	1046.48
3SIE2	1040.417	122.533	1089.573	958.178	312.494	1047.036	936.671	-66.029	1041.119
3SIE3	1045.053	126.709	1089.709	965.267	317.71	1043.752	936.154	-59.823	1044.371
3SIE4	1056.347	124.039	1086.85	976.969	314.964	1042.434	946.642	-62.292	1041.5
3SIE5	1037.874	117.617	1087.902	956.322	308.953	1045.36	927.306	-69.5	1039.224
3SII1	1151.14	63.663	1079.124	1065.712	250.44	1039.74	1051.426	-125.017	1031.942
3SII2	1128.064	67.688	1083.849	1037.961	252.178	1044.652	1035.472	-122.254	1031.91
3SII3	1143.846	66.672	1081.01	1059.568	253.856	1037.337	1044.15	-121.613	1032.642
3SII4	1149.962	61.457	1078.29	1066.23	250.063	1039.28	1047.135	-125.351	1032.492
3SII5	1128.39	65.898	1082.765	1042.927	252.668	1040.194	1031.938	-123.122	1036.526
3SIN1	1071.386	49.338	1097.986	1006.833	242.217	1049.195	960.884	-133.938	1042.094
3SIN2	1074.549	52.294	1095.935	1002.479	245.464	1048.698	961.306	-131.867	1041.683
3SIN3	1069.572	53.533	1091.758	995.256	246.258	1043.166	957.012	-130.951	1040.094
3SIN4	1071.636	51.614	1090.893	1001.09	245.964	1043.196	955.729	-129.905	1040.21
3SIN5	1055.672	49.333	1092.533	987.567	244.359	1043.957	939.494	-130.805	1041.816
3STCal	675.885	-139.546	1452.561	585.759	42.942	1403.069	613.625	-345.611	1383.942
3STE1	782.082	-110.25	1436.041	712.655	80.875	1397.994	676.013	-294.855	1389.906
3STE2	767.481	-101.733	1437.492	695.261	89.558	1396.98	658.87	-288.619	1390.627
3STE3	764.998	-94.24	1437.594	675.177	89.43	1398.764	673.849	-289.577	1387.743
3STE4	773.355	-108.61	1435.68	683.316	76.691	1396.751	677.366	-303.053	1387.463
3STE5	762.117	-103.309	1438.396	670.291	79.354	1393.412	675.023	-298.969	1386.744
3STI1	510.31	-319.418	1426.048	440.549	-125.921	1388.415	394.051	-500.253	1380.922
3STI2	515.561	-361.876	1426.747	452.325	-167.42	1384.31	395.729	-538.36	1383.512
3STI3	503.617	-376.398	1428.676	436.723	-181.217	1388.969	384.136	-553.78	1386.909
3STI4	516.097	-399.293	1425.972	460.499	-201.035	1388.502	386.83	-569.164	1380.668
3STI5	511.158	-413.674	1428.604	498.057	-208.515	1390.431	349.799	-553.972	1382.576

Table C.3 Continued

Trial	Shoulders middle			Shoulders right			Shoulders left	
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
3STN1	536.863	-185.426	1437.374	481.842	11.208	1393.567	417.075	-362.621	1383.505
3STN2	563.004	-167.453	1431.918	483.929	22.888	1387.2	459.8	-355.347	1382.578
3STN3	544.66	-172.708	1433.902	495.09	26.242	1388.442	415.201	-343.201	1384.381
3STN4	533.98	-153.474	1433.899	464.713	41.84	1392.249	420.201	-334.368	1381.768
3STN5	524.258	-157.154	1431.502	477.236	43.502	1389.139	390.526	-324.538	1380.249
4SICal	1067.465	-22.034	1089.68	1000.056	176.468	1034.407	1001.128	-211.306	1014.781
4SIE1	1086.624	-40.581	1095.508	1017.443	162.51	1036.83	984.763	-217.587	1038.874
4SIE2	1073.958	-36.074	1097.333	1004.142	166.266	1035.655	972.262	-213.702	1038.752
4SIE3	1079.624	-40.291	1096.677	1007.25	162.439	1038.471	978.968	-217.743	1038.04
4SIE4	1070.433	-40.449	1096.796	997.186	161.514	1036.725	969.411	-218.708	1038.584
4SIE5	1066.413	-42.859	1097.161	996.326	160.544	1035.68	962.159	-219.019	1037.336
4SII1	1080.702	-8.883	1084.923	1017.729	194.197	1029.242	985.538	-188.475	1024.503
4SII2	1072.735	-12.064	1086.476	1009.495	191.692	1031.637	973.546	-189.027	1022.136
4SII3	1072.985	-14.479	1085.902	1010.67	190.177	1030.968	971.231	-189.964	1021.89
4SII4	1080.506	-12.039	1086.008	1018.065	192.305	1030.018	976.483	-187.529	1026.687
4SII5	1080.202	-12.328	1085.967	1021.827	193.093	1029.63	973.249	-186.442	1026.169
4SIN1	1064.342	-12.161	1096.724	996.868	188.406	1040.458	964.92	-191.738	1039.852
4SIN2	1066.321	-13.983	1095.074	998.905	187.579	1039.107	966.365	-192.662	1037.326
4SIN3	1062.447	-13.452	1095.02	998.656	189.298	1038.017	962.26	-192.266	1035.918
4SIN4	1067.289	-19.2	1093.323	1009.805	185.7	1038.314	959.597	-192.64	1032.586
4SIN5	1059.054	-18.115	1094.923	999.242	186.737	1040.281	951.126	-192.201	1035.286
4STCal	836.557	-4.259	1504.253	768.191	198.916	1452.556	759.155	-192.114	1432.15
4STE1	808.084	-110.122	1492.819	762.413	95.773	1432.685	698.651	-283.529	1437.464
4STE2	790.812	-109.75	1493.572	740.952	95.499	1432.21	679.799	-283.783	1440.341
4STE3	792.699	-117.591	1493.095	751.469	89.531	1433.028	674.253	-286.9	1438.711
4STE4	781.663	-140.765	1493.869	739.203	67.693	1437.193	660.363	-307.817	1436.845
4STE5	776.17	-113.28	1492.222	727.726	94.172	1433.532	656.016	-281.512	1438.158
4STI1	803.888	-2.966	1490.191	755.72	205.406	1435.449	686.968	-173.147	1435.104
4STI2	805.622	1.526	1487.587	751.262	207.575	1429.504	695.139	-173.659	1433.439
4STI3	788.534	1.339	1488.456	735.122	208.715	1431.909	673.737	-170.843	1432.554
4STI4	801.217	1.029	1483.732	747.45	206.815	1427.86	694.928	-175.422	1425.234

Table C.3 Continued

Trial	Shoulders middle		Shoulders right		Shoulders left				
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
4STI5	798.755	-2.71	1484.945	742.752	202.817	1427.135	689.289	-178.932	1428.673
4STN1	854.863	-66.118	1498.179	801.129	141.338	1443.757	741.824	-237.174	1440.112
4STN2	848.5	-72.363	1498.189	790.77	132.571	1444.898	741.829	-247.394	1440.923
4STN3	846.047	-40.649	1499.362	780.277	160.819	1442.263	746.471	-219.829	1444.401
4STN4	840.4	-56.572	1499.123	777.321	146.486	1442.872	735.174	-232.972	1444.409
4STN5	845.008	-37.474	1497.411	776.499	164.586	1440.884	743.884	-215.933	1442.208
5SICal	1123.619	-10.376	1137.889	1019.042	200.388	1058.743	1042.823	-224.033	1040.277
5SIE1	1104.045	-8.8	1148.558	1046.599	216.597	1076.832	994.585	-209.011	1057.224
5SIE2	1095.71	-2.355	1148.954	1042.247	222.505	1072.805	981.394	-200.62	1062.236
5SIE3	1093.53	-1.339	1149.242	1041.93	224.104	1071.984	978.728	-198.579	1062.775
5SIE4	1095.116	3.812	1148.377	1040.964	228.267	1068.115	981.509	-195.502	1064.967
5SIE5	1094.732	-4.9159	1148.739	1040.729	221.534	1073.01	981.185	-202.789	1060.148
5SII1	1163.431	-26.875	1128.195	1074.628	192.393	1060.823	1063.185	-237.141	1052.633
5SII2	1165.928	-27.622	1131.649	1078.69	191.705	1061.305	1063.597	-236.664	1057.702
5SII3	1177.746	-26.87	1129.417	1091.702	192.475	1059.034	1069.826	-233.789	1062.878
5SII4	1188.176	-26.601	1129.358	1100.43	192.599	1058.626	1080.774	-232.905	1058.238
5SII5	1190.93	-29.593	1128.361	1107.272	190.833	1057.615	1081.856	-234.991	1057.848
5SIN1	1116.082	-64.711	1140.339	1066.564	160.955	1066.515	1010.913	-269.605	1052.194
5SIN2	1122.038	-64.351	1142.336	1067.901	161.303	1069.305	1016.489	-268.965	1057.057
5SIN3	1125.346	-65.959	1139.933	1072.537	159.545	1066.323	1020.212	-271.047	1055.248
5SIN4	1127.467	-69.693	1138.68	1072.865	156.107	1066.301	1018.735	-273.441	1055.581
5SIN5	1134.777	-70.751	1136.475	1082.839	154.965	1064.811	1023.816	-274.045	1053.675
5STCal	715.409	-87.566	1507.615	645.51	136.064	1426.176	626.028	-299.917	1409.817
5STE1	787.834	-82.912	1506.093	763.637	147.581	1428.601	642.195	-263.032	1421.316
5STE2	768.958	-79.275	1503.502	746.329	150.966	1424.572	620.365	-257.984	1423.057
5STE3	770.145	-76.797	1503.889	753.47	154.303	1424.831	616.919	-251.929	1423.47
5STE4	749.539	-68.068	1503.432	730.942	161.468	1421.636	597.394	-244.885	1425.72
5STE5	742.27	-73.448	1501.199	710.109	156.864	1422.216	596.069	-254.059	1420.656
5STI1	765.613	-52.223	1497.778	709.026	172.113	1422.894	639.602	-253.303	1421.795
5STI2	782.238	-69.527	1496.299	732.687	156.945	1418.58	648.122	-264.321	1421.728
5STI3	777.51	-61.544	1495.99	726.936	164.697	1418.03	642.519	-256.257	1423.888

Table C.3 Continued

Trial	Shoulders middle		Shoulders right		Shoulders left				
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
5STI4	777.741	-68.072	1495.377	733.444	161.06	1416.891	640.373	-260.74	1422.2
5STI5	790.641	-74.061	1494.938	747.137	154.013	1415.71	653.255	-268.561	1422.754
5STN1	717.913	-146.078	1507.2	734.599	84.531	1433.153	552.06	-311.934	1423.146
5STN2	709.285	-135.493	1505.759	731.898	93.787	1429.273	536.566	-293.48	1422.79
5STN3	710.558	-119.166	1503.94	715.874	108.501	1427.113	548.752	-291.276	1420.606
5STN4	711.87	-124.976	1502.416	707.222	105.209	1425.187	552.308	-302.116	1425.664
5STN5	709.543	-113.265	1503.84	699.606	116.19	1424.864	554.831	-293.462	1424.677
6SICal	1142.608	-193.177	1066.934	1051.257	-14.218	1011.015	1038.922	-372.0	1028.554
6SIE1	1112.906	-150.047	1071.315	1042.718	39.609	1014.689	988.173	-313.728	1026.505
6SIE2	1109.722	-148.69	1071.608	1036.825	40.356	1014.365	985.66	-312.96	1026.557
6SIE3	1145.389	-149.306	1062.272	1070.693	39.305	1006.741	1021.578	-314.434	1020.136
6SIE4	1136.305	-149.023	1064.024	1061.812	39.461	1007.18	1013.027	-314.108	1020.432
6SIE5	1127.781	-150.223	1065.824	1053.425	38.789	1009.416	1003.433	-313.837	1020.719
6SII1	1148.13	-136.769	1053.031	1067.112	50.053	1006.207	1027.948	-304.708	1019.822
6SII2	1148.958	-140.095	1052.133	1067.225	46.642	1005.024	1029.396	-307.905	1018.099
6SII3	1147.469	-140.219	1052.788	1068.108	47.111	1005.84	1027.24	-307.507	1018.233
6SII4	1148.062	-138.372	1052.542	1067.171	48.535	1003.602	1028.014	-305.822	1017.739
6SII5	1149.873	-138.475	1051.524	1065.877	47.753	1003.552	1030.581	-306.861	1016.255
6SIN1	1121.412	-71.231	1071.231	1048.901	117.245	1017.584	997.332	-235.951	1033.028
6SIN2	1120.574	-71.178	1070.203	1048.513	117.234	1015.003	997.287	-235.78	1031.104
6SIN3	1121.425	-66.786	1069.933	1045.084	120.319	1014.989	1000.143	-233.331	1031.997
6SIN4	1122.767	-65.988	1068.655	1048.336	121.599	1011.771	1000.141	-231.508	1030.209
6SIN5	1119.618	-67.85	1068.84	1045.347	120.318	1013.062	996.364	-232.652	1028.955
6STCal	880.643	-196.209	1389.477	792.568	-14.525	1338.344	773.672	-374.141	1353.254
6STE1	786.342	-160.357	1390.92	753.855	38.902	1337.553	634.799	-299.496	1349.749
6STE2	778.61	-165.392	1389.897	746.249	33.793	1335.568	628.586	-305.131	1346.979
6STE3	772.663	-171.579	1392.036	748.405	28.501	1335.787	616.219	-304.78	1349.115
6STE4	770.679	-176.13	1391.367	742.948	23.601	1335.365	617.023	-311.724	1348.435
6STE5	769.217	-179.874	1391.804	741.27	20.285	1338.555	614.18	-315.044	1349.917
6STI1	766.4	-165.592	1375.285	714.672	30.46	1322.297	624.888	-316.54	1338.065

Table C.3 Continued

Trial	Shoulders middle			Shoulders right			Shoulders left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
6STI2	765.997	-167.763	1372.033	713.276	28.257	1320.873	624.594	-319.104	1335.103
6STI3	769.883	-169.725	1369.991	716.832	26.838	1319.624	627.428	-320.102	1332.151
6STI4	764.688	-165.256	1371.685	710.931	31.31	1320.636	622.686	-315.825	1333.744
6STI5	771.78	-166.943	1371.779	716.196	29.26	1322.003	631.167	-318.296	1337.091
6STN1	863.105	-152.542	1392.992	847.072	46.232	1337.217	702.673	-280.753	1356.556
6STN2	867.733	-157.41	1392.139	838.049	40.675	1336.747	715.575	-295.839	1354.014
6STN3	868.202	-155.949	1390.945	838.393	42.5	1336.033	714.713	-292.901	1353.251
6STN4	863.933	-162.516	1390.633	833.406	36.922	1337.601	709.243	-298.728	1353.115
6STN5	862.741	-147.399	1390.981	830.406	51.669	1335.791	708.655	-284.639	1352.597
7SICal	1244.284	27.0426	1064.598	1193.939	203.041	992.207	1145.686	-134.248	1012.44
7SIE1	1242.501	-136.363	1063.242	1236.995	46.385	1015.129	1108.712	-262.585	1005.886
7SIE2	1245.561	-144.343	1059.906	1237.659	38.637	1016.099	1112.767	-271.517	1000.19
7SIE3	1226.3	-142.755	1061.517	1208.212	40.934	1018.545	1102.721	-275.471	996.0861
7SIE4	1224.416	-130.647	1063.124	1211.547	53.987	1012.731	1093.841	-259.069	1000.238
7SIE5	1232.422	-133.218	1062.692	1223.217	50.968	1014.192	1099.579	-259.258	1001.967
7SII1	1256.133	-142.97	1061.667	1251.371	38.922	1007.098	1124.87	-270.273	1004.236
7SII2	1251.749	-133.323	1064.572	1267.781	46.487	1004.616	1102.651	-243.682	1015.145
7SII3	1262.105	-143.342	1058.183	1259.753	40.001	1000.191	1127.085	-267.239	1000.96
7SII4	1271.443	-141.001	1056.628	1272.364	41.927	1001.187	1130.574	-260.366	1003.487
7SII5	1261.118	-145.619	1056.306	1268.537	37.02	1003.28	1119.132	-261.112	1000.034
7SIN1	1279.523	-16.874	1066.819	1265.586	165.971	1004.914	1151.164	-149.109	1015.51
7SIN2	1275.357	-13.364	1068.306	1262.614	168.588	1008.238	1145.487	-143.942	1016.965
7SIN3	1272.602	-14.255	1067.05	1258.272	168.455	1004.683	1145.128	-146.658	1013.312
7SIN4	1276.914	-10.684	1065.58	1260.984	172.497	1001.366	1145.916	-141.193	1014.108
7SIN5	1278.358	-19.516	1065.74	1264.438	163.787	1005.289	1147.127	-148.466	1012.57
7STCal	994.138	32.901	1391.97	978.37	218.573	1329.008	867.183	-108.608	1349.055
7STE1	929.011	-59.969	1390.249	940.913	123.654	1338.734	782.121	-175.379	1337.172
7STE2	874.935	-72.641	1394.578	887.164	110.339	1343.806	730.599	-188.899	1335.661
7STE3	895.918	-78.931	1393.968	922.761	104.348	1340.665	740.562	-180.822	1337.683
7STE4	926.9	-64.477	1388.963	953.774	119.675	1333.796	770.026	-165.055	1334.492
7STE5	903.356	-70.046	1391.961	927.093	113.427	1335.497	748.904	-174.003	1337.221

Table C.3 Continued

Trial	Shoulders middle		Shoulders right		Shoulders left				
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
7STI1	928.618	-111.868	1389.211	948.584	72.617	1335.399	776.437	-217.906	1335.265
7STI2	903.743	-117.417	1390.439	919.578	66.204	1339.468	757.942	-229.658	1330.678
7STI3	906.81	-116.178	1382.106	929.284	67.9	1329.817	752.129	-219.819	1329.649
7STI4 [b]	911.413	-125.463	1380.175	927.151	61.65	1334.562	761.421	-231.194	1319.446
7STI5	947.055	-83.915	1385.612	948.899	102.752	1334.337	806.554	-203.429	1323.741
7STN1	792.434	-158.696	1387.126	806.285	26.894	1333.376	638.876	-266.584	1342.107
7STN2	774.339	-166.856	1389.254	788.848	19.134	1335.616	620.512	-274.603	1342.183
7STN3	816.746	-191.761	1386.729	814.33	-4.996	1334.604	674.819	-314.851	1337.459
7STN4	819.464	-182.586	1391.184	837.262	3.857	1336.214	662.431	-286.196	1343.491
7STN5	848.834	-180.351	1389.506	874.795	5.91	1335.224	688.96	-277.771	1338.503
8SICal	1281.119	61.25	1152.242	1181.735	247.942	1063.777	1205.763	-131.558	1087.701
8SIE1	1260.799	83.606	1125.607	1195.118	283.371	1057.641	1160.097	-89.04	1081.553
8SIE2	1265.716	87.943	1124.224	1200.782	287.889	1056.366	1160.85	-85.175	1083.194
8SIE3	1245.896	88.552	1129.142	1182.853	287.599	1062.568	1142.261	-85.897	1084.903
8SIE4	1267.316	88.426	1120.947	1197.215	286.872	1055.815	1163.771	-84.904	1080.328
8SIE5	1253.526	89.77	1124.459	1182.037	288.706	1059.877	1149.019	-83.777	1084.834
8SII1	1370.66	187.392	1119.725	1295.991	384.972	1058.039	1275.424	7.824	1081.036
8SII2	1368.881	181.596	1121.219	1289.517	382.093	1059.463	1269.808	3.57	1076.453
8SII3	1367.725	179.656	1120.344	1291.28	379.849	1059.234	1267.896	2.992	1078.733
8SII4	1376.387	179.529	1113.993	1301.927	379.147	1050.809	1279.171	1.638	1069.615
8SII5	1378.351	175.263	1115.431	1312.583	375.717	1059.284	1273.492	2.465	1074.846
8SIN1	1321.01	261.137	1138.285	1283.599	463.969	1073.633	1202.927	101.209	1097.165
8SIN2	1323.007	265.683	1138.614	1288.887	466.267	1073.202	1201.751	108.44	1105.492
8SIN3	1319.863	260.826	1137.321	1282.873	463.877	1070.096	1194.316	106.447	1099.381
8SIN4	1250.761	513.443	1051.345	1302.586	320.119	1135.91	1185.25	156.14	1104.158
8SIN5	1313.94	261.618	1138.042	1287.265	464.633	1079.296	1184.309	109.913	1096.528
8STCal	1064.368	27.156	1502.239	978.871	222.644	1423.109	989.36	-162.11	1440.796
8STE1	994.44	33.358	1497.547	935.24	235.107	1437.498	889.49	-136.866	1462.225
8STE2	959.337	32.529	1494.846	914.237	237.871	1429.879	839.239	-130.925	1454.006
8STE3	972.802	19.624	1496.268	925.218	226.12	1432.902	854.779	-143.994	1455.043

Table C.3 Continued

Trial	Shoulders middle		Shoulders right		Shoulders left				
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
8STE4	958.069	31.576	1497.831	910.369	235.363	1434.038	845.321	-133.896	1458.535
8STE5	958.904	9.842	1492.127	919.411	217.025	1431.96	834.195	-148.871	1454.173
8STI1	856.194	120.923	1493.216	784.16	314.55	1443.42	766.795	-52.21	1456.408
8STI2	853.308	119.353	1490.831	774.203	313.017	1433.632	767.798	-58.376	1454.496
8STI3	845.567	135.608	1488.082	757.395	327.497	1429.232	765.241	-46.238	1447.375
8STI4	846.993	112.731	1491.567	780.335	306.762	1439.958	758.087	-61.978	1453.757
8STI5	871.049	119.425	1488.107	792.091	312.622	1431.306	786.445	-59.835	1450.19
8STN1	1086.249	36.551	1495.425	1037.604	239.164	1435.776	980.746	-130.416	1458.707
8STN2	1084.988	32.835	1494.212	1042.18	237.019	1435.301	973.299	-129.334	1458.395
8STN3	1094.453	88.581	1491.76	1026.19	285.388	1433.232	1001.739	-85.896	1455.932
8STN4	1089.746	77.677	1488.365	1046.587	279.986	1429.037	974.8	-83.613	1453.144
8STN5	1090.699	61.552	1487.264	1053.118	267.912	1426.178	965.884	-95.695	1450.41
9SICal	1266.606	-27.543	1126.439	1177.562	168.295	1059.622	1178.527	-216.281	1068.578
9SIE1	1210.224	-12.865	1128.488	1136.796	184.438	1046.685	1111.516	-194.753	1081.635
9SIE2	1210.685	-8.443	1127.787	1130.152	187.311	1049.06	1121.17	-191.834	1086.147
9SIE3	1213.81	-17.74	1127.556	1139.079	182.267	1048.778	1109.463	-198.036	1075.873
9SIE4	1213.198	-18.756	1127.673	1141.996	181.78	1046.752	1102.266	-195.504	1079.458
9SIE5	1213.274	-18.123	1127.256	1140.958	181.842	1051.82	1112.993	-201.532	1077.869
9SII1	1277.168	11.841	1126.002	1208.951	211.24	1056.56	1178.997	-171.153	1076.991
9SII2	1271.501	14.606	1127.874	1199.186	213.339	1056.052	1175.988	-168.475	1080.945
9SII3	1293.493	17.576	1123.979	1224.33	216.398	1058.434	1197.642	-164.152	1078.247
9SII4	1300.925	9.091	1122.058	1236.157	210.132	1054.642	1198.251	-170.554	1077.309
9SII5	1293.267	5.042	1124.871	1226.792	204.712	1055.245	1198.625	-173.566	1081.738
9SIN1	1269.2	-20.88	1129.142	1206.796	176.506	1040.473	1164.522	-202.935	1087.646
9SIN2	1272.782	-30.947	1127.444	1207.753	169.125	1043.164	1163.137	-211.447	1079.802
9SIN3	1272.375	-27.526	1128.845	1216.086	171.928	1052.026	1167.311	-209.124	1082.832
9SIN4	1283.483	-43.47	1125.573	1224.994	158.639	1051.223	1174.839	-222.193	1081.299
9SIN5	1263.501	-36.404	1128.512	1206.356	166.806	1049.934	1149.028	-213.825	1079.792
9STCal	973.808	-21.862	1582.553	927.446	187.015	1522.531	847.2516	-191.673	1528.474

Table C.3 Continued

Trial	Shoulders middle		Shoulders right		Shoulders left				
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
9STE1	1044.219	-29.044	1577.877	978.928	172.665	1501.254	932.967	-204.681	1532.791
9STE2	1048.122	-26.315	1579.448	976.394	172.59	1515.151	951.071	-209.028	1535.215
9STE3	1017.66	2.761	1577.074	945.823	200.574	1498.095	913.958	-179.367	1537.9
9STE4	1022.283	9.382	1577.668	950.203	209.107	1503.453	918.347	-170.692	1534.542
9STE5	1021.538	4.316	1576.28	949.336	204.601	1501.175	914.078	-172.979	1535.614
9STI1	837.743	-41.233	1583.678	790.89	162.428	1516.093	721.789	-210.634	1534.767
9STI2	818.087	-38.087	1583.955	765.708	166.772	1510.626	699.559	-207.883	1532.554
9STI3	832.023	-35.259	1584.891	787.068	170.725	1507.087	706.088	-202.048	1536.154
9STI4	859.426	-23.378	1582.644	813.915	181.951	1511.429	730.451	-190.798	1538.245
9STI5	849.823	-32.92	1584.254	809.358	170.854	1513.86	726.7	-200.212	1542.14
9STN1	914.565	-47.147	1583.766	858.996	153.342	1509.516	808.111	-224.053	1546.203
9STN2	921.186	-56.079	1585.066	877.346	148.576	1510.267	802.206	-228.642	1540.038
9STN3	929.57	-52.596	1582.925	855.596	144.844	1510.373	833.468	-237.123	1541.789
9STN4	925.509	-31.814	1582.748	860.472	165.925	1502.135	820.433	-214.567	1542.925
9STN5	929.411	-41.989	1582.055	856.853	154.281	1507.24	835.203	-226.911	1543.097
10SICal	1248.907	11.0185	1070.489	1167.303	187.023	1027.584	1185.387	-154.96	1036.626
10SIE1	1287.401	-20.045	1058.711	1200.366	160.765	1017.256	1205.029	-172.218	1029.501
10SIE2	1290.705	-19.278	1057.813	1201.676	160.971	1018.181	1208.688	-171.647	1031.309
10SIE3	1286.415	-19.826	1058.215	1194.162	159.323	1020.094	1207.703	-172.464	1032.841
10SIE4	1284.334	-19.613	1057.659	1185.815	158.599	1021.019	1204.098	-173.617	1031.348
10SIE5	1289.149	-18.835	1057.543	1196.088	160.935	1020.377	1206.841	-170.415	1035.149
10SII1	1311.776	-8.16	1056.458	1249.435	177.421	1019.547	1219.723	-152.806	1025.9
10SII2	1259.023	176.196	1021.678	1319.326	-10.383	1054.325	1225.009	-152.82	1026.522
10SII3	1324.278	-8.57	1052.096	1262.656	177.545	1022.825	1231.661	-152.122	1024.057
10SII4	1324.195	-5.5123	1052.256	1261.909	182.843	1023.148	1226.264	-145.999	1030.152
10SII5	1311.128	-21.936	1053.83	1257.319	164.379	1025.724	1216.292	-165.188	1018.827
10SIN1	1317.108	-4.577	1060.747	1254.098	182.078	1021.892	1228.931	-151.754	1024.92
10SIN2	1319.644	0.305	1060.227	1247.874	185.136	1020.798	1233.819	-149.126	1027.525
10SIN3	1319.857	1.023	1059.663	1242.189	184.874	1021.182	1235.979	-148.658	1030.669
10SIN4	1329.271	7.603	1057.139	1246.215	190.741	1020.443	1244.422	-143.99	1030.319
10SIN5	1331.344	1.223	1056.439	1258.997	186.646	1016.172	1242.794	-146.9	1028.987

Table C.3 Continued

Trial	Shoulders middle			Shoulders right			Shoulders left		
	X Avg (mm)	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*	*X Avg (mm)*	*Y Avg (mm)*	*Z Avg (mm)*
10STCal	750.317	-26.316	1457.882	698.532	158.845	1412.381	669.794	-182.705	1423.468
10STE1	828.148	-151.63	1447.662	778.886	41.576	1401.359	717.841	-289.035	1419.495
10STE2	822.086	-173.337	1444.944	785.452	22.354	1405.067	702.342	-301.559	1417.554
10STE3	820.214	-154.546	1442.629	766.71	39.182	1406.618	711.611	-289.079	1419.153
10STE4	831.961	-145.135	1442.23	775.956	47.784	1406.234	723.168	-281.424	1420.387
10STE5	827.302	-155.797	1442.806	772.853	37.381	1407.147	716.518	-289.445	1424.749
10STI1	529.794	-7.334	1446.558	472.708	181.273	1403.173	434.483	-150.356	1416.881
10STI2	541.934	-11.301	1440.139	484.858	178.117	1399.01	443.48	-153.229	1417.5
10STI3	524.866	-13.09	1446.811	472.554	180.155	1400.025	416.094	-151.131	1412.459
10STI4	518.96	-24.958	1445.374	473.965	167.906	1399.43	411.489	-160.197	1419.492
10STI5	536.506	-22.527	1443.695	490.17	171.865	1400.435	427.535	-156.089	1422.181
10STN1	827.622	-95.04	1447.524	768.912	92.844	1408.527	732.487	-238.334	1415.382
10STN2	842.887	-86.138	1445.174	790.191	102.486	1409.663	745.273	-226.69	1415.155
10STN3	834.813	-100.465	1442.844	776.463	87.139	1408.782	741.976	-243.487	1413.663
10STN4	837.004	-82.362	1441.299	764.869	102.294	1405.055	749.945	-229.724	1416.04
10STN5	832.347	-91.711	1442.368	766.787	96.223	1408.991	736.214	-235.257	1415.053

Note: [a] missing all significant portions of data points for Left Sacrum and Right Sacrum.

[b] missing significant data points for Left Sacrum: final 15 seconds used instead of seconds 1-16.

APPENDIX D

ELECTROMYOGRAPHY DATA

Table D.1 Trial Labeling Key

Participant number	Position	Situation	Situation trial number
1-10	SI = Sitting ST = Standing	Cal = Calibration E = ERGObrass I = Instructions N = Natural Posture	1-5

Please see List of Abbreviations or table 4.11 for names of muscles in table D.2.

Table D.2 Average Muscle Activity for Each Trial

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
1SICal	0.007926	0.005991	0.007958	0.120379	0.011491	0.00794
1SIE1	0.005613	0.00706	0.009937	0.09401	0.013088	0.008791
1SIE2	0.005521	0.007154	0.010263	0.090367	0.013095	0.008227
1SIE3	0.005772	0.00669	0.011237	0.083179	0.013033	0.008342
1SIE4	0.005869	0.006301	0.011191	0.080113	0.012506	0.008268
1SIE5	0.00752	0.006426	0.011137	0.08418	0.012175	0.008519
1SII1	0.01215	0.008204	0.007726	0.092152	0.01299	0.00958
1SII2	0.01224	0.008367	0.007874	0.100208	0.013816	0.008695
1SII3	0.007505	0.00777	0.008138	0.09789	0.01306	0.007948
1SII4	0.009197	0.008409	0.008234	0.09191	0.01276	0.007947
1SII5	0.01014	0.008643	0.008018	0.093827	0.012508	0.008139
1SIN1	0.007246	0.005841	0.023329	0.097512	0.010079	0.02884
1SIN2	0.007336	0.005756	0.014825	0.096126	0.011258	0.01478
1SIN3	0.007779	0.005781	0.013028	0.089493	0.010968	0.013532
1SIN4	0.007559	0.0061	0.012544	0.091442	0.011476	0.011337
1SIN5	0.005774	0.005817	0.01196	0.093334	0.011074	0.010865
1STCal	0.036474	0.009707	0.005828	0.141959	0.014797	0.008177
1STE1	0.02397	0.008802	0.008955	0.104924	0.011007	0.009572
1STE2	0.023769	0.009533	0.00871	0.10522	0.01143	0.009196
1STE3	0.024601	0.009182	0.009163	0.109919	0.011084	0.009518
1STE4	0.020064	0.008752	0.008856	0.095574	0.010541	0.009854
1STE5	0.020064	0.008752	0.008856	0.095574	0.010541	0.009854
1STI1	0.047722	0.010496	0.012116	0.139443	0.01469	0.010883

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
1STI2	0.048152	0.028831	0.018828	0.13546	0.016334	0.015604
1STI3	0.057471	0.023201	0.016608	0.142421	0.017872	0.011755
1STI4	0.054599	0.013868	0.0156	0.152396	0.016705	0.011832
1STI5	0.052789	0.014966	0.011996	0.151347	0.016589	0.010789
1STN1	0.036587	0.01064	0.01153	0.126256	0.012942	0.012849
1STN2	0.040858	0.010448	0.01001	0.125194	0.013679	0.011583
1STN3	0.037001	0.010917	0.009343	0.119106	0.013475	0.01002
1STN4	0.038597	0.009682	0.009892	0.125661	0.014449	0.01039
1STN5	0.0441	0.009931	0.009159	0.125176	0.014499	0.010395
2SICal	0.005385	0.005553	0.007287	0.005306	0.005614	0.005368
2SIE1	0.050706	0.007042	0.010701	0.036234	0.007051	0.009401
2SIE2	0.059831	0.006982	0.008819	0.036771	0.007358	0.009174
2SIE3	0.060758	0.008649	0.010134	0.038121	0.009884	0.010826
2SIE4	0.05522	0.009298	0.012591	0.040334	0.010186	0.011739
2SIE5	0.054014	0.010092	0.010631	0.041113	0.01097	0.010612
2SII1	0.058668	0.005318	0.006637	0.055021	0.008546	0.005979
2SII2	0.076924	0.006843	0.0074	0.059491	0.009837	0.006926
2SII3	0.079402	0.006983	0.00699	0.061259	0.009668	0.006544
2SII4	0.080447	0.005892	0.006505	0.06025	0.009651	0.006042
2SII5	0.082173	0.007371	0.009118	0.062004	0.011244	0.008699
2SIN1	0.013554	0.01275	0.013219	0.037172	0.012588	0.011996
2SIN2	0.010011	0.01079	0.009623	0.038453	0.009226	0.007955
2SIN3	0.009751	0.008899	0.009309	0.036415	0.007785	0.007287
2SIN4	0.010102	0.008386	0.008833	0.037192	0.009029	0.007311
2SIN5	0.009021	0.00798	0.00792	0.038933	0.007452	0.007065
2STCal	0.008046	0.00689	0.005808	0.005439	0.005959	0.006202
2STE1	0.046013	0.005032	0.00859	0.036463	0.005181	0.008434
2STE2	0.05433	0.006383	0.008223	0.036727	0.006235	0.007849
2STE3	0.05519	0.007909	0.009182	0.035731	0.00894	0.009358
2STE4	0.049119	0.00761	0.009656	0.035096	0.007962	0.008021
2STE5	0.041988	0.0069	0.008885	0.036142	0.007538	0.008395

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
2STI1	0.053157	0.005605	0.008609	0.051461	0.007694	0.008101
2STI2	0.039287	0.007104	0.010783	0.047429	0.00879	0.008581
2STI3	0.043615	0.007072	0.008809	0.054237	0.009822	0.008773
2STI4	0.041505	0.006245	0.008283	0.047852	0.008024	0.008656
2STI5	0.039648	0.005807	0.007317	0.04783	0.0075	0.007137
2STN1	0.01454	0.006448	0.008281	0.03495	0.005817	0.006993
2STN2	0.008665	0.00596	0.007234	0.037001	0.006381	0.006703
2STN3	0.007642	0.006891	0.007615	0.032889	0.006575	0.007447
2STN4	0.012581	0.011247	0.012335	0.036187	0.009915	0.011386
2STN5	0.009555	0.007665	0.009401	0.037311	0.007267	0.008388
3SICal	0.004543	0.005376	0.004641	0.004348	0.009231	0.005718
3SIE1	0.018191	0.006829	0.004565	0.043349	0.007976	0.006865
3SIE2	0.019748	0.006862	0.004147	0.039441	0.007232	0.005734
3SIE3	0.012544	0.006775	0.004162	0.040541	0.007546	0.006452
3SIE4	0.015635	0.006833	0.004258	0.03963	0.007321	0.006442
3SIE5	0.012543	0.006637	0.00426	0.033052	0.00708	0.006182
3SII1	0.040774	0.008124	0.003833	0.05471	0.009596	0.00699
3SII2	0.049674	0.009192	0.003872	0.058041	0.01102	0.008183
3SII3	0.055837	0.008615	0.00391	0.059774	0.009949	0.007218
3SII4	0.052990	0.008801	0.003983	0.058076	0.010625	0.006613
3SII5	0.049292	0.006951	0.004606	0.051981	0.010911	0.007679
3SIN1	0.020093	0.007053	0.005719	0.044815	0.011037	0.011246
3SIN2	0.024117	0.00718	0.006649	0.046317	0.011335	0.015673
3SIN3	0.023509	0.006956	0.004926	0.045862	0.009688	0.009955
3SIN4	0.027227	0.007979	0.005899	0.046427	0.010658	0.010725
3SIN5	0.023689	0.007763	0.005129	0.046561	0.01154	0.010406
3STCal	0.004591	0.005329	0.004924	0.004392	0.008232	0.005045
3STE1	0.012255	0.005906	0.005083	0.043805	0.009514	0.005518
3STE2	0.017851	0.005855	0.004421	0.036751	0.008313	0.004657
3STE3	0.021727	0.006629	0.003908	0.03854	0.007458	0.004018
3STE4	0.012499	0.006086	0.003732	0.03941	0.00662	0.004093
3STE5	0.010903	0.006038	0.004026	0.038664	0.007736	0.004339

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
3STI1	0.053904	0.0076	0.004223	0.054466	0.00996	0.007631
3STI2	0.052915	0.008259	0.004511	0.058321	0.021201	0.006362
3STI3	0.044153	0.008285	0.004544	0.053461	0.014237	0.006113
3STI4	0.048041	0.007866	0.004073	0.055813	0.017322	0.005978
3STI5	0.047549	0.00672	0.004331	0.059222	0.018427	0.005759
3STN1	0.031477	0.006933	0.005622	0.048451	0.012868	0.007111
3STN2	0.036965	0.007045	0.006713	0.052595	0.021009	0.007695
3STN3	0.033611	0.006703	0.007162	0.049621	0.021966	0.008584
3STN4	0.026971	0.006794	0.008998	0.053533	0.020981	0.011117
3STN5	0.033517	0.006616	0.005995	0.049839	0.013383	0.006518
4SICal	0.005463	0.004763	0.00489	0.006352	0.004251	0.00586
4SIE1	0.044132	0.009767	0.009494	0.0627	0.009412	0.02586
4SIE2	0.044592	0.011508	0.009082	0.062829	0.010665	0.028304
4SIE3	0.047265	0.011346	0.007527	0.061834	0.010129	0.02696
4SIE4	0.045999	0.017271	0.012805	0.062057	0.012589	0.029303
4SIE5	0.043186	0.017289	0.014176	0.062834	0.013118	0.028809
4SII1	0.044788	0.007618	0.005238	0.062418	0.008513	0.019095
4SII2	0.046645	0.012932	0.013372	0.071786	0.011232	0.02283
4SII3	0.049759	0.016342	0.011527	0.067255	0.013272	0.022553
4SII4	0.0484	0.014416	0.010027	0.066361	0.012556	0.023132
4SII5	0.047877	0.015977	0.011901	0.069289	0.013039	0.022565
4SIN1	0.036481	0.011764	0.009127	0.055471	0.009254	0.024245
4SIN2	0.036553	0.011355	0.006685	0.058462	0.008862	0.025057
4SIN3	0.037708	0.012651	0.007377	0.054806	0.009578	0.023751
4SIN4	0.03813	0.012471	0.007343	0.059307	0.009595	0.023141
4SIN5	0.036145	0.012107	0.005895	0.05793	0.008806	0.024615
4STCal	0.005593	0.006275	0.00511	0.008077	0.004348	0.005948
4STE1	0.040201	0.014115	0.0114	0.060623	0.012179	0.016956
4STE2	0.043496	0.016366	0.01192	0.061888	0.012572	0.020069
4STE3	0.041622	0.01613	0.01115	0.05962	0.011698	0.016727
4STE4	0.042317	0.01506	0.0102	0.062306	0.011616	0.017673

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
4STE5	0.042143	0.016749	0.009636	0.063248	0.012814	0.017958
4STI1	0.039404	0.006629	0.006477	0.070436	0.008455	0.020597
4STI2	0.038988	0.011199	0.007827	0.073324	0.011133	0.017875
4STI3	0.040038	0.009626	0.006636	0.072675	0.010392	0.019059
4STI4	0.039892	0.01366	0.008926	0.068539	0.011273	0.018286
4STI5	0.045246	0.014429	0.007439	0.064732	0.012814	0.018548
4STN1	0.037417	0.011107	0.008166	0.056243	0.010203	0.018245
4STN2	0.039084	0.013805	0.008425	0.059383	0.011323	0.019238
4STN3	0.038507	0.01503	0.007886	0.056762	0.010014	0.019675
4STN4	0.038925	0.017109	0.01052	0.061613	0.011751	0.019465
4STN5	0.039214	0.016479	0.011005	0.061202	0.013958	0.018937
5SICal	0.004465	0.0038	0.003803	0.004356	0.004443	0.065398
5SIE1	0.018539	0.004857	0.003641	0.053152	0.004593	0.000225
5SIE2	0.024853	0.00677	0.003617	0.053019	0.004914	0.000242
5SIE3	0.019874	0.006821	0.003537	0.049514	0.005353	0.000209
5SIE4	0.018121	0.006128	0.003556	0.050619	0.005661	0.000221
5SIE5	0.019007	0.006743	0.003734	0.049158	0.005694	0.000229
5SII1	0.022739	0.004437	0.003137	0.067577	0.005153	0.029033
5SII2	0.015882	0.00467	0.003124	0.069978	0.005715	0.03292
5SII3	0.022834	0.004835	0.002996	0.067738	0.005464	0.033613
5SII4	0.022604	0.00531	0.00303	0.072459	0.006651	0.033037
5SII5	0.022206	0.005612	0.003042	0.068305	0.005692	0.026731
5SIN1	0.016671	0.005542	0.00426	0.058143	0.005364	0.036316
5SIN2	0.020413	0.006286	0.004469	0.054342	0.005981	0.050425
5SIN3	0.019081	0.007432	0.004529	0.051844	0.006538	0.059331
5SIN4	0.019916	0.007516	0.004573	0.055736	0.005899	0.032427
5SIN5	0.020925	0.008069	0.004135	0.054288	0.006192	0.032766
5STCal	0.004125	0.003859	0.003908	0.00456	0.004373	0.034796
5STE1	0.012243	0.00677	0.004484	0.048766	0.004267	0.03574
5STE2	0.01612	0.006649	0.004205	0.051024	0.004602	0.048894
5STE3	0.012835	0.006358	0.003746	0.04875	0.004457	0.000282

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
5STE4	0.016025	0.005324	0.003605	0.044349	0.004281	0.000217
5STE5	0.01692	0.005172	0.003583	0.048811	0.004474	0.000198
5STI1	0.022969	0.004078	0.003491	0.067585	0.004596	0.024282
5STI2	0.022889	0.004171	0.003446	0.072332	0.005305	0.05823
5STI3	0.023759	0.004275	0.003564	0.069791	0.005271	0.000198
5STI4	0.020383	0.005072	0.003474	0.065055	0.005119	0.000214
5STI5	0.02449	0.004468	0.003469	0.06286	0.005043	0.000187
5STN1	0.015299	0.006178	0.004791	0.050623	0.005	0.035138
5STN2	0.018919	0.00637	0.004593	0.052659	0.005341	0.035757
5STN3	0.018388	0.005613	0.003923	0.045946	0.005272	0.027059
5STN4	0.019695	0.006111	0.00383	0.049057	0.005354	0.023893
5STN5	0.018452	0.005125	0.003914	0.05426	0.005177	0.032562
6SICal	0.005516	0.002904	0.004535	0.003627	0.005405	0.003542
6SIE1	0.009991	0.005087	0.008417	0.01061	0.008886	0.008636
6SIE2	0.009608	0.004676	0.006601	0.011256	0.006589	0.007851
6SIE3	0.011185	0.004405	0.006171	0.010644	0.006721	0.006714
6SIE4	0.011876	0.004667	0.006839	0.011074	0.006859	0.007103
6SIE5	0.01207	0.004647	0.007001	0.011255	0.006524	0.007135
6SII1	0.012076	0.005312	0.003867	0.011419	0.004785	0.005231
6SII2	0.013317	0.005365	0.006140	0.011794	0.005347	0.006165
6SII3	0.013439	0.005479	0.007437	0.011845	0.006327	0.006923
6SII4	0.014872	0.005522	0.007287	0.012282	0.007977	0.007153
6SII5	0.013964	0.005715	0.006258	0.012676	0.007337	0.006865
6SIN1	0.012348	0.005834	0.006344	0.010482	0.006	0.008075
6SIN2	0.01324	0.006708	0.007434	0.011466	0.009055	0.00853
6SIN3	0.012041	0.005189	0.005717	0.010732	0.006235	0.00785
6SIN4	0.012479	0.005245	0.0057	0.011128	0.006	0.007814
6SIN5	0.01032	0.005697	0.005822	0.011309	0.007744	0.007873
6STCal	0.005355	0.003451	0.005416	0.003585	0.005466	0.00397
6STE1	0.011166	0.005503	0.007627	0.009073	0.008855	0.007283
6STE2	0.011405	0.005427	0.007204	0.009608	0.008009	0.007329

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
6STE3	0.011474	0.005169	0.007096	0.009593	0.006917	0.00722
6STE4	0.012522	0.005541	0.008963	0.01072	0.009554	0.008103
6STE5	0.011509	0.005779	0.008727	0.010415	0.008808	0.007934
6STI1	0.013729	0.006036	0.007988	0.010836	0.009167	0.00769
6STI2	0.016544	0.007284	0.008581	0.012013	0.014281	0.008738
6STI3	0.014184	0.006701	0.007934	0.011544	0.012974	0.008128
6STI4	0.015458	0.006714	0.007715	0.012095	0.011958	0.008242
6STI5	0.014174	0.006222	0.007989	0.012053	0.009409	0.008085
6STN1	0.010413	0.005042	0.006807	0.009728	0.005801	0.006903
6STN2	0.011682	0.005072	0.007365	0.010285	0.005827	0.007413
6STN3	0.01368	0.005416	0.009441	0.011226	0.010665	0.008805
6STN4	0.013292	0.005383	0.007749	0.011154	0.006717	0.008414
6STN5	0.01302	0.006633	0.007577	0.01108	0.010005	0.008296
7SICal	0.003685	0.004083	0.004498	0.004512	0.004802	0.00993
7SIE1	0.028654	0.058471	0.011396	0.128501	0.01082	0.010957
7SIE2	0.028007	0.067263	0.01109	0.108791	0.010461	0.007626
7SIE3	0.026659	0.068563	0.013873	0.103541	0.009794	0.005591
7SIE4	0.033354	0.064784	0.014108	0.121309	0.010428	0.014063
7SIE5	0.024293	0.066463	0.013023	0.139475	0.011048	0.012137
7SII1	0.065149	0.065221	0.009327	0.187575	0.015519	0.028175
7SII2	0.070666	0.059116	0.006582	0.181728	0.015716	0.03079
7SII3	0.06091	0.048856	0.006262	0.191473	0.01523	0.029189
7SII4	0.075373	0.054095	0.006565	0.181953	0.015705	0.028941
7SII5	0.073765	0.055866	0.005908	0.182838	0.015413	0.029802
7SIN1	0.059535	0.044398	0.007832	0.202079	0.013642	0.034082
7SIN2	0.057153	0.064747	0.008863	0.212384	0.014757	0.035703
7SIN3	0.059346	0.038426	0.009121	0.196098	0.012497	0.034698
7SIN4	0.058806	0.045816	0.009314	0.191814	0.012927	0.034836
7SIN5	0.060406	0.062727	0.011256	0.201909	0.014447	0.035748
7STCal	0.003837	0.00721	0.004447	0.004634	0.005832	0.005862
7STE1	0.025218	0.053816	0.021094	0.113455	0.010095	0.025464

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
7STE2	0.022946	0.058262	0.024618	0.100493	0.009978	0.025353
7STE3	0.020834	0.051820	0.022569	0.120301	0.010526	0.027975
7STE4	0.019489	0.049326	0.020992	0.126229	0.011199	0.027732
7STE5	0.02872	0.0533	0.022272	0.130213	0.011775	0.032174
7STI1	0.055833	0.049207	0.019175	0.1728	0.014872	0.034068
7STI2	0.065115	0.058648	0.02331	0.156459	0.012897	0.036518
7STI3	0.060075	0.057138	0.020111	0.168061	0.014899	0.032441
7STI4 [a]	0.072775	0.079752	0.023347	0.182439	0.01615	0.033544
7STI5	0.068747	0.049777	0.025095	0.174185	0.013572	0.030053
7STN1	0.053652	0.045037	0.016817	0.182071	0.012743	0.031859
7STN2	0.056174	0.049693	0.020737	0.17134	0.013389	0.032969
7STN3	0.065307	0.041505	0.018028	0.175985	0.011753	0.028541
7STN4	0.055115	0.050085	0.016835	0.190546	0.01276	0.033039
7STN5	0.064409	0.043849	0.020336	0.180028	0.013006	0.032977
8SICal	0.004121	0.004269	0.00539	0.004577	0.00455	0.00625
8SIE1	0.009536	0.00565	0.004687	0.032038	0.011927	0.004938
8SIE2	0.004656	0.004949	0.00543	0.028313	0.010752	0.005551
8SIE3	0.005263	0.004658	0.004907	0.031175	0.010527	0.005001
8SIE4	0.00586	0.004942	0.005111	0.034066	0.012134	0.004796
8SIE5	0.004616	0.004752	0.004684	0.028679	0.009555	0.004592
8SII1	0.004915	0.005281	0.00505	0.042463	0.01538	0.004945
8SII2	0.004067	0.005427	0.005275	0.046606	0.018981	0.004977
8SII3	0.004107	0.005831	0.005296	0.043419	0.016095	0.00508
8SII4	0.004449	0.005582	0.005336	0.042223	0.016417	0.004875
8SII5	0.009026	0.006623	0.005385	0.047683	0.019032	0.004949
8SIN1	0.00574	0.006097	0.006244	0.035299	0.012647	0.008011
8SIN2	0.005992	0.005437	0.005533	0.036024	0.013136	0.007381
8SIN3	0.004626	0.005133	0.005952	0.04029	0.013855	0.009699
8SIN4	0.004203	0.004606	0.005314	0.021145	0.008008	0.006162
8SIN5	0.007977	0.006952	0.007074	0.031641	0.011322	0.007517
8STCal	0.004072	0.004326	0.004899	0.004592	0.004342	0.004869

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
8STE1	0.004483	0.005143	0.005333	0.028169	0.008647	0.005277
8STE2	0.005223	0.005126	0.005415	0.032684	0.010111	0.005333
8STE3	0.008525	0.009474	0.009968	0.028967	0.009968	0.007943
8STE4	0.004885	0.004714	0.006327	0.031245	0.010054	0.005618
8STE5	0.005137	0.00567	0.006319	0.029126	0.009652	0.0059
8STI1	0.005571	0.005319	0.005386	0.039566	0.01371	0.006702
8STI2	0.005407	0.005122	0.005358	0.037965	0.013732	0.006187
8STI3	0.004804	0.005292	0.006757	0.039951	0.013555	0.007386
8STI4	0.005465	0.005095	0.006387	0.03891	0.013618	0.006961
8STI5	0.004727	0.005134	0.005816	0.040637	0.014948	0.006219
8STN1	0.007497	0.004985	0.005793	0.035265	0.01271	0.005955
8STN2	0.015888	0.012059	0.011056	0.038394	0.014552	0.017401
8STN3	0.007497	0.004985	0.005793	0.035265	0.01271	0.005955
8STN4	0.01475	0.012659	0.013929	0.035153	0.025752	0.011492
8STN5	0.011112	0.009549	0.010284	0.034319	0.012286	0.008703
9SICal	0.004706	0.004119	0.008571	0.004169	0.00522	0.005771
9SIE1	0.026602	0.007503	0.008985	0.074027	0.007781	0.017751
9SIE2	0.040779	0.007662	0.008872	0.07396	0.007888	0.017847
9SIE3	0.041905	0.007604	0.009598	0.0762	0.007831	0.016708
9SIE4	0.03902	0.006936	0.009088	0.07477	0.007919	0.015823
9SIE5	0.04112	0.009471	0.008143	0.082049	0.007652	0.015568
9SII1	0.015515	0.015567	0.008459	0.071489	0.008244	0.01291
9SII2	0.042433	0.008927	0.00978	0.074784	0.007668	0.01173
9SII3	0.012773	0.01015	0.009869	0.068294	0.007591	0.011975
9SII4	0.032762	0.008762	0.009975	0.065669	0.007499	0.011629
9SII5	0.049859	0.007968	0.010525	0.078186	0.00835	0.01085
9SIN1	0.009979	0.006013	0.007777	0.055738	0.007106	0.010958
9SIN2	0.027941	0.006953	0.008297	0.063994	0.007421	0.010493
9SIN3	0.01741	0.006056	0.006084	0.066575	0.007372	0.011393
9SIN4	0.038497	0.005808	0.00878	0.070597	0.007705	0.010041
9SIN5	0.009755	0.00529	0.008674	0.058633	0.007251	0.01134
9STCal	0.004742	0.004194	0.005458	0.004182	0.00532	0.00605

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
9STE1	0.025934	0.007468	0.006349	0.07286	0.007865	0.013374
9STE2	0.006594	0.014713	0.006477	0.048679	0.006674	0.010288
9STE3	0.031887	0.005947	0.006262	0.073591	0.007696	0.012244
9STE4	0.044689	0.009342	0.007005	0.067828	0.007749	0.01185
9STE5	0.03422	0.006035	0.006621	0.073419	0.007872	0.011847
9STI1	0.040093	0.011628	0.009026	0.060536	0.006995	0.008662
9STI2	0.021894	0.011035	0.009503	0.067041	0.007614	0.009599
9STI3	0.040163	0.008559	0.009968	0.069157	0.007507	0.010765
9STI4	0.019476	0.010041	0.00745	0.060781	0.007309	0.009582
9STI5	0.050577	0.009823	0.008799	0.074389	0.007703	0.00918
9STN1	0.039993	0.006478	0.006581	0.063149	0.007487	0.009896
9STN2	0.009784	0.006274	0.006405	0.057691	0.007299	0.010173
9STN3	0.050916	0.006925	0.007877	0.07624	0.007823	0.009312
9STN4	0.030366	0.006769	0.006165	0.060656	0.007269	0.010416
9STN5	0.046959	0.006596	0.007613	0.068277	0.007555	0.009969
10SICal	0.003802	0.004333	0.005188	0.004241	0.006201	0.00426
10SIE1	0.073233	0.005601	0.015121	0.091667	0.006558	0.006432
10SIE2	0.078501	0.005706	0.015246	0.082292	0.00616	0.006812
10SIE3	0.07445	0.005517	0.015685	0.077205	0.006292	0.006956
10SIE4	0.056558	0.005242	0.016368	0.081278	0.006317	0.006651
10SIE5	0.072382	0.005531	0.016759	0.090346	0.006532	0.007913
10SII1	0.078128	0.010354	0.00942	0.101243	0.007518	0.008311
10SII2	0.090623	0.008875	0.009852	0.098147	0.00734	0.008483
10SII3	0.074665	0.00867	0.008723	0.088645	0.007417	0.007569
10SII4	0.05528	0.006335	0.008116	0.085539	0.007022	0.008564
10SII5	0.088341	0.009164	0.010873	0.10087	0.007117	0.007339
10SIN1	0.072418	0.005733	0.010107	0.105266	0.006768	0.008267
10SIN2	0.066864	0.005812	0.013784	0.097882	0.007071	0.008531
10SIN3	0.063365	0.005774	0.015247	0.099723	0.006953	0.007598
10SIN4	0.059683	0.005782	0.013668	0.084022	0.006886	0.00843
10SIN5	0.074786	0.006255	0.012444	0.083622	0.006955	0.008273

Table D.2 Continued

Trial name	RAD	RPD	RLES	LAD	LPD	LLES
10STCal	0.003688	0.004745	0.006204	0.004081	0.004487	0.004711
10STE1	0.044587	0.00543	0.009022	0.076591	0.006101	0.010327
10STE2	0.046044	0.007393	0.008875	0.071445	0.006207	0.007616
10STE3	0.036155	0.005557	0.008637	0.066242	0.006053	0.009815
10STE4	0.042799	0.005432	0.009554	0.075504	0.006166	0.008963
10STE5	0.042683	0.005717	0.008125	0.071726	0.006194	0.008189
10STI1	0.069322	0.00618	0.009435	0.111599	0.007239	0.013937
10STI2	0.063608	0.00563	0.008233	0.093307	0.007083	0.010134
10STI3	0.051397	0.005506	0.009419	0.119916	0.00708	0.013641
10STI4	0.068644	0.006143	0.009414	0.104863	0.00736	0.014184
10STI5	0.056726	0.005591	0.010351	0.085206	0.007062	0.011877
10STN1	0.070483	0.007844	0.012768	0.089237	0.006504	0.010003
10STN2	0.065952	0.008723	0.009049	0.092149	0.006938	0.009359
10STN3	0.072471	0.00753	0.01117	0.082715	0.006652	0.010322
10STN4	0.075067	0.006344	0.01213	0.089603	0.006897	0.010256
10STN5	0.077074	0.006763	0.013139	0.09394	0.006661	0.011043

Note: [a] final 15 seconds used instead of seconds 1-16 to match reflective marker data.

APPENDIX E

SYNTHESIS OF ELECTROMYPGRAPHY, POSITIONAL, AND AUDIO DATA BY PARTICIPANT

Table E.1 Intervention Key

Abbreviation	Meaning
SIE	Sitting with ERGObrass™
SII	Sitting with Instructions
STE	Standing with ERGObrass™
STI	Standing with Instructions

Please see List of Abbreviations or table 4.11 for names of muscles in tables E.2-E.11.

Table E.2 Participant One Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	-15.13%	14.80%	-28.96%	-7.71%	16.48%	-46.89%	-11.24%
SII	43.53%	41.30%	-47.16%	1.73%	18.74%	-46.68%	1.91%
STE	-42.95%	-12.78%	-10.80%	-17.73%	-20.92%	-13.11%	-19.72%
STI	32.26%	76.99%	50.50%	16.04%	19.04%	10.18%	34.17%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	0.249°	-0.04%	0.33%	-0.32%	-0.48%	9.17%	None
SII	1.254°	-2.96%	-3.06%	-3.2%	-0.67%	16.51%	
STE	-0.298°	0.6%	1.72%	0.85%	1.6%	-3.09%	
STI	-0.072°	0.67%	0.67%	-0.12%	1.3%	9.28%	

Table E.3 Participant Two Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	434.96%	-13.81%	8.12%	2.34%	-1.37%	24.36%	75.77%
SII	620.09%	-33.60%	-25.06%	58.38%	6.22%	-17.84%	101.37%
STE	365.52%	-11.45%	-0.74%	1.02%	-0.28%	2.78%	59.48%
STI	309.97%	-16.69%	-2.38%	39.52%	16.34%	0.81%	57.93%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	-0.9906°	-0.305642%	-0.936482%	0.0719%	-0.281216%	-11.22%	Lifetime
SII	1.918133°	-1.642684%	-0.993143%	-1.31718%	-0.717591%	6.12%	
STE		-1.066175%	-0.47183%	0.07119%	-0.287584%	-4.44%	
STI	-3.08342°	0.36452%	1.74884%	2.41372%	-0.750637%	18.89%	

Table E.4 Participant Three Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	-33.70%	-8.11%	-24.47%	-14.77%	-31.52%	-45.39%	-26.33%
SII	109.52%	12.87%	-28.66%	22.87%	-3.98%	-36.76%	12.64%
STE	-53.71%	-10.50%	-38.62%	-22.39%	-56.06%	-44.85%	-37.69%
STI	51.69%	13.61%	-37.14%	10.72%	-10.04%	-22.38%	1.08%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	3.288°	-4.32%	1.94%	-3.02%	-2.38%	21.72%	Current
SII	2.654°	-0.59%	3.04%	0.24%	-3.17%	14.92%	
STE	9.428°	-0.11%	4.61%	-2.33%	-2.82%	8.66%	
STI	3.256°	-0.54%	1.78%	-1.96%	-3.58%	13.61%	

Table E.5 Participant Four Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	21.70%	11.32%	45.72%	9.19%	21.30%	15.25%	20.75%
SII	28.35%	11.50%	42.93%	17.88%	27.16%	-8.80%	19.84%
STE	8.61%	6.65%	18.05%	4.23%	6.34%	-6.46%	6.24%
STI	5.40%	-24.46%	-18.90%	18.46%	-5.56%	-1.25%	-4.39%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	3.516°	-4.19%	-0.08%	-7.0%	-1.8%	17.15%	Current
SII	4.68°	-2.08%	0.99%	-4.17%	-1.43%	35.21%	
STE	4.275°	1.29%	4.9%	-1.49%	-1.99%	34.63%	
STI	4.954°	0.79%	3.8%	-1.27%	-1.66%	35.46%	

Table E.6 Participant Five Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	3.49%	-10.12%	-17.67%	-6.89%	-12.54%	-99.47%	-23.87%
SII	9.54%	-28.64%	-30.21%	26.14%	-4.33%	-26.47%	-9.00%
STE	-18.30%	2.98%	-6.79%	-4.29%	-15.55%	-44.74%	-14.45%
STI	26.16%	-24.94%	-17.14%	33.69%	-3.10%	-46.17%	-5.25%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	9.598°	-0.63%	3.11%	-2.33%	0.63%	37.24%	Current
SII	6.428°	-0.39%	3.72%	-1.14%	0.49%	24.05%	
STE	12.587°	0.57%	4.04%	-3.0%	-2.05%	10.83%	
STI	9.618°	1.89%	5.8%	-0.38%	-1.31%	6.32%	

Table E.7 Participant Six Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	-9.43%	-18.10%	12.93%	-0.50%	1.56%	-6.73%	-3.38%
SII	11.98%	-4.46%	-0.10%	8.89%	-9.31%	-19.44%	-2.07%
STE	-6.46%	-0.45%	1.74%	-7.60%	8.01%	-4.93%	-1.62%
STI	19.33%	19.65%	3.26%	9.48%	48.11%	2.64%	17.08%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	5.215°	-0.003%	1.32%	-1.54%	-0.35%	-6.91%	Current
SII	6.48°	-1.69%	-0.29%	-2.84%	-0.42%	9.15%	
STE	2.187°	0.99%	0.45%	-0.75%	-0.46%	0.21%	
STI	1.181°	2.34%	1.52%	0.89%	-0.53%	4.52%	

Table E.8 Participant Seven Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	-52.25%	27.11%	36.88%	-40.09%	-23.02%	-71.23%	-20.43%
SII	17.14%	10.56%	-25.31%	-7.84%	13.64%	-16.09%	-1.32%
STE	-60.22%	15.79%	20.26%	-34.37%	-15.83%	-12.98%	-14.56%
STI	9.47%	27.96%	19.71%	-5.11%	13.73%	4.54%	11.72%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	-4.699°	1.44%	2.38%	2.69%	-2.0%	1.62%	Current
SII	4.624°	0.16%	1.57%	0.04%	-2.14%	4.86%	
STE	5.034°	1.23%	2.06%	0.36%	-2.24%	2.15%	
STI	6.348°	1.43%	1.76%	1.4%	-2.5%	8.87%	

Table E.9 Participant Eight Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	4.88%	-11.60%	-17.59%	-6.16%	-6.91%	-35.83%	-12.20%
SII	-6.92%	1.84%	-12.54%	35.28%	45.68%	-35.97%	4.56%
STE	-50.21%	-31.89%	-28.80%	-15.81%	-37.92%	-39.26%	-33.98%
STI	-54.22%	-41.31%	-36.61%	10.44%	-10.83%	-32.42%	-27.49%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	0.12°	-4.99%	-1.74%	-6.27%	-1.52%	2.94%	Lifetime
SII	2.127°	-3.08%	-0.73%	-4.36%	-0.78%	5.88%	
STE	3.52°	-9.91%	-7.71%	-10.86%	1.81%	5.94%	
STI	5.479°	-9.27%	-7.85%	-8.83%	0.41%	-3.96%	

Table E.10 Participant Nine Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	82.88%	30.07%	12.80%	20.75%	6.01%	54.35%	34.48%
SII	48.04%	70.57%	22.70%	13.59%	6.78%	8.98%	28.44%
STE	-19.49%	31.67%	-5.56%	3.18%	1.13%	19.77%	5.12%
STI	-3.27%	54.61%	29.17%	1.81%	-0.81%	-3.97%	12.92%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	2.04°	-2.89%	-0.49%	-6.35%	-0.64%	32.96%	Current
SII	4.265°	-0.24%	2.08%	-2.69%	-0.54%	14.65%	
STE	-3.948°	0.48%	0.81%	-2.33%	-1.28%	4.21%	
STI	-5.879°	-1.02%	-1.85%	-2.42%	-1.45%	25.26%	

Table E.11 Participant Ten Synthesized Data

Intervention	*EMG RAD % change from NP*	*EMG RPD % change from NP*	*EMG RLES % change from NP*	*EMG LAD % change from NP*	*EMG LPD % change from NP*	*EMG LLES % change from NP*	*EMG Avg % change from NP*
SIE	5.34%	-5.99%	21.34%	-10.14%	-8.01%	-15.42%	-2.15%
SII	14.81%	47.83%	-27.99%	0.84%	5.14%	-2.03%	6.43%
STE	-41.21%	-20.63%	-24.11%	-19.24%	-8.71%	-11.91%	-20.97%
STI	-14.22%	-21.92%	-19.57%	15.02%	6.45%	25.09%	-1.53%

Intervention	*Degree difference rightward shoulder twist from Cal*	*% change M to M distance from Cal*	*% change L to L distance from Cal*	*% change R to R distance from Cal*	*% change S to S distance from Cal*	*Audio % change from NP*	*PRP*
SIE	-1.199°	0.69%	1.38%	-1.91%	-2.9%	-10.71%	Lifetime
SII	8.239°	0.73%	-0.87%	-2.11%	-12.5	-10.31%	
STE	4.845°	-1.76%	-1.44%	-3.83%	-2.59%	-11.31%	
STI	3.305°	-0.87%	-1.97%	-4.07%	-2.37%	-13.50%	

APPENDIX F

INSTITUTIONAL REVIEW BOARD APPROVALS

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Date:	03/01/2021
Principal Investigator:	Daniel Nebel
Committee Action:	**IRB EXEMPT DETERMINATION – New Protocol**
Action Date:	03/01/2021
Protocol Number:	2102022490
Protocol Title:	Playing Related Musculoskeletal Disorders in Horn Players
Expiration Date:	

The University of Northern Colorado Institutional Review Board has reviewed your protocol and determined your project to be exempt under 45 CFR 46.104(d)(702) for research involving

Category 2 (2018): EDUCATIONAL TESTS, SURVEYS, INTERVIEWS, OR OBSERVATIONS OF PUBLIC BEHAVIOR. Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met: (i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects; (ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or (iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

You may begin conducting your research as outlined in your protocol. Your study does not require further review from the IRB, unless changes need to be made to your approved protocol.

As the Principal Investigator (PI), you are still responsible for contacting the UNC IRB office if and when:

UNIVERSITY OF NORTHERN COLORADO

Institutional Review Board

- You wish to deviate from the described protocol and would like to formally submit a modification request. Prior IRB approval must be obtained before any changes can be implemented (except to eliminate an immediate hazard to research participants).
- You make changes to the research personnel working on this study (add or drop research staff on this protocol).
- At the end of the study or before you leave The University of Northern Colorado and are no longer a student or employee, to request your protocol be closed. *You cannot continue to reference UNC on any documents (including the informed consent form) or conduct the study under the auspices of UNC if you are no longer a student/employee of this university.
- You have received or have been made aware of any complaints, problems, or adverse events that are related or possibly related to participation in the research.

If you have any questions, please contact the Research Compliance Manager, Nicole Morse, at 970-351-1910 or via e-mail at nicole.morse@unco.edu. Additional information concerning the requirements for the protection of human subjects may be found at the Office of Human Research Protection website - http://hhs.gov/ohrp/ and https://www.unco.edu/research/research-integrity-and-compliance/institutional-review-board/.

Sincerely,

Nicole Morse

Nicole Morse
Research Compliance Manager

University of Northern Colorado: FWA00000784

Carter Hall 3002 | Campus Box 143 | Greeley, CO 80639 | Office 970-351-1910 | Fax 970-351-1934

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Date:	07/08/2022
Principal Investigator:	Dan Nebel
Committee Action:	**Expedited Approval - New Protocol**
Action Date:	07/08/2022
Protocol Number:	2104025563
Protocol Title:	Surface Electromyography of the Low Back in Horn Players
Expiration Date:	

The University of Northern Colorado Institutional Review Board has granted approval for the above referenced protocol. Your protocol was approved under expedited category (4) (6) as outlined below:

Category 4: Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)

Category 6: Collection of data from voice, video, digital, or image recordings made for research purposes.

All research must be conducted in accordance with the procedures outlined in your approved protocol.

If continuing review is required for your research, your project is approved until the expiration date listed above. The investigator will need to submit a request for Continuing Review at least 30 days prior to the expiration date. If the study's approval expires, investigators must stop all research activities immediately (including data analysis) and contact the Office of Research and Sponsored Programs for guidance.

If your study has not been assigned an expiration date, continuing review is not required for your research.

For the duration of the research, the investigator(s) must:

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

- Submit any change in the research design, investigators, and any new or revised study documents (including consent forms, questionnaires, advertisements, etc.) to the UNC IRB and receive approval before implementing the changes.
- Use only a copy of the UNC IRB approved consent and/or assent forms. The investigator bears the responsibility for obtaining informed consent from all subjects prior to the start of the study procedures.
- Inform the UNC IRB immediately of an Unanticipated Problems involving risks to subjects or others and serious and unexpected adverse events.
- Report all Non-Compliance issues or complaints regarding the project promptly to the UNC IRB.

As principal investigator of this research project, you are responsible to:

- Conduct the research in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorizations using the currently approved forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any unanticipated problems involving risks to subjects or others and serious and unexpected adverse events.
- Maintain accurate and complete study records.
- Report all Non-Compliance issues or complaints regarding the project promptly to the IRB.

Please note that all research records must be retained for a minimum of three (3) years after the conclusion of the project. Once your project is complete, please submit the Closing Report Form.

If you have any questions, please contact Nicole Morse, Research Compliance Manager, at 970-351-1910 or nicole.morse@unco.edu. Please include your Protocol Number in all future correspondence. Best of luck with your research!

Sincerely,

Michael Aldridge
IRB Co-Chair, University of Northern Colorado: FWA00000784

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Silvia Correa-Torres
IRB Co-Chair, University of Northern Colorado: FWA00000784