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The Anatomy of the Carpal Tunnel and Hand Function of Musicians

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THE ANATOMY OF THE CARPAL TUNNEL AND HAND FUNCTION OF MUSICIANS

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We, the faculty supervising the work of Emily Ann Lorenzen, affirm that the thesis, *The Anatomy of the Carpal Tunnel and Hand Function of Musicians*, meets the high academic standards for original scholarship and creative work established by the Master of Science in Exercise Science and the College of Health Professions. This work also conforms to the editorial standards of our discipline and the Graduate College of Marshall University. With our signatures, we approve the manuscript for publication.

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ABSTRACT

Musicians spend hours perfecting their trade, often leading to overuse injuries of the hand; of specific concern to musicians is carpal tunnel syndrome (CTS). This study evaluated the median nerve cross-sectional area and hand function of musicians and non-musicians. Patients completed the upper extremity and CTS specific function questionnaires. The median nerve cross-sectional area, and the width of the carpal tunnel were measured on ultrasound image. The median nerve cross-sectional area was greater in musicians than the non-musician group. The width of the carpal tunnel did not differ between the groups. Musicians showed higher levels of hand dysfunction than the non-musician. The current research identified between group differences in median nerve cross-sectional area and the level of hand dysfunction of musicians. Understanding the interaction between the anatomy of the wrist and wrist and hand dysfunction will benefit clinicians when evaluating and treating musicians.

CHAPTER 1
INTRODUCTION

Purpose

The purpose of this study was to compare the width of the carpal tunnel and the cross-sectional area of the median nerve in musicians and make comparisons to the same measures in the non-musician control group using diagnostic ultrasound. The study also assessed the hand function in artists to explore relations between the anatomy of the carpal tunnel and hand function. Assessments will be made using diagnostic ultrasound and patient rated outcome measures. The results of this study will provide information on the anatomy and hand function of musicians that will improve the understanding of the development of carpal tunnel syndrome (CTS) in musicians.

Significance

Musicians spend numerous hours perfecting their trade. The long duration and frequency of rehearsals may lead to chronic injuries. Musicians frequently suffer from overuse injuries of the hand, wrist, forearm, upper arm, shoulder, and neck (Fry, 1989). A study done by Lederman (2003) evaluated 1353 musicians and found that 64% suffered from musculoskeletal disorders, 20% had peripheral nerve problems, and 8% had focal dystonia. Of specific concern to musicians are peripheral nerve entrapment syndromes such as CTS (Zaza, 1998). Musicians frequently present clinically with a variety of upper extremity complaints including impairments and disabilities consistent with CTS. Carpal tunnel syndrome often presents with pain and abnormal sensation in the lateral 3 ½ fingers (Baker & Livengood, 2014). The prevalence of CTS in musicians is thought to be higher due to the repetitive hand motions that these individuals perform daily (Markison, Johnson, & Kasdan, 1998).

Repetitive hand motions may lead to anatomical changes in the wrist. The dimensions of the carpal tunnel and the cross sectional area of the median nerve can be viewed and measured using diagnostic ultrasound techniques (Fowler, Munsch, Tosti, Hagberg, & Imbriglia, 2014). Those who suffer from CTS have been found to have a narrower carpal tunnel and a thicker median nerve (Inui et al., 2016). This smaller space is thought to compress the median nerve and cause CTS. CTS patients have been shown to have a larger inlet-to-outlet median nerve cross-sectional area ratio (IOR) compared to healthy controls (Fu et al., 2015). The median nerve decreases in cross-sectional area width as it passes through the carpal tunnel. Research has been conducted on the prevalence of CTS in musicians; however, the width of the carpal tunnel, the cross-sectional area of the median nerve, and the inlet-to-outlet ratio of the median nerve has not been explored in musicians versus non-musicians.

Research Questions

Do musicians have different carpal tunnel dimensions and median nerve cross-sectional areas than those of the non-musician controls?

Do musicians have different inlet-to-outlet ratios than those of the non-musician controls?

Will musicians have decreased hand function based on patient reported outcomes as compared to non-musician controls?

Null Hypothesis

N_1: Musicians do not have different carpal tunnel dimensions and median nerve cross-sectional areas as compared to the non-artists controls.

N_2: Musicians will not have a greater prevalence of hand disability and impairment, and symptoms associated with carpal tunnel syndrome, than non-musicians.

Alternative Hypothesis

H_1: Musicians will have narrower carpal tunnel width at the carpal tunnel inlet and outlet than non-musicians.

$H_{2:}$ Musicians will have larger median nerve cross-sectional areas compared to the non-musician controls.

H_3: Musicians will have a greater inlet-to-outlet ratio as compared to the non-musician controls.

H_4: Musicians will have a greater prevalence of hand disability and impairment, and symptoms associated with carpal tunnel syndrome, than non-musicians.

Limitations

The limitations of this study include:

1. Participants will be from a single college institution.
2. Participants will answer questions honestly regarding previous wrist injury.
3. Examiners will not be blind as to which group (musicians versus non-musicians) they are examining.

Delimitations

The delimitations of this study include:

1. The musician group consisted of students enrolled in Marshall University's music or visual art departments.
2. For the purpose of this study, musicians were defined as Marshall University music students and professors.
3. Researchers were unaware of the prevalence of carpal tunnel syndrome at Marshall University.

Assumptions

The assumptions for this study include:

1. Participants answered questions honestly regarding previous forearm, wrist, and/or hand injury.
2. Participants read and complied with all instructions.

Major Operational Definitions

Carpal tunnel- defined medially by the pisiform and the hook of the hamate and laterally by the tuberosities of the scaphoid and trapezium. The flexor retinaculum covers these bones and creates a tunnel for the flexor tendons (Newington, Harris, & Walker-Bone, 2015).

Carpal Tunnel Syndrome (CTS)- can be defined as entrapment of the median nerve in the carpal tunnel resulting in intermittent paresthesia in the radial 3.5 digits (Duckworth, Jenkins, & McEachan, 2014).

Inlet of the carpal tunnel- median nerve measurement at the level of the scaphoid-pisifrom (Fu et al., 2015).

Median nerve- is a nerve in the forearm that runs through the carpal tunnel and branches to provide motor supply to the thenar muscle group and sensory innervation to the palmar surface of the thumb, index finger, and middle and radial half of the ring finger (Newington et al., 2015).

Musician- A person who plays a musical instrument.

Outlet of the carpal tunnel- median nerve measurement at the level of the hook of the hamate (Fu et al., 2015).

CHAPTER 2
REVIEW OF LITERATURE

Injury Prevalence in Musicians

Musicians present clinically with a variety of complaints including pain, numbness, impaired dexterity, tightness, fatigue, weakness, curling and drooping fingers, paresthesia, and sensory loss (Markison et al., 1998). Common musculoskeletal injuries of musicians include tendonitis and peripheral nerve entrapment syndromes such as carpal tunnel syndrome (Zaza, 1998). Musicians often develop focal dystonia which can be defined as an abnormal movement disorder that occurs when a person attempts to perform a specific task (Markison et al., 1998). Musicians often do not seek treatment for such injuries and continue with their art until they can no longer perform.

Repetitive movements play a large part in overuse injuries in musicians (Gohl et al., 2006). Fry (1989) claimed that there are three factors involved in musicians developing symptoms from overuse. These factors include a lack of physical strength that results in the inability to play for an extended period of time without symptoms, a technique that is strenuous and uncoordinated, and increased intensity and practice time (Fry, 1989). In addition to overuse, some instruments require static and awkward positioning which may lead to fatigue (Quarrier, 1993).

The body parts in musicians that are typically overused include the hand, wrist, forearm, upper arm, shoulder, and neck (Fry, 1989). Nerve entrapment syndromes such as carpal tunnel syndrome represent a large majority of complaints in musicians (Wilson, Watson, & Lee, 2014). Instrumentalists who seek medical care in clinics are often diagnosed with nerve entrapment injuries (Lederman, 2003). It has been well established that artists tend to suffer from carpal tunnel syndrome (Markison et al., 1998). However, little research has been done to compare the dimensions of the carpal tunnel and the cross-sectional area of the median nerve in musicians versus the public.

Anatomy

The carpal tunnel can be found at the proximal palmar wrist. The carpal tunnel runs medially from the pisiform and hook of the hamate to the lateral tuberosities of the scaphoid and trapezium bones. The flexor retinaculum or transverse carpal ligament covers these boney processes and creates a tunnel where the long flexor tendons run through (Katz & Simmons, 2002). The function of the flexor retinaculum is to maintain these flexor tendons in place during wrist flexion (Newington et al., 2015). The median nerve runs from the anterior forearm through the carpal tunnel and into the wrist. The median nerve lies superficial to the flexor tendons (Azami et al., 2014). The median nerve branches to provide motor supply to the thenar muscle group and sensory innervation to the palmar surface of the thumb, index finger, and middle and radial half of the ring finger (Newington et al., 2015).

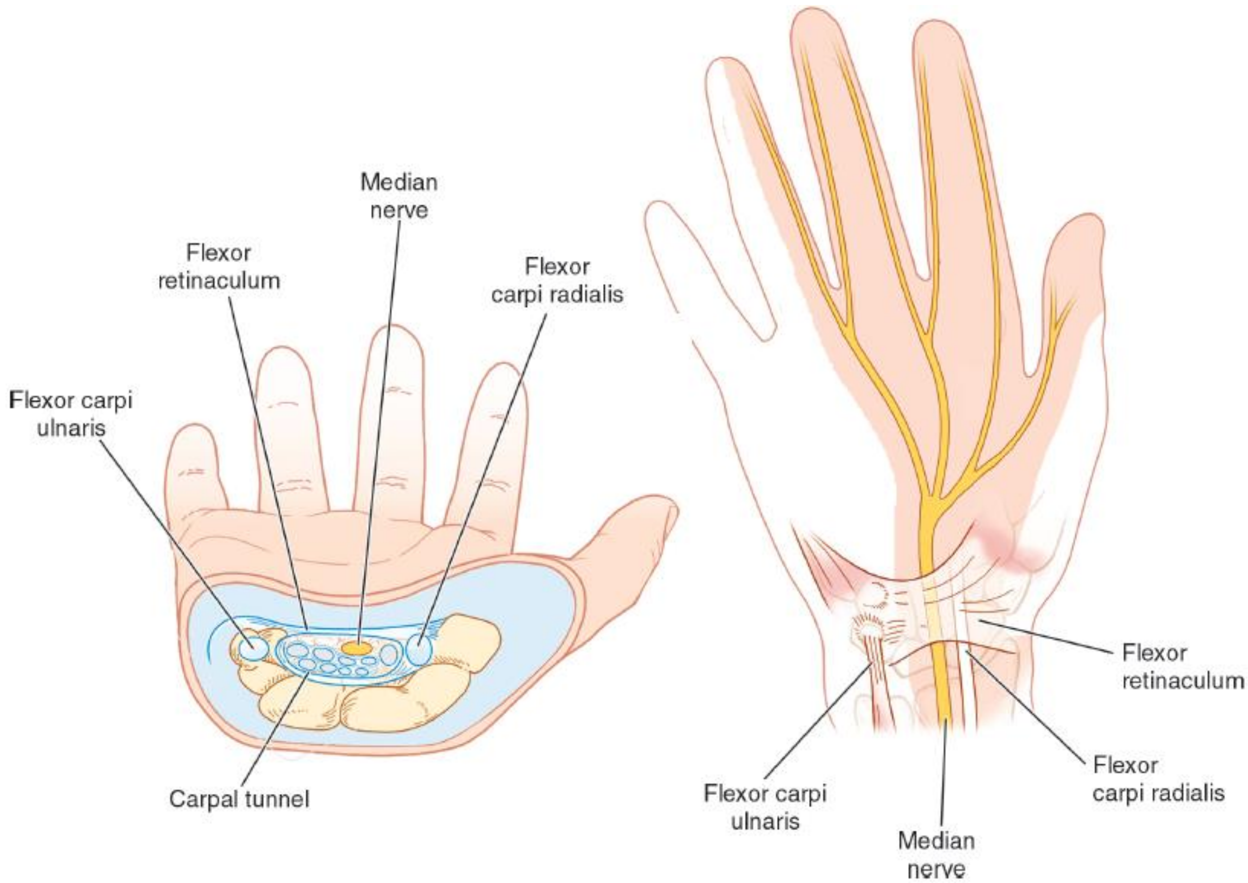

Figure 1.1 Diagram of the anatomy of the carpal tunnel.

[Untitled illustration of the carpal tunnel]. Retrieved August 31, 2017 from http://accessphysiotherapy.mhmedical.com/data/books/1132/p9780071819657-ch012_f050.png

Carpal Tunnel Syndrome (CTS)

CTS is a typical nerve entrapment neuropathy that causes disability in the upper extremity (Jerosch-Herold, Mason, & Chojnowski, 2008). CTS is the most common peripheral entrapment neuropathy (Azami et al., 2014). CTS is present in 3.8% of the population and has a higher prevalence among women (Aboonq, 2015). Those that suffer with CTS experience a loss of function that affects their ability to perform daily activities (Baker & Livengood, 2014). Carpal tunnel syndrome is caused by increased pressure in the carpal tunnel which creates ischemia of the median nerve (Katz & Simmons, 2002). Studies have shown that the earliest detectable signs of low-grade peripheral nerve compression are a reduced epineural blood flow of 20 to 30 mm mercury compression (Gelberman, Rydevik, Pess, Szabo, & Lundborg, 1988) . Median nerve compression at 30 mm mercury causes mild nerve changes and symptoms of hand paresthesia (Gelberman et al., 1988). This increase in pressure, and therefore ischemia, may lead to irreversible nerve dysfunction (Gelberman et al., 1988).

Carpal tunnel syndrome typically presents with numbness and tingling of the lateral three fingers (Duckworth et al., 2014). CTS is characterized by pain, paresthesia, or weakness in regions of median nerve innervation (Tat, Wilson, & Keir, 2015). Symptoms of CTS are often worse at night or in the early morning (Newington et al., 2015). According to Alfonso, Jann, Massa, and Torreggiani (2010), CTS can be classified into three stages. In the first stage, patients report waking up during the night with a sensation of a swollen and numb hand. Patients also report severe pain that radiates from the wrist to the shoulder as well as tingling in their hands and fingers. In the early developmental stages of the disease, no morphologic changes are observable in the median nerve, neurologic findings are reversible, and symptoms are intermittent (Katz & Simmons, 2002). The second stage consists of symptoms during the day and motor deficits. The third stage involves atrophy of the thenar eminence and possible absence of sensory symptoms (Alfonso et al., 2010). The loss of two-point discrimination in the median nerve distribution and thenar atrophy often occur late in the onset of CTS (Katz & Simmons, 2002). CTS is a common neuropathy caused by compression of the median nerve and presents with numbness and tingling in areas of median nerve innervation.

Injury Mechanism

Carpal tunnel syndrome is believed to be caused by overuse of the wrist; however, researchers have found that there are other risk factors that may predispose people to the disease (Atroshi et al., 1999). The risk of CTS is greater in occupations that involve exposure to increased pressure, high force, repetitive work, and vibrating tools (Aroori & Spence, 2008). A study by Kamolz et al. (2004) investigated whether there is a relationship between hand and wrist configurations and the occurrence dimensions. Wrist dimensions of length, palm width, wrist depth, and wrist widths were measured using a standard resolution 7.5 MHz high-resolution probe. Patients with carpal tunnel syndrome diseased hands were compared to those without. Researchers found that square shaped carpal tunnels are associated with carpal tunnel syndrome. Researchers suggest this anatomical abnormality leads to median nerve compression (Kamolz et al., 2004). A study done by Nordstrom, Vierkant, Destafano and Layde, (1997) found six risk factors associated with the development of carpal tunnel syndrome: musculoskeletal conditions, sports participation, possession of a home typewriter, a high body mass index, family history of carpal tunnel syndrome, and poverty income.

Normal pressure in the carpal tunnel ranges from 2 to 10 mm Hg (Werner & Andary, 2002). Researchers utilized a catheter to show that the tunnel pressure was higher in CTS patients than in normal patients (Bauman, Gelberman, Mubarak, & Garfin, 1981). In neutral wrist position, the average pressure in the carpal canal was found to be 32 mm Hg. When the wrist was flexed, the pressure reached a value of 94 mm Hg and reached 110 mm Hg when the wrist was extended. This study shows that repetitive wrist flexion and extension causes an increase in pressure in the carpal tunnel and therefore compression of the median nerve.

A combination of intrinsic and extrinsic factors may lead to carpal tunnel syndrome such as the anatomical shape of the tunnel, repetitive wrist flexion and extension, and other musculoskeletal conditions.

Evaluation and Assessment of CTS

Researchers have debated over how to accurately diagnose carpal tunnel syndrome. There is no gold standard for the diagnosis of carpal tunnel syndrome. The lack of a reference standard for the diagnosis of carpal tunnel syndrome has been speculated to cause a wide range of prevalence of the disease reported in the literature (Duckworth et al., 2014). Special tests, nerve conduction studies, and ultrasonography have all been used to diagnose CTS.

There are several clinical provocative tests that can assist in the CTS diagnosis process. Phalen's maneuver is a special test where the patient flexes the wrist for 60 seconds and reports any pain or paresthesia in the median nerve distribution (Katz & Simmons, 2002). Tinel's sign is a special test where the clinician taps lightly over the flexor retinaculum to elicit radicular symptoms (Newington et al., 2015). Durkan's compression test is similar to Tinel's sign except the examiner applies direct pressure over the carpal tunnel for 30 seconds. A positive test is indicated by the reproduction of numbness or tingling in the distribution of the median nerve within 30 seconds (Durkan, 1994). The sensitivity and specificity of these tests vary widely (Katz & Simmons, 2002). Szabo, Slater, Farver, Stanton, & Sharman (1999) sought to determine the validity of tests or a combination of tests for the diagnosis of CTS. Researchers tested a CTS diseased group, a non-traumatic upper extremity disorder group, and an asymptomatic control group. Subjects completed a self-administered hand diagram and were asked about night pain, symptom duration, and coexistent medical conditions. Phalen's test, Tinel's sign, Durkan's compression test, and Semmes- Weinstein monofilament testing was performed on each group both before and after a Phalen's maneuver for 5 minutes. Analysis of groups 1 and 2 showed that the tests with the highest sensitivity were the Durkan's compression test (89%) and Semmes-Weinstein testing after Phalen's maneuver (83%) and hand diagram scores (76%). The hand diagram and Tinel's sign proved to be the most specific tests (76% and 71%, respectively) (Szabo et al., 1999). A combination of these tests may be useful in diagnosing CTS.

Nerve conduction studies and electromyography can confirm the diagnosis of carpal tunnel syndrome (Alfonso et al., 2010). Although electrodiagnostic studies are considered the most accurate in carpal tunnel syndrome diagnosis, false negative and positive findings have been well documented (Rempel et al., 1998). The combination of electrodiagnostic study findings and symptom characteristics provides the best carpal tunnel syndrome diagnosis (Rempel et al., 1998). The standard electroneurography examination involves measurement of the function of the median nerve sensory conduction velocity across the wrist (Alfonso et al., 2010). In some studies, nerve conduction studies have proven to be very specific; however, false positives and negatives have been noted at a rate of 10-20% (Miedany, Aty, & Ashour, 2004). Nerve conduction studies may be useful in diagnosing CTS, but the procedure is highly invasive and false negatives have been documented. Although this approach is effective for localizing the site of pathology and determining the severity of the condition, electrodiagnostic studies have limitations, such as the inability to provide information about structures surrounding the nerve, the inability to visualize abnormalities intrinsic to the median nerve, and the painful nature of the procedure (Cartwright et al., 2008).

Ultrasound has been found to be a cost-effective alternative to nerve conduction studies to diagnose carpal tunnel syndrome (Inui, et al., 2016). Ultrasonography provides a noninvasive procedure to visualize the median nerve and may be used as a viable diagnostic tool for CTS

(Hobson-Webb, Massey, Juel, & Sanders, 2008). A study done by Fowler et al., (2014) compared ultrasound and electrodiagnostic testing for the diagnosis of carpal tunnel syndrome. These researchers found that ultrasound can be used to confirm carpal tunnel syndrome with better specificity and equal sensitivity as compared with electrodiagnostic testing. The cross-sectional area of the median nerve has been found to be significantly larger in patients with carpal tunnel syndrome compared to normal controls (Inui, et al., 2016). The enlargement of the median nerve in CTS patients is thought to result from large myelinated fibers at the periphery of the fascicles, interfascicular epineurial fibrosis, and/or perineural thickening under chronic nerve compression (Mackinon, Dellon, Hudson, & Hunter, 1985). Azami et al., 2014, conducted a study to determine whether sonography can be an alternative method to nerve conduction study in the diagnosis of CTS. These researchers assessed electrodiagnostically proven CTS patients as well as healthy control subjects. The median nerve cross-sectional area and flattening ratio were measured at three various levels including proximal to the tunnel inlet, at tunnel inlet, and tunnel outlet. Results showed that the median nerve cross-sectional area at the tunnel inlet was 13.31 +/-3.23 mm^2 in CTS diseased hands and 8.57 +/-0.82 mm^2 in non-diseased hands. The cross-sectional area of the median nerve at various levels was significantly greater in the CTS hands than the non-diseased hands (P=0.001). The median nerve is enlarged proximal to the site of the compression in the carpal tunnel, which is supported by pathologic findings during surgery (Tuncali, Barutcu, Terxioglu, & Aslan, 2005). Fu et al., (2015) evaluated the diagnostic value of the inlet-to-outlet median nerve ratio (IOR) in patients with confirmed carpal tunnel syndrome. These researchers examined 46 wrists in 46 patients with CTS and 44 wrists in 44 healthy volunteers. The mean IOR in healthy volunteers (1.0) was smaller than that in CTS diseased patients (1.6, P<0.001). Receiver operating characteristic analysis showed a diagnostic advantage to using the IOR rather than the inlet cross-sectional area ($P<0.01$). These results showed that the ultrasonographic measurement of the cross-sectional area of the median nerve at the carpal tunnel inlet and the IOR are useful in diagnosing CTS.

There are multiple diagnostic tests used to diagnose CTS such as special tests, nerve conduction studies, and ultrasonography. Ultrasound is a viable tool that can be used to non-invasively view the carpal tunnel and median nerve.

Hand Function Assessment

There are several questionnaires that are used to acquire subjective information from patients who suffer from CTS. Questionnaires related to carpal tunnel syndrome used in this study include: the Boston Carpal Tunnel Questionnaire, the Quick Disabilities of the Arm, Shoulder, and Hand, and the Katz and Stirrat Hand diagram. The results of these questionnaires can help clinicians to determine disease severity, patient functionality, and outcome measurements.

The BCTQ is a CTS disease specific questionnaire used to evaluate symptoms and functional ability in CTS patients. A clinical study evaluated the reproducibility, internal consistency, validity, and responsiveness to clinical change of scales for the measurement of severity symptoms and functional status in CTS patients. The scales were found to be highly reproducible (Pearson correlation coefficient, $r= 0.91$ and 0.93 for severity of symptoms and functional status) and internally consistent (Cronbach alpa, 0.89 and 0.91 for severity of symptoms and functional status) (Levine et al., 1993). Greenslade, Mehta, Belward, & Warwick, 2004, conducted a study to measure responsiveness in 57 patients with a clinical diagnosis of CTS by completing the Disabilities of the Arm, Shoulder, and Hand (DASH) and the BCTQ before and after carpal tunnel decompression. These researchers found that responsiveness of the DASH was comparable with the BCTQ with standardized response means of 0.66, 1.07, and 0.62 for the DASH, BCTQ-symptoms, and BCTQ-function (Greenslade et al., 2004). Another study done by Bakhsh, Ibrahim, Khan, Smitham, & Goddard 2012, sought to evaluate and assess the validity, reliability, responsiveness, and bias of the BCTQ, DASH, and Manchester Modified Disabilities of the Arm, Shoulder, and Hand (M(2)DASH) questionnaires. These results were compared to those of nerve conduction studies. The results showed that the DASH and M(2)DASH questionnaires were not as responsive as the BCTQ scores. Researchers recommend that the BCTQ be used to assess early post-operative patient related outcomes for CTS (Bakhsh et al., 2012). Leite, Jerosch-Herold, & Song (2006) conducted a systematic review to determine the validity, reliability, and responsiveness of the BCTQ. These researchers found ten studies that met the inclusion criteria which included studies designed to evaluate one or several psychometric properties of the BCTQ. The BCTQ has shown to be a reliable and valid test to measure symptom severity and functionality in CTS patients. The MCID is 0.74 for the BCTQ (based on the average of both subscales) in distinguishing clinically important differences after carpal tunnel release (Leite et al., 2006).

The Quick Disabilities of the Arm, Shoulder, and Hand (QDASH) is a patient reported questionnaire also designed to measure function and symptoms in the upper extremity. The QDASH is a shortened version of the full-length Disabilities of the Arm Shoulder and Hand (DASH) and provides a region-specific outcome measure (Smith-Forbes, Howell, Willoughby, Pitts, & Uhl, 2016). A study aimed to assess the performance of the QDASH and its cross-sectional longitudinal validity and reliability by extracting QDASH item responses from the DASH questionnaire (Gummesson, Ward, & Atroshi, 2006). The DASH and QDASH scores were compared for the population and for different diagnostic groups. The mean DASH score was 34 (SD 22) and the mean QDASH score was 39 (SD 24). The mean and median QDASH scores were higher than the DASH scores for the different diagnostic groups. The mean difference between the QDASH and the DASH baseline scores were 4.2 (95% CI 3.2-5.3) and follow-up scores were 2.6 (1.7-3.4, and change scores were 1.7 (0.6-2.8) for the population. The ICC values were high for the agreement between the QDASH and DASH, exceeding 0.90 at baseline and follow-up (Gummesson et al., 2006). The DASH includes an optional performing arts module. The performing arts module consists of four items to evaluate disability when playing a musical instrument (Baadjou, de Bie, Guptill, & Smeets, 2017). Researchers sought to examine the psychometric properties of the performing arts module in musicians and found that the module showed good internal consistency (Cronbach's alpha 0.893) (Baadjou et al., 2017). For the purpose of this study, the performing arts module will be included with the QDASH for the visual artist and musician group. These questionnaires will provide specific information relating to musician and visual artists' hand function related to their trade.

Katz & Stirrat, (1990) developed a hand diagram used to provide subjective information on CTS related symptoms. Researchers tested their diagram on 63 patients and made associations between hand diagram ratings and clinical diagnoses. Out of 75 hands that had confirmed CTS diagnoses, 60 had classic or probable ratings for a sensitivity of 80%. In 10 hands without CTS, only one had a probable rating for a specificity of 90%.

These hand function assessment tools will provide researchers with information on the pain and functionality of musicians. Comparisons can be made with anatomical measurements of the carpal tunnel and median nerve to the reported pain and functionality of these participants.

Neurological Assessment

Sensory motor loss is a characteristic of CTS. There are several tests that assess sensory motor loss such as Semmes-Weinstein monofilament (SWM) testing and two-point discrimination testing. SWM is a clinical test that measures the response to a touching sensation of the monofilaments (Yildirim & Gunduz, 2015). The force applied by each monofilament increases with ascending size. Two-point discrimination is also useful in assessing neurological conditions. Two-point discrimination tests the density of touch receptors and requires a high degree of sensory processing (Wolny, Saulicz, Linek, Mysliwiec, & Saulicz, 2016). SWM and two-point discrimination testing are useful clinical tools used to evaluate peripheral nerve injuries and compression syndromes such as CTS.

Treatment

There are several treatment options for carpal tunnel syndrome depending on the severity of the patients' symptoms. Treatment for carpal tunnel syndrome typically involves avoidance of hand motions that exacerbates carpal tunnel syndrome (Newington et al., 2015). The most common conservative measures for the treatment of carpal tunnel syndrome are steroids, non-steroidal anti-inflammatory drugs, diuretics, pyridoxine, and wrist splints (Gerritsen et al., 2002). If conservative treatments do not alleviate symptoms, surgery may be considered. The carpal tunnel release involves an incision that transects the entire carpal tunnel ligament to relieve pressure on the median nerve (Newington et al., 2015).

Conclusion

Musicians suffer from a variety of upper-extremity overuse injuries (Dick et al., 2013). The prevalence of carpal tunnel syndrome in artists is high due to the repetitive hand motions they perform daily (Markison et al., 1998). There is no gold standard on CTS diagnosis; however ultrasound provides a non-invasive procedure that may help in diagnosing CTS along with the patient's reported symptoms. Those that have smaller carpal tunnel distances and larger median nerves have been associated with a higher incidence in developing CTS. Hand function assessment questionnaires and diagrams provide valuable information on disabilities in CTS diseased individuals. The purpose of this study is to determine the difference in carpel tunnel dimensions and the cross-sectional area of the median nerve in musicians as compared to non-musicians. These anatomical measurements can then be compared to hand function based on patient reported outcomes. The population in this study are male and female student musicians as well as non-musician male and female student participants. The carpal tunnel will be measured by taking images of the dimensions of the carpal tunnel and the cross-sectional area of the median nerve using diagnostic ultrasound imaging. The images will be measured, analyzed, and compared. Researchers hypothesize that the dimensions of the carpal tunnel in musicians will be smaller as compared to the controls. Researchers also hypothesize that the median nerve will be larger in musicians than in the non-musicians due to the repetitive motions that musicians perform daily. Finally, researchers hypothesize that these anatomical differences will correlate to decreased hand function based on patient reported outcomes.

CHAPTER 3
METHODS

Purpose

The purpose of this study was to compare the distance of the carpal tunnel and the cross-sectional area of the median nerve in musicians versus the non-musicians control group. Researchers hypothesized that musicians exhibited smaller carpal tunnel distances and larger median nerve areas as compared to non-musicians.

Participants

The participants in the study were college-aged students at Marshall University. There were a total of 76 participants in the study. There were 38 music students and professors in the musician group as well as 38 participants in the control group. A pilot study was performed on seven participants in order to perform sample size calculations. The 95% confidence interval for the minimal detectable change for the width of the carpal tunnel inlet based on the pilot test data was 0.50mm. The sample size calculations were performed using G*Power version 3.0.10 (University Kiel, Germany copyright 1992-2008). Statistical power was established at $1-\beta = 0.80$; statistical significance was set at $p < 0.05$. To detect difference of 0.50mm between groups, a sample size of 75 total participants was required. Following the testing of 15 subjects, analysis revealed that more testing was needed. Participants were recruited from the music department at Marshall University.

IRB Approval

All participants were required to read and sign an informed consent form prior to participation in the study (Appendix B). An IRB application was submitted and approved by the Marshall University Office of Research Integrity (Appendix A).

Exclusion Criteria:

- Participants under the age of 18 were not considered for participation.
- Participants with any medical condition that prevented sitting for prolonged periods of time were not considered for participation.

Inclusion Criteria:

- Music students and professors at Marshall University were considered for participation in the artist group.
- Any student and/or professor at Marshall University was considered for the non-musician group.

Research Design

This study is a between group descriptive study. This study was broken up into four comparisons:

1. Comparison of carpal tunnel distance between groups.
2. Comparison of median nerve cross-sectional area between groups.
3. Comparison of median nerve inlet to outlet ratio between groups.
4. Comparison of hand function between groups.

Independent Variables

Groups

Musicians

Non-musicians

Dependent Variables

Ultrasound Measurements

Carpal tunnel width at the inlet and outlet of the carpal tunnel

Cross-sectional area of the median nerve at the inlet and outlet of the carpal tunnel

Cross-sectional area of the median nerve inlet to outlet ratio

Measurement of hand function

BCTQ

QDASH

Katz & Stirrat hand diagram

Monofilament testing

Two-point discrimination testing

Wrist range of motion

Pinch strength

Musicians and non-musicians at Marshall University filled out a consent form to participate in the study. The participant screening includes the patient reported questionnaires, physical examination, and ultrasound imaging analysis. Participants completed a series of patient-reported questionnaires to assess the level of pain, function, and satisfaction in the forearm, wrist, and hand. Participants underwent a musculoskeletal physical examination of the forearm, wrist, and hand to assess their function. Wrist flexion, extension, pronation, and supination range of motion measurements were obtained. The examiner performed special tests specific to carpal tunnel syndrome including Tinel's sign, Phalen's test, and Durkan's compression test. Monofilament and two-point discrimination testing were conducted. Pinch strength and wrist range of motion were measured. Participants underwent an ultrasound examination of the cross-sectional area of the median nerve and the dimensions of the carpal tunnel. The screening was conducted during a single testing session at the Upper Extremity Research Laboratory of Marshall University School of Kinesiology (Gullickson Hall room 18).

Instrumentation

This study utilized instruments to measure the distance of the carpal tunnel, cross-sectional area of the median nerve and to assess the function of the hand.

- A Mindray M5 Ultrasound scanner with variable frequency 5cm sound head. Shenzhen Mindray Bio-Medical Electronics Co LTD Shenzhen, China was used to assess the distance of the carpal tunnel and the cross-sectional area of the median nerve.
- A chair
- A table
- Ultrasound gel

- The Boston Carpal Tunnel Questionnaire (BCTQ) (Appendix C) was used to assess patient self- reported symptom severity and functionality in patients with CTS (Leite et al., 2006). The BCTQ was originally developed by Levine et al., 1993. The BCTQ uses two scales including the Symptom Severity Scale (SSS) and the Functional Status Scale (FSS). The SSS consists of 11 questions and uses a five-point grading scale. The FSS has 8 items which are rated for degree of difficulty on a five-point scale. Each scale shows a final score which ranges from 1 to 5, with the higher score indicating greater disability. Studies indicate that the BCTQ is a valid, reliable, responsive, and acceptable instrument (Leite et al. 2006).
- The Quick Disabilities of the Arm, Shoulder, and Hand (QDASH) (Appendix D) is an 11 question survey designed to measure physical function and symptoms in the upper extremity (Beaton, Wright, Katz, & Upper Extremity Collaborative, 2005). Participants choose from a 5-item response option for each item to measure function and symptoms in the participants' upper limb.
- The Katz & Stirrat hand diagram (Appendix E) is a self-administered hand diagram test that uses subjective information from the patient for the diagnosis and evaluation of CTS (Katz & Stirrat, 1990).
- Goniometer
- Jamar® Pinch Gauge
- Baseline Tactile Monofilaments
- Baseline 2-Point Discrim-A-Gon
- A blindfold

Procedure

Participants were tested by a certified athletic trainer.

Demographics

Demographic information was obtained including the participant's height, weight, sex, current age, and arm dominance. Further demographic information was obtained related to the participant's musical activities. This information is necessary to explore the differences between subjects with and without wrist pain and disability.

Patient Reported Questionnaires

Boston Carpal Tunnel Syndrome Questionnaire (BCTQ)

After completing the demographic section, participants completed the BCTQ (Appendix C). The symptom severity scale ranges from 1 to 5. General SSS questions range from 1 being normal to 5 being very serious. Other questions pertain to time and vary accordingly. The FSS asked the participants to rate their level of function when performing specific tasks such as writing, buttoning of clothes, etc. The FSS scale ranged from 1 being no difficulty to 5 being the inability to perform the activity at all due to hands and wrists symptoms. Levine et al., (1993) stated that means and standard deviations should be used to calculate the symptom and function scores. Storey et al., (2010) argued that representing 'stem scores' (ordinal data) using means may over-represent the extreme 'stem score' values in the individual's symptom and function scores. Instead researchers suggested that the symptom score totals be used and categorized into Asymptomatic (11), Mild (12-22), Moderate (23-33), Severe (34-44) and Very Severe (45-55) (Storey et al., 2010). Similarly, the functional scores were grouped into Asymptomatic (8), Mild (9-16), Moderate (17-24), Severe (25-32), and Very Severe (33-40). In an effort to avoid overrepresentation of the extreme “stem score”, the latter method was used to score the BCTQ in this study.

Quick Disabilities of the Arm, Shoulder, and Hand (QDASH)

Participants completed the QDASH with ample time (Appendix D). Questions are rated 0 to 5, 0 being no difficulty or pain and 5 being the inability to perform the task or extreme pain. The disability/symptom score is totaled by taking the sum of the responses divided by the total number of responses minus one and multiplied by 25. The maximum score is 100 and indicates a high upper extremity impairment (Harrington, Michener, Kendig, Miale, & George, 2014). The minimally clinically important difference (MCID) for the QDASH was reported as 18.7, MDC_{90} and AUC= 0.66 according to a study done by Smith-Forbes et. al (2016).

Katz and Stirrat Hand Diagram

The participants filled out the Katz and Stirrat hand diagram (ICC: 0.87) (Calfee et al., 2012). The participants marked areas on the hand diagram where they experienced symptoms of pain, tingling, numbness, or diminished sensation. The diagram was then rated as a classic, probable, possible, or an unlikely diagnosis of CTS according to the classification system (Amirfeyz, Gozzard, & Leslie, 2005).

Rating	Description
Classic	Tingling, numbness, or decreased sensation with or without pain in at least two of digits 1, 2, or 3. Palm and dorsum of the hand excluded; wrist pain or radiation proximal to the wrist allowed.
Probable	Same as for classic, except palmar symptoms allowed unless confined solely to ulnar aspect.
Possible	Tingling, numbness, or decreased sensation and/or pain in at least one of digits 1, 2, or 3.
Unlikely	No symptoms in Digits 1, 2, or 3.

Table 1 Rating system for hand diagrams (Katz & Stirrat, 1990).

Physical Examination

Wrist Flexion and Extension

A goniometer was used to measure wrist flexion and extension. The patient was seated with the elbow flexed to 90 degrees and the forearm and wrist in a neutral position. The dorsal-volar technique was used to measure wrist flexion and extension. The distal arm was aligned with the third metacarpal and the proximal arm will be aligned centrally on the forearm (Carter et al., 2009). The goniometer was placed on the dorsal surface for flexion and on the volar surface for extension (Figure 2.1). The participant was instructed to actively flex their wrist as far as possible and the researcher will record the measurement (Figure 2.2). The participant was then instructed to extend their wrist as far as possible and that measurement will be recorded (Figure 2.3). Wrist extension measurements were performed three times each. LaStayo & Wheeler (1994) sought to determine the inter- and intra-rater reliability of three techniques for wrist flexion and extension: placement of the device along the ulnar, radial, or dorsal-volar surfaces of the wrist. These researchers found the dorsal-volar technique of wrist flexion and extension measurements to be the most reliable (LaStayo & Wheeler, 1994).

Figure 2.1 Goniometer placed in neutral position along the lateral forearm, wrist, and hand.

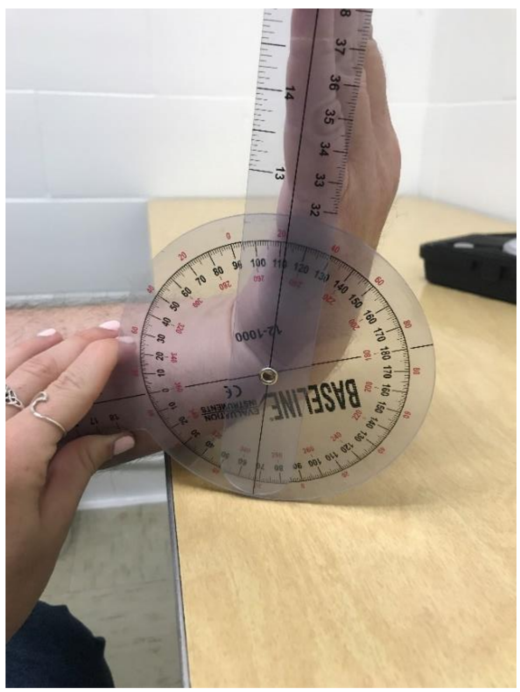

Figure 2.2 Wrist flexion goniometer placement.

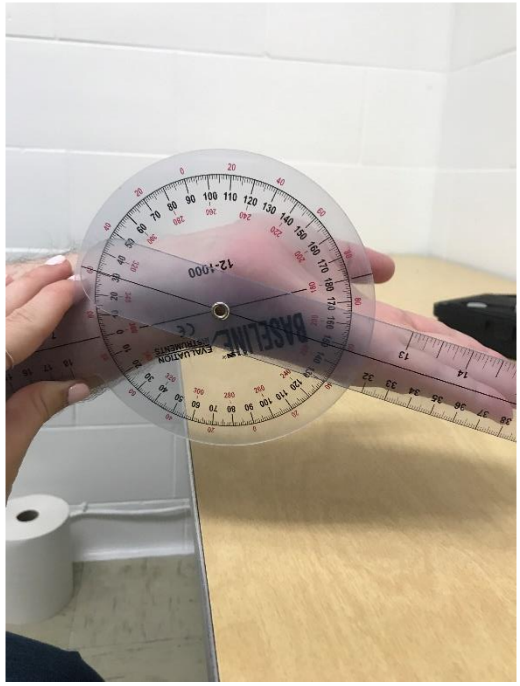

Figure 2.3 Wrist extension goniometer placement**.**

Wrist Pronation and Supination

A goniometer was used to measure participant’s wrist pronation and supination. For pronation, the participant started in a neutral position with the thumb facing superiorly. The stationary arm of the goniometer lined up perpendicular to the wrist. The participant was instructed to pronate their wrist as far as possible and the moving arm of the goniometer followed the distal radius. Similarly, for wrist supination the participant started in a neutral position with the thumb facing superiorly. The stationary arm of the goniometer lined up perpendicular to the wrist. The participant was instructed to supinate their wrist as far as possible and the moving arm of the goniometer followed the distal radius.

Carpal Tunnel Syndrome Special Tests

The researcher performed three special tests on each participant. First, Phalen's maneuver was performed where the participant flexed the wrist for 60 seconds and reported signs of pain or paresthesia in the median nerve distribution as described by Katz & Simmons (2002). The researcher recorded a positive test for any numbness, pain, or tingling. Tinel's sign was performed where the researcher tapped lightly over the flexor retinaculum. A positive test was recorded if the participant reported radicular symptoms into the hand. Durkan's compression test was performed where the clinician applied direct pressure over the carpal tunnel for 30 seconds as described by Durkan (1994). A positive test was recorded if the participant reported a reproduction of numbness or tingling in the distribution of the median nerve within 30 seconds.

Wrist Extension and Flexion Strength Assessment

Wrist extension strength was measured using a handheld dynamometer. The participant started with their wrist pronated and fingers flexed. The researcher placed the dynamometer over the dorsal aspect of the hand over the metacarpal bones. The participant was instructed to extend their wrist and the force measurement on the dynamometer was recorded. The procedure was performed twice and each force was recorded by the researcher. Similarly, wrist flexion was measured using a handheld dynamometer. The participant started with their wrist supinated and fingers extended. The researcher placed the dynamometer over the palmar surface of the metacarpal bones. The participant was instructed to flex their wrist and the force measurement on the dynamometer was recorded. The procedure was performed twice and each force was recorded by the researcher.

Pinch Strength Assessment

Pad and key pinch strength was assessed using a Jamar® Pinch Gauge. The participant was seated with shoulders adducted and neutrally rotated. The participant's elbow was flexed at a 90-degree angle and the forearm and wrist were in a neutral position. The participant was instructed to use the tip of the finger to maximally squeeze the pinch gauge (Figure 3). Three measurements with the maximum force possible were made per finger and the average values was calculated in kilograms-force (Fernandes, Nakachima, dos Santos, Faloppa, & Albertoni, 2013). This procedure was repeated for the pad and key pinch measurements. A study was done to collect normative pinch strength in adults and found that the average index finger tip pinch strength in men ages 20-24 was 18 lbs. of force (+/- 3.5 lbs.) and 11.1 lbs. of force (+/- 2.0) in women (Mathiowetz et al., 1985). This same study found that key pinch strength averaged 26.0 lbs. (+/- 3.5) in men ages 20-24 and 17.6 lbs. (+/-2) in women aged 20-24. A pilot study was performed using nine healthy volunteers at Marshall University. The results of the pinch assessment pilot study are shown in Table 2.1.

	Finger 2	Finger 3	Finger 4
Mean	3.7 (+/-1.9)	3.9 (+/-1.6)	2.5 (+/-0.88)
ICC	0.97	0.96	0.76
SEM 95%	0.69	0.62	0.84
MDC	0.50	0.45	0.61
MDC 95%	0.98	0.88	1.2

Table 2.1 Pad pinch statistics
Pad pinch strength (Kg.) measurement error, (interclass correlation coefficient (ICC), 95% confidence interval of the standard error of the measure (SEM), minimal detectable change (MCD).

Mean	7.4 (+/- 2.0)
ICC	0.94
SEM 95%	0.96
MDC	0.70
MDC 95%	1.4

Table 2.2 Key pinch statistics
Key pinch strength (Kg) measurement error, (interclass correlation coefficient (ICC), 95% confidence interval of the standard error of the measure (SEM), minimal detectable change (MCD).

Figure 3 Pinch strength dynamometry
Index finger pad pinch (Left) and key pinch (right) strength measured in kilograms.

Semmes-Weinstein Monofilament (SWM) Testing

SWM measurements were obtained through the application of Baseline Tactile Monofilaments to each digit with the wrist in a neutral position and the fingers slightly extended. Prior to the test, the researcher applied a large monofilament to the pad of the participants thumb to orient the participant with the sensation they will feel. The participant was blindfolded to limit bias. The researcher began with the lightest monofilament and applied enough pressure to bow the monofilament on the pad of each digit (Figure 4). The participant was instructed to say the word “touch” when the monofilament was felt. The monofilaments were applied three times to the tip of each finger. Once the participant responded “touch” to the same monofilament two times, the monofilament level was recorded. If the participant did not respond “touch” at least two out of three times, the researcher moved to the next largest monofilament and repeated the test. A numeric value was recorded that the logarithm of ten times the force in milligrams require to bow the monofilament (Yildirim & Gunduz, 2015). A study that assessed monofilament testing was performed on 245 volunteers and found that the 200 mg filament was confirmed as normal (Wagenaar, Brandsma, Post, & Richardus, 2014).

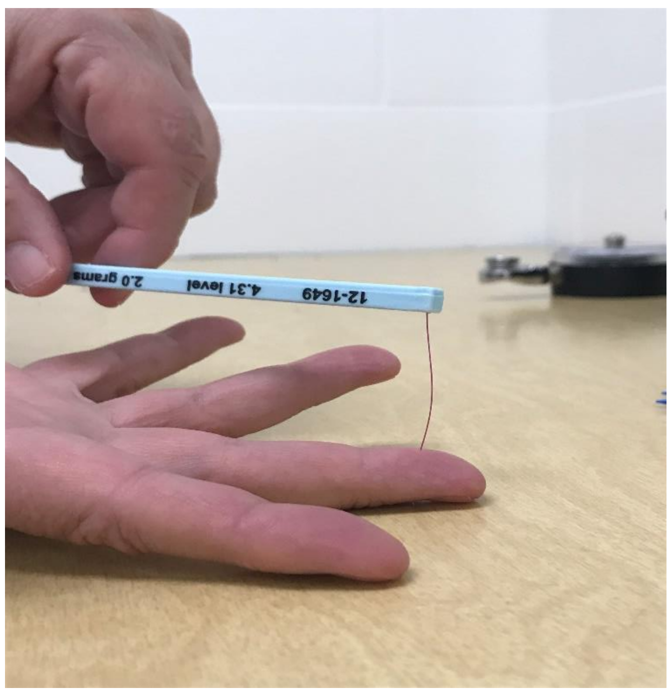

Figure 4 Monofilament testing.

Two-point Discrimination Testing

A standardized Baseline 2-Point Discrim-A-Gon was used. This tool includes two plastic circular discs with spikes placed at different distances from 1 to 15 mm. Prior to the test, the researcher applied one spike and then two spikes to the pad of the participants thumb to orient the participant with the sensation. The participant was blindfolded to limit bias. The discriminator spikes were applied perpendicularly to the long axis of the distal phalanges of the fingers as described by Wolny et al., (2016). The discriminator was placed on the skin with enough pressure for the participant to feel stimulation (Figure 5). The participant was asked to respond “one” or “two” upon application of the stimulus. The test was finished when two of the same answers were achieved from three consecutive trials (Crosby & Dellon, 1989). The normative value for index finger two-point discrimination for men and women ages 20-29 is 4mm (van Nes et al., 2008).

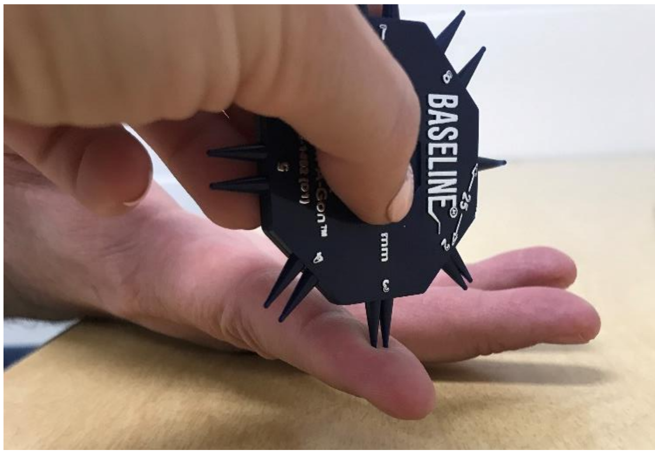

Figure 5 Two-point discrimination testing.

Diagnostic Ultrasound

Ultrasound images of the participant’s dominant wrist were collected. A diagnostic ultrasound unit, (Mindray, Mindray Ltd. And National Ultrasound, Inc., Duluth, GA USA) with an adjustable 8.0-12MHz frequency linear array transducer was used to collect images of the anterior wrist. A detailed evaluation of the carpal tunnel was performed. Two researchers were used to collect the images. The first researcher operated the transducer to obtain images of the median nerve and carpal tunnel. The second researcher operated the imaging aspect of the ultrasound and allowed the transducer to remain in optimal contact while the image was gathered.

Ultrasound procedure

Participants were seated with the forearm resting in a supine position on a table. The fingers were in a resting, slightly extended position. Longitudinal and transverse scans of the median nerve were obtained from the distal segment of the forearm to the carpal tunnel outlet. The volar wrist crease was used as an initial external reference point as described by Azami et al., 2014. The cross-sectional area of the median nerve was measured at two levels including the tunnel inlet and the tunnel outlet as described by Mondelli, Filippou, Gallo, and Frediani, 2008. The researcher identified the median nerve in the longitudinal view at the base of the palm. The researcher then turned the sound head to obtain a transverse view of the carpal tunnel and median nerve at the inlet of the tunnel. Measurements of the cross-sectional area of the median nerve and the carpal tunnel distance were performed using the distance and area features on the ultrasound machine. Median nerve cross-sectional area measurements were performed at the hyperechoic rim of the nerve using the manual tracing technique (Mondelli et al., 2008). The carpal tunnel was measured from the anteroposterior distance from the flexor retinaculum to the boney floor of the carpal tunnel. Images of the carpal tunnel were taken at the inlet and outlet of the tunnel. The inlet-to-outlet median nerve area ratio (IOR) was calculated as such: cross-sectional area of the median nerve at carpal tunnel inlet/cross-sectional area at carpal tunnel outlet.

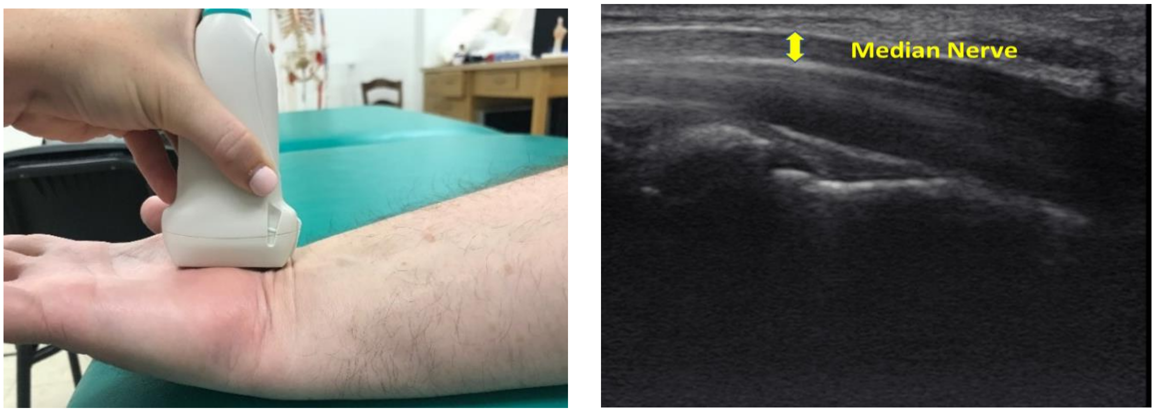

Figure 6 Longitudinal ultrasound head placement and image
The left image shows the ultrasound head placement during the longitudinal view of the carpal tunnel. The right image shows ultrasound image of the longitudinal view of the median nerve.

Figure 6.2 Transverse ultrasound head placement and image
The left image shows the transverse ultrasound head placement at the carpal tunnel inlet. The right image shows the transverse view of the median nerve.

Figure 6.3 Ultrasound head placement at the carpal tunnel outlet

Pilot Study Results

A pilot study was conducted on nine healthy volunteers at Marshall University to establish the reliability of all ultrasound measurements and to determine measurement error for sample size calculations. Results showed that the mean distance at the carpal tunnel inlet was 8.73mm (STDEV = 0.94) with an SEM of 0.35 (SEM 95% = 0.69), an ICC value of 0.86, and an MDC of 0.50mm (MDC 95% = 0.98). The mean distance at the carpal tunnel outlet was 8.0 mm (STDEV = 0.87mm) with an SEM of 0.36 mm (SEM 95% = 0.70mm), an ICC value of 0.83, and an MDC of 0.50mm (MDC 95% = 0.99mm). The mean cross-sectional area of the median nerve at the tunnel inlet was 0.79 mm^2 (STDEV = 0.19 mm^2) with an SEM of 0.11mm^2 (SEM 95% = 0.22 mm^2), an ICC value of 0.66, and an MDC of 0.15 mm^2 (MDC 95% = 0.31 mm^2). The mean cross-sectional area of the median nerve at the tunnel outlet was 0.61 mm^2 (STDEV = 0.18) with an SEM of 0.10 (SEM 95% = 0.2 mm^2), an ICC value of 0.66, and an MDC of 0.14 mm^2 (MDC 95% = 0.28 mm^2).

Statistical Analysis

The data analysis consisted of examining the BCTQ and QDASH questionnaires and the Katz and Stirrat Hand Diagram and comparing the cross-section area of the median nerve and carpal tunnel dimensions between groups. Categorical variables were analyzed using χ^2 analysis. An analysis of variance (ANOVA) was used to analyze differences between the groups and their associated procedures. A 2-way ANOVA (location by group) with repeated measures on location (inlet, outlet) was performed using the SPSS version 22.0 (IBM Corp., Rochester, NY, USA). Statistical significance was determined at $p < 0.05$.

CHAPTER 4

RESULTS

There were a total of 76 participants in the study, 38 in the musician group and 38 in the non-musician control group. Participant demographics and patient reported questionnaire outcomes can be found in Table 3. There were no statistically significant ($p > 0.05$) differences in age, sex, height, or weight between the musician and control groups.

Demographic Data		
Groups	Musician	Control
Age (Years)	(*M*=22.7, *SD*=8.3)	(*M*=21.8, *SD*=2.1)
Male (Prevalence Percentage)	16 (42%)	24 (63%)
Female (Prevalence Percentage)	22 (58%)	14 (37%)
Mean Height (cm)	(*M*=173.9 , *SD*=9.9)	(*M*=170.6, *SD*=10.1)
Mean Weight (kg)	(*M*=97.9, *SD*=30.3)	(*M*=76.3, *SD*=16.6)
Mean Daily Practice (Hours)	(*M*=2.4, *SD*=1.1)	0
Mean Weekly Practice (Days)	(*M*=5.3, *SD*=1.4)	0
Mean Weekly Practice (Hours)	(*M*=13.4, *SD*=7.8)	0
Wrist function (percentage of function out of 100)	96%	98%

Table 3 Participant demographics
Demographics of age, sex, height, weight, practice time descriptions, and percentage of wrist function compared between the musician and control groups.

QDASH and QDASH Performance Results

The musician group had a higher statistically significant QDASH score (10.0 ± 9.5) as compared to the control group (4.4 ± 9.9) ($p = 0.014$). These results indicate a higher dysfunction amongst musicians. The QDASH performing arts section was 18.2 ± 3.0 amongst musicians.

BCTQ Results

BCTQ symptom and functional scores reported using the Storey method can be found in tables 4-5.

	Musicians	Control	Statistical Significance
Asymptomatic	9	32	(n=76) ($\chi2$ = 29.967, p = 0.00)*
Mild	27	4	
Moderate	2	2	

Table 4 BCTQ symptom scores
BCTQ symptom scores compared between the musician and control groups. The asterisk (*) indicates a significant difference in symptom scores between the musician and control groups (n = 76) ($\chi2$ = 29.967, p = 0.00).

	Musicians	Control	Statistical Significance
Asymptomatic	15	30	(n=76) ($\chi2$ = 11.989, p = 0.02)*
Mild	21	7	
Moderate	1	1	

Table 5 BCTQ functional scores
BCTQ functional scores compared between the musician and control groups. The asterisk (*) indicates a significant difference in symptom scores between the musician and control groups (n =76) ($\chi2$ = 11.989, p = 0.02).

Hand Diagram Results

The musician group had statistically significantly more participants with symptoms of carpal tunnel syndrome as compared to the control group for both the right (χ^2 = 8.328, p = 0.040) and left (χ^2 = 13.323, p = 0.004) hand according to the Katz and Stirrat hand diagram (Tables 6 and 7).

	Musicians	Control
Classic	2	1
Probable	6	0
Possible	4	2
Unlikely	26	35

Table 6 Right hand diagram results

	Musician	Control
Classic	3	1
Probable	5	0
Possible	5	0
Unlikely	25	37

Table 7 Left hand diagram results

Range of Motion Measurements

Wrist range of motion measurements can be found in Table 8. The musician group had significantly less wrist flexion range of motion on the right (man difference = 11.9 ± 17.2°, t= -2.99, p = 0.004) and left (measurement difference = 11.2 ± 17.6°, t = -2.75, p = 0.007) compared to the controls' right.

	Musician (Mean ± SD)	Control (Mean ± SD)
Right Wrist Extension	52.8 ± 12.5°	54.2 ± 11.0°
Left Wrist Extension	49 ± 13.4°	52.7 ± 12.7°
Right Wrist Flexion	58.9 ± 16.1°*	70.8 ± 18.4°*
Left Wrist Flexion	54.1 ± 17.0°*	65.3 ± 18.3°*
Right Wrist Pronation	80.3 ± 12.9°	80.3 ± 12.9°
Left Wrist Pronation	83.4 ± 13.8°	85 ± 11.1°
Right Wrist Supination	81.7 ± 16.7°	85.5 ± 12.3°
Left Wrist Supination	84.5 ± 15.1°	89.5 ± 9.5°

Table 8 Wrist range of motion measurements
Wrist range of motion measurements compared bilaterally between groups. The asterisk (*) marks a statistically significant difference between wrist flexion on both the right and left sides between groups.

Carpal Tunnel Syndrome Special Test Results

The positive Tinel's sign was statistically significantly higher on the right side in the musician group (n = 6) more frequent than the control group (n = 1) (χ^2 = 3.934, p = 0.047). The positive Tinel's sign was statistically significantly higher on the left side in the musician group (n=7) more frequent than the control group (n=0) (χ^2 =7.929, p = 0.005). The positive Phalen's test was statistically significantly higher on the right side in the musician group (n=8) more frequent than the control group (n = 1) (χ^2 = 6.176, p = 0.013). The positive Phalen's test was statistically significantly higher on the left side in the musician group (n=6) more frequent than the control group (n = 0) (χ^2 = 6.514, p = 0.011). The positive Durkan's compression test was seen on the right side in the musician group (n = 10) more frequent than the control group (n=6), but was not significant (χ^2 = 1.411, p = 0.235). The positive Durkan's compression test was statistically significantly higher on the left side in the musician group (n=13) more frequent than the control group (n = 1) (χ^2 = 12.608, p = 0.000).

Strength Measurements

There were no statistically significant differences between the musician and control group compared bilaterally for the wrist flexion and extension strength, grip and pinch strength measurements (Tables 9 – 12).

	Musician (Mean ± SD)	Control (Mean ± SD)
Right Wrist Extensor Strength	12.1 ± 2.1 kg	14.6 ± 10.2 kg
Left Wrist Extensor Strength	11.7 ± 2.2 kg	12.2 ± 2.5 kg
Right Wrist Flexion Strength	12.1 ± 2.2 kg	12.9 ± 2.2 kg
Left Wrist Flexion Strength	12.9 ± 2.3 kg	13.4 ± 2.2 kg

Table 9 Wrist extension and flexion strength measurements
There were no significant differences in left and right wrist extension and flexion strength measurements between the musician and control groups.

	Musician (Mean ± SD)	Control (Mean ± SD)
Right Grip Strength 2	35.2 ± 12.8 kg	35.3 ± 10.3 kg
Left Grip Strength 2	33.2 ± 12.5 kg	33.4 ± 10.2 kg
Right Grip Strength 3	30.1 ± 12.2 kg	31.7 ± 9.9 kg
Left Grip Strength 3	29.4 ± 11.7 kg	30.3 ± 9.7 kg

Table 10 Grip strength measurements

Grip strength measurements at levels two and three compared bilaterally between groups. There were no significant differences in right and left grip strength measurements between the musician and control groups.

	Musician (Mean ± SD)	Control (Mean ± SD)
Right Pinch Strength 2nd Finger	3.3 ± 1.5 kg	3.7 ± 1.5 kg
Left Pinch Strength 2nd Finger	3.6 ± 1.7 kg	3.4 ± 1.4 kg
Right Pinch Strength 3rd Finger	3.5 ± 1.6 kg	3.6 ± 1.6 kg
Left Pinch Strength 3rd Finger	3.2 ± 1.5 kg	3.4 ± 1.3 kg
Right Pinch Strength 4th Finger	1.8 ± 1.2 kg	2.0 ± 1.2 kg
Left Pinch Strength 4th Finger	1.7 ± 1.1 kg	1.8 ± 1.0 kg

Table 11 Pinch strength measurements

Pinch strength measurements in fingers two through four compared bilaterally between groups. There were no significant differences in pinch strength measurements in fingers two through four compared bilaterally between the musician and control group.

	Musician (Mean ± SD)	Control (Mean ± SD)
Key Grip Right	7.7 ± 1.7 kg	7.6 ± 1.7 kg
Key Grip Left	7.5 ± 2.0 kg	7.2 ± 1.9 kg

Table 12 Key grip strength measurements

Key grip strength measurements compared bilaterally between the musician and control groups. There were no significant differences in key grip strength measurements between the musician and control groups compared bilaterally.

Two-Point Discrimination Testing (2PD)

The results of the 2PD test can be found in tables 13 (right hand) and 14 (left hand).

Digit	2PD Category (mm)	Musicians per Category	Controls per Category	Statistical Significance
Right 1st digit	2	5	9	$\chi2 = 1.556$, $p = 0.459$
	3	26	24	
	4	7	5	
Right 2nd digit	2	5	9	$\chi2 = 4.586$, $p = 0.205$
	3	31	25	
	4	1	4	
	5	1	0	
Right 3rd digit	2	8	13	$\chi2 = 2.865$, $p = 0.413$
	3	26	21	
	4	3	4	
	5	1	0	
Right 4th digit	2	3	12	$\chi2 = 7.890$, $p = 0.048$*
	3	28	23	
	4	6	3	
	5	1	0	
Right 5th digit	2	7	11	$\chi2 = 3.551$, $p = 0.169$
	3	21	23	
	4	10	4	

Table 13 Right hand 2PD measurements
2PD measurement results for the right hand compared between the musician and control groups. The asterisk (*) indicates a statistically significant difference in the right fourth digit between the musician and control groups ($p < 0.05$).

Digit	2PD Category (mm)	Number of Musicians per Category	Number of Controls per Category	Statistical Significance
Left 1st digit	2	4	11	$\chi2 = 4.388$, p = 0.111
	3	30	25	
	4	4	2	
Left 2nd digit	2	13	12	$\chi2 = 2.188$, p = 0.335
	3	21	25	
	4	4	1	
Left 3rd digit	2	8	8	$\chi2 = 0.162$, p = 0.922)
	3	27	26	
	4	3	4	
Left 4th digit	2	6	9	$\chi2 = 1.020$, p = 0.601
	3	26	25	
	4	6	4	
Left 5th digit	2	8	12	$\chi2 = 2.267$, p = 0.519)
	3	22	18	
	4	7	8	
	5	1	0	

Table 14 Left hand 2PD measurements
2PD measurement results for the left hand compared between the musician and control groups.

Monofilament Test

The results of the monofilament test can be found in tables 15 (right hand) and 16 (left hand).

Digit	Monofilament grams of force	Number of Musicians per Category	Number of Controls per Category	Statistical Significance
Right first digit	0.07	27	35	$\chi 2 = 5.801$, $p = 0.055$
	0.4	10	3	
	2.0	1	0	
Right second digit	0.07	25	33	$\chi 2 = 4.986$, $p = 0.083$
	0.4	12	5	
	2.0	1	0	
Right third digit	0.07	30	35	$\chi 2 = 2.718$, $p = 0.257$
	0.4	6	2	
	2.0	2	1	
Right fourth digit	0.07	29	35	$\chi 2 = 3.674$, $p = 0.159$
	0.4	7	2	
	2.0	2	1	
Right fifth digit	0.07	27	35	$\chi 2 = 6.032$, $p = 0.049$*
	0.4	9	3	
	2.0	2	0	

Table 15 Right hand monofilament test results
Monofilament test results for the right hand compared between the musician and control groups. The asterisk (*) indicates a statistically significant difference in the right fifth digit compared between the musician and control groups (n = 76) ($\chi 2 = 6.032$, $p = 0.049$).

Digit	Monofilament Category (mg)	Musicians per Category	Controls per Category	Statistical Significance
Left first digit	0.07	30	37	$\chi2 = 6.231$, $p = 0.044$*
	0.4	7	1	
	2.0	1	0	
Left second digit	0.07	26	33	$\chi2 = 3.713$, $p = 0.054$
	0.4	12	5	
Left third digit	0.07	27	36	$\chi2 = 7.619$, $p = 0.022$*
	0.4	10	2	
	2.0	1	0	
Left fourth digit	0.07	27	36	$\chi2 = 7.886$, $p = 0.019$*
	0.4	8	2	
	2.0	3	0	
Left fifth digit	0.07	27	34	$\chi2 = 4.137$, $p = 0.126$
	0.4	9	3	
	2.0	2	1	

Table 16 Left hand monofilament test results
Monofilament test results for the left hand compared between the musician and control groups. The asterisk (*) indicates a statistically significant ($p < 0.05$) difference in the left first third, and fourth digits compared between the musician and control groups.

Carpal Tunnel Width Measurements

There were no significant differences in the carpal tunnel widths at the inlet and outlet between groups compared bilaterally. The mean right carpal tunnel inlet width for musicians was 8.9 ± 1.1 mm. and 8.5 ± 1.1 mm. for the control group. The mean left carpal tunnel inlet was 9.2 ± 1.2 mm. for musicians and 8.9 ± 1.2 mm. for the control group. The mean right carpal tunnel outlet width was 7.5 ± 0.9 mm. for musicians and 7.4 ± 0.7 mm. for controls. The mean left carpal tunnel outlet width was 7.5 ± 0.7 mm. for the musicians and 7.6 ± 0.8 mm. for controls.

Median Nerve Cross-Sectional Area Measurements

The median nerve cross-sectional area was significantly greater at the carpal tunnel inlet on both the right and left sides as compared to the control group ($p < 0.05$). The mean median nerve cross-sectional area in the right carpal tunnel inlet was 9.4 ± 2.4 mm^2 in musicians and 7.9 ± 1.6 mm^2 in the control group ($t = 3.190$, $p = 0.002$). The mean median nerve cross-sectional area in the left carpal tunnel inlet was 9.1 ± 2.0 mm^2 in musicians and 8.2 ± 1.5 mm^2 in the control group ($t = 2.134$, $p = 0.036$). The mean median nerve cross-sectional area was not significantly different at the carpal tunnel outlet on either the right or left sides compared between groups.

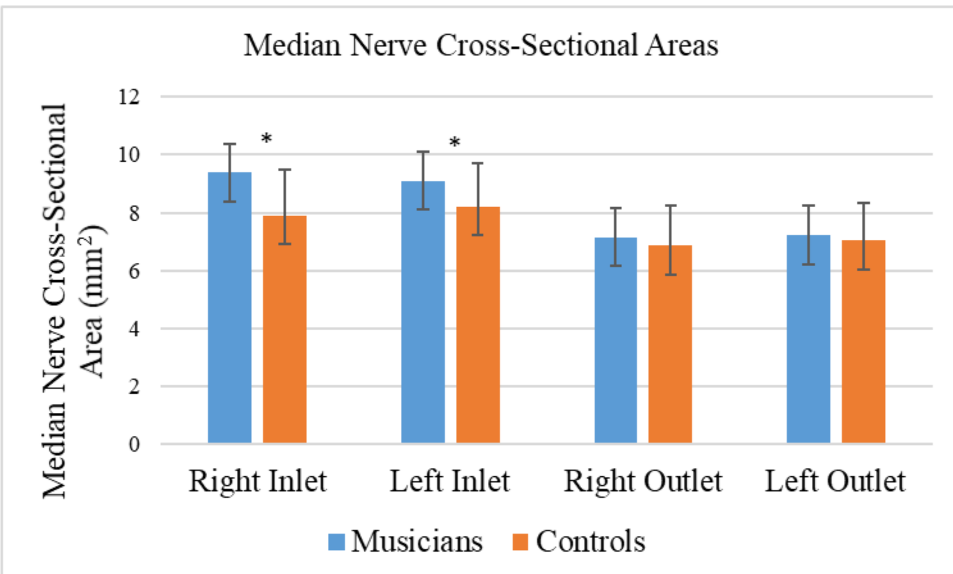

Figure 7 Median nerve cross-sectional area measurements at the carpal tunnel inlet and outlet
Median Nerve Cross-Sectional area measurements at the carpal tunnel inlet and outlet were compared bilaterally between groups. The asterisk (*) marks a statistically significant difference between the median nerve cross-sectional area measurements at the right and left carpal tunnel inlets between the musician and control group.

Inlet-to-Outlet Ratio of Median Nerve

The IOR in both the right and left sides was significantly greater in the musician group as compared to the control group. The right side IOR was 1.3 ± 0.3 in musicians and 1.1 ± 0.2 in the control group ($t = 3.006$, $p = 0.004$). The left side IOR was 1.2 ± 0.2 in musicians and 1.1 ± 0.2 in the control group ($t = 2.138$, $p = 0.036$). These measurements can be seen in Figure 8.

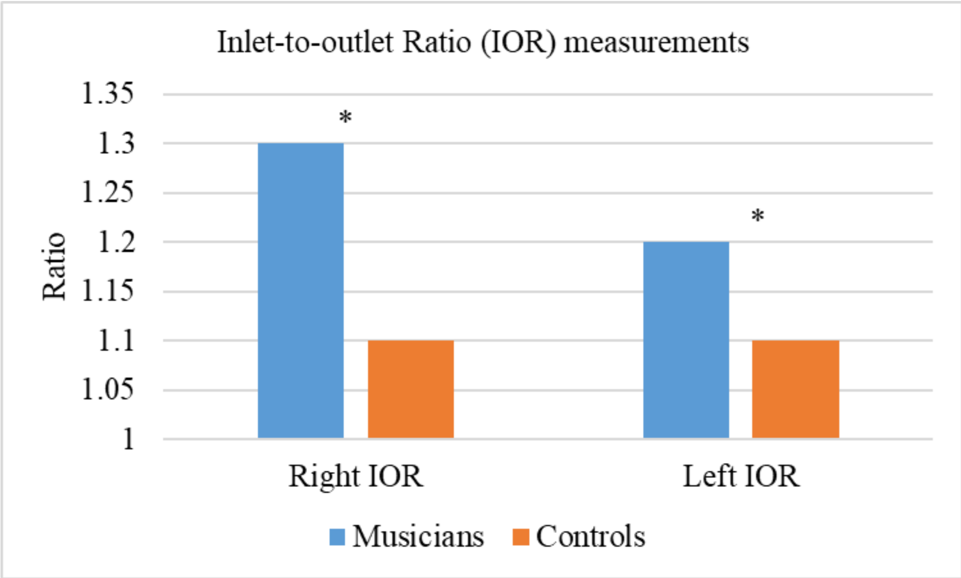

Figure 8 Inlet-to-outlet ratio measurements
The inlet-to-outlet ratio measurements compared bilaterally between the musician and control group. The asterisk (*) marks a statistically significant difference in IOR values between the musician and control group on both the right and left side.

CHAPTER 5
DISCUSSION

Summary of Current Study

The musician group had a larger median nerve cross-sectional area at the carpal tunnel inlet, a larger inlet-to-outlet ratio, less wrist flexion range of motion, decreased monofilament sensation, and higher reported disability and CTS symptoms as compared to the non-musician control group. These differences were observed in both the right and left sides of each group.

Current Study in the Context of Relevant Studies

Several studies have identified musculoskeletal conditions as common among musician populations, specifically peripheral nerve entrapments such as carpal tunnel syndrome (Zaza, 1998, Fry, 1989, Markison et al., 1998). However, research has not been conducted to identify differences in the carpal tunnel dimensions, median nerve cross-sectional areas, IOR's, and hand function among musicians. The first hypothesis of the current investigation was not supported; there was not a difference in the width of the carpal tunnel between musicians and non-musicians. The findings of the current study support the remaining hypotheses and help explain the high prevalence of carpal tunnel syndrome in musicians.

The musician group had a QDASH score of 10.0 ± 9.5. These results are less than those reported by Ajidahun, Mudzi, Myezwa, & Wood (2016) who found that string instrumentalists had a QDASH score of 12.9 ± 13.2. These results may differ due to differences in the inclusion criteria of musician participants. For this study, all musicians were included instead of only string instrumentalists. These results indicate a higher dysfunction amongst musicians. Although the results of the QDASH showed that the musicians had a higher dysfunction than the controls, the minimal clinically important difference (MCID) for the QDASH is 15.91 points (sensitivity, 79%; specificity, 75%) (Franchignoni et al., 2014). The QDASH performing arts section was 18.2 ± 3.0 amongst musicians in this study. The level of disability as determined by the QDASH of the current study are consistent with the result reported by Ajidahun et al., (2016) (18.0 ± 20.5).

The mean median nerve cross-sectional area was statistically greater in the musicians as compared to the control group (Figure 7). This result partially supports the second hypothesis of the current investigation. The mean median nerve cross-sectional area in the carpal tunnel inlet in musicians was 9.4 ± 2.4 mm^2 on the right and 9.1 ± 2.0 mm^2 on the left. Zahng et al. (2015) reported a mean cross-sectional area at the carpal tunnel inlet of 12.86 ± 4.83 mm^2 in a CTS diseased group. Many studies have reported cross-sectional areas of the median nerve at the carpal tunnel inlet cut-off values for diagnosing CTS, ranging from 9 to 15 mm^2 with 57–98% sensitivity and 51–100% specificity (Zahng et al., 2015). A meta-analysis reported that a cross-sectional area at the carpal tunnel inlet ≥ 9mm^2 is the best single diagnostic criterion of CTS (Tai, Wu, Su, Chern, & Jou, 2012). Using this criteria, the musicians would fall into a CTS diagnosis category on both the right and left sides. The mean median nerve cross-sectional area for the control group was 7.9 ± 1.6 mm^2 on the right side and 8.2 ± 1.5 mm^2 on the left. These results are slightly less than the controls used in the Zahng et al. (2015) study who showed a mean median nerve cross-sectional area at the carpal tunnel inlet of 8.55 ± 1.56 mm^2. These differences between studies may be due to the small sample size used in their study which only had 23 controls. The findings of the current study are consistent with mechanisms leading to the development of carpal tunnel syndrome.

There was no significant difference in the cross-sectional area of the median nerve at the carpal tunnel outlet between groups. This finding was also reported in a previous study where the cross-sectional area at the carpal tunnel outlet was 9.2 ± 2.8 mm^2 in a CTS diseased group and 8.3 ± 1.3 mm^2 in a control group (p=0.492) (Fu et al., 2015). This finding was explained due to ultrasonography being an operator-dependent test and measurements of the median nerve cross-sectional area at the carpal tunnel outlet are more technically difficult than at the inlet (Visser, Smidt, & Lee, 2008).

The musicians had a significantly higher IOR on both the right 1.3 ± 0.3 and left 1.2 ± 0.2 sides as compared to the controls (Figure 8). This finding supports the third hypothesis of the current investigation. Fu et al. (2015) examined the carpal tunnels of forty-eight clinically diagnosed CTS patients and forty-eight healthy volunteers. The control group mean IOR was 0.8 and the CTS diseased group had a mean IOR of 1.7. The musician group in the present study had IORs that were higher than the control group used in Fu et al. (2015); however, it was not as high as the CTS diseased hand group. Fu et al. (2015) recommended an optimal diagnostic cutoff value IOR of 1.3. Although the musicians were not clinically diagnosed with CTS, many would fall into the CTS diagnosed category based on their IOR scores. Zahng et al. (2015) further examined the differences in IOR values between mild, moderate, and severe CTS diseased hands. Using the cut-off values from the receiver operating characteristic curve, the area under the curve of the IOR indicated that the best cut-off value to discriminate between mild versus moderate and severe was 1.29 and the cut-off value for moderate versus severe was 1.52 (Zahng et al., 2015). According to these values, the musicians right hands would fall into the moderate category and their left hands would fall into the mild category.

The fourth hypothesis of the current investigation was supported; musicians did have greater levels of disability and impairment along with a greater prevalence of carpal tunnel syndrome symptoms then non-musicians. The mean wrist flexion for the musician group was 58.9° on the right side and 54.1° on the left side. The control group had 70.8° on the right side and 65.3° on the left side. Normal wrist flexion is 73° (Klum, Wolf, & Hahn, 2012). These results may be explained by further exploring the way the musicians' hands are positioned while playing their instruments.

There were no significant differences in two-point discrimination testing between the musicians and controls except for the right fourth digit (Table 13). Normal is considered to be any measurement ≤ 6mm (Louis et al., 1984). These results are consistent with Robinson & Kincaid (2004) who found that string players did not have statistically significant differences in two-point discrimination sensory threshold compared to the non-musician control group. However, these results oppose those of Sims, Engel, Hammert, & Elfar, (2015) who found musicians to be able to discriminate between narrower distances than controls in the left second, fourth, and fifth digits and the right fifth digit. The methods used by Sims et al., (2015) differed from the current study in that these researchers chose to avoid calluses found on the fingertips of string, harp, and guitar players. These differences may also be explained due to the different statistical analysis used between the current study and Sims et al., (2015). The differences shown in this study were found using a frequency count as opposed to Student t tests.

The musicians had increased sensory thresholds using monofilament testing in the right fifth digit, left first digit, left third digit, and left fourth digit (Tables 15-16). Normal was considered to be 0.07 g and below (Weinstein, 1993). These results are consistent with Robinson & Kincaid (2004) who found that the musicians had increased sensory thresholds in both hands compared to the non-musicians although they were not statistically significant. Researchers recommended further research with a larger sample of musicians to determine whether the low power of the study led to the absence of significant differences. These results oppose those of Sims et al., (2015), who found the musicians to be more sensitive than controls. These differences may come down to the methods, exclusion criteria, and statistical analysis used in their study.

Limitations of the Study

Participants were recruited from a single university. Playing time was not accounted for or standardized in the study. Some musicians had just finished playing before participating in the study which may have had an impact on the results.

There were four participants in the musician group that were identified as outliers in regard to age as compared to the mean age of 22.7 ± 8.3. These participants all had a negative Tinnel's sign and showed no differences in monofilament or two-point discrimination testing. These older participants had a higher IOR ranging from 1.05-1.94 as compared to the rest of the musician group. A female piano player had wrist pain within 6 months rated as a 3/10 and had reduced her playing activity. This participant's IOR was 1.94 on the right and 1.84 on the left. The results of this single participant show that the CTS disease may progress and inhibit playing time as musicians age.

Further Research

Since CTS is often diagnosed in an older population than was used for this study, further research should be conducted to determine the progression of CTS symptoms in musicians as they progress through their musical career. These results will provide clinicians with valuable information to consider when making treatment decisions. Research should also be conducted to further explore the differences in instrument type and carpal tunnel dimensions and hand function among musicians. Research should be done to answer questions such as: why do musicians have larger median nerves? Which musical instrument types lead to CTS? Does hand dominance play a part in the development of CTS in musicians? Certain instruments require more movement in one hand as compared to the other which may lead to differing symptoms compared bilaterally. This information will allow clinicians to understand anatomical anomalies associated with different instrument types. Statistical analysis should also be done to correlate hand dominance to anatomical differences and symptoms. These outcomes will allow clinicians to be aware of risk factors associated with musicians and to have a detailed knowledge of CTS in musicians and the appropriate treatment.

Conclusion

The results of this study partially support H_1 in that the musicians demonstrated a larger median nerve cross-sectional area as compared to the non-musician controls. The results supported H_{1-2} and H_2 in that the musicians had a greater IOR and the differences in the anatomy of the carpal tunnel were associated with a greater prevalence of disability and impairment associated with carpal tunnel syndrome as compared to the control group. These results show that musicians may be more susceptible to developing CTS. Clinicians may use this information when evaluating and treating musicians for CTS.

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APPENDIX A: IRB APPROVAL

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Mark Timmons
Marshall University, Dept. of Kinesiology

RE: IRBNet ID# 1110980-1
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Timmons:

Protocol Title:	[1110980-1] The Anatomy of the Carpal Tunnel and Hand Function of Artists	
Expiration Date:	September 5, 2018	
Site Location:	MU	
Submission Type:	New Project	APPROVED
Review Type:	Expedited Review	

In accordance with 45CFR46.110(a)(4), the above study was granted Expedited approval today by the Marshall University Institutional Review Board #1 (Medical) Vice Chair for the period of 12 months. The approval will expire September 5, 2018. A continuing review request for this study must be submitted no later than 30 days prior to the expiration date.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley,MA, CIC at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.

APPENDIX B: INFORMED CONSENT FORM

Informed Consent to Participate in a Research Study

The Anatomy of the Carpal Tunnel and Hand Function of Artists

Mark K Timmons PhD ATC, Principal Investigator

Marshall University IRB

Approved on:	9-5-17
Expires on:	9-5-18
Study number:	1110980

Introduction

You are invited to be in a research study. Research studies are designed to gain scientific knowledge that may help other people in the future. You may or may not receive any benefit from being part of the study. There may also be risks associated with being part of research studies. If there are any risks involved in this study then they will be described in this consent. Your participation is voluntary. Please take your time to make your decision, and ask your research doctor or research staff to explain any words or information that you do not understand.

Why Is This Study Being Done?

Hand pain caused by carpal tunnel syndrome effects many artists. The purpose of this study is to increase the understanding over how the anatomy of the wrist effect hand pain and function in artists.

How Many People Will Take Part In The Study?

About 60 people will take part in this study. A total of 75 subjects are the most that would be able to enter the study.

What Is Involved In This Research Study?

During the study you will first fill out a questionnaire about your wrist and hand, then the researcher will perform a brief examination of your wrist and hand. During the examination you will be asked to perform several contractions of your wrist muscles. After the examination the researcher will use an ultrasound machine to make several images of your wrists in order to measure the width of several structures of the carpal tunnel. During the ultrasound imaging you will be asked to sit down and your arm will be placed in several a positions that allows the researcher to image your wrist. The questionnaire, shoulder examination, motion testing and ultrasound imaging will take about 45 minutes to complete.

How Long Will You Be In The Study?

You will be in the study for one testing sessions that will take about 45 minutes to complete.

You can decide to stop participating at any time. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff to discuss what follow up care and testing could be most helpful for you.

Subject's Initials ________

The study doctor may stop you from taking part in this study at any time if he/she believes it is in your best interest; if you do not follow the study rules; or if the study is stopped.

What Are The Risks Of The Study?

Being in this study involves some risk to you. You should discuss the risk of being in this study with the study staff.

You should talk to your study doctor about any side effects that you have while taking part in the study.

Risks and side effects related to the testing session include: increased wrist or hand pain, muscle soreness, muscle fatigue and reduced wrist or hand strength. These risks and side effects are temporary and are no greater than the risks associated with any physical exercise program. These side effects can be reduced by stretching exercises, and applying either moist heat or ice. **If you experience pain that you would describe as being more than 7 out of 10 you should stop the testing session contact your doctor.**

There may also be other side effects that we cannot predict. You should tell the research staff about all the medications, vitamins and supplements you take and any medical conditions you have. This may help avoid side effects, interactions and other risks. There are no funds available for compensation for any injury that occurs as a result of your participation in this study.

Are There Benefits To Taking Part In The Study?

If you agree to take part in this study, there may or may not be direct benefit to you. We hope the information learned from this study will benefit other people in the future. The benefits of participating in this study may be: You will gain information about the function of your wrist and hand.

What Other Choices Are There?

You do not have to be in this study to receive treatment. You should talk to your doctor about all the choices you have. If you chose not to be in this study you should start or continue with treatment plan prescribed by your doctor.

What About Confidentiality?

We will do our best to make sure that your personal information is kept confidential. However, we cannot guarantee absolute confidentiality. Federal law states that we must keep your study records private. Nevertheless, certain people other than your researchers may also need to see your study records. By law, anyone who looks at your records must keep them completely confidential.

Those who may need to see your records are:

- Certain university and government people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. These include the Marshall University Institutional Review Board (IRB) and the Office of Research Integrity (ORI). Other individuals who may look at your records include: *the*

Subject's Initials ________

federal Office of Human Research Protection, This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety.

If we publish the information we learn from this study, you will not be identified by name or in any other way.

What Are The Costs Of Taking Part In This Study?

There are no costs to you for taking part in this study. All the study costs, including any study medications and procedures related directly to the study, will be paid for by the study. Costs for your regular medical care, which are not related to this study, will be your own responsibility.

Will You Be Paid For Participating?

You will not be paid if you decide to participate in this study.

Who Is Funding This Study?

This study is being sponsored by Marshall University School of Kinesiology

What Are Your Rights As A Research Study Participant?

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Refusing to participate or leaving the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff first to learn about any potential health or safety consequences.

Whom Do You Call If You Have Questions Or Problems?

For questions about the study or in the event of a research-related injury, **contact the study investigator, Mark K Timmons ATC, PhD at (304)696-2925**. You should also call the investigator if you have a concern or complaint about the research.

For questions about your rights as a research participant, **contact the Marshall University IRB#1 Chairman Dr. Henry Driscoll or ORI at (304) 696-7320.** You may also call this number if:

- You have concerns or complaints about the research.
- The research staff cannot be reached.
- You want to talk to someone other than the research staff.

You will be given a signed and dated copy of this consent form.

Subject's Initials ________

SIGNATURES

You agree to take part in this study and confirm that you are 18 years of age or older. You have had a chance to ask questions about being in this study and have had those questions answered. By signing this consent form you are not giving up any legal rights to which you are entitled.

____
Subject Name (Printed)

____ __________________
Subject Signature Date

____ __________________
Person Obtaining Consent Date

____ __________________
Principal Investigator Date

Subject's Initials ________

APPENDIX C: BOSTON CARPAL TUNNEL SYNDROME QUESTIONNAIRE

Boston Carpal Tunnel Syndrome Questionnaire (BCTQ)

(一) Symptom severity scale (11 items)

	1	2	3	4	5
1. How severe is the hand or wrist pain that you have at night?	Normal	Slight	Medium	Severe	Very serious
2. How often did hand or wrist pain wake you up during a typical night in the past two weeks?	Normal	Once	2 to 3 times	4 to 5 times	More than 5 times
3. Do you typically have pain in your hand or wrist during the daytime?	No pain	Slight	Medium	Severe	Very serious
4. How often do you have hand or wrist pain during daytime?	Normal	1-2 times / day	3-5 times / day	More than 5 times	Continued
5. How long on average does an episode of pain last during the daytime?	Normal	＜10minutes	10~60 Continued	＞60minutes	Continued
6. Do you have numbness (loss of sensation) in your hand?	Normal	Slight	Medium	Severe	Very serious
7. Do you have weakness in your hand or wrist?	Normal	Slight	Medium	Severe	Very serious
8. Do you have tingling sensations in your hand?	Normal	Slight	Medium	Severe	Very serious
9. How severe is numbness (loss of sensation) or tingling at night?	Normal	Slight	Medium	Severe	Very serious
10. How often did hand numbness or tingling wake you up during a typical night during the past two weeks?	Normal	Once	2 to 3 times	4 to 5 times	More than 5 times
11. Do you have difficulty with the grasping and use of small objects such as keys or pens?	Without difficulty	Little difficulty	Moderately difficulty	Very difficulty	Very difficult

(二) Functional status scale (8 items)：

	No difficulty	Little difficulty	Moderate difficulty	Intense difficulty	Cannot perform the activity at all due to hands and wrists symptoms
Writing	1	2	3	4	5
Buttoning of clothes	1	2	3	4	5
Holding a book while reading	1	2	3	4	5
Gripping of a telephone handle	1	2	3	4	5
Opening of jars	1	2	3	4	5
Household chores	1	2	3	4	5
Carrying of grocery basket	1	2	3	4	5
Bathing and dressing	1	2	3	4	5

APPENDIX D: QUICK DISABILITIES OF THE ARM, SHOULDER, AND HAND

THE *Quick*DASH

OUTCOME MEASURE

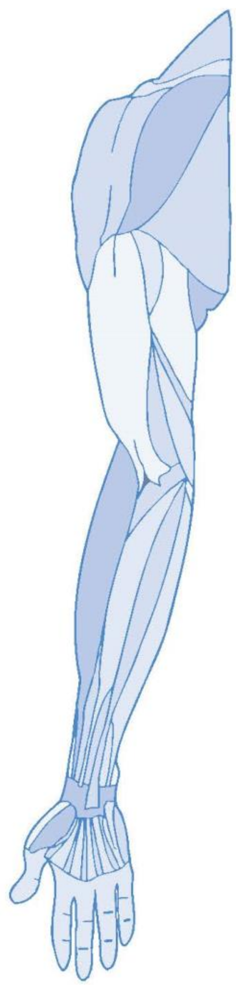
INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer *every question*, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your *best estimate* of which response would be the most accurate.

It doesn't matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.



*Quick*DASH

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Do heavy household chores (e.g., wash walls, floors).	1	2	3	4	5
3. Carry a shopping bag or briefcase.	1	2	3	4	5
4. Wash your back.	1	2	3	4	5
5. Use a knife to cut food.	1	2	3	4	5
6. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
7. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
8. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*	NONE	MILD	MODERATE	SEVERE	EXTREME
9. Arm, shoulder or hand pain.	1	2	3	4	5
10. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

*Quick*DASH DISABILITY/SYMPTOM SCORE = $\left(\left[\frac{\text{sum of n responses}}{n}\right] - 1\right) \times 25$, where n is equal to the number of completed responses.

A *Quick*DASH score may <u>not</u> be calculated if there is greater than 1 missing item.

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:________________________________

❐ I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:________________________________

❐ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may not be calculated if there are any missing items.

APPENDIX E: KATZ AND STIRRAT HAND DIAGRAM

Please show on the diagram below where you have experienced numbness, tingling, burning, or pain **by shading in the problem area.**