RELATIONSHIP BETWEEN BIOMECHANICS AND PLAYING-RELATED PAIN IN FLUTISTS

By

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Abstract

Playing-related pain and injury are widespread and impactful issues for musicians at all levels, from students to professionals. While there is a body of literature explaining the prevalence of playing-related pain across instrumental musicians, there is little research into injuries endured specifically by flutists, the mechanics of playing the flute, and biomechanical parameters associated with increased playing-related pain. This thesis develops a research protocol to describe common flute-related pain and injury, the standard biomechanics of flute playing, and the relationship between these two factors. Biomechanics are studied through motion capture analysis with an upper limb model. Information on medical history, playing habits, and acute and chronic pain is gathered through a set of comprehensive questionnaires. The completion of this study was impacted significantly by COVID-19, but this thesis presents a thorough protocol, background, and educated hypotheses to guide future research in this area.

Table of Contents

Introduction

Playing-related pain and injury are significant issues in the education and careers of performing musicians, with studies estimating the prevalence of playing-related injury estimated to be between 39% and 87% of adult musicians.[1] This issue has gained significant attention in the past 30 years and in that time several studies have investigated the prevalence,[2] risk factors,[3] and management[4] of playing-related musculoskeletal pain in a variety of populations. Still, there is limited research into injury patterns specific to the flute. The asymmetric positioning required to play the flute may put flutists at additional risk for musculoskeletal injury,[5] and the most common pain complaints in flutists are in the neck, shoulders, upper back, and wrists.[6] Some biomechanical research into injury mechanisms and prevention exists, primarily for pianists[7] and string players,[8] but there is minimal existing research in the biomechanics of flute playing[9,10] and its relationship to playing-related musculoskeletal pain. Fully addressing the relationship between biomechanics and playing-related pain and injury is a long-term project that requires substantial funding, time, personnel, and participation from musicians and music schools worldwide. However, this type of

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[1] C. Zaza, "Playing-Related Musculoskeletal Disorders in Musicians: A Systematic Review of Incidence and Prevalence," *CMAJ* 158, no. 8 (1998).

[2] B. J. Ackermann, D. T. Kenny, and J. Fortune, "Incidence of Injury and Attitudes to Injury Management in Skilled Flute Players," *Work* 40, no. 3 (2011).

[3] LeAnne Thompson, "Risk Factors for Flute-Related Pain among High School and College Students" (University of North Texas, 2008).

[4] K. Lonsdale, E. L. Laakso, and V. Tomlinson, "Contributing Factors, Prevention, and Management of Playing-Related Musculoskeletal Disorders among Flute Players Internationally," *Med Probl Perform Art* 29, no. 3 (2014).

[5] Rachel F Bellisle, "The Biomechanics of Music Performance" (Senior Thesis Project, University of Rhode Island, 2017).

[6] Ibid.

[7] J. P. Baeyens et al., "Effects of Rehearsal Time and Repertoire Speed on Extensor Carpi Radialis Emg in Conservatory Piano Students," *Med Probl Perform Art* 35, no. 2 (2020).

[8] S. L. Gorniak et al., "The Impact of Musical Training on Hand Biomechanics in String Musicians," *Hand (N Y)* 14, no. 6 (2019).

[9] S. Albrecht et al., "Individuality of Movements in Music--Finger and Body Movements During Playing of the Flute," *Hum Mov Sci* 35 (2014).

[10] I. Artigues-Cano and H. A. Bird, "Hypermobility and Proprioception in the Finger Joints of Flautists," *J Clin Rheumatol* 20, no. 4 (2014).

large-scale study requires foundational knowledge on flute-specific injury patterns, basic biomechanics of flute playing, and technical viability of systems used to gather biomechanics data in order to guide the experimental design and hypotheses of a broader research program. Development of this research and creation of appropriate hypotheses requires review of the research into biomechanics and pain in other musical instruments because of the limited existing literature in flutists. The goals of this thesis are to review existing literature relating to musculoskeletal injury and biomechanics in musicians and specifically flutists and to design a technical framework and hypothesis for future biomechanics analysis of flute players. The intent is that this long-term work would provide insight into effective methods for injury prevention and management in flute players.

Background

Playing-Related Musculoskeletal Pain in Musicians

Research in various populations has estimated the prevalence of playing-related pain to be 84%,[11] 76%,[12] 77.2%,[13] and 83%.[14] Playing-related pain is detrimental to career longevity[15] and has negative effects on the physical, emotional, social, and financial well-being of affected musicians.[16] Despite the clear consequences of playing-related pain and injury, research in this field is limited. The first studies on playing-related pain were conducted in the 1980s[17,18,19] and focused primarily on defining the issue of overuse injuries in musicians and examining prevalence of these injuries in professional classical musicians. Since then, there has been significant research into injury prevalence in specific regions of the body, with most studies focusing on an individual or small subset of universities[20 ,21,22] or professional orchestras.[23,24 ,25] Additional systematic

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[11] B. Ackermann, T. Driscoll, and D. T. Kenny, "Musculoskeletal Pain and Injury in Professional Orchestral Musicians in Australia," *Med Probl Perform Art* 27, no. 4 (2012).

[12] H. Gembris et al., "High-Performing Young Musicians' Playing-Related Pain. Results of a Large-Scale Study," *Front Psychol* 11 (2020).

[13] P. Berque, H. Gray, and A. McFadyen, "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)," *Med Probl Perform Art* 31, no. 2 (2016).

[14] C Panebianco, "Musculoskeletal and Other Performance Related Disorders in South African Undergraduate Music Students," *Journal of Occupational Health and Epidemiology* 6, no. 2 (2017).

[15] A. Steinmetz et al., "Frequency, Severity and Predictors of Playing-Related Musculoskeletal Pain in Professional Orchestral Musicians in Germany," *Clin Rheumatol* 34, no. 5 (2015).

[16] C. Zaza, C. Charles, and A. Muszynski, "The Meaning of Playing-Related Musculoskeletal Disorders to Classical Musicians," *Soc Sci Med* 47, no. 12 (1998).

[17] A. H. Lockwood, "Medical Problems of Musicians," *N Engl J Med* 320, no. 4 (1989).

[18] F. H. Hochberg et al., "Hand Difficulties among Musicians," *JAMA* 249, no. 14 (1983).

[19] H. J. Fry, "The Treatment of Overuse Syndrome in Musicians. Results in 175 Patients," *J R Soc Med* 81, no. 10 (1988).

[20] K. Lonsdale and O. K. Boon, "Playing-Related Health Problems among Instrumental Music Students at a University in Malaysia," *Med Probl Perform Art* 31, no. 3 (2016).

[21] A. Nawrocka et al., "Musculoskeletal Pain among Polish Music School Students," Ibid.29, no. 2 (2014).

[22]Panebianco, "Musculoskeletal and Other Performance Related Disorders in South African Undergraduate Music Students."

[23] K. Viljamaa et al., "Musculoskeletal Symptoms among Finnish Professional Orchestra Musicians," *Med Probl Perform Art* 32, no. 4 (2017).

[24] Steinmetz et al., "Frequency, Severity and Predictors of Playing-Related Musculoskeletal Pain in Professional Orchestral Musicians in Germany."

[25] L. Heredia et al., "Playing-Related Problems among Musicians of the Orquesta Buena Vista Social Club® and Supporting Bands," *Med Probl Perform Art* 29, no. 2 (2014).

reviews and meta-analyses[26,27,28,29,30] provide further insight to the prevalence of playing-related musculoskeletal injuries and the common treatment methods. While some work has been done to instrument-specific injury patterns in instruments like the trombone,[31] violin,[32] piano,[33] and flute,[34,35] these have not yet been fully characterized, and there is limited information on mechanisms of injury, risk factors, prevention, and treatment for playing-related pain and injury.

There have been many recent efforts to address this issue. Performing arts medical centers such as those affiliated with University of North Texas, Northwestern University, and University of Washington provide healthcare to musicians, dancers, and actors that focuses on the specific needs of performing arts professions. Self-management methods including Alexander Technique, Feldenkrais Method, and Body Mapping have gained significant popularity among musicians and within music schools. The National Flute Association created a Performance Health Committee and to address musician injuries and management. The Performing Arts Medicine Association has recently started offering a certificate class in Performing Arts Medicine for healthcare providers and music educators, in addition to publishing the Journal *Medical Problems of Performing Artists*, one of the oldest journals specific to this field of research and first published in 1986. Additionally,

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[26] Zaza, "Playing-Related Musculoskeletal Disorders in Musicians: A Systematic Review of Incidence and Prevalence."

[27] R. J. Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians," *Muscle Nerve* 27, no. 5 (2003).

[28] J. Currey et al., "Performing Arts Medicine," *Phys Med Rehabil Clin N Am* 31, no. 4 (2020).

[29] C. Cruder et al., "Patterns of Pain Location in Music Students: A cluster Analysis," *BMC Musculoskelet Disord* 22, no. 1 (2021).

[30] J. Betzl, U. Kraneburg, and K. Megerle, "Overuse Syndrome of the Hand and Wrist in Musicians: A Systematic Review," *J Hand Surg Eur Vol* 45, no. 6 (2020).

[31] E. Wallace, D. Klinge, and K. Chesky, "Musculoskeletal Pain in Trombonists: Results from the Unt Trombone Health Survey," *Med Probl Perform Art* 31, no. 2 (2016).

[32] F. B. Kochem and J. G. Silva, "Prevalence and Associated Factors of Playing-Related Musculoskeletal Disorders in Brazilian Violin Players," Ibid.32, no. 1 (2017).

[33]CY Ling, FC Loo, and TR Hamedon, "Playing-Related Musculoskeletal Disorders among Classical Piano Students at Tertiary Institutions in Malaysia: Proportion and Associated Risk Factors," Ibid.33, no. 2 (2018).

[34] Ackermann, Kenny, and Fortune, "Incidence of Injury and Attitudes to Injury Management in Skilled Flute Players."

[35] J. Stanhope and S. Milanese, "The Prevalence and Incidence of Musculoskeletal Symptoms Experienced by Flautists," *Occup Med (Lond)* 66, no. 2 (2016).

the National Association of Schools of Music recently added an accreditation requirement for schools of music to educate students on injury prevention and maintenance of hearing, vocal, and musculoskeletal health.[36] There is an abundance of interest in identifying new methods for injury prevention and management that address the needs of musicians.

In general, playing-related injuries appear to be more common in the upper limbs, neck, and upper back[37,38] and are usually the result of overuse, as opposed to acute injury.[39,40] However, acute traumatic injuries incurred outside of musical performance and practice also have significant impacts of the playing abilities of musicians.[41] Beyond general overuse injuries, specific injury diagnoses common in musicians include thoracic outlet syndrome,[42] nerve entrapments such as carpal tunnel syndrome,[43] and focal dystonia.[44] In wind players, temporomandibular joint syndrome may also be a common injury.[45] Studies in both professionals and students have seen higher prevalence of playing-related pain and injury in females than males.[46,47,48,49] Work-related stress, performance anxiety, lack of sleep, and lack of physical activity have been found to be risk

[36] "Handbook 2020-21," (National Association of Schools of Music, 2021).
[37] Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians."
[38] Cruder et al., "Patterns of Pain Location in Music Students: A cluster Analysis."
[39] Lockwood, "Medical Problems of Musicians."
[40] Betzl, Kraneburg, and Megerle, "Overuse Syndrome of the Hand and Wrist in Musicians: A Systematic Review."
[41] W. J. Dawson, "Hand and Upper Extremity Trauma in High-Level Instrumentalists: Epidemiology and Outcomes," *Work* 7, no. 2 (1996).
[42] Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians."
[43] A. G. Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," *Hand Clin* 19, no. 2 (2003).
[44] Currey et al., "Performing Arts Medicine."
[45] Ibid.
[46] F. B. Kochem and J. G. Silva, "Prevalence and Associated Factors of Playing-Related Musculoskeletal Disorders in Brazilian Violin Players," *Med Probl Perform Art* 32, no. 1 (2017).
[47] Lockwood, "Medical Problems of Musicians."
[48] A. Nawrocka et al., "Musculoskeletal Pain among Polish Music School Students," *Med Probl Perform Art* 29, no. 2 (2014).
[49] Cruder et al., "Patterns of Pain Location in Music Students: A cluster Analysis."

factors for performance-related musculoskeletal disorders.[50,51,52] While increased years playing the instrument has been shown to have a protective effect against playing-related musculoskeletal disorders,[53] factors including daily hours spent playing the instrument, warm-up time before practicing, instrument weight, continuous playing time, and being a music student have been correlated with increased likelihood of musculoskeletal health complaints.[54,55,56]

Prevention of playing-related musculoskeletal injuries is of the utmost importance, especially to music schools, who bear responsibility for the professional success of their students. Injury monitoring, screening, and education programs have been shown to be effective at reducing incidence of playing-related injuries and the time for students to seek medical treatment if they are affected by injury.[57,58,59] Increases in practice time, which may happen in intensive music programs, were correlated with a significant increase in musculoskeletal pain.[60] One prospective study examined both a physical activity program and a biopsychocosical prevention course consisting of classes on body posture and performance psychology in music students.

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[50] V. A. E. Baadjou et al., "Systematic Review: Risk Factors for Musculoskeletal Disorders in Musicians," *Occup Med (Lond)* 66, no. 8 (2016).

[51] N. Ballenberger, D. Möller, and C. Zalpour, "Musculoskeletal Health Complaints and Corresponding Risk Factors among Music Students: Study Process, Analysis Strategies, and Interim Results from a Prospective Cohort Study," *Med Probl Perform Art* 33, no. 3 (2018).

[52] A. Nawrocka et al., "Health-Oriented Physical Activity in Prevention of Musculoskeletal Disorders among Young Polish Musicians," *Int J Occup Med Environ Health* 27, no. 1 (2014).

[53] Baadjou et al., "Systematic Review: Risk Factors for Musculoskeletal Disorders in Musicians."

[54] Y. Kaufman-Cohen and N. Z. Ratzon, "Correlation between Risk Factors and Musculoskeletal Disorders among Classical Musicians," Ibid.61, no. 2 (2011).

[55] I. Foxman and B. J. Burgel, "Musician Health and Safety: Preventing Playing-Related Musculoskeletal Disorders," *AAOHN J* 54, no. 7 (2006).

[56] Ballenberger, Möller, and Zalpour, "Musculoskeletal Health Complaints and Corresponding Risk Factors among Music Students: Study Process, Analysis Strategies, and Interim Results from a Prospective Cohort Study."

[57] T. Clark, A. Williamon, and E. Redding, "The Value of Health Screening in Music Schools and Conservatoires," *Clin Rheumatol* 32, no. 4 (2013).

[58] C. Y. Ling, F. C. Loo, and T. R. Hamedon, "Knowledge of Playing-Related Musculoskeletal Disorders among Classical Piano Students at Tertiary Institutions in Malaysia," *Med Probl Perform Art* 31, no. 4 (2016).

[59] E. Wallace, D. Klinge, and K. Chesky, "Musculoskeletal Pain in Trombonists: Results from the Unt Trombone Health Survey," Ibid., no. 2.

[60] J. Robitaille, Y. Tousignant-Laflamme, and M. Guay, "Impact of Changes in Playing Time on Playing-Related Musculoskeletal Pain in String Music Students," Ibid.33, no. 1 (2018).

Unfortunately, the specifically tailored course did not yield significantly better outcomes than the physical activity, but the study did not compare these to a control group receiving neither intervention.[61] Exercise-based interventions may provide some benefits for injury prevention and possible treatment,[62] but there is not yet a standardized exercise-based intervention and there are many barriers for implementing these types of programs.[63] Certain stretches, including gentle wrist and elbow stretches, in addition to good nutrition, hydration, and awareness of muscle fatigue may also aid in preventing repetitive stress injuries in musicians.[64]

The cornerstone of prevention and treatment for overuse injuries is rest, but limiting performance time may be difficult or impossible for musicians.[65] Radical rest treatment, an established treatment for playing-related musculoskeletal pain, relies on complete cessation of all pain-causing activities, even those outside of music.[66] Once all pain is eliminated, the individual then gradually rebuilds strength in the affected limb. One challenge with a radical rest program is the inability for the musician to make a living or make progress toward their education during the period of complete rest. There are documented negative financial and psychological impacts to complete rest in injured musicians,[67,68,69] and some musicians may avoid seeking medical attention

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[61] V. A. E. Baadjou et al., "Preventing Musculoskeletal Complaints in Music Students: A Randomized Controlled Trial," *Occup Med (Lond)* 68, no. 7 (2018).

[62] S. H. Lee et al., "Intervention Program in College Instrumental Musicians, with Kinematics Analysis of Cello and Flute Playing: A Combined Program of Yogic Breathing and Muscle Strengthening-Flexibility Exercises," *Med Probl Perform Art* 27, no. 2 (2012).

[63] A. T. Ajidahun et al., "Barriers and Facilitators in Implementing an Exercise-Based Injury Prevention Program for String Players," *Work* 64, no. 4 (2019).

[64] G. A. Shafer-Crane, "Repetitive Stress and Strain Injuries: Preventive Exercises for the Musician," *Phys Med Rehabil Clin N Am* 17, no. 4 (2006).

[65] Ibid.

[66] Fry, "The Treatment of Overuse Syndrome in Musicians. Results in 175 Patients."

[67] C. A. Guptill, "The Lived Experience of Professional Musicians with Playing-Related Injuries: A Phenomenological Inquiry," *Med Probl Perform Art* 26, no. 2 (2011).

[68] D. Bourne, A. Hallaran, and J. Mackie, "The Lived Experience of Orchestral String Musicians with Playing Related Pain," Ibid.34, no. 4 (2019).

[69] J. Stanhope and P. Weinstein, "Should Musicians Play in Pain?," *Br J Pain* 15, no. 1 (2021).

for playing-related injuries due to a fear of being told to stop playing.[70] Additionally, recent pain research suggests that complete avoidance of pain-causing activities may induce a fear response that increases the likelihood of developing chronic pain symptoms.[71]

While complete rest may not be an appropriate treatment, reduction of playing time is a valuable part of a comprehensive treatment program.[72] Beyond rest, common methods for injury management include anti-inflammatory and pain-relieving medication, modified practice schedules, and general fitness regimens.[73] As previously mentioned, body awareness techniques such as Alexander Technique, Feldenkrais Method, and Body Mapping, are commonly used for injury management and have community support among musicians and positive anecdotal evidence,[74,75,76] but lack quantitative, prospective, and controlled studies. Similarly, there is limited evidence suggesting that Osteopathic Manipulative Treatment may be beneficial in musicians experiencing playing-related pain, but prospective and controlled studies are required before a definitive conclusion can be made regarding the efficacy of this therapy.[77] In sports medicine, physical therapy is a primary aspect of injury treatment, but evidence-based physical therapy approaches to musician injuries are minimal.[78] Still, physical therapy, in addition to cross-training exercise regimes may aid in injury management.[79] Finally, treatment may consist of splinting,

[70] Shafer-Crane, "Repetitive Stress and Strain Injuries: Preventive Exercises for the Musician."

[71] Stanhope and Weinstein, "Should Musicians Play in Pain?."

[72] Fry, "The Treatment of Overuse Syndrome in Musicians. Results in 175 Patients."

[73] Ibid.

[74] M. Schlinger, "Feldenkrais Method, Alexander Technique, and Yoga--Body Awareness Therapy in the Performing Arts," *Phys Med Rehabil Clin N Am* 17, no. 4 (2006).

[75] J. Davies, "Alexander Technique Classes Improve Pain and Performance Factors in Tertiary Music Students," *J Bodyw Mov Ther* 24, no. 1 (2020).

[76] R. C. Wolf et al., "Effect of the Alexander Technique on Muscle Activation, Movement Kinematics, and Performance Quality in Collegiate Violinists and Violists: A Pilot Feasibility Study," *Med Probl Perform Art* 32, no. 2 (2017).

[77] M. S. Kiepe et al., "Effects of Osteopathic Manipulative Treatment on Musicians: A Systematic Review," Ibid.35 (2020).

[78] C. Chan and B. Ackermann, "Evidence-Informed Physical Therapy Management of Performance-Related Musculoskeletal Disorders in Musicians," *Front Psychol* 5 (2014).

[79] Ibid.

bracing, or instrument-specific modifications designed to improve ergonomics,[80] and these treatments may benefit from additional information of standard musician biomechanics and biomechanics of playing-related pain and injury.

Playing-related musculoskeletal pain in musicians is a pervasive issue, but its presentation is so diverse in different instruments that general studies on injury prevalence may not be sufficient to characterize symptoms, evaluate risk factors, and determine appropriate treatments. Existing literature provides a basis for understanding common injuries, preventions, and treatments, but lacks specialized information for specific instruments and fails to provide mechanisms of injury beyond the generic umbrella of overuse injuries. Further research into flute-specific injury patterns, risk factors, and treatments as well as correlation of biomechanics parameters to playing-related pain, may help bridge this gap and advance injury prevention and treatment in flutists.

Musician Biomechanics

Repetitive strain injuries, such as those common in musicians, are typically associated with specific patterns of body movement.[81] The biomechanics of music performance may help explain the posture, positioning, and movements associated with playing-related pain and injury in order to modify these for injury prevention.[82] Existing studies on musician biomechanics can be broadly categorized into studies examining posture, muscle activation, or joint kinematics. Of these, many of the studies in muscle activation and joint kinematics focus specifically on hand and finger biomechanics, since the precise coordination of the fingers is paramount to virtuosic playing.[83]

[80] J. Boyette, "Splinting for Adaptation of Musical Instruments," *Work* 25, no. 2 (2005).
[81] D. G. Smith et al., "Relationship between Glenohumeral Internal Rotation Deficit and Medial Elbow Torque in High School Baseball Pitchers," *Am J Sports Med* 47, no. 12 (2019).
[82] Dawson, "Hand and Upper Extremity Trauma in High-Level Instrumentalists: Epidemiology and Outcomes."
[83] S. D. Bella and C. Palmer, "Rate Effects on Timing, Key Velocity, and Finger Kinematics in Piano Performance," *PLoS One* 6, no. 6 (2011).

Additionally, much of the existing research on musician biomechanics was conducted on pianists or string players, with very few studies on wind or brass instruments.

The primary methods used to examine hand and finger biomechanics in musicians are marker-based motion capture systems, which are used to study joint kinematics,[84,85,86,87] and electromyography (EMG), which gives data on muscle activation patterns.[88,89] These studies have shown changes in hand and finger biomechanics with musical training, including decreases in intrinsic muscle strength,[90] increased finger independence,[91] and increased range of motion in the finger joints.[92] Motion capture analysis of pianists showed an increase in finger height movement amplitude and decrease in anticipatory movement with faster performance tempo.[93] An EMG study in pianists revealed decreases in mean voluntary muscle contraction in the extensor carpi radialis after 2 hours and 4 hours of practicing, and generally higher mean voluntary contraction with faster tempo than slower tempo.[94] While hand and finger EMG studies are limited in other instruments, EMG has been shown to be feasible for measuring muscle activation while playing in the hand and forearm of violinists.[95]

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[84] Ibid.

[85] S. Furuya, A. Nakamura, and N. Nagata, "Acquisition of Individuated Finger Movements through Musical Practice," *Neuroscience* 275 (2014).

[86] Y. Kaufman-Cohen et al., "The Correlation between Upper Extremity Musculoskeletal Symptoms and Joint Kinematics, Playing Habits and Hand Span During Playing among Piano Students," *PLoS One* 13, no. 12 (2018).

[87] Albrecht et al., "Individuality of Movements in Music--Finger and Body Movements During Playing of the Flute."

[88] Baeyens et al., "Effects of Rehearsal Time and Repertoire Speed on Extensor Carpi Radialis Emg in Conservatory Piano Students."

[89] P. Cattarello, R. Merletti, and F. Petracca, "Analysis of High-Density Surface Emg and Finger Pressure in the Left Forearm of Violin Players: A Feasibility Study," Ibid.32, no. 3 (2017).

[90] Gorniak et al., "The Impact of Musical Training on Hand Biomechanics in String Musicians."

[91] Furuya, Nakamura, and Nagata, "Acquisition of Individuated Finger Movements through Musical Practice."

[92] Ibid.

[93] Bella and Palmer, "Rate Effects on Timing, Key Velocity, and Finger Kinematics in Piano Performance."

[94] Baeyens et al., "Effects of Rehearsal Time and Repertoire Speed on Extensor Carpi Radialis Emg in Conservatory Piano Students."

[95] P. Cattarello, R. Merletti, and F. Petracca, "Analysis of High-Density Surface Emg and Finger Pressure in the Left Forearm of Violin Players: A Feasibility Study," Ibid.32, no. 3 (2017).

Outside of the hand and wrist, both surface EMG and fine wire EMG have been used to study muscle activation and recruitment patterns in the shoulders and forearms of violinists and cellists, particularly in the bowing arm. As expected, these studies revealed higher muscle activation while playing than in a static position.[96] Furthermore, there was higher muscle activity in the left than right forearms of violinists.[97] A study in cellists showed significant differences in muscle activation patterns in the shoulder with changes in bowing technique, use of different strings, and varying dynamic levels.[98] Similar dynamics-based differences were seen in the muscle activation patters in the right shoulder of violinists.[99] While EMG studies can provide specific information on muscle usage, they do not give information on body movement and kinematic changes between body segments.

Postural and kinematic studies in musicians have generally used marker-based motion capture analysis[100,101,102] and, in some cases, pressure sensor plates to examine weight distribution.[103] Other less used techniques for studying kinematics include photography-based angle measurements,[104] and wearable motion sensors such as inertial measurement units (IMUs).[105] Upper body kinematic studies are limited to the violin and cello, with the only

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[96] S. Mann et al., "Surface Electromyography of Forearm and Shoulder Muscles During Violin Playing," *J Electromyogr Kinesiol* 56 (2021).

[97] Ibid.

[98] D. L. Rickert et al., "The Use of Fine-Wire Emg to Investigate Shoulder Muscle Recruitment Patterns During Cello Bowing: The Results of a Pilot Study," Ibid.23, no. 6 (2013).

[99] J. F. Reynolds et al., "Development of Three-Dimensional Shoulder Kinematic and Electromyographic Exposure Variation Analysis Methodology in Violin Musicians," *Ergonomics* 57, no. 7 (2014).

[100] L. Hopper et al., "Torso and Bowing Arm Three-Dimensional Joint Kinematics of Elite Cellists: Clinical and Pedagogical Implications for Practice," *Med Probl Perform Art* 32, no. 2 (2017).

[101] C. Spahn et al., "Comparing Violinists' Body Movements While Standing, Sitting, and in Sitting Orientations to the Right or Left of a Music Stand," Ibid.29 (2014).

[102] E. Wolf et al., "Marker-Based Method for Analyzing the Three-Dimensional Upper Body Kinematics of Violinists and Violists: Development and Clinical Feasibility," Ibid.34, no. 4 (2019).

[103] C. Spahn et al., "Comparing Violinists' Body Movements While Standing, Sitting, and in Sitting Orientations to the Right or Left of a Music Stand," Ibid.29, no. 2 (2014).

[104] F. J. Bejjani and N. Halpern, "Postural Kinematics of Trumpet Playing," *J Biomech* 22, no. 5 (1989).

[105] Reynolds et al., "Development of Three-Dimensional Shoulder Kinematic and Electromyographic Exposure Variation Analysis Methodology in Violin Musicians."

kinematic study in the flute focusing specifically on finger motion.[106] Existing upper body biomechanics studies using motion capture have used marker sets consisting of nine,[107] twenty-seven,[108] or thirty-one[109] markers to identify segments of the upper body. The predominant biomechanical parameters examined in these studies were bilateral shoulder angles, which was generally calculated as the angle between the upper arm and thorax, thus comprising movement of the sternoclavicular, acromioclavicular, and glenohumeral joints,[110] bilateral elbow angles, bilateral wrist angles, and thorax orientation relative to the laboratory coordinate system. While one study found high ranges of motion in the right shoulder, elbow, and wrist in violinists compared to relatively static left upper limb joints,[111] another found generally higher ranges of motion in the left, rather than right, elbow angle.[112] This study also showed more symmetrical posture well as decreased trunk motion when standing, rather than sitting, which is hypothesized to be related to significant self-reported lumbar back pain in violinists.[113] Overall, these studies provide an overview of typical body motion while playing string instruments, but discuss the lack of research in this area.

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[106] Albrecht et al., "Individuality of Movements in Music--Finger and Body Movements During Playing of the Flute."

[107] C. Spahn et al., "Comparing Violinists' Body Movements While Standing, Sitting, and in Sitting Orientations to the Right or Left of a Music Stand," *Med Probl Perform Art* 29, no. 2 (2014).

[108] L. Hopper et al., "Torso and Bowing Arm Three-Dimensional Joint Kinematics of Elite Cellists: Clinical and Pedagogical Implications for Practice," Ibid.32 (2017).

[109] E. Wolf et al., "Marker-Based Method for Analyzing the Three-Dimensional Upper Body Kinematics of Violinists and Violists: Development and Clinical Feasibility," Ibid.34, no. 4 (2019).

[110] L. Hopper et al., "Torso and Bowing Arm Three-Dimensional Joint Kinematics of Elite Cellists: Clinical and Pedagogical Implications for Practice," Ibid.32, no. 2 (2017).

[111] E. Wolf et al., "Marker-Based Method for Analyzing the Three-Dimensional Upper Body Kinematics of Violinists and Violists: Development and Clinical Feasibility," Ibid.34, no. 4 (2019).

[112] C. Spahn et al., "Comparing Violinists' Body Movements While Standing, Sitting, and in Sitting Orientations to the Right or Left of a Music Stand," Ibid.29, no. 2 (2014).

[113] Ibid.

Injuries and Biomechanics in Flutists

The asymmetrical and elevated position required to play the flute may put flutists at higher risk for playing-related pain and injury in the upper extremities.[114] The most commonly reported areas for playing-related pain in flutists are in the neck, back, shoulders, wrists, forearms, and hands.[115,116] Lifetime prevalence of musculoskeletal pain in flutists has been estimated between 33% and 95%,[117] and this extremely wide range may be caused by different definitions of musculoskeletal pain used in questionnaires, variety in populations studied, from primary school students to adult professional musicians, and reporting bias since people who experience pain may be more likely to complete a survey about playing-related pain that those who are unaffected. Of playing-related musculoskeletal disorders reported by flutists, the majority were chronic, lasting longer than three months, and pain was primarily located in the upper extremities.[118] It has been estimated that on average 31% of playing time is affected by playing-related pain, and pain caused flutists to stop practicing about 29% of the time.[119] As with other instruments, primary risk factors for playing-related pain included long periods of practice with minimal rest, sudden increases in practice time, and heightened performance anxiety.[120] Additionally, women were more likely to report musculoskeletal pain than men,[121] which aligns with results seen in other studies on

[114] S. Koppejan et al., "Hand and Arm Problems in Flautists and a Design for Prevention," *Ergonomics* 49, no. 3 (2006).

[115] Lonsdale, Laakso, and Tomlinson, "Contributing Factors, Prevention, and Management of Playing-Related Musculoskeletal Disorders among Flute Players Internationally."

[116] Cari Spence, "Prevalence Rates for Medical Problems among Flautists: A Comparison of the Unt-Musician Health Survey and the Flute Health Survey," *Medical Problems of Performing Artists* 16, no. 3 (2001).

[117] Stanhope and Milanese, "The Prevalence and Incidence of Musculoskeletal Symptoms Experienced by Flautists."

[118] Ackermann, Kenny, and Fortune, "Incidence of Injury and Attitudes to Injury Management in Skilled Flute Players."

[119] Thompson, "Risk Factors for Flute-Related Pain among High School and College Students".

[120] Ackermann, Kenny, and Fortune, "Incidence of Injury and Attitudes to Injury Management in Skilled Flute Players."

[121] Lonsdale, Laakso, and Tomlinson, "Contributing Factors, Prevention, and Management of Playing-Related Musculoskeletal Disorders among Flute Players Internationally."

musician injuries. Studies in flutists have shown a high prevalence and impact of playing-related pain in children,[122] adolescents,[123] college students,[124] and professional musicians,[125] highlighting the importance of research into injury prevention and management in flutists.

There is a defined relationship between biomechanics and overuse injuries,[126] with specific biomechanical parameters during motion or at rest seen as risk factors for overuse injuries in both athletics[127,128] and occupational health.[129] It is thus reasonable to assume that biomechanics of flute performance may correlate to playing-related pain. As discussed, this research has begun in musicians, but most existing studies examine either pianists or high string players, with few studies on flutists or any wind or brass instrument. All existing studies in this area focus primarily on hand and finger biomechanics, looking at kinematics while playing,[130] joint range of motion and hypermobility,[131] muscle strength and rotation speed,[132] and force balances in the fingers to support the positioning of the flute.[133] Finger kinematics analysis revealed fast finger motion during larger

[122] Sonia Ranelli, Anne Smith, and Leon Straker, "Playing-Related Musculoskeletal Problems in Child Instrumentalists: The Influence of Gender, Age and Instrument Exposure," *International Journal of Music Education* 29, no. 1 (2011).

[123] Thompson, "Risk Factors for Flute-Related Pain among High School and College Students".

[124] Ackermann, Kenny, and Fortune, "Incidence of Injury and Attitudes to Injury Management in Skilled Flute Players."

[125] Lonsdale, Laakso, and Tomlinson, "Contributing Factors, Prevention, and Management of Playing-Related Musculoskeletal Disorders among Flute Players Internationally."

[126] C. N. Maganaris et al., "Biomechanics and Pathophysiology of Overuse Tendon Injuries: Ideas on Insertional Tendinopathy," *Sports Med* 34, no. 14 (2004).

[127] Smith et al., "Relationship between Glenohumeral Internal Rotation Deficit and Medial Elbow Torque in High School Baseball Pitchers."

[128] J. Chorley, R. E. Eccles, and A. Scurfield, "Care of Shoulder Pain in the Overhead Athlete," *Pediatr Ann* 46, no. 3 (2017).

[129] A. Kozak et al., "Association between Work-Related Biomechanical Risk Factors and the Occurrence of Carpal Tunnel Syndrome: An Overview of Systematic Reviews and a Meta-Analysis of Current Research," *BMC Musculoskelet Disord* 16 (2015).

[130] Albrecht et al., "Individuality of Movements in Music--Finger and Body Movements During Playing of the Flute."

[131] Artigues-Cano and Bird, "Hypermobility and Proprioception in the Finger Joints of Flautists."

[132] Thompson, "Risk Factors for Flute-Related Pain among High School and College Students".

[133] Koppejan et al., "Hand and Arm Problems in Flautists and a Design for Prevention."

movements and slower motion during smaller movements,[134] which is similar to results seen in the clarinet and piano.[135,136] There is considerable variation in finger motion between individuals,[137] but there is no existing study examining if these differences in motion relate to playing-related pain. Force balance analysis showed that gravitational force causes the flute to rotate, and compensatory force from the base of the left index finger is required to prevent this rotation, especially on notes that don't use the right hand. This compensatory position increases wrist extension and tension along the tendons of the wrists, which may relate to playing-related injuries.[138] Variation in flute positioning may change this force balance and wrist tension, but this has not been studied. Flutists have been seen to have a greater range of motion in the finger joints than the general population, but the causation of this relationship is not yet understood.[139] Lower pinch strength and wrist flexibility have been correlated with increased playing-related pain in both the left and right sides, even though the overall reported pain was higher in the right upper extremity than the left.[140] Existing literature provides evidence that biomechanics of flute playing differ from the biomechanics of other instruments due to the asymmetrical position, and support a relationship between flutist biomechanics and playing-related pain and injury. However, limited knowledge of baseline flute biomechanics and correlations to playing-related pain hinder the development of biomechanics-based interventions for prevention and treatment of playing-related pain in flutists.

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[134] Albrecht et al., "Individuality of Movements in Music--Finger and Body Movements During Playing of the Flute."

[135] Bella and Palmer, "Rate Effects on Timing, Key Velocity, and Finger Kinematics in Piano Performance."

[136] Caroline Palmer et al., "Movement-Related Feedback and Temporal Accuracy in Clarinet Performance," *Music Perception* 26, no. 5 (2009).

[137] Albrecht et al., "Individuality of Movements in Music--Finger and Body Movements During Playing of the Flute."

[138] Koppejan et al., "Hand and Arm Problems in Flautists and a Design for Prevention."

[139] Artigues-Cano and Bird, "Hypermobility and Proprioception in the Finger Joints of Flautists."

[140] Thompson, "Risk Factors for Flute-Related Pain among High School and College Students".

COVID-19 Modifications

The initial goal for this thesis project was to collect, at minimum, pilot data on biomechanics of flute playing, flute playing-related pain, and the relationship between these. However, data collection was severely restricted and delayed due to the COVID-19 pandemic. Because of this, no biomechanics data collection was possible. While survey-based data can be collected remotely, delays in modifying this project limited the time available for this data collection and there was not sufficient survey data collected to report at this time. Instead, the review of existing literature was expanded, and significant effort was put into the technical development of this project. This background, developed methods, and informed hypotheses are presented here in the hope that they can serve as a guide for this research to be conducted once conditions allow.

Study Design

Population and Recruitment

This study was approved by the Institutional Review Board at the University of Arizona (approval #2006748521). Subjects were recruited from collegiate flute students at the University of Arizona and adult amateur and professional flutists in Southern Arizona involved with the Arizona Flute Society and Tucson Flute Club. This population was chosen to ensure reasonable variation in the playing habits, age, and musical training of participants. Exclusion criteria were (1) previous non-music related musculoskeletal injury in the neck, back, or upper extremities within the last year; (2) any injury of the neck, back, or upper extremity requiring surgery in the past two years; and (3) any chronic pain conditions such as fibromyalgia or complex regional pain syndrome. The informed consent document and screening questionnaire are presented in Appendix A. Participants were given the option to opt-in to biomechanics data collection or to only participate through completing surveys for the patient reported outcomes measures. This modification allowed for greater remote participation and improves the quality of the patient reported outcomes dataset for independent analysis, since the expected sample size to report only survey data is higher than the sample size needed for the biomechanics study. Future studies could potentially increase the size of the population for subject recruitment by expanding the geographical area, either by allowing participation from any area for the survey-only portion of the study, which can be conducted fully online, or by establishing multi-site collaboration for biomechanics data capture at additional institutions.

Power Analysis

Existing studies in musician biomechanics have sample sizes of four,[141] ten,[142] 16,[143] 18,[144] 19,[145] and 31[146] subjects. Survey based studies looking at large musician populations with subjects playing a variety of instruments typically have sample sizes ranging from around 100[147,148,149] to multiple hundreds,[150,151] with 408 subjects in the largest study identified.[152] Existing survey based studies focusing on a single instrument have sample sizes of 20,[153] 30,[154] 106,[155] 192,[156] and 316.[157] For this study, the goal is to have approximately 20 participants in the full biomechanics study. If patient reported outcome data from the surveys is intended to be analyzed and presented without biomechanics data, the goal would be to have at 40-50 participants enrolled in the survey portion of the study.

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[141] Bella and Palmer, "Rate Effects on Timing, Key Velocity, and Finger Kinematics in Piano Performance."

[142] Baeyens et al., "Effects of Rehearsal Time and Repertoire Speed on Extensor Carpi Radialis Emg in Conservatory Piano Students."

[143] Bejjani and Halpern, "Postural Kinematics of Trumpet Playing."

[144] Mann et al., "Surface Electromyography of Forearm and Shoulder Muscles During Violin Playing."

[145] Spahn et al., "Comparing Violinists' Body Movements While Standing, Sitting, and in Sitting Orientations to the Right or Left of a Music Stand."

[146] L. Hopper et al., "Torso and Bowing Arm Three-Dimensional Joint Kinematics of Elite Cellists: Clinical and Pedagogical Implications for Practice," Ibid.32 (2017).

[147] K. Lonsdale and O. K. Boon, "Playing-Related Health Problems among Instrumental Music Students at a University in Malaysia," Ibid.31, no. 3 (2016).

[148] P. Berque, H. Gray, and A. McFadyen, "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)," Ibid., no. 2.

[149] C. M. Sousa et al., "Playing-Related Musculoskeletal Disorders of Professional Orchestra Musicians from the North of Portugal: Comparing String and Wind Musicians," *Acta Med Port* 30, no. 4 (2017).

[150] Dawson, "Hand and Upper Extremity Trauma in High-Level Instrumentalists: Epidemiology and Outcomes."

[151] Ackermann, Driscoll, and Kenny, "Musculoskeletal Pain and Injury in Professional Orchestral Musicians in Australia."

[152] Steinmetz et al., "Frequency, Severity and Predictors of Playing-Related Musculoskeletal Pain in Professional Orchestral Musicians in Germany."

[153] Ackermann, Kenny, and Fortune, "Incidence of Injury and Attitudes to Injury Management in Skilled Flute Players."

[154] Thompson, "Risk Factors for Flute-Related Pain among High School and College Students".

[155] Kochem and Silva, "Prevalence and Associated Factors of Playing-Related Musculoskeletal Disorders in Brazilian Violin Players."

[156] CY Ling, FC Loo, and TR Hamedon, "Playing-Related Musculoskeletal Disorders among Classical Piano Students at Tertiary Institutions in Malaysia: Proportion and Associated Risk Factors," Ibid.33, no. 2 (2018).

[157] E. Wallace, D. Klinge, and K. Chesky, "Musculoskeletal Pain in Trombonists: Results from the Unt Trombone Health Survey," Ibid.31 (2016).

Biomechanics Data Collection

Technical Considerations

To the author's knowledge, there are only two existing publications detailing motion capture biomechanics models in flutists. One of these is a model development study that used an eight-camera Vicon system with a marker set consisting of 23 markers that captured the torso, upper extremities, and head. This model utilized two AMTI force plates to measure force through each foot.[158] The second study used an eight camera Qualisys system and 12 markers at major anatomical coordinates to define body motion as well as small markers on each fingertip, to examine finger motion and markers on each end of the flute to define finger motion relative to the plane of the instrument.[159] Interestingly, this study used a flute with a non-reflective coating to eliminate error in the motion capture system, while this same coating was not used in the other model development study.

Because of the use of retroreflective markers in motion capture biomechanics, reflective objects, such as prosthetic devices, or in this case, a flute, have the potential to create significant errors in data collection due to the appearance of "ghost markers" caused by light reflection off the flute. However, testing in this system did not seem to be impacted by the presence or absence of the flute, which may have to do with the high variability in light reflection off the flute, so no one position reflects light in the same direction for long enough to appear as a marker. Regardless of cause, this allows for simple testing in the lab without modifications to the surface of the flute. Another concern with this models was that the positioning of the flute would block camera

[158] S. H. Lee et al., "Intervention Program in College Instrumental Musicians, with Kinematics Analysis of Cello and Flute Playing: A Combined Program of Yogic Breathing and Muscle Strengthening-Flexibility Exercises," Ibid.27 (2012).

[159] Albrecht et al., "Individuality of Movements in Music--Finger and Body Movements During Playing of the Flute."

visibility of certain markers, especially those on the sternum, but this again was not a major issue in practice. The use of a music stand could also restrict marker visibility, but testing with a music stand proved to be functional as long as the top of the music stand was lower than the xiphoid process of the sternum and the music stand was not placed on the force plate.

Motion Capture Methods

Motion capture will be conducted with a nine-camera Vicon motion capture system using the Vicon plug-in-gait upper body model, which consists of 24 reflective markers (Figure 1, Table 1)[160] that define the thorax and left and right upper limbs (Figure 2), and an AMTI force plate used to gather center-of-pressure data regarding how the participant stands throughout the trial. After placement of the marker set, subjects will be given ten minutes to play their typical warm-up exercises both to prepare for playing and to become more comfortable playing with the attached markers. Following static calibration, subjects will perform selected exercises chosen by a university flute professor to be of relatively low difficulty for most adult flutists. Participants will also play a 30-60 second excerpt of a piece of their choosing that they find challenging. The goal of this is to get both a standardized measure where each participant plays the same music, and a measure with approximately standardized difficulty per performer. Each of these trials will be completed three times with up to five minutes of rest between trials. The Vicon plug-in-gait model provides outcome parameters for bilateral shoulder angles, elbow angles, and wrist angles. Additional data processing in MATLAB allows for the calculation of velocity and acceleration of each of these joints throughout the trial.

[160] "Upper Limb Model Product Guide," (Vicon Motion Systems Limited, 2007).

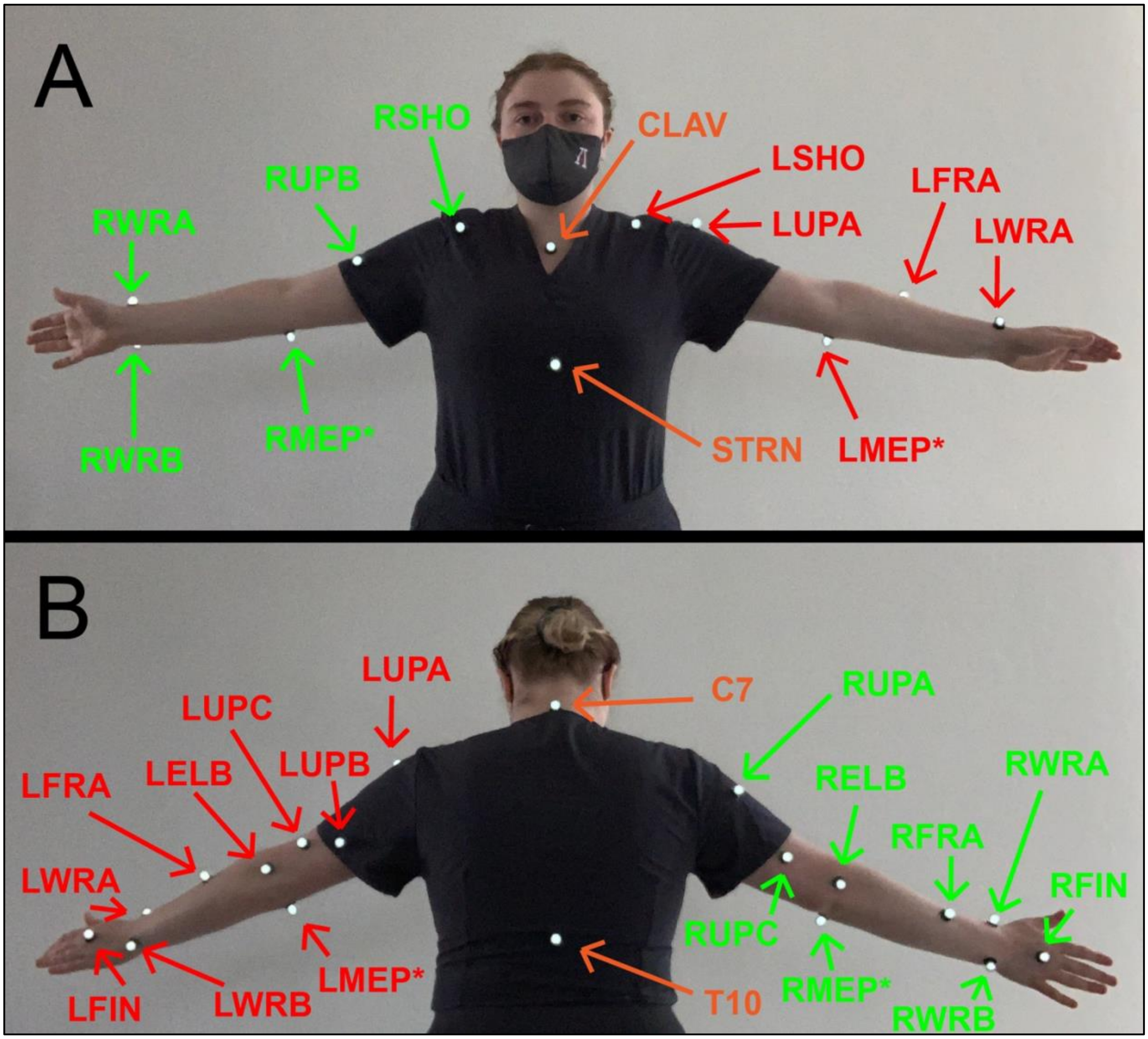

Figure 1: Vicon plug-in-gait upper body model marker set from (A) the front and (B) the back with labeled markers
* indicates markers used for only the static trials that are removed for dynamic trials

Table 1: Marker labels and placement for the Vicon plug-in-gait upper body model
*indicates markers used for only the static trials that are removed for dynamic trials

Marker Label	Location Description
C7	Spinous process of the seventh cervical vertebrae
T10	Spinous process of the tenth thoracic vertebrae
CLAV	Jugular notch between left and right sternal-clavicular joints
STRN	Xiphoid process of the sternum
LSHO	Left acromio-clavicuar joint
LUPA	Lateral left upper arm (asymmetric with RUPA)
LUPB	Lateral left upper arm (asymmetric with RUPB)
LUPC	Lateral left upper arm (asymmetric with RUPC)
LELB	Lateral epicondyle of the left humerus
LMEP*	Medial epicondyle of the left humerus
LFRA	Lateral left forearm (asymmetric with RFRA)
LWRA	Left radial styloid process (center of wrist joint on thumb side)
LWRB	Left ulnar styloid process (center of wrist joint in pinky joint side)
LFIN	Just proximal to the base of the left third matacarpal
RSHO	Right acromio-clavicular joint
RUPA	Lateral right upper arm (asymmetric with LUPA)
RUPB	Lateral right upper arm (asymmetric with LUPB)
RUPC	Lateral right upper arm (asymmetric with LUPC)
RELB	Lateral epicondyle of the right humerus
RMEP*	Medial epicondyle of the right humerus
RFRA	Lateral right forearm (asymmetric with LFRA)
RWRA	Right radial styloid process (center of wrist joint on thumb side)
RWRB	Right ulnar styloid process (center of wrist joint in pinky joint side)
RFIN	Just proximal to the base of the right third metacarpal

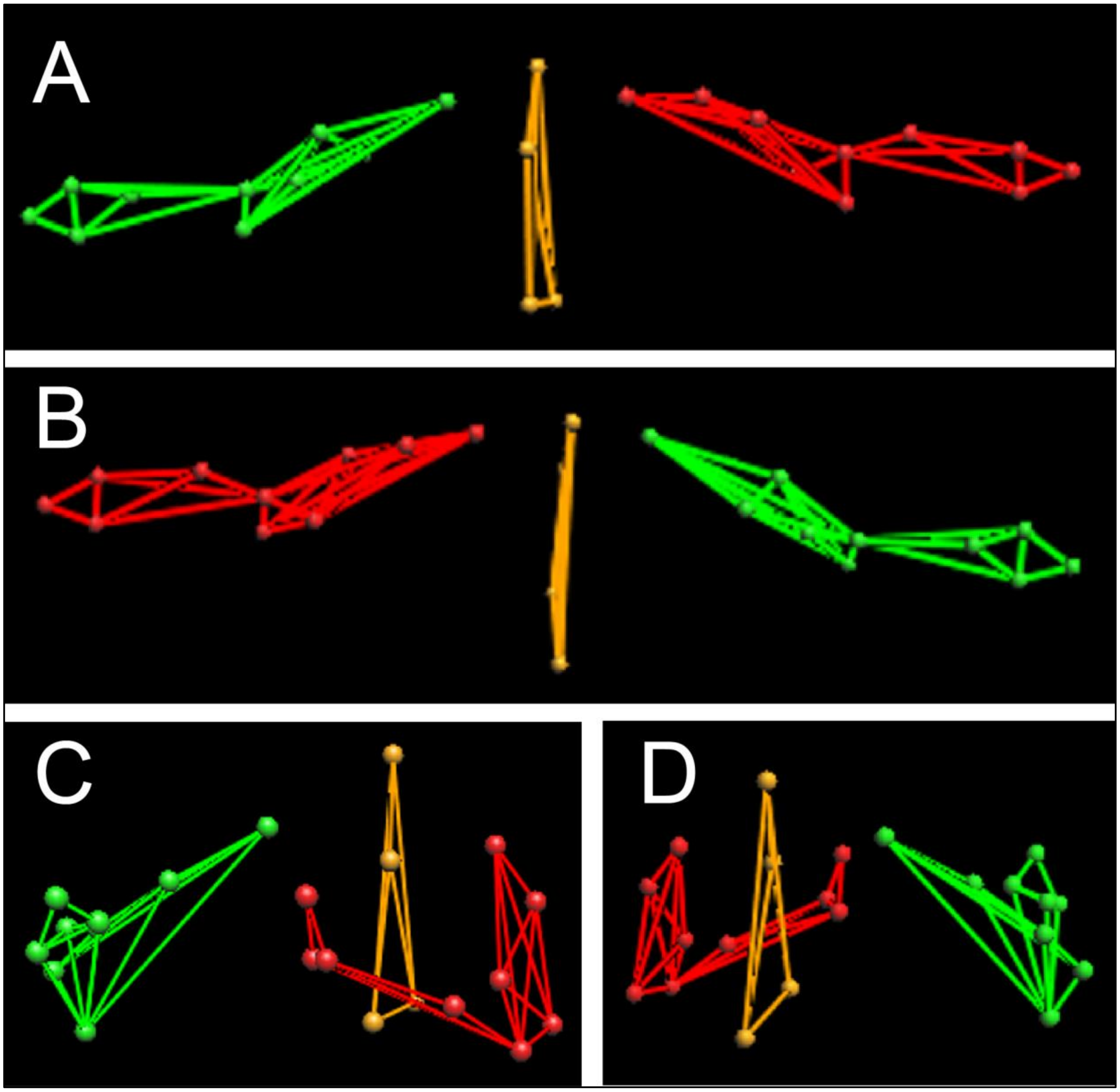

Figure 2: Processed upper body model in the Vicon workspace showing the thorax (orange), left arm (red), and right arm (green) body segments from (A) the front in a static trial, (B) the back in a static trial, (C) the front during a dynamic trial while playing flute, and (D) the back during a dynamic trial while playing flute

Patient Reported Outcomes Measures

Demographics and Background Information

Patient reported outcomes questionnaires consist of a series of eight surveys asking about medical history, playing habits, and pain while playing and at rest. Full questionnaires are included in Appendix C. Survey data will be collected through REDCap, a HIPAA compliant web-based data collection and storage system. The first survey asks about demographics and background, specifically age, gender, race, and ethnicity, as well as questions about occupation and exercise. These include asking the current occupation, whether manual labor is required, average hours per day of standing and of working on a computer, hours a week of exercise, and preferred modes of exercise. The next survey collects information on medical history, specifically surgeries in various areas of the body, past and current overuse injuries in the upper body, and the Charlson Comorbidity Index, a standardized tool for assessing risk factor based on age and presence of specific medical conditions.[161] Next is two surveys consisting of a series of questions about musical activity and practice habits, which are based on existing literature around overuse injuries in flutists.[162,163] These questions gather data on the time participants have played the flute, any large gaps in playing over one year, hours per week spent playing the flute in a variety of settings, including lessons, individual practice, and ensemble rehearsals, percent of time spent on c flute versus other instruments in the flute family, and time spent on any non-flute musical instruments. Additionally, the survey asks about frequency and duration of practice sessions, physical warm-ups before practicing, breaks during practice sessions, and practice sessions ending because of fatigue or physical pain.

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[161] M. Charlson et al., "Validation of a Combined Comorbidity Index," *J Clin Epidemiol* 47, no. 11 (1994).

[162] Thompson, "Risk Factors for Flute-Related Pain among High School and College Students".

[163] Ackermann, Kenny, and Fortune, "Incidence of Injury and Attitudes to Injury Management in Skilled Flute Players."

Playing-Related Musculoskeletal Pain

The final four surveys focus specifically on physical pain. Two of these ask about acute pain while playing and at rest at 17 locations on the body (Figure 3). Each location on the body is also labeled in the survey in order to limit confusion about the precision of locations based on the marked dots in the figure (Table 2). For each condition of either while playing or at rest, participants are asked to rate their average pain in that location on a visual acuity scale from "no pain" to "worst pain imaginable" and these slider locations are then converted to a numerical value between 0 and 100, where 0 corresponds with "no pain" and 100 corresponds with "worst pain imaginable." Finally, the PROMIS pain intensity and pain interference scales were used to give an overall snapshot of a participant's experienced pain and the impact on their activities of daily living. The PROMIS pain intensity questionnaire asks about pain intensity in the last seven days with pain at its best and worst and current average level of pain. The PROMIS pain interference questionnaire is an adaptive measure that asks certain questions dependent on previous answers from a large question bank regarding the interference of pain on daily activities in order to generate an overall score. These are both standard, validated measurement tools used to evaluate pain in a variety of research and clinical settings.[164,165]

[164] D. A. Revicki et al., "Development and Psychometric Analysis of the Promis Pain Behavior Item Bank," *Pain* 146, no. 1-2 (2009).

[165] D. Amtmann et al., "Development of a Promis Item Bank to Measure Pain Interference," Ibid.150, no. 1 (2010).

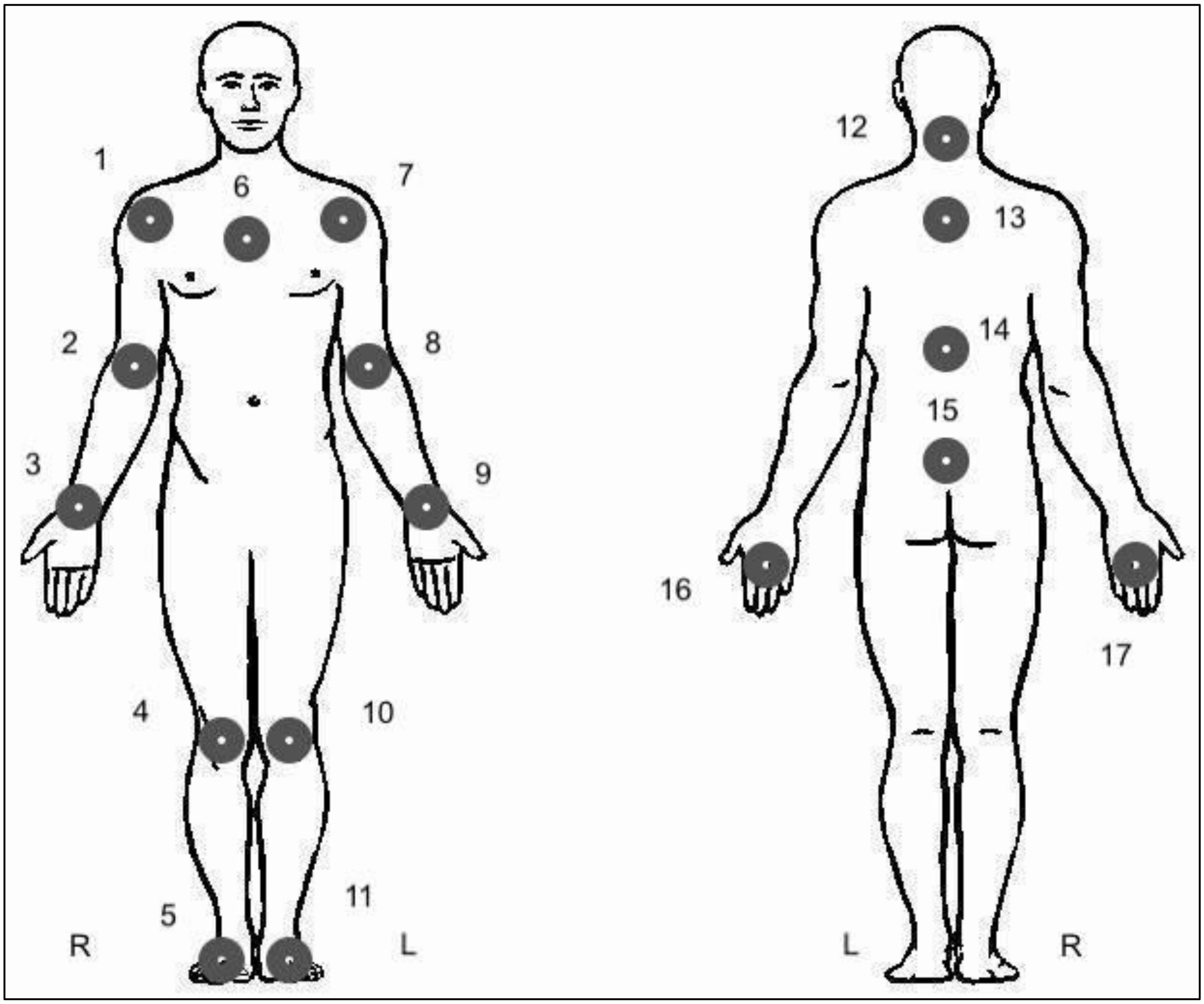

Figure 3: 17 locations on the body where participants were asked to rate acute pain while playing flute and at rest on a visual acuity scale

Table 2: Location descriptions for each of the 17 pain locations in Figure 3

Location	Identifier
1	Right Shoulder
2	Right Elbow
3	Right Wrist
4	Right Knee
5	Right Ankle
6	Chest
7	Left Shoulder
8	Left Elbow
9	Left Wrist
10	Left Knee
11	Left Ankle
12	Neck
13	Upper Back
14	Mid Back
15	Low Back
16	Left Hand
17	Right Hand

Statistical Analysis

Biomechanics of Flute Playing

Trials will be normalized to the length of the exercise or excerpt and averaged to create mean curves for each joint angle over the trial. For each trial, the mean, standard deviation, and range will be calculated for the angle, velocity, and acceleration of each joint included in this analysis, which are the bilateral shoulders, elbows, and wrists. The center-of pressure values will be averaged for each trial and analyzed with a t-test to determine if there was significant stance asymmetry, and the standard deviation of the center-of-pressure over each trial will be calculated to examine stance variability. Differences in average angle, standard deviation, and range of joint angles and velocities between contralateral joints will be examined with a t-test paired by trial. This will yield significant differences between the left and right opposing joints, which may indicate a greater risk of injury in one side than the other. Coordination of movement between contralateral joints will be calculated through continuous relative phase, and differences in mean absolute relative phase, which is the average of continuous relative phase across each trial, between the wrist, elbow, and shoulder will be analyzed with a three-way ANOVA split by joint, trial type, and subject. Differences in each biomechanical parameter between the simple and complex musical excerpts will be analyzed using t-tests paired by subject. Finally, correlation analyses will be done using Pearson's Correlation Coefficient to determine any significant correlations between age or years of flute playing with the above described biomechanics parameters, and t-tests will be used to determine any gendered-differences in these biomechanics. Additional correlation analyses between various biomechanical parameters may be conducted depending on the specific hypothesis addressed since examining each possible correlation by be prohibitively time consuming. All statistical tests will be conducted with a significance value $\alpha = 0.05$.

Common Flute-Related Musculoskeletal Pain

Descriptive statistics including mean, median, range, and standard deviation will be calculated for specific values of interest from the patient reported outcomes dataset. Two-way ANOVA with Tukey post-hoc analysis will be used to examine differences in acute pain between subjects and locations. T-tests will also used to identify any locations, both while playing and at rest, with a significantly higher average pain scores than zero, which represents the null hypothesis of complete absence of acute pain in that location. Further analyses will be conducted only for the locations that showed significantly higher than zero average pain across the participant population. Correlation analyses will be done using Pearson's Correlation Coefficient to determine if there is a significant correlation between average hours per week of playing and acute pain while playing in each of the anatomical locations as well as between hours of playing and overall pain intensity and interference, as measured with the PROMIS scales. Correlation analyses will also be done to determine if there is a correlation between age or years of playing with acute pain in specific locations and in overall pain. T-tests paired by subject will be used to analyze differences in acute pain while playing between contralateral joints. Subjects will split into groups by responses to yes or no questions and t-tests were used to analyze differences in acute pain in specific locations and overall pain based on factors such as physical warm-ups, occupations requiring manual labor, and taking breaks during practice sessions. All statistical tests will be conducted with a significance value $\alpha = 0.05$.

Relationship between Biomechanics and Playing-Related Pain

Correlation analyses will be conducted using Pearson's Correlation Coefficient to examine the relationship between average angle, standard deviation, and average angular velocity at each joint measured with pain in that location (eg. right shoulder angle and right shoulder pain). Participants will be categorized into groups based on biomechanical parameters, such as "low left wrist angle" and "high left wrist angle" for parameters with clearly defined categories and differences in average pain at each of the 17 locations between these two groups will be analyzed with t-tests. Correlation analysis will be conducted between center-of-pressure and pain at each of the 17 locations. For overall pain intensity and pain interference, and for pain in locations where pain was significantly higher than zero while playing or at rest (as determined through a t-test in the previous section) multiple regression models to determine the relative contribution of each biomechanical factor (joint angles, standard deviations, and velocities and stance balance) to the variation in pain reported. This should allow for clear evaluation of biomechanical parameters associated with overall pain and with pain in each of the most common locations for playing-related pain in flutists. Since this is an observational study, these statistics do not provide information on causational relationships, but this knowledge may guide future interventional studies designed to modify playing biomechanics in order to prevent or treat playing-related pain conditions.

Hypotheses

The information intended to be collected through this study is a comprehensive dataset designed to answer a variety of research questions. Given the lack of research in this area, there are unanswered questions unique to the biomechanics and patient reported outcomes sections of this study that would provide valuable information to this field of research even without the combined analysis for which this study was designed. These hypotheses for each area of the study come from the literature, preliminary research, anecdotal discussions, and personal experience with playing-related pain.

Biomechanics of Flute Playing

I hypothesize that there will be a greater variation in angle (higher standard deviation) in the joints in the right arm (shoulder, elbow, and wrist) as compared to the contralateral joints due to the asymmetric position of the flute.

I hypothesize that there will be high coordination of motion between the left and right wrists, and this this coordination will be significantly higher than the coordination between contralateral shoulders and elbows. This is because the balance of the instrument requires a balance of forces applied to the flute from each hand, so increased flexion or extension in one wrist should require compensatory positioning in the contralateral wrist.

I hypothesize that there will be a binomial distribution in wrist angles, with obvious clusters of higher and lower wrist angle participants because of the two predominant schools of traditional versus Rockstro flute positioning[166]. An additional cluster may be seen because of the modified Rockstro position.

[166] Karen A Lonsdale, "Understanding Contributing Factors and Optimizing Prevention and Management of Flute Playing-Related Musculoskeletal Disorders" (Griffith University, 2011).

I hypothesize that there will be significant differences in left wrist angle between flutists playing a flute with an in-line versus offset G key.

I hypothesize that stance balance, as measured by the center-of-pressure force plate, will indicate slightly greater weight on the right foot than the left, and that there will be greater variation in stance balance when playing the challenging musical excerpt than the simpler excerpt.

I hypothesize that greater variation in stance balance will be correlated with increased joint angle variation especially in the shoulders and elbows in order to maintain the horizontal position of the flute against the chin with movement in the lower body.

I hypothesize that there will be a significant negative correlation between years playing and variation of angle in many, if not all, of the joints examined, since individuals who have been playing longer are more likely to have a less variable positing for the flute.

I hypothesize gendered differences in wrist angles due to the generally smaller hand size in women versus men and the need for compensatory movement of the wrist to support the flute with a smaller hand size.

Flute-Related Musculoskeletal Pain

I hypothesize that the most common locations for playing-related pain identified in this study of flutists will be in the wrists, right shoulder, and neck based on results seen in previous studies in flutists.[167,168]

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[167] Spence, "Prevalence Rates for Medical Problems among Flautists: A Comparison of the Unt-Musician Health Survey and the Flute Health Survey."

[168] Stanhope and Milanese, "The Prevalence and Incidence of Musculoskeletal Symptoms Experienced by Flautists."

Based on the results from previous studies, I hypothesize that there will be significantly higher overall pain intensity and interference in women than men.[169,170]

I hypothesize that there will be a significant positive correlation between hours of playing per week and acute pain in each location with significantly higher than zero average pain.

I hypothesize a that there will be significantly less pain reported in each pain location with higher than zero average pain in the participants who do physical warm-ups before playing and in the participants who take breaks during practice sessions.

I hypothesize a significant positive correlation between age and number of locations with above zero pain reported, as well as between age and overall pain intensity and interference.

I hypothesize significantly higher average pain in upper extremity joints on the right side of the body as compared to the contralateral joints because of the asymmetric positioning of the flute.

Relationship Between Biomechanics and Playing-Related Pain

I hypothesize that greater variation of angle and greater average angular acceleration in any individual joint will be correlated with increased pain while playing in that joint.

I hypothesize that the predicted binomial distribution of bilateral wrist angles will be correlated with differences in left and right wrist and hand pain while playing and at rest.

I hypothesize that higher right shoulder angle (meaning the right arm is more abducted) will be associated with increased right shoulder pain due to the increased torque on the shoulder caused by the more elevated position of the arm.

[169] Lockwood, "Medical Problems of Musicians."
[170] Cruder et al., "Patterns of Pain Location in Music Students: A cluster Analysis."

I hypothesize that greater variation in stance balance will be correlated with increased pain in the low back and mid back while playing because people experiencing back pain may be more likely to shift their weight to attempt to decrease experienced pain.

I hypothesize that there will be significant differences in acute pain while playing in the left wrist and left hand between flutists playing a flute with an in-line versus offset G key.

I hypothesize that ipsilateral wrist, elbow, and shoulder angles and angle variation will all contribute to the regression models for acute pain in each of the shoulders.

I hypothesize that the left and right wrist angles will be the dominant contributing factors to the regression model for pain in each wrist and each hand.

I hypothesize that the main contributions to the regression models for neck and upper back pain will be stance balance, age, and left and right shoulder angles.

Conclusion

The goals of this study are to describe the biomechanics of flute playing, examine patterns and potential risk factors for playing-related pain and injury in flutists, and investigate correlations between biomechanical parameters and playing-related pain. Biomechanics are studied through motion capture analysis with an upper body model and center-of-pressure force plate. Playing-related pain data comes from a series of questionnaires. These two data sets can be analyzed independently to report typical flute biomechanics or pain patterns, or together to yield associations between specific biomechanical parameters and experienced playing-related pain.

Biomechanics of music performance, especially in flutists, are poorly understood. While some previous research has explored upper body kinematics in pianists and high string players, there are no comparable existing studies in flutists. The asymmetric positioning of the flute is likely to be reflected in asymmetric biomechanics and a potentially greater risk of playing-related pain and injury. There is a high prevalence of playing-related pain and injury in musicians, and several governing organizations have begun adopting policies and creating committees to address the issue of injury prevention, treatment, and education. Quantitative biomechanics research, including the study described here, can be used to develop these protocols and to design health promotion programs for musicians.

While this thesis was majorly impacted by research restrictions and delays from the COVID-19 pandemic, this thesis examines significant background to current knowledge of playing-related pain and injury and performance biomechanics in musicians, especially flutists, provides a guide to conducting this study when conditions allow, and discusses a variety of hypotheses for future data analysis from this comprehensive data set. Better understanding the typical pain patterns and biomechanics of flute players may help in the design of injury prevention programs, medical treatments, flute education methods, and potentially future innovations on the instrument. Reduction of playing-related pain is critical for the long-term career viability of flutists, and this study can provide thorough information regarding the relationship between biomechanics and playing-related pain in flute players in order to inform flutists, music educators, and medical providers on potentially effective interventions to maintain musculoskeletal health.

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A-1: Informed Consent Document

T502a – Consent Form

The University of Arizona Consent to Participate in Research

Study Title:

Relationship Between Biomechanics and Playing-Related Pain in Flutists

Principal Investigator: L. Daniel Latt, MD PhD, Brian Luce DMA

This is a consent form for research participation. It contains important information about this study and what to expect if you decide to participate. Please consider the information carefully. Feel free to discuss the study with your friends and family and to ask questions before making your decision whether or not to participate.

There are no direct benefits to the individual from participation in this study. –

1. Why is this study being done?

The purpose of this study is evaluate flute playing biomechanics along with playing-related musculoskeletal pain to look for correlations between biomechanical parameters and pain.

2. How many people will take part in this study?

A minimum of 12 and maximum of 50 participants.

3. What will happen if I take part in this study?

You will fill out a screening questionnaire to determine if you meet the inclusion and exclusion criteria for the study. This will take approximately 10 minutes. If you do not meet the inclusion criteria, your participation will end here. If you meet the inclusion criteria, you will be given the opportunity to participate in the remainder of the study.

Should you choose to do so, you will be asked to donate approximately 2-3 hours of your time to participate in this study. You will have small reflective markers placed on your pelvis, back, chest, shoulders, arms, and wrists and will be asked to wear a headband will markers on it. You will be asked to play a few scales and exercises selected by a collegiate flute professor as well as your individually chosen piece of music in the lab environment while standing on a force plate and being recorded with infrared cameras to track motion and a standard video and audio recorded used to ensure motion capture data is accurate. You will then be given a set of eight surveys to complete on a computer or other electronic device that ask about your musculoskeletal health history, playing habits, and acute and chronic pain.

4. How long will I be in the study?

Participation in this study will take approximately two hours, with a maximum length of three hours, and will take place on one day.

5. Can I stop being in the study?

Your participation is voluntary. You may refuse to participate in this study. If you decide to take part in the study, you may leave the study at any time. No matter what decision you make, there will be no penalty to you and you will not lose any of your usual benefits. Your decision will not affect your future relationship with The University of Arizona nor with Banner University Medical Center. If you are a student or employee at the University of Arizona or Banner University Medical Center, your decision will not affect your grades or employment status.

6. What risks, side effects or discomforts can I expect from being in the study?

The main risks associated with participation in this study includes loss of time and potential release of private data. Every effort will be made to keep your information secure, but there is a small risk that an unauthorized person may see this information. During the biomechanics collection, there is a small chance you may have slight skin irritation due to marker placement or that you may experience any pain you typically experience while playing flute.

7. What benefits can I expect from being in the study?

There is no direct benefit to subjects for participation in this research study. Others may benefit in the future as the findings of this study can help develop improved training and/or rehabilitation protocols to prevent playing-related pain and injury in flutists.

8. What other choices do I have if I do not take part in the study?

You may choose not to participate without penalty or loss of benefits to which you are otherwise entitled. You may withdraw from the study at any time and request that your data be removed from the study and destroyed.

9. Will my study-related information be kept confidential?

Efforts will be made to keep your study-related information confidential. However, there may be circumstances where this information must be released. For example, personal information regarding your participation in this study may be disclosed if required by state law. Your data will be assigned a code number. The list connecting your name to this code will be kept in an encrypted and password protected file. Only the research team will have access to the file. When the study is completed and the data have been analyzed, the list will be destroyed. No identifiable information, including audio and video recording, will be used for presentation or reporting purposes. Audio and video recordings will only be used to ensure data collection accuracy and will be destroyed once data processing is complete. And professors who currently or may in the future teach any student participating in this study will not have access to any identifiable data until after all student participants have graduated.

Also, your records may be reviewed by the following groups (as applicable to the research):

- The University of Arizona Institutional Review Board or Office of Responsible Research Practices

10. What are the costs of taking part in this study?

The cost of participating in this study is associated only to the loss of time.

11. Will I be paid for taking part in this study?

You will not be paid for participating in this study.

12. What happens if I am injured because I took part in this study?

If you suffer an injury from participating in this study, you should seek treatment. The University of Arizona has no funds set aside for the payment of treatment expenses for this study.

13. What are my rights if I take part in this study?

If you choose to participate in the study, you may discontinue participation at any time without penalty or loss of benefits. By signing this form, you do not give up any personal legal rights you may have as a participant in this study.

You will be provided with any new information that develops during the course of the research that may affect your decision whether or not to continue participation in the study.

You may refuse to participate in this study without penalty or loss of benefits to which you are otherwise entitled.

An Institutional Review Board responsible for human subjects research at The University of Arizona reviewed this research project and found it to be acceptable, according to applicable state and federal regulations and University policies designed to protect the rights and welfare of participants in research.

14. Who can answer my questions about the study?

For questions, concerns, or complaints about the study you may contact Dr. Daniel Latt at (520) 626-4024.

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact the Human Subjects Protection Program at 520-626-6721 or online at http://orcr.arizona.edu/hspp.

If you are injured as a result of participating in this study or for questions about a study-related injury, you may contact Cindy Fastje at 520-626-7512.

Signing the consent form

I have read (or someone has read to me) this form, and I am aware that I am being asked to participate in a research study. I have had the opportunity to ask questions and have had them answered to my satisfaction. I voluntarily agree to participate in this study.

I am not giving up any legal rights by signing this form. I will be given a copy of this form**.**

______________________	______________________
Printed name of subject	**Signature of subject**
	______________________ **AM/PM**
	Date and time

<u>Investigator/Research Staff</u>

I have explained the research to the participant or the participant's representative before requesting the signature(s) above. There are no blanks in this document. A copy of this form has been given to the participant or to the participant's representative.

______________________	______________________
Printed name of person obtaining consent	**Signature of person obtaining consent**
	______________________ **AM/PM**
	Date and time

A-2: Screening Questionnaire

Please complete the survey below to determine if you meet the criteria for participation in the study.
Thank you!

1)	What is your first name?	__________________
2)	What is your last name/family name?	__________________
3)	What is your email address?	__________________
4)	What is your phone number?	__________________
5)	What is your preferred contact method?	◯ Email ◯ Phone ◯ I would like to opt-out of any future communication including notification of publication of this research
6)	Have you been diagnosed with a chronic pain condition (e.g. fibromyalgia, complex regional pain syndrome)	◯ Yes ◯ No
7)	If yes, what chronic pain condition have you been diagnosed with?	__________________
8)	Within the last year, have you experienced a non-music related injury to the neck, back, or upper extremities?	◯ Yes ◯ No (This includes any wrist, hand, shoulder, elbow, neck, or back injury that was not caused in part by playing a musical instrument)
9)	If yes, what injury did you have and how did it occur?	__________________
10)	Within the past two years, have you had any injury of the neck, back, or upper extremity requiring surgery?	◯ Yes ◯ No (This includes all injuries, whether or not they are related to playing a musical instrument)
11)	If yes, what injury/surgery did you sustain?	__________________
12)	Research Staff - Indicate screening completion	◯ Yes ◯ No

B-1: Demographics and Background

Please enter your contact information, demographics, and background below before contining on to other surveys.

1) What is your date of birth?

____
(Year/month/day)

2) Age

____

3) What is your gender?

◯ Female
◯ Male
◯ Other
◯ Prefer not to answer

4) Are you Hispanic or Latino?

◯ Hispanic or Latino
◯ Not Hispanic or Latino

5) Which one or more of the following best describes your race?

☐ White
☐ Black or African American
☐ Asian
☐ Native Hawaiian or other Pacific Islander
☐ American Indian or Alaska Native
☐ Other (please specify below)

6) If other, please specify

____

7) What is your current occupation?

____

8) Does your occupation require manual labor?

◯ Yes
◯ No

9) Do you regularly lift greater that 25 pound objects? This can be in your occupation or any other activities (housework, exercise, hobbies, etc..)

◯ Yes
◯ No

10) How many hours per day are you typically standing?

____

11) How many hours a day do you typically spend working on a computer?

____

12) How many hours per week do you typically exercise?

____

13) If you exercise regularly, what activities do you typically do?

- ☐ Running (outdoor or treadmill)
- ☐ Bicycling (outdoor or stationary)
- ☐ Walking
- ☐ Other cardio (eg. elliptical, rowing machine, etc...)
- ☐ Weightlifting or strength training
- ☐ Cardio workout classes
- ☐ Strength training classes
- ☐ Yoga, pilates, or barre
- ☐ Swimming
- ☐ Team sports (basketball, soccer, baseball, football, volleyball, etc...)
- ☐ Other (list below)

14) If other, please elaborate

____

B-2: Medical History

This survery asks about your medical history.

Have you had any previous surgeries on your neck or back?	◯ Yes ◯ No
How many surgeries have you had on your neck?	__________________
How many surgeries have you had on your back?	__________________
What was the date of your most recent neck or back surgery?	__________________
Please list the type and year for all neck and back surgeries	__________________
Have you had any previous surgeries on your arms (shoulders elbow, wrist, and hand)?	◯ Yes ◯ No
How many surgeries have you had on your left arm?	__________________
How many surgeries have you had on your right arm?	__________________
How many surgeries have you had on your hands and wrists? (both left and right sides, these may overlap surgeries reported in the above two questions)	__________________
When was your most recent arm surgery?	__________________
Please list the type and year for all arm, hand, and wrist surgeries	__________________
Have you had any surgeries on your legs or feet? (hips, knees, ankles, feet)	◯ Yes ◯ No
How many surgeries have you had on your left leg?	__________________
How many surgeries have you had on your right leg?	__________________
When was your most recent leg surgery?	__________________
Please list the type and year for all arm, hand, and wrist surgeries	__________________

Have you had any other surgeries?	◯ Yes ◯ No
Please list the type and year for all other surgeries	__________________________
Have you ever had an overuse injury in your neck or back?	◯ Yes ◯ No
Please list the year of diagnosis, description of injury, and the time (in months) this injury affected you for each overuse injury to your neck/back	__________________________
Are you currently affected by an overuse injury in your neck or back?	◯ Yes ◯ No
How long ago (in years) did your most recent neck or back overuse injury stop affecting you?	______________________
How many overuse injuries to your neck or back have you experienced?	______________________
Have you ever had an overuse injury in your shoulders or elbows?	◯ Yes ◯ No
Are you currently affected by an overuse injury in your shoulders or elbow?	◯ Yes ◯ No
How long ago (in years) did your most recent shoulder or elbow overuse injury stop affecting you?	______________________
How many overuse injuries in your shoulders or elbows have you experienced? (count injuries separately on each side of the body)	______________________
On which side or sides have your shoulder or elbow overuse injuries been?	☐ Left ☐ Right
Please list the year of diagnosis, description of injury, and the time (in months) this injury affected you for each overuse injury to your shoulders and/or elbows	__________________________
Have you had an overuse injury in your hands and/or wrists?	◯ Yes ◯ No
Are you currently affected by an overuse injury in your hands or wrists?	◯ Yes ◯ No
How long ago (in years) did your most recent hand or wrist overuse injury stop affecting you?	______________________
How many overuse injuries in your hands or wrists have you experienced? (count injuries separately on each side of the body)	______________________

On which side or sides have your shoulder or elbow overuse injuries been?	☐ Left ☐ Right
Please list the year of diagnosis, description of injury, and the time (in months) this injury affected you for each overuse injury to your hands and/or wrists	__________________________________
Please check any conditions you currently have or have previously been diagnosed with or check none	☐ Myocardial infarct ☐ Congestive heart failure ☐ Peripheral vascular disease ☐ Cerebrovascular disease (except hemiplegia) ☐ Dementia ☐ Chronic pulmonary disease ☐ Connective tissue disease ☐ Ulcer disease ☐ Mild liver disease ☐ Diabetes ☐ Diabetes with end organ damage ☐ Hemiplegia ☐ Moderate or severe renal disease ☐ Solid tumor (non metastatic) ☐ Leukemia ☐ Lymphoma, Multiple myeloma ☐ Moderate or severe liver disease ☐ Metastatic solid tumor ☐ AIDS ☐ None
Please select your age in years	○ Under 50 ○ 50 - 59 ○ 60 - 69 ○ 70 - 79 ○ 80 - 89 ○ 90 - 99
Charleson Comorbidity Index score:	____________________________

B-3: Musical Activity

This survey asks questions about your musical activity.

At what age did you begin playing flute?	______________________
Since you began playing, have you taken more than a year off of playing (I.e. stopped playing flute for at least a year)?	◯ Yes ◯ No
How many years total have you been playing the flute? (include time before and after any breaks in playing)	______________________
For how many years have you been continuously playing the flute? (continuous includes breaks in playing shorter than one year)	______________________
How long has it been since you switched instruments/got a new flute?	______________________

The next questions relate to the time spent playing flute. Enter an average amount of time you spend on each of the musical activities below in hours per week. For the purposes of these questions, all types of flutes (piccolo, alto, bass) should be included.

Practicing Flute:	______________________ (Average hours spent practicing the flute each week)
Flute Lessons (receiving)	______________________ (Average hours per week spent as a student in a flute lesson)
Flute Lessons (teaching)	______________________ (Average hours per week spent teaching flute lessons)
Ensemble Rehearsals:	______________________ (Average hours per week spent in rehearsal for any ensemble (large ensemble, chamber, etc..))
Performing:	______________________ (Average hours per week spent performing (including all gigs))
Total Flute Time	______________________ (Average hours per week spent on the flute (calculated))

The next questions ask about the time you spend playing different types of flutes. The options are c flute, piccolo, alto flute, and bass or contrabass flute. For these questions, use the slider to indicate the approximate percentage of your time spent on each instrument. The total percentage must add up to 100

What percent of your time playing is spent on a c flute?

0 (none) — 100 (all of playing time)

(Place a mark on the scale above)

What percent of your time playing is spent on a piccolo?

0 (none) — 100 (all of playing time)

(Place a mark on the scale above)

What percent of your time playing is spent on alto flute?

0 (none) — 100 (all of playing time)

(Place a mark on the scale above)

What percent of your time playing is spent on bass or contrabass flute?

0 (none) — 100 (all of playing time)

(Place a mark on the scale above)

Please edit values above to equal 100 percent

How many performances (large ensemble, small ensemble, gigs, etc..) do you do in a typical year?

____

Time spent on any other musical instruments

____
(Average time spent on other instruments per week)

Other Instruments:

____
(Please list any other instruments you play regularly (included in above field))

B-4: Practice Habits

This survey asks more detailed questions about your practice habits.

1) How many days per week do you typically practice?

____

2) How long are your typical practice sessions?

____
(Average length in hours of practice sessions)

3) Do you typically do a physical warm up before practicing?

◯ Yes ◯ No ◯ Sometimes
(Physical warm-up is any non-musical activity including stretching, heat, etc..)

4) How much time do you spend doing a physical warm up before practicing?

____
(Average time on physical warm-ups before playing)

5) What physical warm-ups do you typically do before practicing flute?

____

6) Do you typically take breaks while practicing?

◯ Yes ◯ No ◯ Sometimes
(Do your typical practice sessions include any or multiple breaks?)

7) How frequently do you take breaks while practicing?

____
(Break every ____ hours)

8) How long are your typical practice breaks?

____
(Average time in minutes of breaks while practicing)

9) What do you do during your practice breaks?

____

10) How often do you end practice sessions due to physical fatigue?

Never Always

(Place a mark on the scale above)

11) How often do you end practice sessions due to physical pain?

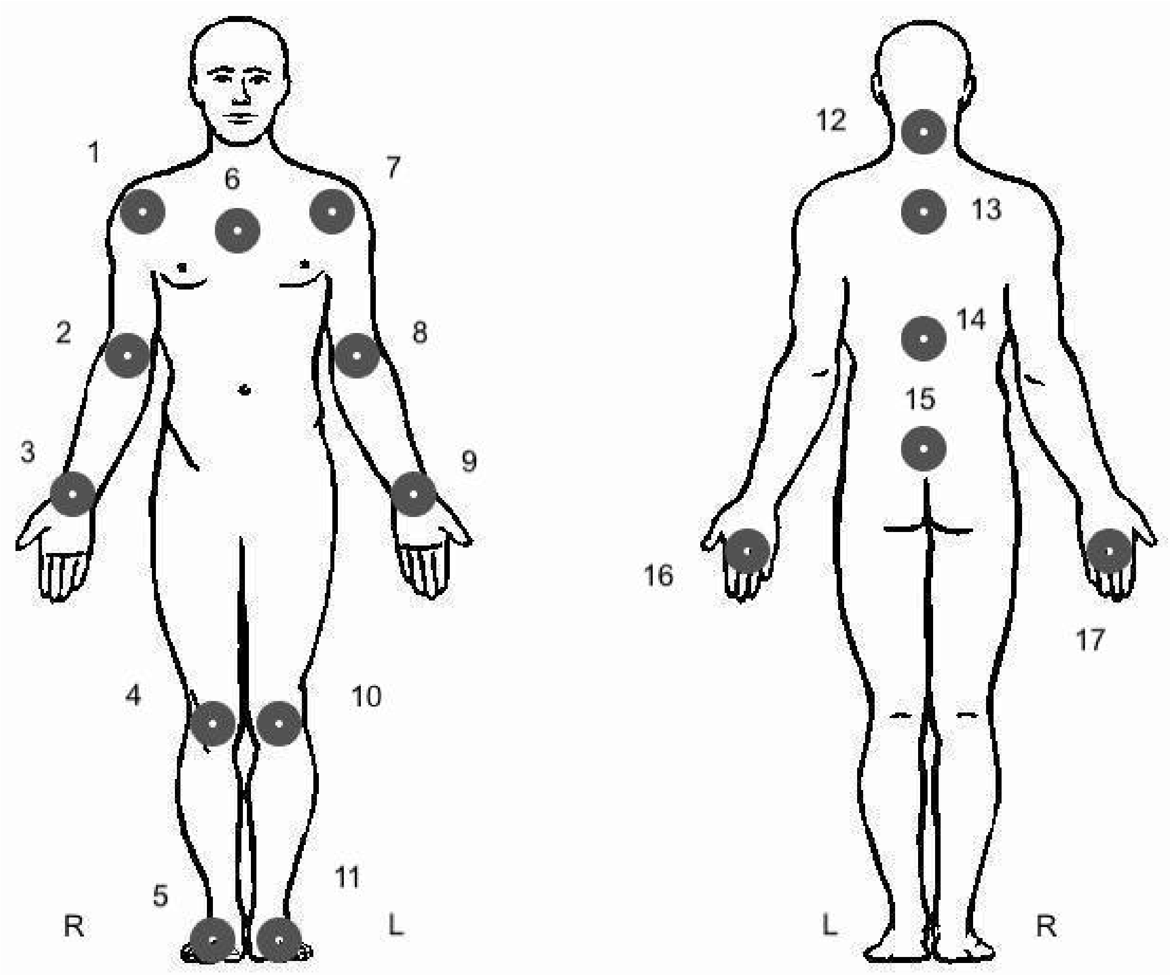
Never Always

(Place a mark on the scale above)

B-5: Acute Pain while Playing

Please answer the following questions regarding pain you have in specific locations while playing the flute

The next questions will ask you to rate your average pain in each of the spots on this image while playing. It is important that these values are averages of your pain only while you are actively playing the flute.



1) 1 - Right shoulder

No pain — Worst pain imaginable

(Place a mark on the scale above)

2) 2 - Right elbow

No pain — Worst pain imaginable

(Place a mark on the scale above)

3) 3 - Right wrist

No pain — Worst pain imaginable

(Place a mark on the scale above)

4) 4 - Right knee

No pain — Worst pain imaginable

(Place a mark on the scale above)

5) 5 - Right Ankle

No pain — Worst pain imaginable

(Place a mark on the scale above)

6) 6 - Chest
No pain — Worst pain imaginable
(Place a mark on the scale above)

7) 7 - Left shoulder
No pain — Worst pain imaginable
(Place a mark on the scale above)

8) 8 - Left elbow
No pain — Worst pain imaginable
(Place a mark on the scale above)

9) 9 - Left wrist
No pain — Worst pain imaginable
(Place a mark on the scale above)

10) 10 - Left knee
No pain — Worst pain imaginable
(Place a mark on the scale above)

11) 11 - Left ankle
No pain — Worst pain imaginable
(Place a mark on the scale above)

12) 12 - Neck
No pain — Worst pain imaginable
(Place a mark on the scale above)

13) 13 - Upper back
No pain — Worst pain imaginable
(Place a mark on the scale above)

14) 14 - Mid back
No pain — Worst pain imaginable
(Place a mark on the scale above)

15) 15 - Low back
No pain — Worst pain imaginable
(Place a mark on the scale above)

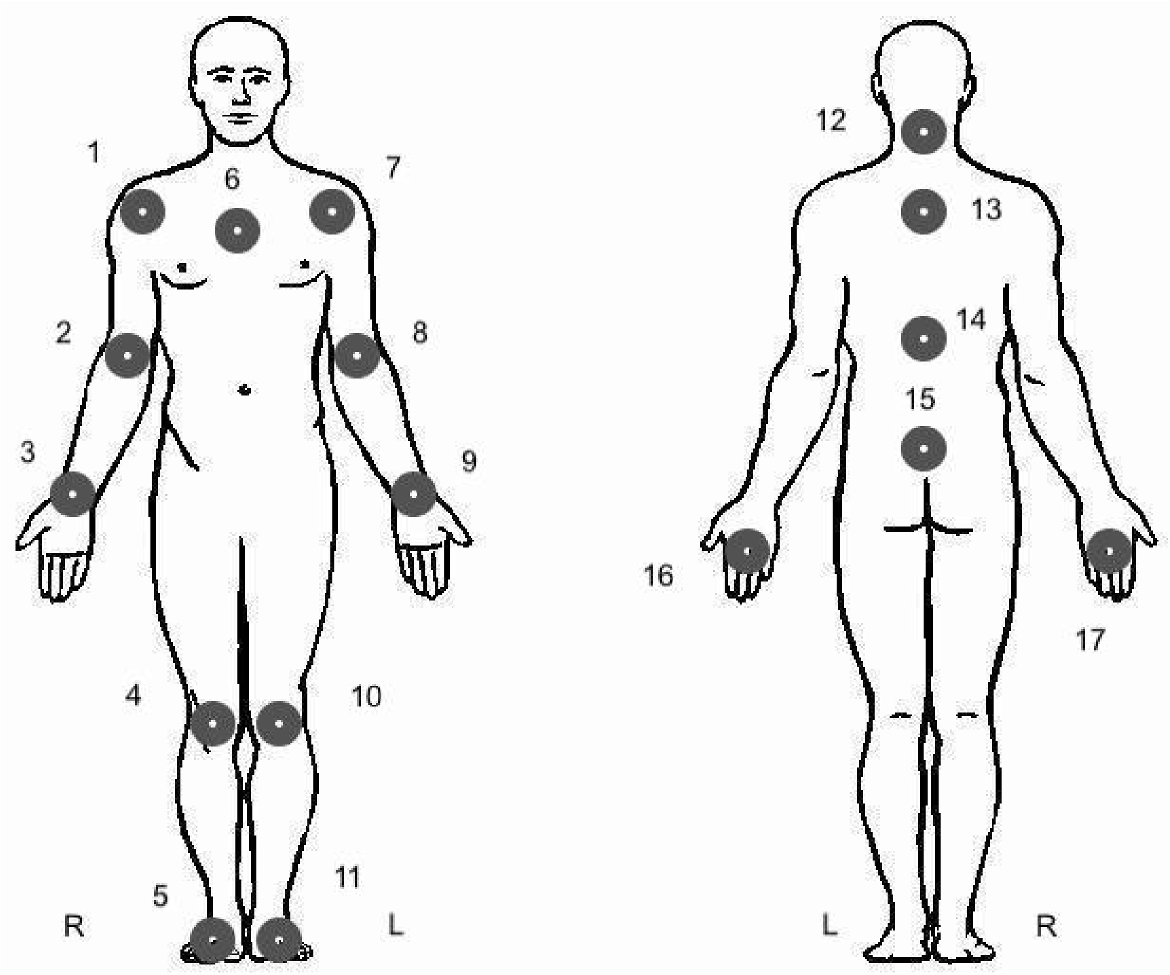
16) 16 - Left hand
No pain — Worst pain imaginable
(Place a mark on the scale above)

17) 17 - Right hand
No pain — Worst pain imaginable
(Place a mark on the scale above)

B-6: Pain at Rest

Please respond to the following questions regarding pain you have in specific locations at rest

Similarly to the last set of questions, these questions inquire about pain at rest. This should represent any baseline pain you have while you are not playing flute.



1) 1 - Right shoulder

No pain — Worst pain imaginable

(Place a mark on the scale above)

2) 2 - Right elbow

No pain — Worst pain imaginable

(Place a mark on the scale above)

3) 3 - Right wrist

No pain — Worst pain imaginable

(Place a mark on the scale above)

4) 4 - Right knee

No pain — Worst pain imaginable

(Place a mark on the scale above)

5) 5 - Right Ankle

No pain — Worst pain imaginable

(Place a mark on the scale above)

6) 6 - Chest

No pain — Worst pain imaginable

(Place a mark on the scale above)

7) 7 - Left shoulder

No pain — Worst pain imaginable

(Place a mark on the scale above)

8) 8 - Left elbow

No pain — Worst pain imaginable

(Place a mark on the scale above)

9) 9 - Left wrist

No pain — Worst pain imaginable

(Place a mark on the scale above)

10) 10 - Left knee

No pain — Worst pain imaginable

(Place a mark on the scale above)

11) 11 - Left ankle

No pain — Worst pain imaginable

(Place a mark on the scale above)

12) 12 - Neck

No pain — Worst pain imaginable

(Place a mark on the scale above)

13) 13 - Upper back

No pain — Worst pain imaginable

(Place a mark on the scale above)

14) 14 - Mid back

No pain — Worst pain imaginable

(Place a mark on the scale above)

15) 15 - Low back

No pain — Worst pain imaginable

(Place a mark on the scale above)

16) 16 - Left hand

No pain — Worst pain imaginable

(Place a mark on the scale above)

17) 17 - Right hand

No pain — Worst pain imaginable

(Place a mark on the scale above)