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Clarinet Thumb-rest Function: The Pedagogy of Positioning and Electromyography Evidence

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CLARINET THUMB-REST FUNCTION: THE PEDAGOGY OF POSITIONING AND ELECTROMYOGRAPHY EVIDENCE

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ABSTRACT

Clarinetists bear the weight of their instrument on their right thumb using a small metal attachment called a thumb-rest. The soprano clarinet weighs only two pounds, but many hours of playing can cause general discomfort to severe overuse injury throughout the upper right limb. There is a debate within the clarinet community about the best position of the thumb-rest, yet no quantitative research has been conducted on this issue.

This document establishes a historical and modern context for the use of the clarinet thumb-rest. It reviews traditional and non-traditional medical approaches that individuals use to help clarinetists with supporting the instrument. This document presents data and analysis from an electromyography (EMG) study of 20 healthy student and professional clarinet players. It discusses current approaches to supporting the instrument with after-market products and modifications to the instruments and addresses the implications for the pedagogy of clarinet right-hand support.

Surface EMG recordings of superficial muscles that control the right thumb, wrist, and arm were taken during held note and finger exercises trials at three different thumb-rest position heights. Hand size and experience level were considered. Researchers found a significant main effect of rest position in the *biceps brachii, abductor pollicis brevis, abductor pollicis longus, extensor carpi radialis* and *flexor carpi ulnaris*. There was no main effect of hand size in the muscles. Because opposing muscles had contrasting patterns of activation regardless of hand size, there is no conclusive support to change the standard position for thumb rests. Some interactions between variables such as exercise number, position, and size enrich the understanding of the biomechanics of clarinet playing. Future research avenues are proposed.

PART I

CHAPTER 1: INTRODUCTION & METHODS OF ANALYSIS

Clarinetists bear the weight of their instrument on their right thumb using a small metal attachment on the lower half of the instrument called a thumb-rest. The soprano clarinet weighs only two pounds, but many hours of playing with this weight on the thumb can cause general discomfort to severe overuse injury throughout the upper right limb. There is a debate within the clarinet community about the best position of the thumb-rest, yet no quantitative research has been conducted on this issue.

This document provides a historical and modern context for the use of the clarinet thumb-rest. It presents the history of the first thumb-rests and how they changed over time. It reviews traditional and non-traditional medical approaches that individuals use to help clarinetists with these issues. This document presents data and analysis from an electromyography study of 20 clarinet players playing with different thumb-rest positions. It discusses current approaches to supporting the instrument, and provides a commentary on the pedagogy of right hand support for clarinetists.

The study used electromyography (EMG) recordings to investigate muscle activity of the right-hand thumb, wrist, and arm during the static hold of the thumb of clarinet playing. The researchers altered the thumb-rest position on the instrument to simulate alterations clarinet players currently make.[1] Many factors that contribute to supporting the instrument are considered: hand size, movement of the upper limb, practice habits, and injury experience.

This research illuminates how each player uses muscular force to hold their instrument. If a certain experimental condition reduces muscle activation, the investigation could spark a more

[1] The researchers include the author, Kathryn Young, and her research partner, Dr. Sara Winges, Assistant Professor of Kinesiology, Louisiana State University.

informed discussion about prevention of injury and rehabilitation for musicians that bear weight on their thumb. Results from the research assist both beginning and advanced players towards efficient injury-free movement, influence physical guidelines for training clarinetists, and provide better-informed care in the event of injury.

Part I of the monograph will explain the context for thumb-rest debate among clarinetists. This will include a history of the clarinet development, the factors that led to the thumb-rest, and the most important elements of the clarinet that have changed over the past three hundred years for the thumb-rest. In order to understand the mindset of clarinetists today, Part I will touch on pedagogical views of supporting the clarinet and explain what alternative approaches players are taking when they struggle with the instrument.

Part II of this monograph will first describe the anatomical foundation for the upper limbs of clarinet players. It will then review some of the injuries associated with supporting the clarinet and describe some of the traditional and non-traditional approaches for resolving these injuries.

Part III will present electromyography data of a study conducted by the researchers. This study monitored the muscle activity of 20 clarinetists as they played music with three different thumb-rest positions. Other factors such as hand size, playing level, and injury history were also included in the analysis of the recorded EMG data.

CHAPTER 2: THE HISTORY AND DEVELOPMENT OF THE CLARINET THUMB-REST

2.1 Overview of Clarinet Development from 1696-1850

The clarinet's predecessor was an instrument called a chalumeau that may have been used as early as the 12th century.[2] It flourished during the late Baroque period and into the early Classical period (ca. 1740s – 1770s). The chalumeau contained a single cylindrical bore with eight tone holes and produced a sound with the vibration of a single heteroglot reed.[3] [4] Just like the modern clarinet, the fundamental range of the chalumeau was an interval of a 12th (19 half steps). The top tone holes of the chalumeau were drilled across from each other, which prevented the chalumeau from easily over blowing to other pitches.[5] Some chalumeaus had two keys to close and open tone holes at the top of the instrument called "speaker keys."[6]

This simple instrument coexisted with the clarinet (invented ca. 1690) until nearly 1775 before the clarinet began surpassing it in popularity. Early chalumeaus originally served as a folk instruments, but art composers such as Gluck (Vienna versions of *Orfeo* (1762), *Alceste* (1767)), Johann Joseph Fux (*Julo Ascanio* and *Pulcheria*) and Leopold Mozart (*Divertimento* K188) (240b) wrote for the instrument.[7] The chalumeau would appear as an alternative to the oboe in pastoral or love scenes, almost as a predecessor to W.A. Mozart's clarinet writing in *Cosi fan tutte*.[8] [9] Telemann (1681-1767) used alto and tenor chalumeaus long after he added the first

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[2] Eric Hoeprich, *The Clarinet*, The Yale Musical Instrument Series (New Haven: Yale University Press, 2008), 20.
[3] Heteroglot reeds are reeds that are separate from the instrument. This is distinguished from idioglot reeds in which part of the instrument is fashioned into a vibrating section.
[4] Hoeprich, 11.
[5] Colin Lawson, *The Early Clarinet: A Practical Guide* (Cambridge: Cambridge University Press, 2000), 10.
[6] Hoeprich, 20; Lawson, 3.
[7] Lawson, 10.
[8] Other composers that used the chalumeau in their works included Telemann, Gluck, Johann Joseph Fux, and Christoph Graupner. In some compositions, both chalumeaus and clarinets are used together to capitalize upon the low register of chalumeaus and the higher register of the clarinets.
[9] Lawson, 8.

clarinet into his orchestration in 1721.[10] He used chalumeaus in particularly special moments, like the passion-oratorio *Seliges Erwagen*, "where they are combined with muted horns, bassoons and muted strings at the beginning of the eight meditation 'Es ist vollbracht' ('It is finished')."[11] [12]

In ca. 1690, an instrument maker named Johann Cristoph Denner made significant adjustments to existing chalumeau models and created what are now considered to be the first clarinets. The two top tone holes (that were directly opposed in chalumeaus) were shifted to an off-set position, allowing the clarinet to easily overblow to overtones above its fundamental register.[13] Changing the position of one of the speaker keys transformed its function from simply adding one note to serving as a *register key* to facilitate overblowing to new pitches. The new aptitude for playing in both registers pushed the clarinet towards a path of longevity for performers, composers, and instrument makers.

From about 1700 to 1800, the clarinet was modified slowly with two primary objectives. The first was to improve its overblowing capability through changes in the bore and positioning of the register key. The second goal was to increase chromatic possibilities by adding up to five keys for venting, trilling, and alternate fingerings. The addition of keys began to add some minimal weight to the instrument. By ca. 1750s -1760s, the four-keyed clarinet became a standard among performers.[14] Soon after, the five-keyed clarinet emerged as an extremely popular clarinet from the 1770s on into the nineteenth century. Five-keyed clarinets had Ab/Eb

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[10] Lawson, 8.
[11] Lawson, 12.
[12] More information about the repertoire of chalumeau can be found in (Lawson, 2000).
[13] The upper or 'clarino' register, aided by the register key, plays third harmonics, a perfect twelfth higher than the fundamentals. The altissimo range, aided by the register key and venting with the first left-hand hole, plays fifth harmonics, a major seventeenth (that is a perfect twelfth plus a major sixth) above the fundamental. The clarinet is therefore overblows at the twelfth, and a seventeenth when in the altissimo.
[14] Lawson, 11.

and F#/C# keys, which allowed for more fingering options . This five-keyed instrument is considered the archetypal "classical clarinet." It was incredibly popular system for key work and examples of the five-keyed instrument continued to be manufactured into the early 20th century.[15]

An unusually accelerated period of clarinet development past the five-keyed clarinet occurred from 1800-1850. This growth was borne out of a dynamic relationship between composers, instrument makers, and clarinetists. Composers wrote created more demanding repertoire, and the ingenuity of inventors opened more opportunities for clarinetists and composers alike. The tonal and sonic possibilities of the instrument were revolutionized by adding keys, drilling larger tone holes, thickening instrument walls, reinventing pads, and crafting mouthpieces capable of generating greater volume.[16] W.A. Mozart's advice to write for the clarinet "always in the keys of C major and F major" quickly became obsolete for composers such as Franz Schubert, Louis Spohr, Carl Maria von Weber and Felix Mendelssohn took advantage of the evolving instrument.[17]

As instrument makers fed the desire of composers for chromatic possibilities with more keys and tone holes, composers wrote even more challenging music that inspired further modifications to the clarinet. This cyclic influence continued at such a rapid pace that the Louis-Auguste Buffet 1843 Boehm-system clarinet with ring keys, relocated tone holes, and seventeen keys was wildly different from turn of the 19th century five-keyed clarinets.[18] While changes regarding tone holes and key additions are generally well documented,[19] a detailed description of

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[15] Albert R. Rice, *The Clarinet in the Classical Period* (New York: Oxford University Press, 2003), 13.
[16] Hoeprich, 124.
[17] Hoeprich, 124.
[18] Hoeprich, 124.
[19] Rice; Hoeprich.

how these rapidly changing instruments were supported by the *thumbs* of clarinetists is sparse in the literature. Below we will trace the conditions that led to the addition of the thumb-rest and its placement over time in order to establish a historical reference for the rest of this research project.

2.2 Origins of the Clarinet Thumb-rest

Clarinet players today are often mystified by the origins of the thumb-rest placement on their instruments. To establish a historical context for this question, we can look to certain changes throughout the clarinet's development that caused the addition of the thumb-rest and its placement. We can also learn about how past players and instrument-makers conceptualized the balance of the instrument through resources such as fingering charts.

From surviving instruments and illustrations, researchers know that roughly the first four decades (ca.1690-1750s) of the clarinet's development, the instrument could be played with either hand on the bottom.[20] The bell, or bottom-most section of the instrument, had a one tone hole or two small "paired" tone holes. These could be covered by the right hand pinky (R4) or by the left pinky by rotating the bell to meet the other hand. In the 1740s, a third key was added to the lower back/side portion of the instrument key to be played by the lower hand thumb. With this addition, creative solutions were created to maintain the ability to use either hand on the bottom to manage both the keywork and tone holes. Two tone holes in the bell joint were drilled and the one not in use had to be plugged with wood or wax.[21]

It is not clear how quickly the right hand-below position became predominate among players. As early as 1738, Joann Philipp Eisel's treatise *Musicus Autodidaktos* instructs readers

[20] Hoeprich, 25.
[21] Hoeprich, 26.

to use the right hand on bottom (Erfurt, 1738).[22] As late as 1821, inventor and clarinetist Iwan Müller's *Methode pour la nouvelle clarinette et clarinette-alto* also instructed players to use the right hand on the lower joint,[23] perhaps revealing that it was not exclusively the normal practice at this point. There is no particular reason given by these authors for this preference. Perhaps with a majority of the population being right-handed, this stronger hand was deemed better suited for the task.

2.3 Relationship between keys and the first thumb-rests

Starting in the first decade of the 19th century, different European instrument makers added extra keys, soon reaching six-, seven-, and eight-keyed instruments.[24] A list of German instrument makers who built clarinets during the first decades of the nineteenth century includes just under 30 different names.[25] Additional keys could produce a more accurate and complete tone for each note (in lieu of cross fingerings), easier trills, improved tuning and quality of sound, and smoother transitions between notes during legato passages.[26]

One of the most influential clarinet innovators was Iwan Müller, who collaborated with instrument makers to create the first clarinet that would play in all tonalities. His 1809 11-keyed clarinet, and 1811 and 1821 versions of 13-keyed clarinets featured many new modifications including moving the ab/eb2 and f/c2 tone holes, adding an external speaker pipe, creating key cup pads filled with felt material, drilling countersunk tone holes, and instrument-mounted pillars to mount the keys.[27] Müller's 13-keyed clarinet was rejected by a committee at the Paris

[22] Albert R. Rice, "Email Research," Email message to author, August 7, 2014.
[23] Albert R. Rice, "The Development of the Clarinet as Depicted in Austro-German Instruction Source, 1732-1892," in *Tradition Und Innovation Im Holzblasinsttrumentenbau Des 19 Jahrhunderts*(Augsburg: Wissner, 2012).
[24] Rice, *The Clarinet in the Classical Period*, 40.
[25] Hoeprich, 28.
[26] Rice, *The Clarinet in the Classical Period*, 14.
[27] Rice, *The Clarinet in the Classical Period*, 11; Hoeprich, 133.

Conservatoire in 1812 (speculated now to be based on nationalistic pride). Despite the initial rejection, this model became very popular throughout Europe for its improvements in chromatic playing and tone consistency.[28]

Müller is also attributed with adding the first thumb-rest to help clarinetists manage the abundance of key demands and extra weight.[29] His version of his 13-keyed clarinet that became popular in the 1820s had no lower joint keys that were used by the thumb – a feature that was common in many previous models of clarinets. This lack of keys "freed" the thumb to serve in just a supportive role.[30] The diaspora of Müller's models across Europe likely helped propagate the use of the right hand thumb in a solely supportive role and the switch to thumb-rests by other instrument-makers. Müller and other instrument-makers added so many keys that the increased use of the pinky fingers and extra metal weight demanded the addition of a thumb-rest: "With the advent of the thirteen-keyed clarinet arose the popularity of the thumb-rest added to the back of the lower joint, to assist the player in supporting the instrument's extra keywork."[31]

Two main styles of early thumb-rests existed. Carved out sections (concave) and protrusions (convex) in the body of the clarinet are called "integral thumb-rests." These varied greatly in shape and size between instrument makers and were probably adjusted to individual performer preferences.[32] See Figure 2.1 for Backofen's 1824 finger chart for 12-keyed instruments with a notch protruding off the back of the instrument for a thumb-rest.

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[28] Hoeprich, 133.
[29] Hoeprich, 133.
[30] Rice, *The Clarinet in the Classical Period*, 70.
[31] Lawson, 40.
[32] Rice, August 7, 2014; Rice, August 7, 2014.

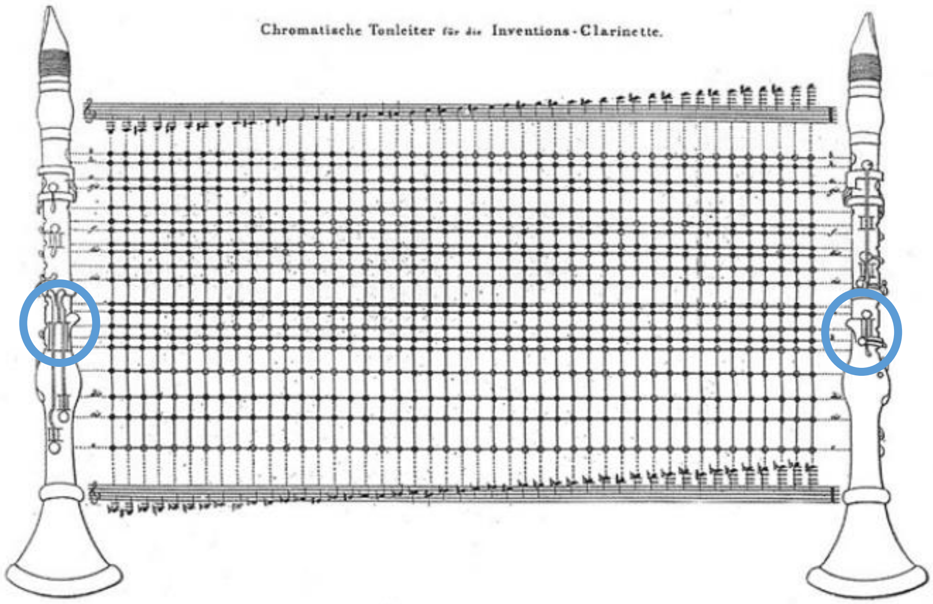

Figure 2.1 Twelve-key fingering chart, Backofen, *Anweisung zur Clarinette*, Leipzig 1824.[33]
Circles identifies the thumb-rests.

Non-integral rests were any attachments made to the clarinet after the body of the instrument was made. For manufacturers, these small additions could be fashioned and attached more easily than carving the body of the instrument. These were much more popular and were the precedents for the thumb-rests we have today.[34] Non-integral thumb-rests were generally small metal attachments, but could take other forms such as the concave mother of pearl attachment in Figure 2.2 a & b. Figure 2.2a contains photos of an angled alto clarinet, in high-pitch G, likely made in Austria or Italy about 1815, in the Royal College of Music Museum (no. 84). The player would use this as a gripping point for the pad of their thumb. Dr. Rice indicates that it has a mother-of-pearl thumb-rest that may have been a later addition that was screwed into the wood (see Figure 2.2b).

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[33] Rice, "The Development of the Clarinet as Depicted in Austro-German Instruction Source, 1732-1892," 98.
[34] Rice, August 7, 2014.

Figure 2.2a Foreground: Full body view of anonymous angled alto clarinet likely in high pitch G, likely made in Austria or Italy about 1815, in the Royal College of Music Museum (no. 84).[35]

Figure 2.2b Close up view of angle alto clarinet in high pitch G. with an integral rest made of mother of pearl. The mouthpiece is to the left of the thumb-rest, the bell of the instrument is to the right. Players would use this as an extra surface for thumb grip when holding the instrument. This may have been added on after the instrument was produced.[36]

The earliest printed source to depict a brass or metal thumb-rest is Stephan Koch's fingering chart, *Tonleiter für die Klarinette des Herrn Koch Instrumentmacher in Wien* (Vienna: S.A. Steiner and Co., ca. 1817) for a 12-key clarinet.[37] Common examples of this style can be found in the work of French instrument maker Jean-Jaques Baumann and others from the 1820s onward.[38]

Thumb-rests were becoming more popular turn of the 19th century, but not all clarinet makers immediately followed suit. Some continued to add thumb keys rather than thumb-rests. Thumb keys for the right hand were used as long lever mechanisms to open and close tones holes

[35] Rice, August 7, 2014.
[36] Rice, August 7, 2014.
[37] Rice, August 7, 2014.
[38] Rice, August 7, 2014.

on the instrument that the other fingers could not reach.[39] The few existing examples of Iwan Müller's clarinets sometimes have thumb keys for the thumb to depress.[40] Two examples from the first half of the 19th century show early examples of clarinets with thumb keys but not rests: first, an Adler 15-key clarinet with two brass thumb keys (Bamberg, 1840s, private collection), and second, a Stengel 15-key clarinet with two thumb keys (Bayreuth, 1830s, Leipzig University collection, no. 1495)[41] (see Figures 2.3 and 2.4). The Adler Müller clarinet has beautiful curved brass thumb keys. One, at the back of the instrument reaches quite high on the lower joint and is used by pushing down on the key.[42] It sits opposite the first tone hole of the lower joint, requiring the player to reach up for that task. The Stengel 15-key clarinet (see Figure 2.4) has two thumb keys as well as a thumb-rest. One thumb key lies above the thumb-rest and one is positioned below. This requires the player to lift the thumb away from the thumb-rest in order to play the upper thumb key and balance the instrument without the thumb. This may indicate that the brass thumb-rest was added after the instrument was made.

Figure 2.3 Adler 15-key clarinet with metal thumb key, whole instrument, left, close up of thumb-rest, right. Mouthpiece is in the upwards direction, bell is towards the bottom direction in the close up photo.[43]

[39] Lawson, 19.
[40] Rice, 2014.
[41] Rice, 2014.
[42] Rice, 2014.
[43] Rice, 2014.

Figure 2.4 Stengel 15-keyed clarinet from Bayreuth, 1830s, Leipzig University collection, no. 1495. There are two thumb keys and a non-integral brass thumb-rest. Mouthpiece is to the left.[44]

2.4 Large instrument support

Clarinets are made in a "family" – or a collection of different sizes and pitches. Larger clarinets, such as altos, basset horns, and bass clarinets are inherently heavier and were often supported by slings or straps.[45] A bass clarinet by Adolphe Sax nicely a metal thumb-rest as well as a metal semi-circle soldered to the top of the thumb-rest. This semi-circular ring serves as an attachment point for a supportive strap (see Figure 2.5).[46] It is undeniable that weight was the driving factor that pushed for the addition of the clarinet thumb-rest.

Figure 2.5 Bass clarinet by Adolphe Sax, Paris, ca. 1850 showing the thumb-rest with a ring attached. From the Museo Internazionale e Biblioteca, Bologna, no. 1849.[47]

[44] Rice, 2014.
[45] Rice, 2014.
[46] Rice, 2014.
[47] Rice, August 7, 2014.

2.5 Narrowing angle of the clarinet

Performances until the 19th century held the clarinet at a wide angle away from the body. This practice is still found in some folk settings throughout Europe. Without a thumb-rest, a wider angle helped the hands counteract the force of gravity and prevent the instrument from falling. Two additional factors contributed to this practice: the reed-position and the weight of the instrument.

On early clarinets, the reed was fastened on the upper part of the mouthpiece and contacted the upper lip.[48] The position pushed performers to hold the instrument at a wide angle to avoid digging their top teeth into the vibrating reed. This was the prominent method in France and Germany until the 1840/50s. In southern Italy, such as Naples, the reed-up position continued as late as the mid-20th century.[49] Dr. Rice, an expert in clarinet history, suggests that the reed on top provides a "greater variety of articulation; particularly light and pointed staccato."[50] Dr. Rice insists that the changing angle of the clarinet and reed position did not influence the use of clarinet thumb-rests once they were added after the mid-19th century.[51]

A critical reason that early clarinet players were able to perform with no thumb-rest was the light weight of the early instruments. Early clarinets were constructed with a wider variety of woods; the most popular were boxwood and rosewood. The historian Dr. Rice, contributed this synopsis:

> Generally, boxwood clarinets are very light (about a third the weight of a modern instrument), easy to hold and play without a thumb-rest. Boxwood was the most popular wood to use in turning a clarinet, pear, plum, and other light woods have been used. Ivory and ebony were sometimes used on 18th century clarinets but both are only a bit heavier

[48] Hoeprich, 91.
[49] Rice, August 7, 2014.
[50] Rice, 2014.
[51] Rice, 2014.

> than boxwood when used with a five or six key clarinet. African black wood and cocus wood are heavier and denser woods and were the choice of many makers by the 1820s when 13-key clarinets began to be made in large numbers.[52]

The African black wood that Dr. Rice references is also known as grenadilla or mpingo. At 1.2-1.25 gram/cubic centimeter, it is considered one of the densest woods currently milled. Boxwood has a density of about .95-1.1 gram/cubic centimeter.[53] Because of the differences in wood density and keywork, boxwood clarinets may have weighed about $\frac{1}{3}$ to $\frac{1}{2}$ the weight of modern clarinets.[54] The weight of modern grenadilla Bb soprano clarinets is not standard between brands or models, but ranges from about 800 – 907 grams (1.8 – 2 pounds).[55]

Various woods, metals and composites have been transformed into beautiful clarinets of different weights. According to Dr. Rice, early brass skeletal model clarinets with five or six keys are quite light and similar in weight to boxwood instruments.[56] In contrast, German double-wall metal instruments made during the 1830s were far heavier but were usually equipped with a thumb-rest.[57]

After the advent of mass-manufactured clarinets in the 20th century, grenadilla has become the industry standard for its resistance to cracking during the vigorous drilling process. Some opinions vary if grenadilla truly provides the best sonority for clarinets. Occasionally, modern manufacturers used boxwood during the nineteenth century which produced a slightly sweeter tone; and some specialty instrument makers use other varieties of wood today.[58]

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[52] Rice, 2014.
[53]Oliver Seely, "Physical Properties of Common Woods," www.csudh.edu http://www.csudh.edu/oliver/chemdata/woods.htm (accessed August 5, 2014).
[54] Dr. Rice mentioned in his correspondence that boxwood instruments may have been up to ½ the weight of a modern instrument. His prediction of 1/3 the weight of a modern instrument would likely be more appropriate for clarinets with 3-5 keys.
[55] H.J.H. Fry, "Overuse Syndrome in Clarinetists," *The Clarinet*, 13(3) 1987, 48.
[56] Rice, August 7, 2014.
[57] Rice, August 7, 2014.
[58] Rice, August 7, 2014.

The narrowing angle of the clarinet after performance practice and instrument weight changes impacted the demands on clarinet players and increase the need for thumb-rest support. In a study on forces exerted on oboes, which are very similar in construction and weight to clarinets, Smutz et al. (1995) found that lateral (vertical) and pulpar (angle away from the body) force were affected by the instrument angle.[59] As the oboe was pulled in toward the body (more vertical), the lateral force increased and the pulp force decreased.[60] This result occurred regardless of the thumb-rest positions on the oboe.[61] Similarities in size, shape, and weight between clarinets and oboes justify the prediction that similar changes in force occur as the clarinet is drawn closer to the body.

2.6 Placement of clarinet thumb-rests

The placement of the thumb-rest influences the way in which performers can hold the instrument. During the 18th and 19th nineteenth centuries, the placement of the thumb-rest was not standardized.[62] In his book *The Clarinet in the Classical Period,* Rice indicates thumb-rests in the 18th century were sometimes created between the fourth and fifth finger holes[63] -- quite low by today's standards. A fingering chart of a 12-key clarinet by J.G. H. Backofen in 1824 contains a drawing of a clarinet with the thumb-rest across from the second tone hole and middle finger (see Figure 2.1 on page 9). The inconsistency in thumb-rest placement confirms that instrument makers each chose a unique position based on "the size of their own fingers and hands"[64] or their customers' requests. The ferrule (or bulge between the instrument joints) was

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[59] W.P. Smutz et al., "Load on the Right Thumb of the Oboist," *Medical Problems of Performing Artists* 10, no. 3 (1995): 97.
[60] Smutz et al., "Load on the Right Thumb of the Oboist," 97.
[61] Smutz et al., "Load on the Right Thumb of the Oboist," 97.
[62] Rice, August 7, 2014.
[63] Rice, 2013, pg. 13.
[64] Rice, August 7, 2014.

not a traditional point for a thumb support, says Dr. Albert Rice: “The ferrules (wood or ivory) are always too far down the tube to use as thumb-rests.”[65] [66]

Thirteen-key clarinets from the original Buffet Crampon workshop around 1825 had the thumb-rest placed 5 mm below the center of the right-hand second tone hole which is controlled by the middle finger.[67] Over time, clarinet makers have altered the position of the first and second tone holes, making comparisons between instruments difficult. The most important factor for thumb-rests is the relative position of the thumb to the index and/or middle finger. When Buffet Crampon began making the first Boehm-system clarinets in 1843, the thumb-rest was also placed 5 mm below the center of the second tone hole.[68]

Dr. Rice writes, “With the creation of large factories after 1850 in France, England, Germany, Italy, and later in the U.S., a standard position for each maker was established for a screwed-on thumb-rest.”[69] Again, the weight of the new grenadilla instruments was almost double that of original boxwood clarinets. This weight increase would have been an important factor in selecting a permanent thumb-rest location. Mass manufacturing inherently reduces personalization for each customer. So, when large companies began using factories to make their clarinets and standardized their thumb-rest positions, players were strongly pushed towards using these positions. Some players went to repairmen to move the thumb-rest, but the vast majority learned to use this position.

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[65] Contacting museums to archive measurements of historical instruments will be considered for a follow up project to this current research.

[66] An unusual early 1830s instrument has a cut down ferrule (the bulge between pieces of the instrument). This location may have been used as a thumb-rest on this particular instrument.(Rice, 2014)

[67] Mona Lemmel, "Spare Parts Manager, Buffet-Crampon," Email message to author, September 26, 2014.

[68] Lemmel, September 26, 2014.

[69] Rice, August 7, 2014.

2.7 Balance of the clarinet

The task of holding the clarinet is complex because the weight of the instrument is balanced by two contact points: the thumb-rest and the mouth. The musculature of the oral cavity, lips, and jaw create the embouchure. The hands on the instrument and the embouchure holding the mouthpiece work to maintain the clarinet's position during playing. The hands and embouchure react to the forces of the clarinet. The angle of the instrument and individual anatomy dictate how each clarinet player balances the instrument.

2.7.1 Early concepts of balance

Historical documents enrich our understanding of how early clarinetists thought about the hand and the balance of the instrument. Clarinet fingering charts from 1769-1830 were wildly inconsistent due to the wide diversity of clarinet styles and instrument makers.[70] Through the 18th and 19th centuries, vendors would sell instrument styles ranging from 4- to 15- keyed instruments at the same time, and fingering charts would follow each of these instruments throughout the world.[71] Instructions to add extra fingers for instrument support are particularly noteworthy for the topic of clarinet support.

Norwegian bandmaster L.N. Berg was the first to list a *Stutzfinger*, or alternate support finger, within a fingering chart for a 3-key clarinet.[72] *Stutzfinger* are also known as "buttress fingerings," which makes reference to architectural supports of European gothic cathedrals. These fingerings were residual techniques from earlier recorder and chalumeau playing.[73] Fingers acted as tools for supporting and balancing the instrument before thumb-rests were

[70] Rice, *The Clarinet in the Classical Period*, 80.
[71] Rice, *The Clarinet in the Classical Period*, 80.
[72] Rice, *The Clarinet in the Classical Period*, 237, note 20.
[73] "Recorder Methods and Materials," http://www.aswltd.com/adultmet.htm (accessed June 23, 2014).

added. They can also change the intonation of notes. On the clarinet, certain notes allow for the addition of fingers that may not change the pitch.[74] These extra fingers slightly raise or lower the intonation of a pitch by modifying which tone holes vent the pressurized air passing through the instrument.

Indications for additional support from the right third finger appear in Backofen's *Anweisung zur Klarinette* (ca. 1803) and Fröhlich's *Vollständige Theoretischpracktische Musikschule* (ca. 1810-1811).[75] Castillon's *Supplément a l'Encyclopedie* (1776) lists the pinky E/B key as a buttress fingering which also doubles as a resonance fingering to improve tone quality.[76]

Buttress fingerings served two purposes: balance the instrument and help with intonation. The German root "Stutz" translates to *support*; this reveals the original intent of these fingerings. Support was essential for instrument balance before the thumb rest was added to the instrument. When the thumb rest became the primary means of supporting the clarinet, the term "buttress fingerings" was transformed. Players still used some buttress fingerings but began calling them "resonance fingerings." "Resonance fingerings" emphasizes improvements in tone and intonation that can also be achieved with extra fingers. The label "buttress fingerings" has a strong connotation of support and balance, but "resonance fingering" shifts focus to the tonal effects. This switch in labels reflects the transforming perception of the role of the thumb versus the fingers to hold the clarinet.

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[74] The acoustical properties of clarinets can be found in Gibson, 1998. In the most basic sense, changing the length of the distance the player's air travels through the clarinet by covering or uncovering tone holes causes the instrument to produce different pitches. Sometimes extra fingers can be used on pitches that will not change this distance enough to produce a separate pitch. O.L. Gibson, *Clarinet Acoustics* (Bloomington, IN: Indiana University Press, 1998).
[75] Rice, *The Clarinet in the Classical Period*, 81.
[76] Rice, *The Clarinet in the Classical Period*, 81.

2.7.2 20th century concepts of balance

A powerful tradition of clarinet balance was established by clarinet pedagogue Daniel Bonade. He was an incredibly influential figure in American clarinet playing of the 20th century. His teaching was based on achieving a beautiful tone, and he insisted on the importance of keeping the instrument "in" towards the body. This recommendation for a close angle of the clarinet was passed through many circles of players and teachers as a key for improving tone. Changing the angle of an instrument inherently modifies the size and direction of the forces exerted on the clarinet by the body.

In addition to the angle of the clarinet, physical anatomy influences the balance of the instrument. Each individual has a unique oral cavity, lip formation, jaw shape, and dental structure which affect the placement of the instrument in the mouth. This in turn causes players to modify the angle of the instrument in order to achieve the quality of sound desired. The most famous example of extreme playing position due to mouth structure is Robert Marcellus. His pronounced overbite caused him to draw the clarinet close to his body so that it was nearly vertical.[77] This position did not hinder his beautiful orchestral playing. It did change the balance of mouthpiece pressure on his top teeth and embouchure, and the forces his thumb exerted to support the instrument at that angle.

A key to holding the instrument is the word "balance." This word has connotations of equilibrium, stability, and equipoise. Ultimately, the goal of clarinetists is to achieve balance and distribution of the instrument's weight and reducing muscular work while still being able to play with the tone and finger technique they desire. One variable that players and teachers do not yet understand is the influence of thumb-rest position on the delicate balance of the instrument. In a

[77] Deborah Chodacki, Interview by Kate Young, Baton Rouge, LA, September 1, 2014.

study of different thumb-rest positions on oboes, Smutz et al. found no difference in lateral and pulpar forces for different rest positions.[78] This research team only changed the position of the thumb-rests one centimeter in either direction of the normal thumb-rest. Today, clarinetists change their thumb-rest much more than one centimeter (See Section 2.8).

All objects have a center of mass that changes as the object is manipulated in space, this can affect our ability to successfully interact with them. For example knives and swords are carefully balanced by craftsmen to create efficient and effective weapons. It is possible that clarinets may be optimized for balance based on the point that the thumb-rest is attached. Unfortunately, there is no standard metric for estimating this balance because every player's anatomy is unique and may require different points to balance the instrument.

2.8 Changes to clarinets within the past fifty years

Comprehensive reviews of clarinet development through the 19th and 20th century are found in a number of sources.[79] Instrument makers are constantly revisiting their designs and modifying them, which may influence the ways in which clarinetists balance modern instruments. Anecdotally, some clarinetists believe injuries have increased in the last decade. An increase in injuries could result from numerous causes. There may be a pure increase in the number of clarinet players, increased medical attention focused on injuries, more publications about injuries, or players deciding to work on their injuries rather than take themselves out of the profession. Another source of potential injuries are modifications to clarinets within the past 50 years such as widening walls and thumb-rest changes.

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[78] Smutz et al., "Load on the Right Thumb of the Oboist," 97.
[79] Hoeprich.

2.8.1 Widening of walls

Mark Jacobi is a Philadelphia-based repairman known for his exquisite craftsmanship and skill in clarinet repair and innovation. During an interview, Jacobi mentioned that the walls of the clarinet have been increasing in thickness over the past few decades.[80] Thickening clarinet walls creates a heavier instrument which changes the muscular demands to support the instrument. Jacobi believes that the hands must wrap around the slightly larger circumference which may change the amount of flexion required by the fingers to depress the keys; possibly even causing them to stay in a slightly extended position rather than completely at rest.[81]

2.8.2 Thumb-rest shape and size

Thumb-rest design is another factor that may influence the interaction between performer and instrument. Since the addition of the thumb-rest by Iwan Müller and his contemporaries at the turn of the 19th century, many styles and shapes for the accessory have been created. Recently the thumb-rest shape has changed within numerous companies to become larger. The Buffet Crampon computer system indicates that their larger thumb-rest was introduced in 2002, but may have been modified slightly in the past few years under the same part number.[82] The fixed thumb-rest is about 14 mm wide, the newer adjustable thumb-rest is about 18 mm wide. Figure 2.6 shows the two styles side by side. Smaller thumb-rests were standard for the Buffet Crampon company from 1835 – 2002.[83]

Physically, a larger thumb-rest would disperse the contact force on the thumb over a larger area if the player allowed it to rest the total surface area on the thumb. Certain products on the market offer this solution (See page 51 for All Thumbs REST). A variety of thumb-rest styles

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[80] Mark Jacobi, Interview by John Coppa, Philadelphia, PA, April, 2014.
[81] Jacobi, Interview by Coppa, 2014.
[82] Lemmel, September 26, 2014.
[83] Lemmel, September 26, 2014.

exist on professional and student model clarinets today. When trying out these styles, the physical sensation of the instrument does change with the different sizes and shapes.

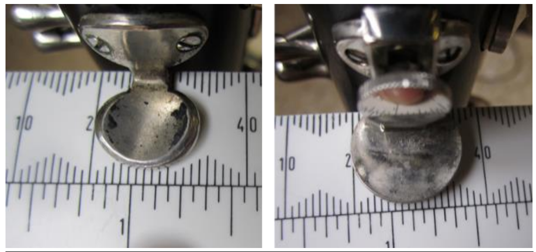

Figure 2.6 Buffet Crampon thumb-rests, top view looking down on clarinet, from clarinet adjustable model on left and fixed model on right (Photos by author)

Opinions among clarinetists differ about the thumb-rest size change. Some believe a larger place of contact for the thumb should be more comfortable for more players. Others believe a smaller thumb-rest makes it easier to find a single balance point for the instrument, reduce variability in the grip on the instrument, and helps certain muscles become well developed at the task of supporting the instrument.[84] Some clarinet makers have followed this preference and create smaller thumb-rest sizes. Rossi clarinets currently have a thumb-rest size that feels very similar in size to the traditional, smaller Buffet models from the 1980s (see Figure 2.7).

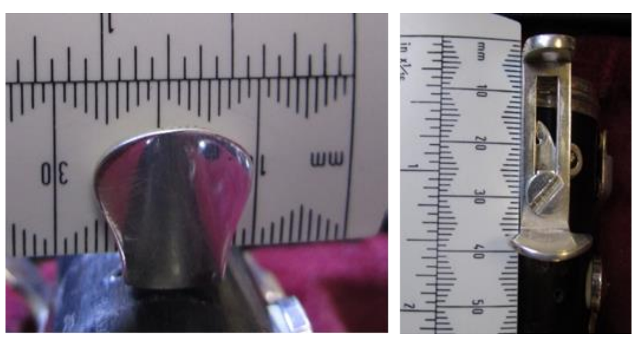

Figure 2.7 Pictures of Luis Rossi thumb-rest. Bottom view, looking up length of clarinet (left) and hind view from directly behind clarinet (right), (Photos by author).

[84] Chodacki, 2014.

2.9 Adjustable thumb-rests

Instrument makers have created adjustable thumb-rests to provide players with more options for thumb position. Adjustable thumb-rests usually have an extended portion that can be mounted to the instrument via a screw mechanism. This extension allows the thumb-rest to be altered in a vertical direction.

According to M. Maurice Vallet, the curator of the Buffet-Crampon collection, the first adjustable thumb-rests were created in the 1970s.[85] The 1975 Buffet RC Prestige model definitively came with an adjustable thumb-rest.[86] Figure 2.8 shows an early adjustable thumb-rest from Jack Brymer's book, *Clarinet* (1976).[87]

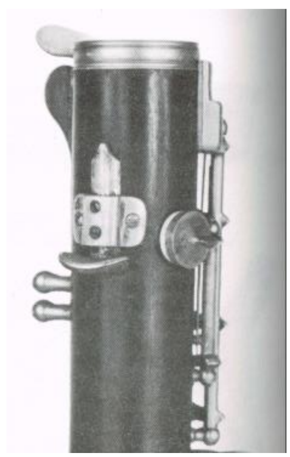

Figure 2.8 Adjustable thumb-rest from ca. 1976 as seen in Jack Brymer's *Clarinet.*[88] Mouthpiece would be in the upwards direction in this photo.

The adjustable thumb-rests immediately changed the relationship between players and their instruments. The thumb-rests were able to be moved higher, and the thumb was brought above the traditional position across from the middle finger/second tone hole. Again, because the tone holes of each instrument are in slightly different locations on the instrument body, it is

[85] Lemmel, September 26, 2014.
[86] Lemmel, 2014.
[87] Brymer, 1976, pg. 100.
[88] Brymer, 1976, pg. 100.

important to refer to the thumb's position as a function of index and middle finger location. The most recent version of the Buffet Crampon adjustable thumb rest puts the thumb 5 mm below the middle of the first tone hole when in the highest position (see Figure 2.9) and 19 mm below the middle of the first tone hole in the lowest position. This lowest position is also about 15 mm above the traditional fixed thumb-rest position.

For an even higher position, some players choose to have their thumb-rest redrilled (See next section). Many models now (Selmer, Rossi, Yamaha) have created thumb-rests that can place the thumb both lower and higher than the traditional Buffet Crampon position.

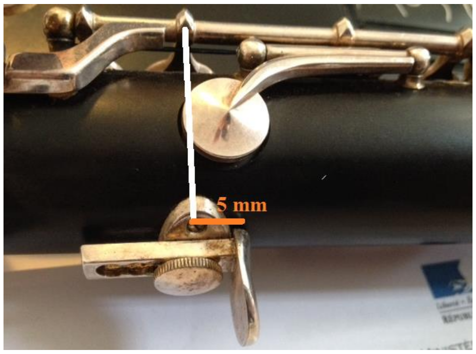

Figure 2.9 Buffet Crampon R13 Bb clarinet with modern thumb-rest screw holes in line with right index finger ring key arm. This adjustable thumb-rest is at the highest position. Picture provided by Buffet Crampon factory, and modified with lines by author. Mouthpiece would be to left in this close up photo.

Since about 2010, adjustable thumb-rests come standard on virtually every brand of clarinet. Each clarinet manufacturer (and model) has different adjustable thumb-rest ranges, but Backun, Yamaha, Henri-Selmer, and Buffet Crampon all have a range of 10 mm.[89] Figure 2.10 shows different styles of current adjustable thumb-rest models in Backun, Yamaha, Selmer, and Ridenour brand clarinets. Each has a unique design, but achieves the same goal of giving flexibility of thumb position to the customers.

[89] Measurements taken by author at 2014 International Clarinet Society ClarinetFest in Baton Rouge, LA.

Adjustable thumb-rests do not redistribute the clarinet's weight to other locations on the body like neck straps or pegs. They also do not change contact point, width, surface area, or dimensions of the clarinet as alternative thumb-rests such as the Kooiman, Ridenour, All Thumbs Rest, or Ergo Woodwind Comfortplayer products do (Chapter 4). Adjustable thumb-rests do change the physical relationship between the thumb and the other digits, perhaps changing the muscular demands of the task.

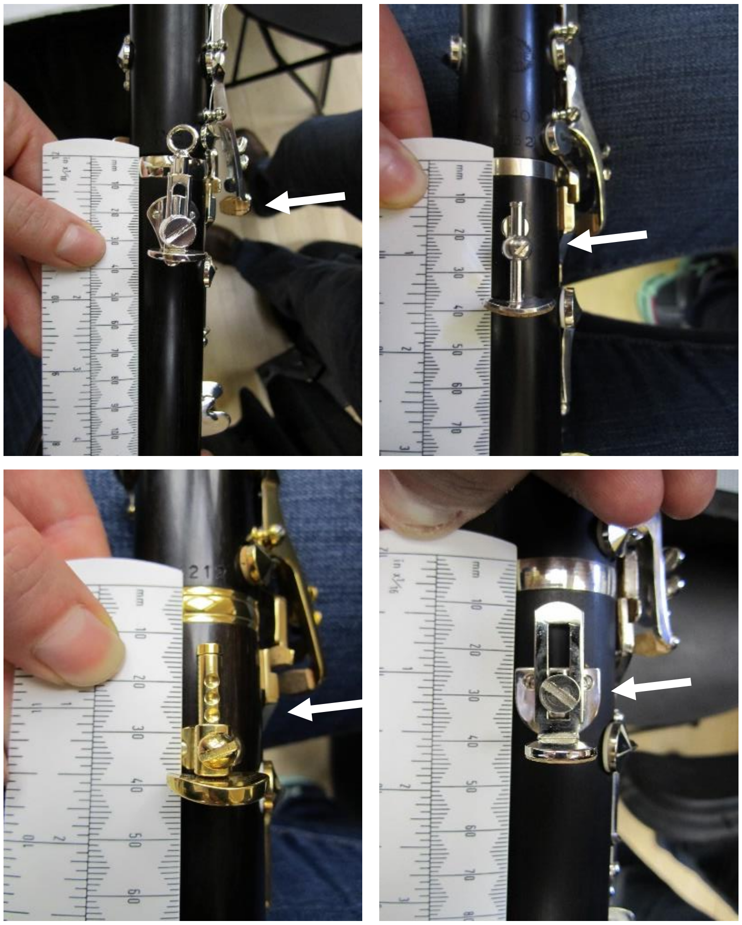

Figure 2.10 Adjustable thumb-rests from 2014 models, indicated by white arrows. Backun (top left), Selmer (top right), Yamaha (bottom left) and Ridenour (bottom right) all in a variety of height positions. The design of each company is slightly different.

There is a popular belief that changing the height of the thumb-rest will benefit clarinet players and their health. It is often suggested as a solution for those who have pain issues.[90] Furthermore, many players that learned to play on traditional thumb-rests have switched to adjustable thumb-rests. Chad Burrow, Professor of Clarinet at the University of Michigan, learned to play on a traditional thumb-rest position but struggled to find a comfortable position. Before adjustable thumb-rests were available, Burrow flipped the thumb-rest upside down to get a higher position, and later had the thumb-rest redrilled higher. He now places the adjustable thumb-rest in the highest position possible in order to "fit a more natural comfortable position for the hand."[91]

While the current prevalence of adjustable thumb-rests is undeniable, some voices in the clarinet community are concerned about the trend.[92] Some believe the number of injuries among clarinetists has increased after the use of adjustable thumb-rests and believe the balance point of the instrument is better at a fixed, lower position.[93]

2.10 Redrilled thumb-rests

An increasingly popular option for clarinetists is to have the thumb-rest re-drilled on a different location of the instrument. Most thumb-rests are attached to the body of the instrument with two small screws about 3mm in length. It is very simple for a repairman to take the original thumb-rest screws out, place the thumb-rest in a different location and use an electric drill to insert the screws somewhere else on the instrument.

[90] S. Archer-Capuzzo, "Practice and Performance Related Injuries: Preventing and Treating Injuries through Smart Practice Techniques," ClarinetFest 2008 www.clarinet.org/clarinetFestArchive.asp?archive=107 (accessed April 7, 2014). Larry Guy, *Hand & Finger Development for Clarinetists* (Stony Point, NY: Rivernote Press, 2007).
[91] Chad Burrow, "Research Email," Email message to author, 2014.
[92] Chodacki, Interview by Young, 2014; Jacobi, Interview by Coppa, 2014.
[93] Chodacki, 2014.

Generally, when this procedure is done, the rest is moved to a higher position in relation to the other right hand digits to create more direct opposition of the thumb and index finger. This technique goes beyond the simple adjustable thumb-rest in giving players even more options for placement of the thumb. Re-drilled thumb-rest holes can establish a higher thumb position than most adjustable thumb-rests.

Redrilling thumb-rests is an extremely popular topic in online discussion forums of clarinetists. Most commenters acknowledge that an individual's preference should be the primary guideline for picking a new location for the rest.[94] Repairmen report that they have increasing demands for this procedure from their clients, and that invariably, the requests are for a higher position than the traditional rest.[95] More specifically, players more frequently request their thumb-rests be place so their index finger and thumb are opposed.[96]

The process of redrilling the thumb-rest is supported among many clarinetists worried about injury. In a presentation at the 2008 International Clarinet Association conference Dr. Sonia Archer-Capuzzo said,

> Because our right thumbs bear the weight of the clarinet, we are also at risk of developing [inflammatory injuries], which involve swelling of the tendons that control the thumb and can cause pain in the thumb that may spread up through the wrist. To help prevent or treat De Quervain's [a painful type of tendonitis of the thumb area], try using support devices, like neck straps or the FHRED; also consider moving your thumb-rest higher on the lower joint of the clarinet to put the thumb in a more comfortable position.[97]

Within this suggestion is a powerful message: 21st century musicians are cognizant of the physical risks of their craft and are willing to change their playing or instrument to avoid or

[94] "Buffet Thumbrest Too Low," Woodwind.org http://test.woodwind.org/clarinet/BBoard/read.html?f=1&i=108424&t=108424 (accessed June 19, 2014).
[95] Jacobi, Interview by Coppa, 2014; Steve Koivisto, Interview by Kate Young, 2014; Sebastien Fontaine, Interview by Kate Young, August 1, 2014.
[96] Fontaine, 2014.
[97] Archer-Capuzzo,

rehabilitate injury. This is a shift from an older mentality of players that would decide not to pursue a career if they were not "built" for the instrument, or would step away from performing when medical issues arose. The new mindset reflects the powerful new push towards altering the thumb-rest position. These adjustments are born out of a desire to create a more ergonomic playing position, but there is no quantitative research to guide these changes.

In his book *Hand & Finger Development for Clarinetists*, pedagogue Larry Guy acknowledges that finding a comfortable spot to support the clarinet can be a difficult:

> Ideally, the clarinet should be supported entirely by the RH thumb, because this allows the fingers total freedom of movement. In reality, many players experience difficulty supporting the clarinet in this manner over long hours of daily playing. If the player experiences fatigue in the RH thumb or hand, a neck strap can be beneficial so long as it does not interfere with the movement of the LH thumb. … To lessen strain avoid placing the RH thumb on the thumb-rest too near the tip of the thumb. Most players find a good spot between the thumb nail and the thumb joint.
>
> *Some players like to position the thumb-rest higher so that the RH thumb is placed more nearly opposite the first finger*. This can be comfortable for some players and not for others, so take care when experimenting with this position in order to avoid injury. It alters the "balance" of the instrument, and players are recommended to abandon this position at the first sign of pain.[98] *(Emphasis added)*

Larry Guy points out that injury can still occur when a thumb-rest is moved and alludes to the "balance" that players must find with the instrument.[99] More research about this topic will improve musicians' ability to make informed decisions for their own approach.

2.11 Conclusion

The shift to reed-down playing, increase in weight, and addition of keys changed the demands and balance of the instrument. There are so many keys on modern French and German-system clarinets, a thumb-rest is absolutely necessary to play the instrument.

98 Guy, 55.
99 Guy, 55.

Instruments in the past were designed differently by each maker customized to player's demands. With the switch to factory-made instruments in the late 19th century, instrument makers chose a standard location for the thumb-rest. In the 21st century, adjustable thumb-rests and other support systems have become more common. Some clarinetists believe traditional, lower placements of the thumb-rest serve players best, while others believe more ergonomic options are possible. This debate deserves quantitative research about how the body reacts to different thumb-rest positions.

PART II

CHAPTER 3: THE ANATOMY OF A CLARINETIST

Clarinetists must maintain a static hold to support the weight of their instrument. Each player has a unique morphology which dictates how the task of holding the clarinet can be accomplished. The many thumb-rest support alternatives found in Chapter 10 reveal the widespread need for extra help with this task. The medical issues of musicians are often lateralized, meaning shifted to one side or the other. For woodwind players, the lateralization of injury often occurs to the right side, which supports their instruments. This demands a deeper understanding of the exact ways in which players use their bodies with their instruments.

A chain of skeletal and muscular support helps players hold up the clarinet. This begins with the contact point of the hand and instrument. It continues through the wrist, the forearm, past the elbow, and through the upper arm to the shoulder. The shoulder is connected to the trunk which also helps stabilize the arm. This section will explore the skeletal and muscular structure of this support chain. All information in this section is based upon the Tortora and Nielson Principles of Human Anatomy, 12th edition unless otherwise cited.[100]

3.1 Skeletal structure

The hand can be divided between the palm and the digits. The palm contains five metacarpal bones. The proximal ends of the metacarpals articulate with the wrist bones and the distal ends articulate with the first phalange each finger (digit). Digits II-V contain three small bones called phalanges (proximal, middle, and distal). The thumb only has two phalanges.

[100] Gerard J. Tortora and Mark T. Nielsen, *Principles of Human Anatomy*, 12th ed. (United States of America: John Wiley & Sons, Inc., 2012).

Three structural arches created by the bones of the hand help maintain stability when holding objects.[101] These arches are the proximal transverse arch, the distal transverse arch, and the longitudinal arch (See Figures 3.1 and 3.2).[102] The proximal transverse arch occurs along the carpometacarpal joint of each digit and stays relatively fixed even when the hand is open. The distal transverse arch is found at the metacarpophalangeal joint (knuckles) and is more mobile than the proximal transverse arch.[103] The 1st, 4th, and 5th metacarpals are able to rotate around the 2nd and 3rd metacarpals to create variations in width and shape of this arch.[104] The longitudinal arch reaches down the length of the palm along the axis of the third digit. It can flatten slightly when the digits are extended and deepen into a pronounced curve when the digits are flexed.[105]

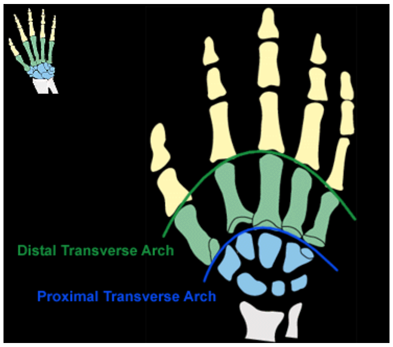

Figure 3.1 Proximal and Distal Transverse Arches of the Human Hand[106]

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[101] L. Richards and J. Loudon, "Bone Arches," University of Kansas Medical Center, School of Allied Health http://classes.kumc.edu/sah/resources/handkines/bone/arches.html (accessed August 27, 2014); Jaume Rosset i Llobet, *The Musician's Body: A Maintenance Manual for Peak Performance*, ed. George Odam (Burlington, VT: Ashgate Publishing Company, 2007), 36.
[102] Richards and Loudon,
[103] Richards and Loudon,
[104] Richards and Loudon,
[105] Richards and Loudon,
[106] Richards and Loudon, ; Richards and Loudon,

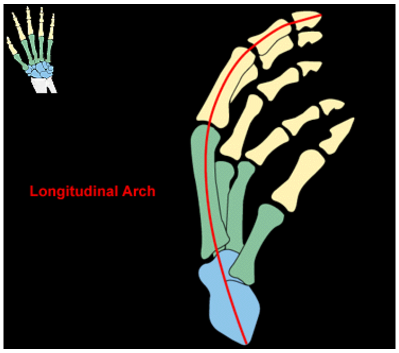

Figure 3.2 Longitudinal Arch of the Human Hand[107]

The proximal transverse arch is of the most interest to clarinet players' thumbs. Essentially this arch divides the hand in two long halves. Movement of the thumb (pollex) can expand or collapse this arch: when a clarinetist holds the thumb across from their index finger the proximal transverse arch would be more neutral, when a clarinetist holds their thumb across from their middle finger the proximal transverse arch would become more collapsed. The topic of maintaining hand arches while playing clarinet is addressed in detail in Harger (2012) who used motion capture data to investigate the shape of the hand of professional players.[108]

The thumb has three synovial joints: the *carpometacarpal joint* (CMC), the *metacarpophylangeal joint* (MCP) and the *interphalangeal joint* (IP). These three joints together make the thumb the most mobile digit. The CMC joint is a synovial saddle joint that connects the first metacarpal with the trapezium carpal bone. A saddle joint contains two bones where one bone is saddle shaped (the trapezium) and the other bone (the first metacarpal) fits into it, Figure 3.3. This special joint allows for flexion, extension, abduction, adduction and circumduction of the pollex. The CMC joint of the thumb must remain stable in order to hold the clarinet and is the first major skeletal structure in the chain of upper limb support for this task.

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[107] Richards and Loudon,
[108] Stephanie Harger, "An Investigation of Finger Motion and Hand Posture During Clarinet Performance" (Arizona State University, 2011).

The MCP joint joins the thumb metacarpal and the proximal phalanx of the thumb. Between the proximal and distal phalanges is the IP joint which bends the tip of the thumb. Some clarinetists rest their instrument beyond this joint and some rest the clarinet directly on this joint.

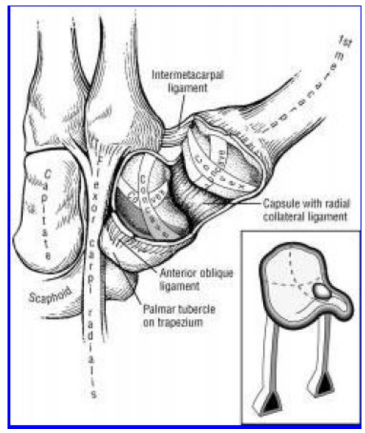

Figure 3.3 A dissected view of the *carpometacarpal* joint of the human hand. A large joint compartment and shape of the articulating bones allow for wide angles of movement.[109]

The thumb has two fundamental planes of movement: CMC flexion/extension and CMC adduction/abduction. This means the CMC joint can move in planes perpendicular and parallel to the palm. Its loose joint capsule allows for extra rotation in the metacarpal when it moves in the two planes. CMC flexion and abduction can be combined to create CMC opposition. CMC extension and adduction can combine to produce CMC reposition, Figure 3.4.

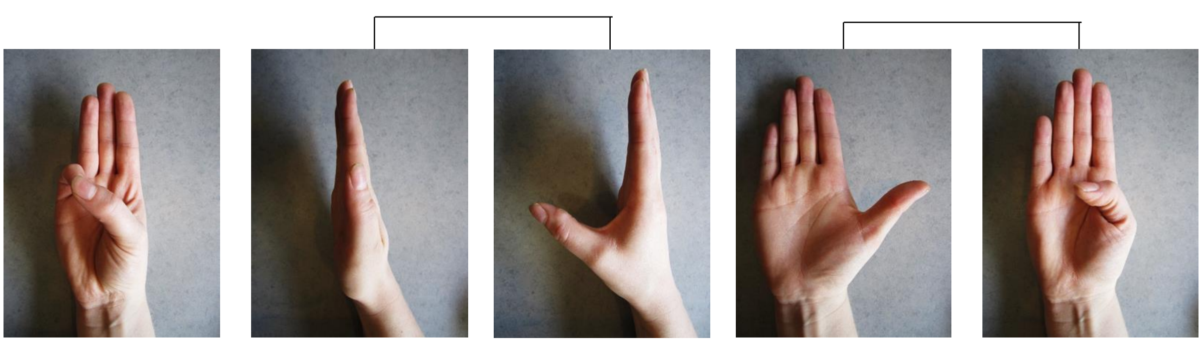

Figure 3.4 Isolated thumb motions. From left to right: Opposition, Reposition, Abduction, Extension, and Flexion. Bars show pairs of opposing motion. Photos by author (9/1/2014).

[109] D.A. Neumann and T. Bielefeld, "The Caropometacarpal Joint of the Thumb: Stability, Deformity, and Therapeutic Intervention," *Physical Therapy* 33, no. 7 (2003): 387.

Supporting the clarinet requires a static hold of the pollex in a combination of movements that is unique to each player's anatomy. The type and degree of CMC movement depends on the hand position that each clarinetist selects.

The thumb transfers weight to the wrist joints. The wrist is a collection of eight small bones that each have numerous contact points with the other bones of the wrist and hand. These bones are called carpal bones from the Latin name for the wrist, the carpus. Carpal bones are arranged in two rows: the proximal row - which articulates with the distal end of the ulna and radius to form what is called the "wrist joint," and the distal row which articulates with the metacarpals of the digits. From lateral to medial, the scaphoid, lunate, triquetrum, and pisiform form the proximal row of the wrist. From lateral to medial, the trapezium, trapezoid, capitate, and hamate form the distal row. The carpal tunnel, a common site of inflammation, is formed by the concave space made by the pisiform and hamate (ulnar side), and the scaphoid and trapezium (radial side) and is closed off by the *flexor retinaculum* connective tissue.

Motions of the wrist include flexion and extension in two planes. Radial deviation (abduction, movement towards the thumb) and ulnar deviation (adduction, movement towards the little finger) occur in a dorsopalmar axis at the radiocarpal and midcarpal joints passing through the capitate bone. Flexion (palmar flexion, tilting towards the palm) and extension (dorsiflexion, tilting towards the back of the hand) occur in a transverse axis passing through the capitate bone. Through a combination of these motions, the wrist can achieve many positions, Figure 3.4. The bones of the wrist provide strength and rigidity, while the muscles and tendons that act on the wrist provide flexibility in position. Clarinetists take advantage of these wrist positions by combining them with different thumb postures to best support their instrument.

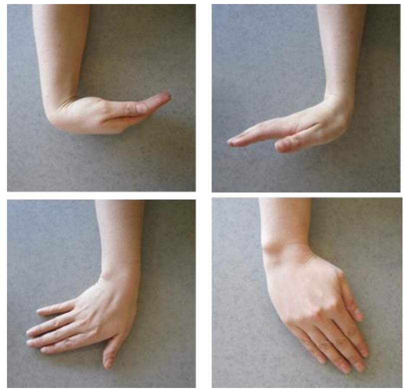

Figure 3.5 Positions of the wrist. Top: Flexion (left) and Extension (right), Bottom: Ulnar deviation (left) and Radial deviation (right). (Photos by author 09/10/2014).

The wrist transfers the weight of the clarinet to the forearm. The radius and ulna bones provide structure through the forearm and connect the hand and wrist to the elbow. The ulna articulates with the pisiform and hamate bones of the wrist towards the pinky side of the hand, and the radius articulates with the scaphoid and trapezium bones of the wrist towards the thumb. At the elbow, the radius and ulna articulate with the humerus of the upper limb. When the forearm is prone (with palm facing up) the radius and ulna are parallel. When the forearm is supine (palm facing down) the radius and ulna cross each other.

The elbow joint is a hinge joint between the upper arm and forearm. The skeletal and connective tissues limit the movement of the joint to just the flexion and extension of the forearm, yet provide strength in the joint. The elbow joint is formed between the trochlea and capitulum portions of the humerus, the trochlear notch of the ulna, and the head of radius. Clarinetists keep this joint partially flexed in order to bring the right hand to the instrument. The upper arm consists of the humerus bone which connects the elbow to the shoulder.

The shoulder is the most proximal joint in the chain of arm support. For the motor task of clarinet playing, the shoulder must stabilize the entire chain of support for the instrument and tap into the strength of the torso. It must prepare the entire joint to bear weight and hold the humerus

in a steady position, while minimizing the amount of tension in the body. The shoulder is a ball-and-socket joint formed by the head of the humerus and the glenoid cavity of the scapula. It allows for flexion, extension, hyperextension, abduction, adduction, medial rotation, lateral rotation, and circumduction of the arm. Its loose articular capsule, a sac that surrounds the joint between the scapula and humerus, allows for its wide range of motion. For clarinet playing, the shoulder does not utilize a large range of motion. Small changes in the shoulder position would be magnified down the chain at the contact point with the clarinet and so are avoided.

The skeletal structure of the upper limb provides the basis for holding the clarinet. Layered above the bones and joints are muscles and connective tissue. These tissues both move and stabilize the underlying structure to hold the clarinet.

3.2 Muscular control

Humans have a complex network of muscles that work in antagonistic pairs to give gross and fine motor control. Muscles are often divided into functional categories such as muscles that flex joints and those that extend them. They are also divided by the layers in which they are found on the body: those close to the bone are "deep," those that are found towards the skin are more "superficial."

The thumb is stabilized by both extrinsic muscles which originate outside the hand, and intrinsic muscles which originate inside the hand. The extrinsic muscles include the *flexor pollicis longus, abductor pollicis longus, extensor pollicis brevis* and *extensor pollicis longus*. The intrinsic muscles that move the thumb include the *abductor pollicis brevis, opponens, flexor pollicis brevis, adductor pollicis, palmar interosseous* and *first dorsal interosseous* (Table L1). Five ligaments act on the carpometacarpal joint: the anterior oblique, ulnar collateral,

intermetacarpal, posterior oblique, and radial collateral. These ligaments help stabilize the joint which has limited support from its curved bone surfaces.

After the thumb is stabilized, the wrist and forearms are the next steps in the muscular chain of support for holding the clarinet. The muscular design of the forearm maximizes the motor possibilities and limits bulk by utilizing a system of tendons. Long tendon connections from the forearm muscles pass through and around the narrow wrist. This allows for the wrist and hand to be flexible and well controlled, yet free of the larger extrinsic muscles that are housed in the forearm. To maximize this efficiency, some muscles are multitendoned – meaning their tendons attach to multiple locations. Multitendoned muscles create the framework for synergistic combinations of muscle movements to achieve many combinations of finger and wrist movement.

Anterior muscles flex the wrist, hands, and fingers and posterior muscles extend the wrist at their insertion points. The extensor carpi radialis longus and brevis, extensor digitorum, extensor digit minimi, abductor pollicis longus, extensor pollicis longus and brevis and extensor indicis all extend the wrist, Table L5, Appendix L. The flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum superficialis, and flexor digitorum profundus all flex the wrist. Information about their origins, insertions, and actions on the wrist are found in Table L4, Appendix L.

A network of interosseous membranes provide connective support between bones above and below the wrist. For example, interosseous membranes can be found between the radius and ulna, as well as within the hand. Dense sheaths of connective tissue, called fasciae, hold the tendons and muscles of the hand close to the bones of the hand. Deep fasciae of the wrist are thickened into fibrous bands called retinacula. The flexor retinaculum lies over the flexor

tendons on the palmar surface of the wrist and the extensor retinaculum lies over the extensor tendons on the dorsal surface of the wrist. Structural support from these connective membranes help accomplish the task of holding the clarinet. They oppose each other to create a wrist posture that is stable and is neutral.

To play the clarinet, the forearm must be semi-prone. The muscles that act specifically on the forearm bones – the radius and ulna – are the *pronator teres, pronator quadratus*, and *supinator*, Table L8 of Appendix L.

Next in the chain of muscular support for the upper limb are the eight skeletal muscles that control flexion and extension of the elbow joint. Partially flexing the elbow joint raises the forearm to a horizontal position in order to hold the clarinet. The biceps brachii, brachialis and brachioradialis all flex the elbow to raise the forearm. The triceps brachii and the anconeus work as extensors to stabilize the forearm in one position once weight of the clarinet is placed on the hand. Information about these muscles can be found in Appendix L, Table L3.

Connective tissue is crucial for the structural support to the elbow joint. Four main components create stability within the elbow: articular capsule, ulnar collateral ligament, radial collateral ligament, and annular ligament of the radius. These ligaments keep the radius, ulna and humerus connected together at the elbow. See Appendix L Table L6 for descriptions of these structures.

The final area for muscular support of the clarinet is the shoulder. Many muscles help both main osseous components of the shoulder joint – the humerus and the scapula – move together to increase range of motion and provide stability. Some muscles move the scapula (shoulder blade) and girdle (area that surrounds the humerus head), while some specifically move the upper arm by acting on the humerus Table L9, Appendix L.

Three ligament divisions surround the shoulder which help give support to the skeletal muscles around the joint. These include the coracohumeral ligament, three glenohumeral ligaments and the transverse humeral ligament. The ligaments of the shoulder help stabilize the two bones of the joint and maintain a strict plane of motion. They provide the stability needed to hold an object for extended periods (like a clarinet). Four bursae, cushion-like structures, help pad the joint and prevent pain from bone on bone contact: subscapular bursa, subdeltoid bursa, subacromial bursa, and subcaracoid bursa. For clarinet players, the use of the shoulder is critical to hold the instrument with stability. As seen in Chapter 4, some players rely on neck straps and pegs to help with this support by taking away some of the work from the shoulder. Clarinet players generally do not move the humerus very much while they are playing. That static hold of muscles that control the scapula and girdle are critical for transferring the weight of the clarinet to the torso.

3.3 Passageways for tendons and nerves in the wrist and neck

Circulatory tissues (arteries and veins) and nervous tissue (nerves) must reach all parts of the support chain that clarinetists use. These tissues can become inflamed or damaged if they do not have the proper space and environment to move. Two particularly dangerous points for these tissues are the neck and the wrist.

In the wrist, the multitendoned muscles that move digits II-V, nerves and circulatory tissues all share the same narrow passageway through the bony carpal tunnel and arch of the wrist. Any excessive friction or inflammation from one tissue in this narrow passageway can cause compression and issues for the rest of the tissues and the hand as a whole. Clarinetists can help prevent injury by maintaining a neutral wrist and hand arch. This means they must not over

extend or over flex their wrist or compress along their natural hand arches in order to protect these passageways.

The nerves that reach the arm and hand all branch off of the brachial plexus, a complex network of cranial and some thoracic nerves. The brachial plexus is situated where the base of the neck meets the shoulder. Passage of nerves through the neck and brachial plexus put the upper limb at risk of injury if the neck is compressed or strained. See Figure 3.5 for the general location of the brachial plexus.

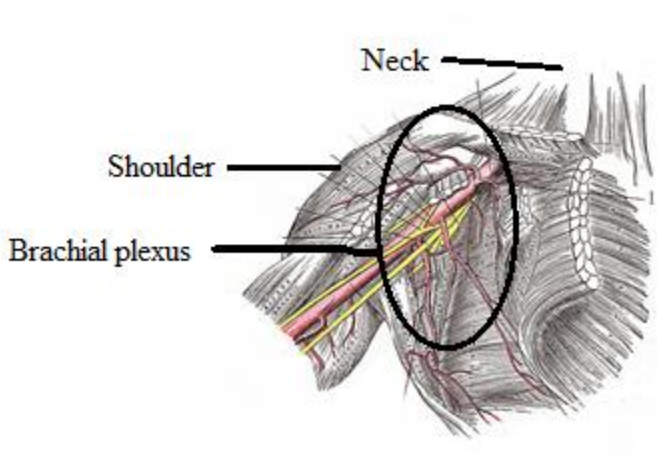

Figure 3.6 Brachial plexus near shoulder and neck.[110]

The shoulder is innervated by the medial and lateral pectoral, dorsal scapular, thoracodorsal, axillary, upper and lower subscapular, long, thoracic, suprascapula, and musculocutaneous nerves. Muscles of the elbow are innervated by the median, radial and musculocutaneous nerves. The ulnar, radial, and median nerves innervate the forearm, wrist and hand. The ulnar and median nerves are responsible for the flexors of the wrist, while the radial nerve alone creates efferent output for wrist extension.

[110] Henry Gray, *Anatomy of the Human Body*, ed. Warren H. Lewis, 20 ed. (Philadelphia: Lea & Febiger, 1918), 523., modified by author.

3.4 Conclusion

A complete understanding of body mechanics is a fundamental skill that instructors and performers should have. It empowers them to make better choices based on the realities of their bodies. For clarinetists, understanding the chain of skeletal and muscular support in their upper limb is crucial. The right upper limb must utilize all elements of its structure to hold up the instrument and also execute complex motor tasks with different fingers.

CHAPTER 4: PREVENTION AND TREATMENT APPROACHES FOR MUSICIANS

4.1 Introduction of overuse and musician injury

Information that already exists about clarinetists and their bodies when looking at this topic of thumb-rest positions. Clarinetists not only feel discomfort when supporting their instruments, they frequently encounter mild to severe injury from playing their instruments. Taking a brief look into existing research will establish the current context of clarinetist injury with thumb-rests. This section will not fully explore the topics of all injury which has been addressed in other documents.[111] It will help establish the context of how musicians conceptualize injury and touch on the different ways in which they cope with difficulties of holding the clarinet.

The medical community divides musician's upper limb injuries into three main categories: musculoskeletal issues, nerve entrapment conditions, and focal dystonias.[112] Musculoskeletal disorders consist of a range of muscle, tendon, and joint pain and are often referred to as *overuse injuries*.[113] [114] Nerve entrapment conditions include inflammatory problems such as carpal tunnel syndrome. Focal dystonias are thought to be a product of the neurological plasticity that often comes with intense musical training.

Of these three conditions, musculoskeletal issues are the most common. In a specialty clinic that treats performing artists, pain is the primary complaint of approximately 85% of the

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[111] J.K. McIlwain, "Common Injuries among College Clarinetists: Definitions, Causes, Treatments, and Prevention Methods" (Florida State University, 2010).
[112] A.G. Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," *Hand Clinics* 19, no. 2 (2003): 231.
[113] The label "tenosynovitis" is also sometimes used as a replacement for "overuse." The origin of this label is described in Fry (1987):44, 35-40.
[114] H.J.H. Fry, "Overuse Syndrome of the Upper Limb in Musicians," *Medical Journal of Australia* 144, no. 4 (1986): 183.

patients seen.[115] For woodwind patients of this clinic, 52% of those diagnosed had a musculoskeletal disorder.[116] Regional types of musculoskeletal problems where there is no direct pain point are called *overuse injuries.* This label is a catch-all identification for situations in which “any biological tissue – muscle, bone, tendon, ligament, etc. – is stressed beyond its physical limit.”[117] Physical exams which produce little result except “tenderness in the forearm muscles, especially the wrist extensors, and the intrinsic hand muscles” would generally lead to a diagnosis of *overuse*.[118] Inflammation of the tendons, ligaments and bones is common in musicians.[119]

4.2 Existing research on musician injury

The research and treatment of performing artists have increased rapidly since the 1980s. Journal articles provide advice for medical practitioners that may begin consulting musician patients.[120] These introduce medical professionals to musician- and instrument-specific conditions such as common playing postures and practice habits. Published demographic surveys of orchestral musicians and conservatory students also provide information about the relationships between certain pain and injury in specific musician populations.[121] These published articles struggle to uniformly identify discomfort that instrumental musicians feel and use terms like: disease or disorder, tenosynovitis or strain, overuse or fatigue, etc.

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[115] R.J. Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians," *Muscle & Nerve* 27, no. 5 (2003): 551.
[116] Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians."
[117] McIlwain, 29.
[118] McIlwain, 28.
[119] R.E. Markison, "Tendinitis and Related Inflammatory Conditions Seen in Musicians," *Journal of Hand Therapy* 5, no. 2 (1992): 80.
[120] Brandfonbrener, 2003, pg. 231
[121] Fishbein, 1988; Fry, 1986, 1987

Musician's upper limb injuries are divided into three main categories: musculoskeletal issues, nerve entrapment conditions, and focal dystonia . Musculoskeletal issues consist of muscle, tendon, and joint pain and are often labeled *overuse injuries* . Nerve entrapment conditions include inflammatory problems such as carpal tunnel syndrome. Focal dystonias are motor control issues thought to be a by-product of excessive neural plasticity that often comes with intense musical training.[122] Of these three types of injuries, musculoskeletal issues are the most common for musicians.[123] Patterns of musculoskeletal issues can be traced to instrument-specific risk factors and total playing time per week.[124]

Symptoms in musicians are often lateralized to one side of the body or another. This lateralization typically follows instrument-specific patterns. For example, woodwind patients in a Cleveland clinic were treated for right arm pain 44% of the time, and treated for left arm pain only 20% of the time. Dr. Brandfonbrener, a clinician that treats musicians, believes that woodwind players' most frequent pain sites are associated with the requirements of supporting each instrument. She lists the right thumb as a common problem area for the static load of clarinets and oboes.[125] Research on the specific musculoskeletal demands will help scientists understand the intricacies and dangers of each instrument.

Playing a musical instrument is one of many activities that involve static postures. Athletic wall squats, yoga postures and workplace tasks require humans to hold static postures with their muscles. Yet for there are health risks associated with sustained static postures. A Centers for Disease Control and Prevention (CDC) report on workplace health found "there is

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[122] V. Candia et al., "Effective Behavioral Treatment of Focal Hand Dystonia in Muscians Alters Somatorsensory Cortical Organization," *Proceedings of the National Academy of Sciences* 100, no. 13 (2003): 7942.
[123] Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians," 552.
[124] Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians," 552.
[125] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 236.

strong evidence that working groups with high levels of static contraction, prolonged static loads, or extreme working postures involving the neck/shoulder muscles are at increased risk for neck/shoulder musculoskeletal disorders (MSDs).[126] Clarinet players (as well as oboists and saxophonists) that support their instrument with static postures and play with repetitive motions are therefore at a higher risk for injury. It is not yet known if altering thumb-rest positions could help reduce the risk for musculoskeletal injuries for clarinetists (See Chapter 9 for information). When clarinetists are injured there are traditional and nontraditional approaches for regaining wellness and functionality of their bodies.

4.3 Traditional medical treatment

Traditional medical treatment will often treat musician injuries in the same way as small sports related injuries. This includes rest, medication, ice and heat therapy, exercise to increase muscle strength, splinting, practice modification, specialist or therapist referrals, and possible surgery.[127] An overview of treatment and prevention regimens can be found in (McIlwain, 2010).[128]

Published case studies and literature reviews list “rest” as the predominant treatment for musician musculoskeletal issues. Rest is logical to allow irritation and inflammation to naturally subside, but it does not address underlying causes of the injury and therefore may provide limited long term value. Extended rest during the career of a musician carries with it many emotional and professional repercussions. Emotionally, many musicians strongly tie their personal identity to their careers and rest can be considered devastating. There may be stigma from peers if a

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[126] V. Putz-Anderson, B.P. Bernard, and S.E. Burt, *Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremit, and Low Back* (Cincinnati: Department of Health and Human Services (National Institute for Occupational Safety and Health), 1997), 5b-1.
[127]McIlwain, 35.
[128] McIlwain.

musician is injured. In one study, they predicted their total population of injured students was below the total prevalence at a school because "some students with problems did not wish to be 'uncovered' or they may have been afraid of losing the goodwill of their teacher." In terms of career maintenance and reputation, professional musicians feel pressure to consistently perform at their best. One study claims that the "difference between 95% recovery of an injured finger and 100% recovery may mean the difference between a world-class performing career as a violinist and obscurity." The realities of rest and the competitive environment for musicians can create unhealthy situations where musicians avoid professional help for medical problems for fear of stigma or emotional stress.

A compromise between full playing and total rest is "relative rest." This reduction in playing duration and overall amount is the suggested approach by numerous doctors as the most effective way to help musicians.[129] [130] This allows for the emotional and physical drawbacks of rest to be balanced with the necessity of time for inflammation to be reduced.[131]

4.4 Musician-directed approaches to preventing and treating injury

Resources for instrumental musicians' injuries have increased as more attention is given to workplace and musician injuries. A growing consciousness that musicians serve as "athletes" of highly refined and repetitive movements has led to more research, discussion, and proactive approaches for musicians, their workplace and injuries. Many musicians agree that awareness of their bodies' needs are important, but few partake in the precautions that other performing artists such as dancers or athletes regularly do.[132] To respond this the need of musicians, some medical

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[129] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 237.
[130] Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians," 557.
[131] Lederman, "Neuromuscular and Musculoskeletal Problems in Instrumental Musicians," 557.
[132] Rosset i Llobet, vii.

experts are focusing their efforts into musician-centered clinics.[133] Simultaneously, some musicians have committed extensive time to mastering medical concepts and applying them to their own playing and teaching.

At an annual International Clarinet Association conference, Dr. Sonia Archer-Capuzzo presented information about injury prevention methods during a talk entitled *Practice and Performance Related Injuries: Preventing and Treating Injuries through Smart Practice Techniques*.[134] A clarinetist who dealt with injury herself, Dr. Archer-Capuzzo shared the advice and research that she had done to rehabilitate herself. She focused on warming up and cooling down, mental practice, stretching, breaks while playing, organizing practice for consistency and variety, and broadening mental focus.[135] This is a fairly representative list of the approaches taken by many other musicians.

Below is a brief description of injury prevention concepts that relate to woodwind players. Included in each subheading is a method of how certain musicians deal with each topic traditionally, how medical professionals that work with musicians might contribute, and if available, how the scientific literature can be used to understand the topic more.

4.4.1 Warming up

"Warming up" is a term that is commonly associated with athletics, as a preparation for the strenuous work of any sport. Some musicians already play a "warm up" on their instruments, including long held notes (long-tones), or patterned exercises such as scales, intervals, and

[133] Centre for Physiology in the Arts in Catalonia; The Cleveland Clinic in Cleveland, Ohio; The Performing Arts Clinic in the Brigham and Women's Hospital in Boston, Massachusetts; The Clinic for Performing Artists at Virginia Mason in Seattle, Washington; and even the BAPAM: British Association for Performing Arts Medicine in London. Many other exist throughout Europe and the United States today.
[134] Archer-Capuzzo,
[135] Archer-Capuzzo,

variations. A different kind of warm up that medical sources describe includes gentle physical activity for about 10-20 minutes *before* going to the instrument.[136] In her book entitled The Athletic Musician, Barbara Paull defines warming up as “using muscles gently and smoothly for a few minutes to increase the blood flow through them without stressing them.”[137] *The Musician’s Body* book recommends that readers introduce a warm-up before playing to improve elasticity, warm the muscles, tendons and joints, improve technical performance, delay the onset of fatigue, and prevent injuries.[138] Some recommended warm up possibilities include: taking short brisk walk, dancing, swing arms as if marching and do repeated self-hugs and releases, warm up wrists and hands by massaging real or imaginary hand lotion into hands and fingers.[139]

Scientific literature confirms that muscular and musculotendinous injuries can be reduced with a warm up regimen.[140] Clarinet pedagogy books make some references to the idea of slowly working into a full paced practice session. Clarinet pedagogue David Pino suggests to note when one’s clarinet playing is particularly tense and avoid fast, technical passages until one’s muscles are relaxed.[141]

4.4.2 Cooling down

Cooling down is a term familiar to athletes. *The Musicians Body* recommends adding a cool-down after playing into the daily routine. This would include gradually reducing the level of activity over a 5-minute period to help eliminate metabolic waste products and prevent injuries from cumulative work already done. Then a post-practice cool-down of stretches would finish

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[136] Rosset i Llobet, 92.
[137] Barbara and Christine Harrison Paull, *The Althetic Musician: A Guide to Playing without Pain.* (London: The Scarecrow Press, Inc., 1997), 110.
[138] Rosset i Llobet, 92.
[139] Paull, 110.
[140] A. J. Fradkin, B. J. Gabbe, and P. A. Cameron, "Does Warming up Prevent Injury in Sport? The Evidence from Randomised Controlled Trials?," *Journal of Science and Medicine in Sport* 9, no. 3 (2006): 214.
[141] David Pino, *The Clarinet and Clarinet Playing* (Mineola: Dover Publications, Inc., 1980), 74.

the process of cooling down.[142] For clarinetists, stretches may include spreading and compressing fingers (ab- and adducting), opening and closing hands (flexing and extending fingers), stretching the palms, thumb, and wrist, and stretching the upper arms and back.[143]

Cooling down is less common than warm-ups among musicians. Perhaps this is from lack of training, or just a desire to move on from their practice session. One study on athletes indicated: "Inadequate or no cool down and a lack of adequate stretching may predispose [athletes] to tight muscles and longer recovery time after each game or practice."[144]

4.4.3 Mental practice

Mental practice is the act of imagining the process of playing a piece of music. Within the athletic community, the tradition of mental imagery is particularly robust – going back for centuries.[145] The primary benefit of mental practice is less physical interaction with the instrument which reduces strain and overuse. Mental practice provides musicians with the opportunity to create effective motor programs without adding the physical strain of the instrument.[146] [147]

This type of practice is a skill that must be developed, but can be highly effective for learning if musicians can master it. Anecdotes indicate that certain famous musicians were

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142 Rosset i Llobet, 92.

143 Rosset i Llobet, 94.

144 Á Árnason et al., "Soccer Injuries in Iceland," *Scandinavian Journal of Medicine & Science in Sports* 6, no. 1 (1996): 40.

145 Association for Applied Sport Psychology, "Sport Imagery Training," http://www.appliedsportpsych.org/resource-center/resources-for-athletes/sport-imagery-training/ (accessed September 26, 2014).

146 Paull, 137. N. Mizuguchi, H. Nakata, and K. Kanosue, "Effector-Independent Brain Activity During Motor Imagery of the Upper and Lower Limbs: An Fmri Study," *Neuroscience Letters* (2014): 1872; T. Schack et al., "Mental Representation and Motor Imagery Training," *Frontiers in Human Neurosciece* 8, (2014): 1662.

147 Motor programs are abstract representations of movement that centrally (in the central nervous system) organizes and controls the many degrees of freedom involved in performing an action (Schmidt, Richard A.; Lee, Timothy Donald (2005). Motor control and learning: a behavioral emphasis. Champaign, IL: Human Kinetics. ISBN 978-0-7360-4258-1. OCLC 265658315)

skilled in mental practice including pianists Glenn Gould and Arthur Rubenstein, and violinist Fritz Kreisler.[148] The *Musicians Body* recommends combining mental and physical practice. For beginners to mental practice, some suggest imagining the physical movements of playing the music and imagining the sounds you will produce at slow tempo.[149]

The neurological research community has found strong support for mental practice. Mental practice can cause the supplemental motor cortex areas such as the supplementary motor area (SMA), premotor cortex, and parietal cortex to activate in similar patterns as if it were actually planning to execute an actual movement performing the action.[150] In the primary motor cortex, mental practice can initially improve motor performance by acting on the preparation and anticipation of movements.[151] For players who have difficulty holding their clarinets, mental practice is a valuable tool for reducing time with the instrument but still developing motor patterns to be drawn upon in future performances.

4.4.4 Stretching

Stretching is used as a tool for athletes and musicians to care for their muscles and connective tissues. The act of stretching consists of pulling a body region or extremity away from its most anatomically neutral position in either an active or passive way.[152] Some musicians believe stretches are a good transition between rest and activity.

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[148] Diana Allan, "Mental Rehearsal Can Work for You," Peak Performance For Musicians http://www.musicpeakperformance.com/mental-rehearsal-can-work-for-you/ (accessed July 15, 2014).

[149] Rosset i Llobet, 12.

[150] Mizuguchi, Nakata, & Kanosue, 2014; Schack, Essig, Frank, & Koester, 2014.

[151] P.L. Jackson et al., "Functional Cerebral Reorganization Following Motor Sequence Learning through Mental Practice with Motor Imagery," *NeuroImage* 20, no. 2 (2003): 1171.

[152] Segen's Medical Dictionary. © 2012 Farlex, Inc.

The three main categories of stretching are static, dynamic, and pre-contraction stretches.[153] The most common type is static stretching: "where a specific position is held with the muscle on tension to a point of a stretching sensation and repeated."[154] Dynamic stretches can be divided between active and ballistic movements. Phil Page describes:

> Active stretching generally involves moving a limb through its full range of motion to the end ranges and repeating several times. Ballistic stretching includes rapid, alternating movements or 'bouncing' at end-range of motion; however, because of increased risk for injury, ballistic stretching is no longer recommended.[155]

Research suggests that static stretching is effective at increasing range of motion.[156] The greatest change in range of motion (ROM) with a static stretch occurs between 15 and 30 seconds and most researchers suggest that 10 to 30 seconds is sufficient for increasing flexibility.[157]

Static stretching should be used after the body has already been actively used rather than as part of a warm up routine. Static stretches performed immediately before exercise have been shown to reduce dynamometer-measured muscle strength and performance in running and jumping.[158] For athletes, stretching was not shown to reduce the incidence of overall injuries, but in some studies there is some evidence that stretching can reduce musculotendinous injuries.[159]

Books that provide stretches for all musicians include *The Athletic Musician: a Guide to Playing without Pain* by Paull and Harrison and *The Musician's Body: A Maintenance Manual for Peak Performance* by Rosset i Llobet. Suggestions specifically for clarinetists can be found

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[153] Phil Page, "Current Concepts in Muscle Stretching for Exercise and Rehabilitation," *International Journal of Sports Physical Therapy* 7, no. 1 (2012): 109-119.
[154] Page, "Current Concepts in Muscle Stretching for Exercise and Rehabilitation," 109.
[155] Page, "Current Concepts in Muscle Stretching for Exercise and Rehabilitation," 109.
[156] Page, "Current Concepts in Muscle Stretching for Exercise and Rehabilitation," 109.
[157] Page, "Current Concepts in Muscle Stretching for Exercise and Rehabilitation," 109.
[158] Page, "Current Concepts in Muscle Stretching for Exercise and Rehabilitation," 109.
[159] Page, "Current Concepts in Muscle Stretching for Exercise and Rehabilitation," 109.

in two articles by Michael Webster in *The Clarinet* magazine.[160] When used correctly, stretches can increase flexibility in the muscles and joints and maintain comfort for musicians' bodies.

4.4.5 Exercise: increasing strength

After inflammation has been reduced, exercise is a commonly prescribed treatment for musicians. It is true that muscular imbalances occur in individuals that specialize in certain activities (musicians, athletes, workers). It is assumed that muscle strengthening will help musicians correct muscular imbalances created by the instrument and avoid fatigue when playing.[161] In *The Musician's Body*, the author writes: "Properly trained muscles will create new muscle fibers and will help activate fibers to help meet performance demands."[162]

Brandfonbrener cautions that medical professionals should take care when prescribing exercise of physical therapy for each specific individual and instrument type.[163] In her own practice she considers "posture and supportive muscles, range of motion, the need for endurance versus strength, and the particular stresses imposed in supporting specific instruments."[164] Brandfonbrener believes that postural exercises to enhance spine supports and scapular functioning are beneficial for most musicians.[165] Musicians require muscular endurance rather than high levels of brute strength.[166] Therefore, light resistance training with many repetitions would be more beneficial for musicians than heavy weight training.[167]

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[160] Michael Webster, "The Home Stretch: Part I," *The Clarinet* 34, no. 1 (2006); Michael Webster, "The Home Stretch: Part Ii," *The Clarinet* 34, no. 2 (2007).
[161] Rosset i Llobet, 5.
[162] Rosset i Llobet, 5.
[163] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 231.
[164] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 237.
[165] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 237.
[166] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 237.
[167] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 237.

Clarinetists require muscular endurance in their entire upper limb, neck, and upper back to support the instrument. They also have a pattern of lateralization of injury to the right side of their bodies.[168] When working with physical therapists to create a workout regimen, clarinetists should explain or demonstrate the requirements of holding and playing their instrument.

4.4.6 Breaks while playing

Medical professionals, researchers, and musicians agree that periodic rests from activity can help reduce muscle strain and fatigue. Some believe that breaks may be instrumental in preventing overuse syndrome for musicians.[169] Fry writes, "A five-minute break [every 20-30 minutes] allows the muscle and joint ligaments to recover so that they are more responsive at the beginning of the next practice segment, as well as being rested and therefore less fatigued."[170]

Taking breaks while playing can be controlled by the player in a practice setting. It may be more difficult to achieve frequent breaks when in a group rehearsal setting. Most orchestra contracts establish that breaks will be taken about every 1-1 ½ hours in order to prevent overworking the musicians' bodies.

4.4.7 Consistent playing level

A drastic change in the amount of playing can be a dangerous trigger for health issues in musicians.[171] Changes in professors, attendance at summer festival camps, new repertoire and competitions can all trigger student musicians to increase their total playing time each day. This puts increased strain on their bodies which can lead to injury. In a book geared towards helping musicians avoid injury, a medical professional urge readers: "Don't rapidly increase volume of

[168] Fry, "Overuse Syndrome of the Upper Limb in Musicians," 183.
[169] Fry, "Overuse Syndrome of the Upper Limb in Musicians," 183.
[170] Fry, "Overuse Syndrome of the Upper Limb in Musicians," 183.
[171] Fry, "Overuse Syndrome of the Upper Limb in Musicians," 183.

playing, difficulty, or intensity of tasks."[172] In a study on overuse syndrome in Australian music schools, researchers found that: "There was virtually a 100% correlation between the onset of symptoms and an increase in the time multiplied by intensity of music practice."[173] Eventually chronic muscle fatigue can translate into overuse syndromes.[174]

4.5 Alternative healing concepts

According to researchers, musicians experience pain in greater numbers than actually seek medical assistance. Among Australian college clarinetists, 83% of a polled group experienced pain, but only 21% sought out medical help.[175] Furthermore, only 21% of pain-affected music students surveyed at the Brigham Young University sought help from a physician.[176]

In lieu of traditional medical professionals, performing artists commonly seek alternative health care providers and practitioners. Musicians may distrust traditional medical approaches and avoid them for fear of being told to rest or have mandatory surgery. When extended rest is prescribed, musicians may feel emotionally or financially restricted and that their physician may not understand their workplace environment.[177] In contrast, alternative health care professionals may appear to be more familiar with the emotional and physical needs of musicians, making them a more inviting option for musicians.[178] Alternative therapies may include osteopathic, chiropractic, and naturopathic physicians; therapists who specialize in massage, dietary

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[172] Rosset i Llobet, 90.
[173] H.J.H. Fry, "Prevalence of Overuse (Injury) Syndrome in Australian Music Schools," *British Journal of Industrial Medicine* 44, (1987): 38.
[174] Rosset i Llobet, 90.
[175] Fry, "Prevalence of Overuse (Injury) Syndrome in Australian Music Schools," 183.
[176] R.R. Pratt, S.G. Jessop, and B.K. Niemann, "Performance-Related Disorders among Music Majors at Brigham Young University," *International Journal of Applied Mechanics* 1, no. 2 (1992): 7.
[177] Paull, 6.
[178] W. J. Dawson, "Hand and Upper Extremity Problems in Musicians: Epidemiology and Diagnosis," *Medical Problems of Performing Artists* 3, no. 1 (1988).

manipulations, and reflexology; and practitioners of body awareness techniques such as the Alexander Technique, Autogenic Therapy, Feldenkrais Method, and Yoga.[179] These methods are based on extensive traditions but a description of each method is beyond the scope of this project.

This section will focus on the Alexander Technique and Body Mapping. Both are approaches to teaching and treating performing artists that focus on understanding the human body and learning to utilize it efficiently. They are based on a fundamental viewpoint: pain from playing an instrument can come from: a medical condition or illness, trauma such as a sprain (both of which can be treated through medical science, or inefficient use of the body.[180]

The Alexander Technique was developed by Frederick Matthias Alexander (1869-1955) in response to his own vocal strain as an orator.[181] The Alexander Technique – known as AT – is a method of mental and physical instruction that helps students to release tension in their neck, spine and joints. The goals of AT are to alleviate bodily strain, avoid misuse injuries, and gain efficient use of the mind and body as one unit labeled the "self."[182] A critical component of AT is the concept of "primary control." This is defined as the "automatic postural reflexes in the body that allow for effortless uprightness."[183] In order to allow for the "primary control" to guide movement, students of AT practice releasing tension in the atlantooccipital joint between the skull and the spine and then letting reflexes naturally move the body.[184] The focus placed on the head/neck relationship does not mean that AT is only about outward appearances of upright

[179] McIlwain, 38.
[180] T. Mark, *What Every Pianist Needs to Know About the Body* (Chicago: GIA Publications, Inc. , 2004), 1.
[181] P. Alcantara, *Indirect Procedures* (Oxford: Clarendon Press, 1997).
[182] Alcantara.
[183] L. Pearson, *Body Mapping for Flutists: What Every Flute Player Needs to Know About the Body* (Chicago: GIA Publications, Inc., 2006), 9.
[184] Alcantara.

posture. Instead, AT teaches its students to elegantly use tension and relaxation as tools to achieve tasks without over-exerting themselves or misusing their bodies.

Alexander Technique instruction is generally customized for each individual's needs. Hundreds of AT practitioners teach in individual, group, retreat, and conference settings. Books such as *Indirect Procedures* and *Body Learning* give readers access to AT who are not within reach of qualified practitioners.[185]

American Schools of music and drama acknowledge the value in injury prevention for their students and have begun to offer AT classes.[186] In Europe, prevention programs were introduced as early as 1988 in one Norwegian school.[187] For clarinetists, AT instructors can help achieve healthy breathing and explore the ways in which they can naturally support their instrument with the natural structure of their arms and hands.

Body Mapping (BM) is an offshoot of the Alexander Technique developed by Barbara and William Conable.[188] Both are trained AT teachers. The primary belief of BM, is that an individual's mental body conceptualization will influence the physical use of the body. Teachers of BM help performers create appropriate mental representations of their body, while Alexander Technique teachers focus on physically guiding students to release mental and physical obstacles for more effective movement.[189]

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[185] Michael Gelb, *Body Learning: An Introduction to the Alexander Technique*, 2nd ed. (Henry Holt and Company, 1996). Alcantara.

[186] For example: Louisiana State University, Eastman School of Music, Julliard Conservatory, Peabody Conservatory etc. (Patrick A McGuire, "Musicians Heal Thyself," Peabody Magazine http://www.peabody.jhu.edu/past_issues/fall09/musician_heal_thyself.html (accessed June 8, 2014).).

[187] C. Spaulding, "Before Pathology: Prevention for Performing Artists," *Medical Problems of Performing Artists* 3, no. 4 (1988).

[188] Pearson, xv.

[189] J. P. Woodman and N. R. Moore, "Evidence for the Effectiveness of Alexander Technique Lessons in Medical and Health-Related Conditions: A Systematic Review," *International Journal of Clinical Practice* 66, no. 1 (2012).

In addition to the published materials of the founders of BM, there is a collection of other books that focus on the specific needs of certain performing artists. These books include BM guides for flutists, oboists, choirs, dancers and pianists.[190] Each book teaches performers the musculoskeletal anatomy as it pertains to their activity and provides notes on how to avoid misusing this anatomy.

Many people believe deeply in the benefits of these two alternative methods. Over 15 research studies have been conducted on the Alexander Technique method.[191] They show strong evidence for effectiveness of Alexander Technique lessons for chronic back pain and moderate evidence in Parkinson's-associated disability.[192] Other research has shown that 15 lessons of AT can improve overall musical and technical quality, and a lower heart rate in low pressure performance situations.[193] While AT and BM are noninvasive resources for many performers with medical issues, they are not a form of medical "therapy." At their core, AT and Body Mapping serve as education methods which can instill trust in performing artists, foster awareness, and occasionally provide alternatives to invasive medical procedures.

There are some limitations of the Alexander Technique and Body Mapping methods. Practitioners, while extensively trained, are not medical professionals and may not always correctly diagnose problems that need true medical attention.[194] Another limitation of these

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[190] B. Conable, *What Every Musician Needs to Know About the Body: The Practical Application of Body Mapping to Making Music* (Portland: Andover Press, 2000); Mark; R. Gilmore, *What Every Dancer Needs to Know About the Body* (Portland: Andover Press, 2005); Pearson; Stephen Caplan, *Oboemotions: What Every Oboe Player Needs to Know About the Body* (Chicago: GIA Publications, 2009).
[191] Woodman and Moore, "Evidence for the Effectiveness of Alexander Technique Lessons in Medical and Health-Related Conditions: A Systematic Review."
[192] Woodman and Moore, "Evidence for the Effectiveness of Alexander Technique Lessons in Medical and Health-Related Conditions: A Systematic Review," 98.
[193] E. R. Valentine et al., "The Effect of Lessons in the Alexander Technique on Music Performance in High and Low Stress Situations," *Psychology of Music* 23, no. 2 (1995): 129.
[194] Please note that this is also quite possible in clinical settings.

alternative methods is the length of the process. It is accepted within the AT community that it may take an individual many months or years of lessons to master the techniques.

4.6 Conclusion

While we understand the human anatomy and some of the risks for injury that clarinet-playing poses, there is still a lack of information about the clarinet-playing task itself. Within the clarinet community, there is a debate about how to approach the support of the instrument. Instrument makers have made adjustable thumb-rests, players get their thumb-rests redrilled even higher, and there are dozens of neck straps, pegs and thumb-rest alternatives for players who wish to try those for a source of relief. Understanding the intricacies of physically playing the clarinet will help illuminate which of these approaches are valuable and which are not.

PART III

CHAPTER 5: QUANTITATIVE RESEARCH ON STATIC LOADING TASKS

Woodwind players commonly experience a lateralization of their injuries to the right side of their bodies, which supports the weight of the instrument.[195] This may be avoided if there are healthier ways to hold the instruments, yet limited quantitative research exists. With this research, we would like to explore how the stabilizing muscles of the elbow, wrist and thumb interact with the clarinet to gain a better understanding of this motor task.

5.1 Clarinet task

Playing the clarinet requires stability in the right-hand thumb position, and simultaneous freedom of movement in the other digits. Static loading is a term used by engineers and biomechanical researchers to describe a "non-varying" force that must be resisted and can be adopted for this task. For ergonomics expert Christine Pomerenke a static load is the amount of stress that occurs when there is no movement, such as the strain on a back after standing in one position for a sustained time.[196] In the clarinet task, the right-hand thumb must exert continuous vertical and horizontal forces against the instrument to keep it in a stable position.

When exerting a sustained force, the body uses a system of progressively recruiting more motor units in order to use an appropriate amount of force for a task. Exerting static forces creates conditions that limit oxygen delivery to muscles performing the task, which in turn poses a risk of muscle fatigue and strain.[197] This is process is described in *The Musician's Body:*

> If you want your thumb to support the weight of a saxophone for example, the nerves stimulate only a small proportion of these fibers, first some and then others, to achieve a

[195] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 234.
[196] Christine Pomerenke, "Email: Static Loading," Email message to author, August 27, 2014.
[197] Rosset i Llobet, 1.

> particular degree of muscle tension that avoids the same fibers always doing the work and becoming fatigued.[198]
>
> When muscle fibers have to work without oxygen (i.e. the activity level is extremely high or the muscles are highly tensed (because the muscle fibers themselves compress the flow of blood to the muscles and therefore, prevent both fuel and oxygen from reaching them.) – Less energy is released and residues accumulate in the muscle – leads to early onset of fatigue.[199]

"Static loading" is not a term used in the field of kinesiology research; instead terms such as "postural hold" or "static postures" are more common. Musicians describe the clarinet task as "holding" (somewhat active in connotation), "supporting" (somewhat passive), or "balancing" (vague). For this research, the term "static posture" will be used.

A previous Chesky et al (2000) study looked at the effects of elastic neck straps on forces against the right thumb during clarinet playing. In their review, they describe the clarinet task in this way:

> During performances, only the right thumb remains stationary and statically loaded by the weight of the clarinet. The thumb also steadies the instrument during finger movements and generates a certain amount of force towards the performer's mouth. Depending on the exact posture used, the forces on the right thumb are produced by a combination of the flexors and abductors of the carpometacarpal joint in combination with abductors of the metacarpophalangeal joint. In relation to the clarinet, a total or composite force is generated from both a radial force produced by mostly flexors of the carpometacarpal and metacarpophalangeal joints, and an axial force produced mostly by abductors of the carpometacarpal joint. A composite force angle results from the relative contribution of the radial and axial forces.[200]

The axial and radial forces created by thumb flexors and abductors play an essential role in the clarinet task. This research group found that elastic neck straps elicited a reduction in the axial forces created by the abductors such as the abductor pollicis longus, but not the radial forces created by the flexors such as the abductor pollicis brevis.

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198 Rosset i Llobet, 1.
199 Rosset i Llobet, 1.
200 K.S. Chesky, G. Kondraske, and B. Rubin, "Effect of Elastic Neck Strap on Right Thumb Force and Force Angle During Clarinet Performance," *Journal of Occupation and Environmental Medicine* 42, no. 8 (2000).

5.2 EMG research and other static tasks

Electromyography (EMG) is the recording of the electrical activity of muscle tissue using electrodes on the skin (surface) or inserted into the muscle. An electromyograph detects the electrical potential generated by skeletal muscle fibers (cells) both when these fibers are electrically or neurologically activated.[201] This technique is used in the medical field to identify nerve and muscle dysfunction, or problems with nerve-to-muscle signal transmission.[202] Researchers also rely on EMG to help them study motor behavior in animals and humans.

Static tasks are occasionally studied with EMG research. For example, surface EMG was combined with center of pressure information to investigate stretching effects on one-legged balancing tasks.[203] EMG has been used to measure the static muscles of a handwriting task,[204] and the cocontraction of wrist extensors and flexors to stabilize a mechanically unstable manipulandum.[205] Furthermore, a muscular exhaustion weight lifting task at various elbow angles was measured with EMG.[206] These studies establish a precedent for using EMG as an analytical tool for researching static tasks such as holding the clarinet with the thumb.

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[201] Mayo Clinic, "Treatments and Procedures: Electromyography (Emg)," Mayo Foundation for Medical Education and Research http://www.mayoclinic.org/tests-procedures/electroconvulsive-therapy/basics/why-its-done/prc-20014183 (accessed May 26, 2014).

[202] Mayo Clinic.

[203] B.N. Lima et al., "The Acute Effects of Unilateral Ankle Plantar Flexors Static-Stretching on Postural Sway and Gastrocnemius Muscle Activity During Single-Leg Balance Tasks," *Journal of Sports Science Medicine* 13, no. 3 (2014).

[204] P.H. de Almeida et al., "An Electromyographic Analysis of Two Handwriting Grasp Patterns," *Journal of Electromyography & Kinesiology* 23, no. 4 (2013).

[205] T. E. Milner et al., "Inability to Activate Muscles Maximally During Cocontraction and the Effect on Joint Stiffness," *Experimental Brain Research* 107, no. 2 (1995).

[206] N. K. Mamaghani et al., "Changes in Surface Emg and Acoustic Myogram Parameters During Static Fatiguing Contractions until Exhaustion: Influence of Elbow Joint Angles," *Journal of Physiological Anthropology and Applied Human Science* 20, no. 2 (2001).

5.3 Motivation for current research

Pedagogical opinion about clarinet support with the right upper limb does not have a uniform approach to utilizing the thumb-rest (see Chapter 9). Furthermore, there is a wealth of alternative support products that have not been studied (see Chapter 10). The task of supporting the clarinet needs extra attention from researchers. In addition, two past studies were influential in inspiring this current research project.

A University of Arizona DMA student conducted thesis research on clarinet hand positions using a motion-tracking glove system.[207] Position markers were used to evaluate three dimensional finger and wrist postures of professional-level clarinetists. The project presented angle information for the subjects' hand and compared them to pedagogical models. A tennis ball model was the most realistic; however, all models needed adjustment. Harger found that subject hand size was correlated with the thumb-rest placement on the thumb.[208]

The second study that inspired the current research topic was created by Smutz et al. in 1995. This team measured force data in the static posture of oboists' thumbs with two thin load cell sensors.[209] They used a simulated oboe and two thumb-rest styles which provided different thumb-rest placement on the thumb and thumb height on the instrument. Force cells recorded lateral (against gravity) and pulpar (against the instrument) force generated by the thumb against the oboe. The researchers also used an electromagnetic positioning system to take measurements of joint angles (IP, CMC rotation, and CMC ab/adduction). They found inconsistent results: one thumb-rest option reduced the forces for some players, while the second thumb-rest option

[207] Harger.
[208] Harger.
[209] Smutz et al., "Load on the Right Thumb of the Oboist," 97.

reduced the forces for other players. They encouraged further research to address why modified thumb-rests might reduce the incidence rate of overuse injuries.

No laboratory has conducted EMG research of the static loading in musicians' hands, so this project will be a crucial first foray into this topic. This research involves novel methods and considerations by combining EMG research, static loading research, and music performance in one study. It addresses some of the shortcomings of the Harger (2012) and Smutz et al. (1995) studies.

The Harger (2012) study of joint angles lacked information about the muscle activity required to create the joint angles described. Their small sample size only included professional players, eliminating possible comparisons with those players that are still working to master each aspect of playing. The Smutz et al. study of oboe forces unfortunately lacked actual playing from the participants, reducing their ability to generalize their results to true playing situations. The Chesky et al. (2000) study combines actual clarinet playing with load cells similar to those in the Smutz et al study, but the main focal point of this study was the influence of neck straps. Building off of these studies, we sought to explore the role of muscles in clarinet playing. A deeper understanding of what occurs at the muscular level of clarinetists will be a huge tool for the pedagogical community. We included students and professionals, and those with large and small hand sizes. We used real instruments and real musical examples in order to create realistic practicing environments. Most importantly, we used a novel application of EMG research to study the relationships of the muscles as clarinetists played at different thumb-rest positions. As we discover more about the static loading of the thumb in clarinet players, other instrumentalists that have similar support tasks with their right hand upper arm such as saxophonists, oboists and flutists may benefit from having this data.

CHAPTER 6: METHODS

6.1 Subjects

Subjects were 20 clarinetists, 18 years and older. Participants were recruited through the personal contacts of the researcher and her advisor, the Louisiana clarinet community, the email newsletter of the International Clarinet Association, and a flyer in the International Clarinet Association 2014 Baton Rouge, LA Conference welcome bags.

For more detailed information about the subjects and their groupings, see Chapter 7: Results. The experimental protocol was approved by the Louisiana State University Institutional Review Board.

6.2 Materials

Table 6.1 List of Materials

Two QP511 Grass amplifiers
National Instruments A/D board with 8 channels
Eight bipolar pre-gelled 1 cm diameter surface electrodes
Labview software to record EMG input
MATLAB software to process EMG data
SAS software to run statistical analysis
Kinovea software for video analysis
Desktop computer to run Labview and MATLAB programs
Data collection form
Google documents online questionnaire
One Rossi thumb-rest
Custom low thumb-rest extension
Buffet R13 Bb clarinet
Custom wooden camera stand
Horizontal camera mount
Tripod
Two digital video cameras

The two QP511 Grass Amplifiers, National Instruments A/D board with 8 channels for sensors, bipolar pre-gelled 1 cm diameter surface electrodes, desktop computer, and one video camera were from the lab of Sara Winges. A custom Labview script (National Instruments) was used to record EMG data from the sensors.

The data collection sheet was created by the researchers in Microsoft Word. The questionnaire was created in the Google Docs Form creator. This form allowed for participants to fill out their answers electronically. The identities of participants were kept anonymous through a number code system.

A custom wooden camera stand was built by the researcher K. Young. The stand extends above the player and a store-bought ALZO Horizontal Camera Mount-Tripod Accessory (Black)1072 brought the video camera directly over players' hands as they played. A tripod and second camera were used for the side camera angle.

A Buffet Crampon R13 Bb clarinet was provided by Deborah Chodacki for the experiment. Luis Rossi, Chilean clarinetist and instrument-maker, provided one of his thumb-rests for the experiment. His thumb-rest is the most vertically adjustable available today and easily allowed us to achieve "high" and "normal" thumb-rest positions.

6.3 Preparations

6.3.1 Thumb-rest positions

A "normal" thumb rest position was selected as 17 mm below the center of the first tone hole. This position places the thumb between the index and middle finger of the right hand and is within 1-2 mm of the modern Buffet Crampon adjustable thumb rest at its lowest position. As a reference, this "normal" location was 8 mm above the center of the second tone hole and it was created by drilling the Rossi thumb-rest so that it would match this positions at its lowest point.

A simulation of a re-drilled thumb-rest was used as the “high” position and was located 2 mm above the center of the first tone hole. This placed the thumb directly across the clarinet from the index finger and was created with the Rossi adjustable thumb-rest at its highest position. The “low” position was made with removable handmade cork attachments and was 11 mm below the center of the second tone hole. Cork was adhered with a special craft glue (E600) to a trimmed pencil cushion that snuggly fit around the thumb-rest. This cork was trimmed and sanded to mimic the curvature and size of the existing Rossi thumb-rest, (see Figure 6.1). The extension could be easily be attached and removed from the original rest very quickly.

Figure 6.1 Images of thumb-rest extension.[210]

With the normal thumb-rest position 17 mm below the center of the first tone hole, the high and low positions were both about 19 mm away from the central position. The high position places the thumb opposite the index finger, the neutral position places the thumb opposite the middle finger, and the low rest places the thumb almost opposite the third finger. On the instrument used for the experiment, these positions were 34 mm, 53 mm, and 71 mm below the top of the lower joint (high, normal, and low respectively). See Figure 6.2 for an image of each position.

For average use, Rossi’s thumb-rest provides an excellent range of motion (20 mm) which would satisfy even more than the most commonly used thumb-rest positions. The addition

[210] Photos by author (10/1/2014).

of the low position in this research was important to add an experimental contrast to the high rest position. Because it is about 10 mm below the center of the second tone hole, it sits about 5 mm lower than the traditional fixed Buffet Crampon thumb-rest in relation to the middle finger. The researchers did not find any examples of players redrilling the thumb-rest lower like this, but it served as a reference against the other two positions.

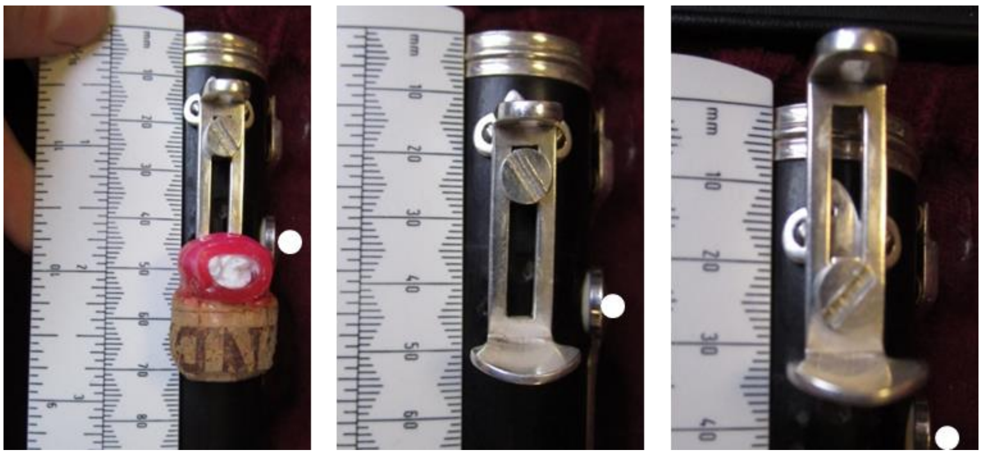

Figure 6.2 Image of each experimental thumb-rest position, back view. From left to right, Low Position with extension, Normal Position, and High Position. Note the different scales of the three thumb-rest positions. The white dot is placed at the same key cup in each photo for reference. Photos by author (10/1/2014).

6.3.2 Video analysis

In an attempt to recreate the CyberGlove® component of Harger's study, the researchers initially planned on using a motion tracking system to measure joint angles of the participants. A motion tracking system uses four special video cameras to specifically track reflective surfaces adhered to a participant and give data in a three dimensional framework. These reflective surfaces may be small spheres or a tape-like material. During pilot studies, we discovered that the anatomical marker points we intended to measure (Index finger MCP, Pollex MCP, etc.) were too close together for the tracking system to effectively work. The clarinet itself was also an obstacle for the sensitive video cameras. Without motion tracking systems, we used video

recorders to observe the motion of the hands and upper limb. In order to validate the use of video recorders and visual markers as a method for observing joint motion, we depended on the background pilot study that Smutz et al. performed. Smutz and his research team experimented on cadavers and found that motion markers on the superficial skin on joints was a valid methodology for measure thumb motions and bone position.[211] This helped validate our video recorder method. We used washable marker directly on the skin above the joints we wanted to measure. The cameras were carefully placed at horizontal planes to the marker points to avoid depth distortion. For a view of the experimental area (see Figure 6.3).

Figure 6.3 Experimental layout with participant, top camera, and EMG channel lines running behind the participant.[212]

The researchers used Kinovea to analyze the captured video data. Kinovea is open-source video software that primarily serves the athletic training community. The 0.8.15 version used for this research offers tools to modulate videos and analyze movement between frames of each video. These tools range from the simple addition of lines and titles to complex functions like

[211] Smutz et al., "Load on the Right Thumb of the Oboist."
[212] Photo by author (8/5/2014)

motion tracking of a point, angle calculation and distance calculation, both manually on individual frames and across frames along with the video.

For the EMG clarinet experiment, 2-D video recordings and Kinovea analysis tools helped control for variables such as excessive motion and clarinet angle. The videos were a source for information regarding hand size, thumb position, grip style, index finger position, and upper limb angles of the subjects. One video camera was placed on a tripod to the right of each participant, and another was suspended directly above the participant's limbs via a stand (built by the experimenter) and a horizontal camera mount. Levels were used to check if the camera lenses were perpendicular to the participant in order to maximize accuracy.

A small pilot study was used to examine the accuracy of Kinovea's distance and angle prediction. Two wooden dowels with wooden spheres on each end, measuring 200 mm, were used as reference items in each video, (see Figure 6.4). These dowels were used to calibrate the Kinovea software's distance tool. The original and a copy dowel reference item were carefully placed in the same plane as the forearms in both the top and side direction to avoid distortion due to camera lenses. Short videos from each camera were uploaded into the Kinovea program, and frozen for a single frame. Using the software's calibration tool the wooden dowel was given a length of 200 mm, as measured from the center of each sphere.[213] After calibrating the distance of the dowel in each camera angle, another line was drawn between the marker dots on the arm of the researcher.

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[213] The spheres were added to the dowel to assist in correctly placing Kinovea's line tool which has a sphere on the end of each line. This way, the software's end circles could overlay with the wooden spheres for accuracy.

Figure 6.4 Wooden dowel, serves as reference length for Kinovea analysis.[214]

Based on the calibrated information, the Kinovea software predicted the length on the researcher's hands, which was verified using a ruler. The process of uploading the same video into the program, calibrating the distance of the ruler, and using Kinovea to measure the marker points on the arm was repeated five times for both the side and top camera views. Data and the reported error from these trials are listed in Tables 6.2a and 6.2b. For the top camera: the range of error from actual measurement .5 to -2.8 mm or .71-4.0% for 70 mm. For the side camera: the range of error from actual measurement -1.8 through .8 mm or 1.95-4.39% of 41 mm.

Table 6.2a Kinovea error measurements using the top camera.

Top Camera Markers	actual distance (mm)	Calculation				
		1	2	3	4	5
Dowel (calibrated)	200	200	200	200	200	200
Index finger to wrist Marker	70	70.5	69	67.2	69	69.4
Error from actual (70 mm)	0	0.5	-1	-2.8	-1	-0.6

Table 6.2b Kinovea error measurements using the side camera.

Side Camera Markers	actual distance (mm)	Calculation				
		1	2	3	4	5
Dowel (calibrated)	200	200	200	200	200	200
Two points on forearm	41	39.4	39.2	40	41.8	39.8
Error from actual (41 mm)	0	-1.6	-1.8	-1	0.8	-1.2

[214] Photos by author (10/1/2014).

6.4 Experimental protocol

Before the day of testing, subjects filled out an online questionnaire that asked about their playing history and habits, and their experience with injury and injury prevention (Appendix H). When each participant came to the lab, s/he signed an informed consent form (Appendix D).

The data collection form was then used to take basic information about the subject as well as arm and hand measurements. The arm was measured from the shoulder to the tip of the extended middle finger. The hand was traced on the data collection form and measured for length, palm width, and pinky-thumb span (see Figure 6.5).

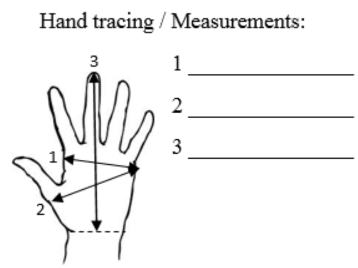

Figure 6.5 Hand measurement locations, taken from Data Collection Form Appendix F

After taking the measurements of each participant, his/her right sleeve was rolled up and fixed with a Velcro tie to allow for the entire area to be unobstructed. One-centimeter dots were placed on the subject's arm with washable blue marker as targets for the video data. These points are listed in Table 6.3.

Once the visual markers were in place the researchers used rubbing alcohol and cotton gauze to clean the subjects' arms. This cleaned oil and dirt that would interfere with the EMG sensor recordings. The pre-gelled sensors were sticky, but extra medical tape was on hand to secure any sensors did not immediately stay in place.

Researchers then asked the participants to flex or move certain muscles to identify the muscle targets. Anatomy books were used as a reference for muscle location and direction. The

muscles that were chosen for this experiment were the *triceps brachii* long head (TRI), *biceps brachii* short head (BIC), *abductor pollicis brevis* (APB), *abductor pollicis longus/extensor pollicis brevis* (APL), *first dorsal interossei* (FDI), *extensor carpi radialis* (ECR), *brachioradialis* (BRA) and *flexor carpi ulnaris* (FCU). Their abbreviations, channel numbers, and anatomical functions of each muscle are listed in Table 6.4.

Table 6.3 Target Positions for video analysis.

Anatomical Marker Target	Marker	Camera	Rationale
Thumb CMC	1	Top	Thumb angle Distance to Index CMC Wrist angle
Index CMC	2	Top	Distance to Thumb CMC Wrist angle
Distal Radius/Scaphoid (Along radial collateral ligament)	3	Top	Distance to Thumb CMC Distance to Index CMC Wrist angle
Distal end of Ulna	4	Side[215]	Fifth digit position
Medial epicondyle of humerus	5	Side	Forearm angle Shoulder angle
Proximal end of Radius	6	Side	Forearm angle
Deltoid (near head of humerus)	7	Side	Shoulder angle
Fifth Digit CMC	8	Side	Fifth Digit position

[215] Initially, marker 4 on the distal end of the ulna was intended to determine forearm angle. The 2-D video tools only provide accurate distance information for objects in the same plane, so the natural angle of the forearm away from the camera towards the medially/centrally positioned clarinet distorted this view. The marker on the proximal end of the radius (marker 6) was added to better measure the elbow of the forearm to the upper arm.

Table 6.4 Muscle Targets for EMG sensors

Muscle Target for Sensor	Abbreviation	EMG Channel	Muscle function
Triceps Brachii	TRI	1	Forearm extension, stabilize elbow joint
Biceps Brachii	BIC	2	Forearm flexion, wrist stabilization
Abductor Pollicis Brevis	APB	3	Thumb opposition, flexion
Abductor Pollicis Longus /Extensor Pollicis Brevis	APL	4	Thumb reposition, extension
First Dorsal Interosseous	FDI	5	Flexes, radially abducts and pronates index MCP joint; radially adducts the thumb basal joint
Extensor Carpi Radialis	ECR	6	Wrist extensor and stabilizer
Brachioradialis	BRA	7	Forearm flexion
Flexor Carpi Ulnaris	FCU	8	Wrist flexor and stabilizer

The eight EMG sensors were divided into groups of opposing muscles: TRI vs. BIC and BRA, ECR vs. FCU, APB vs. APL. To verify the placement of sensors, researchers had the participants complete actions while recording from the EMG sensors, Table 6.5. From the readings, muscles could be isolated and adjusted.

Table 6.5 Tests for correct muscle/sensor placement

Muscle	Test
TRI & BIC	Flex and extend at elbow joint
APB	Oppose thumb across palm, extend downwards
APL	Reoppose thumb, extend upwards.
FDI	Move index finger towards and away from thumb
ECR	In pronated position, flex and extend hand towards ceiling and then floor. Should also be active during rotation of the forearm at the wrist/elbow axis.
FCU	From pronated position, flex and extend hand towards ceiling and then floor.
BRA	Active during rotation of the forearm at the wrist/elbow axis. Should be silent during wrist flexion/extension.

The brachioradialis and extensor carpi radialis are extremely close to each other along the proximal portion of the forearm, yet their origin and insertion points differentiate their roles for this task. In order to distinguish the brachioradialis and the extensor carpi radialis when placing

the sensors, a forearm rotation test (which activates ECR and BRA) and a wrist flexion/extension task (which only activates ECR) were both used.

The muscles selected for this experiment were chosen based on their expected involvement in the clarinet motor task and their accessibility as superficial muscles. After the pilot study, the anterior deltoid was removed from the list and the brachioradialis was added. In the pilot study the anterior deltoid was static for all tasks. This is relevant data for understanding shoulder stabilization but it was decided that more thumb-relevant information may come from the brachioradialis. The brachioradialis (BRA) flexes the forearm, especially when the hand is held with the thumb pointing up (semi prone position).[216] Clarinet playing involves this semi prone position, making this muscle a good candidate for the study.

The process of filling out the data collection sheet, placing the different markers, and testing the EMG sensors took about 20 minutes. Step by step instructions for the entire protocol can be found in Appendix G.

6.4.1 Subject instructions

Participants were told a summary of the tasks that they would be completing and were given specific instructions. They were told to avoid supporting the clarinet with their knees, thighs, legs, or right index finger. No neck straps or extra support devices were allowed. They asked to play as naturally as possible while sitting calmly in the chair.

The angle of the clarinet was not dictated by the researchers. The angle of the clarinet can influence the muscles that support the clarinet. A wider angle away from the torso may increase pulpar force from muscles like the *abductor pollicis brevis, flexor pollicis brevis* and *adductor pollicis brevis*. A narrower angle of the clarinet, closer to the torso, may increase lateral forces

[216] D.B. Jenkins, *Hollinshead's Functional Anatomy of the Limbs and Back*, 8th ed. (Phiadelphia: W.B. Saudners Company, 2002), 129-130.

from the wrist flexors and extensors and thumb repositioners *extensor pollicis longus* and/or *extensor pollicis brevis*. Participants were instructed to maintain a normal playing angle because we did not want to force them into an unnatural position and disrupt their muscle activity. In the analysis phase this was measured with the side view video camera and the Kinovea software in order to alert the researchers to any within-subject changes.

The thumb posture of each participant (or “grip style”) was not dictated by the researchers. Asking players to change their thumb position raised a high risk for acute muscular changes that would influence the data. Studying the effect of different grips on the same participant would require a long-term learning study. This sort of study was not feasible given time constraints and is uncommon in EMG research because of the difficulties in placing sensors in the same locations over multiple months. The top and side cameras recorded visual information about the hand position and the questionnaire that participants filled out also asked about their approach to their thumb position. Ultimately, this study is about the effects of the thumb-rest position, regardless of grip style.

Participants were free to use whichever embouchure style they normally use. From the questionnaire data, it was clear that all 20 participants use a single-lipped embouchure with their top teeth directly on the mouthpiece.

6.4.2 Holds and exercises

The experiment was divided into three blocks of activity with a period of rest between each block to prevent fatigue. Each of the three blocks were assigned one thumb-rest position (normal, high or low thumb-rest). Every participant’s first block was the normal rest position. The rest positions for the second and third blocks were randomized within the small and large hand size groups. All three blocks contained the same playing tasks, in the same order.

Within each rest position block there were four activities. First, a static posture without the weight of the clarinet was taken. Each subject held the instrument and then maintained their hand posture as one researcher gently lifted the clarinet out of their hands. This initial posture provided an extra reference point for each block for the EMG analysis.

The second component of each block was 10 held notes, called PreHold. Each note was held at a medium volume for three seconds, for one trial. The notes reflect a wide range of postures involved with playing the clarinet: no fingers, all fingers, high and low ranges, the same fingerings with and without the register key. Certain fingerings were chosen by the researcher to maximize the data from the readings and also to standardize the examples between subjects. This exercise reflects a true static holds of the shoulder, elbow, wrist, thumb, and other digits. Appendix H shows the 10 held notes, and Figure I1-I4 in Appendix I show the fingerings for each note.

The third component was a group of ten exercises. Eight were finger exercises taken from the method books of Hyacinthe Klose and Larry Guy.[217] The remaining two exercises were an F Major scale and a three-octave chromatic scale. Each finger exercise was repeated as many times as necessary to fill a six second recording span and was repeated for five trials.[218] The scales were timed so one performance of the scale would take six seconds. Researchers elected to have five trials for the exercises to allow for better averaging, and eliminated repetitions of holds because they were so consistent in pilot experiments. The participants began playing when they were ready, and were told when to stop. The researcher at the computer would start the trial immediately after the player began.

[217] Guy; Hyacinthe Klose, *Celebrated Method for the Clarinet*, ed. Simeon Bellison, Complete Edition ed. (New York, NY: Carl Fischer, 1946), 44.
[218] In the pilot study, three trials were used, but we found that one unusual trial could skew the data when averaged. Therefore, five trials was deemed an amount that would reduce the effect of outliers.

The exercises were selected to isolate particular tasks for the players. For example, exercise 2 required the right hand pinky to alternate between two keys and the right hand to lift and depress the index finger and third digit (see Figure 6.6). Fingerings were chosen by the researcher to standardize recordings among the different participants.

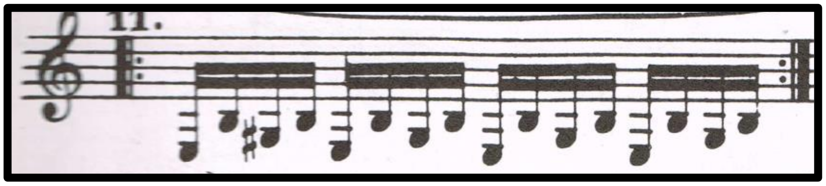

Figure 6.6 Exercise 2 – an example from the playing sheet.[219]

Table 6.6 contains a list of the demands each exercise places on the player.

Table 6.6 Table of demands that each exercise placed on the player

Demands	Cross Break	Pinkies	Large Leaps	Side key 1	Left Hand
Exercises	7	1, 6, 2	4, 7, 8	3, 1	5

To guide participants towards a consistent speed (within subjects and between subjects), a tempo of quarter note = 76 beats per minute was given before each exercise. The metronome click was turned off before the participants began the exercise so their muscle movements would not be altered by the external stimulus of the metronome. Two of the exercises (3 and 4) were in a different meter; the participants were instructed to keep the speed of the sixteenth note the same.[220] If a participant's pace deviated too greatly, the trial was thrown out, and they were asked to repeat it. This happened very rarely, and only to the youngest participants. Two factors led the researchers to turn off the metronome while the participants played. First, this experiment aimed to look at overall muscle activation, not aim to isolate specific muscle bursts – making the

[219] Klose, 44.
[220] This modulation of tempo posed no problem to the participants. It had the effect of slowing the tempo just slightly for those two exercises.

temporal aspect of playing not as important. Second, there is no exact way to identify the exact time of note initiation with a normal acoustic clarinet. Some electronic pianos (and very few acoustic pianos) have been outfitted with equipment to detect the moment a note is initiated making EMG studies with piano players at specific tempos more feasible. An electronic clarinet has not been created that can measure this temporal information.

The final component of each of the three blocks was second hold group, called PostHold. This was executed in the exact same way as the PreHold and served as a measure of fatigue over the course of the block.

After each four-part block, the clarinet was taken from the participant, swabbed, and the thumb-rest position was adjusted. Between blocks the cameras were both paused, sensors were taped down as needed, and the participant was given a full five minute rest to recover.[221] During each block, the participants were free to comment about their experience, including any discomfort or notes about the different thumb-rests. These comments were recorded by the researcher in the data collection form for each participant. Each block lasted for 15-30 minutes, with the entire experiment lasting about 1.5 hours. After all three blocks were completed, the sensors were removed and alcohol swabs were used to clean off the arm of the participant.

6.5 Treatment of data

6.5.1 Treatment of EMG data

The raw EMG data was rectified to make all values positive. This allowed for further analysis such as the calculation of means. It was then filtered with a low pass 5 Hz cutoff zero-phase distortion to reduce unneeded noise in the signal. The researcher began the trial as soon as she heard the player begin and the trial was ended by the Labview script after the set trial length

[221] Five minutes rest after 20-30 minutes of activity was described by Fry (1986) as a sufficient break to avoid fatigue and allow the “muscle and joint ligaments to recover so that they are more responsive” (183).

had elapsed. In order to remove errors in the initiation of recording, 500 ms of EMG data was cut off of the beginning and end of each trial.

The amplitude of the data was normalized by subtracting the minimum value in each channel and then dividing by the maximum value of that channel. Normalizing data mathematically represented each muscle activity as a percentage of the maximum activity. This key step in analyzing EMG data allows for direct comparisons between muscles and subjects. Without normalizing the data, individual differences in physiology (muscle length, ratios of slow to fast-twitch fibers, recruitment patterns or firing frequency) and the successful placement of sensors can influence the data.[222]

MATLAB scripts were used to find and plot means of the participant's muscle activity in the holds and the exercises. SAS software was used to perform a one-way mixed model ANOVA with repeated measures (SAS command: proc-mixed) to find what variables were significantly different from each other.[223] Because of the study design, Kenward-Roger adjustments were made for F and T tests. The standard $p<0.05$ was set as the significance level for these tests.[224]

ANOVAs were run on the influence of various variables. In the experience ANOVA these were: hand size (small or large), position, note, size*position, size*note, position*note, size*position*note for each of the eight muscles. Another eight ANOVAs were run with influence of experience (student or professional) instead of hand size. Not every effect was significantly different, but ANOVA results do not identify these individual differences. A Tukey

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[222] J. Vrendenbregt and G. Rau, "Surface Electromyography in Relation to Force, Muscle Length and Endurance. ," in *New Developments in Electromyography and Clinical Neurophysiology*, ed. J.E. Desmedt(Basel, Switzerland: Karger, 1973).

[223] Dr. Blouin of the Experimental Statistics Department identified this as a completely randomized design.

[224] This ratio ($p<0.05$) means that if a hypothetical researcher were to conduct the exact same study, there is less than a 5% chance that he would get the same results just by chance. When we see a value of $p<0.05$, we can safely reject the null hypothesis. In this case, the null hypothesis is that there is no significant difference based on experience level or hand size.

test, a form of pairwise comparisons, was used post-hoc to find out which specific items were significantly different.

6.5.2 Treatment of Questionnaire Data

The Google Docs Questionnaire form exported all data into a Microsoft Excel spreadsheet. This information was taken and reported in the results section.

6.5.3 Treatment of Video data

Visual analysis of the video data was performed using Kinovea software. See the Chapter for Future Research for how the video data was prepared and future use of this material.

CHAPTER 7: RESULTS

7.1 Subjects

Twenty clarinetists (13 female, 26.2 ± 9.578 years old) participated in the study. The majority of subjects (70%) were between the ages of 19-26. Subjects 16 and 19 were left handed, all other subjects were right handed. Due to large differences in age and muscle activity, subject 20 was not included in the statistical analysis.

Arm length and three measures of right hand size were taken for each subject, Table N1, Appendix N. The 19 subjects were divided into two groups based on hand length from the base of the palm to the tip of the middle finger (Measurement 3 in Appendix F for Data Collection Form). The subjects' hand lengths ranged from 15.5 – 20.5 cm (16.54 ± 8.33 cm long). We used a cutoff of 18.15 cm for the large hand size group. This was slightly smaller than the 18.9 cm standard that was used in the Harger study of six professional clarinet players.[225] Nine subjects (seven male) were in the large hand group and 10 female subjects were in the small hand size group.

The subjects were also classified by experience levels: students and professionals. The student level players were all college-level players; the professional-level players either played in a professional symphony or subbed regularly with these groups. There were seven professionals (subject 20 is a professional but was not included in the statistical analysis) and 12 students. See Table 7.1 for details about the subjects, hand size, and experience level.

[225] Harger.

Table 7.1. Subject information, asterisk denotes large hand group

Subject	Sex	Age	Height	Years Playing	Experience	Hand length (cm)
1	M	29	6'2"	19	P	20*
2	F	20	5'1"	9	S	15.5
3	F	20	5'8.5"	11	S	18.75*
4	M	23	6'2"	12	P	19.75*
5	F	20	5'1"	11	S	16
6	F	25	4'11"	14	S	15.5
7	M	24	6'	15	P	19.5*
8	F	21	5'9"	10	S	18*
9	M	32	5'8"	21	P	19*
10	M	23	6'2"	15	P	20.5*
11	F	23	5'7"	15	S	17.5
12	M	19	5'11'	8	S	19*
13	F	29	5'9"	18	P	17.5
14	F	40	5'10'	30	P	17.4
15	F	30	5'3"	17	S	16.5
16	F	20	5'	10	S	16.5
17	F	20	5'1/2"	10	S	16.5
18	F	26	5'1"	16	S	16.5
19	M	20	5'10"	8	S	18*
20	F	60	5'7"	45	P	16.5

7.2 Questionnaire data

Details pertaining to the subjects' thumb-rests are in Table N3 of Appendix N. All subjects reported they take breaks while playing, all players have a warm-up regimen, and all play with a single lipped embouchure. Sixty-seven percent of the subjects currently teach. Eighty five percent of the subjects had an adjustable thumb-rest, while 15% (3) subjects use a fixed thumb-rest. All subjects reported they "sometimes" experience discomfort or pain when playing the clarinet, Table N2, Appendix N. Three subjects reported that they had been diagnosed with an injury: one overuse injury, one torn rotator cuff (from tennis), and one pinched nerve (C5).

7.3 Internal study control of acute muscle changes

A challenge of every study on motor tasks is acute changes in the muscles. An unfamiliar task can cause initial over-exertion, making comparisons with other data difficult. For this task, the researchers were concerned about participants having an elevated activation to the high rest compared to the normal rest. In order to test for acute changes, we found one participant with a redrilled thumb-rest. It was predicted that if there were acute effects due to changing rest positions, subject 10 would have an opposite response than the rest of the participants. A plot of all participants in all muscles for the exercises by thumb-rest position established that the control participant did not have a significantly different result than the other participants (see Figure Q1, Appendix Q). Thus, any changes observed in this study were not considered to be due to acute changes in the muscles stemming from an over-exertion of an unfamiliar task.

7.4 EMG data

The EMG data results will be presented in functional groups of muscles. The APB, APL, and FDI all act on the thumb and will be presented first. The ECR and FCU will be presented as

the wrist stabilizers. The TRI, BIC, and BRA will be grouped together as muscles that control the elbow and rotate the forearm.

A one way ANOVA with repeated measures was conducted for the main effects of the thumb-rest position (high, normal, and low thumb-rest), experience (student and professional), hand size (small and large), notes (10 notes), and exercises (10 exercises). The main effect of a single variable is considered across all of the other variables. For example, the main effect of experience level in the ANOVA of notes would be across all hand sizes, thumb-rest positions, and notes. The notes and exercises compare performance of individual notes or exercises across all experience levels, positions, and hand sizes. A post-ANOVA test of contrasts was used to identify interactions between the different variables. This test compares the difference between two or more levels of one variable across all levels of another variable. An example in this study would be the comparison of performance by the small and large hand size groups for each note.

When ANOVA reveals significant main effects or significant interactions, it means that the null hypothesis (that there was no difference between the levels of the variable (i.e. small vs. large hands)) can be rejected and we can accept that there is a difference. To further investigate where exactly there were differences, Tukey post-hoc tests can be used to look at pair-wise comparisons between specific items.

7.4.1 Thumb stabilizers: APB/APL/FDI

7.4.1.1 Main effect of Thumb-rest Position

The primary focus of this research was the influence of thumb-rest position on the eight selected muscles. For the APB and APL there was a significant main effect of thumb-rest position in the 10 held notes (Table 7.2a and b) and in the 10 exercises (Table 7.3a and b). There was no significant main effect of thumb-rest position for the FDI.

Table 7.2a Summary of Experience ANOVA F values of Hold Positions by Effect

Muscle	Note Hold (9,459)	Position (2,34)	Experience (1,17)	Experience* Note (9,459)	Position* Note (18,459)	Experience* Position (2,34)
TRI	3.69^	ns	ns	1.97*	ns	ns
BIC	9.59^	3.84*	ns	Ns	ns	ns
APB	9.44^	5.32**	5.28*	Ns	3.52^	ns
APL/EPB	19.55^	29.97^	ns	Ns	ns	ns
FDI	20.01^	ns	ns	3.48^	ns	ns
ECR	13.40^	8.80^	ns	2.70**	ns	3.47*
BRA	5.07^	ns	ns	Ns	ns	ns
FCU	19.64^^	12.34^	ns	Ns	ns	ns

* = p<0.05, ** = p<0.01, ^ = p<0.001, ns=not significant

Table 7.2b Summary of Hand Size ANOVA F values for Hold Positions

Muscle	Note Hold (9,459)	Position (2,34)	Position* Note (18,459)	Size*Note (9,459)
TRI	5.49^	ns	ns	Ns
BIC	10.49^	4.02*	ns	Ns
APB	9.87^	4.89*	3.60^	Ns
APL/EPB	25.32^	32.74^	ns	Ns
FDI	19.52^	ns	ns	4.38^^
ECR	13.20^	11.63^	ns	Ns
BRA	4.69^	ns	ns	Ns
FCU	22.17^	12.25^	ns	Ns

* = p<0.05, ** = p<0.01, ^ = p<0.001, ns=not significant.

Table 7.3a Summary of Experience ANOVA F values on Exercise performances

Muscle	Exercise (9,459)	Position (2,34)	Experience* Exercise (9,459)	Position* Exercise (2,34)
TRI	14.19^^	ns	Ns	Ns
BIC	3.40^^	ns	Ns	Ns
APB	26.07^^	6.25*	Ns	3.30^^
APL/EPB	45.85^^	42.03^^	2.41*	1.93*
FDI	67.12^^	ns	3.00**	Ns
ECR	120.78^^	5.64^	Ns	Ns
BRA	12.35^^	ns	4.62^^	Ns
FCU	127.15^^	21.13^^	2.28*	Ns

*p<0.05, **p<0.01, ^p<0.001, ns=not significant.

Table 7.3b Summary of Hand Size ANOVA F values on Exercise performances

Muscle	Exercise (9,459)	Position (2,34)	Hand Size (1,17)	Size* Exercise (9,459)	Position* Exercise (2,34)
TRI	16.28^^	ns	8.65**	ns	ns
BIC	3.97^^	ns	ns	3.09**	ns
APB	29.22^^	6.70**	ns	1.98*	3.76^^
APL/EPB	59.03^^	45.87^^	ns	6.21^^	2.24**
FDI	72.41^^	ns	ns	3.12**	1.68*
ECR	153.91^^	7.49**	ns	8.68^^	ns
BRA	15.73^^	ns	ns	1.91*	ns
FCU	162.11^^	23.92^^	ns	5.29^^	ns

*p<0.05, **p<0.01, ^p<0.001 ns=not significant.

The APB and APL stabilize the thumb with opposing motion. They have opposite patterns of activity to the high, normal, and low thumb-rest positions, when the APL had the highest activation in the low thumb-rest position, the APB had its lowest activation, and vice versa (see Figure 7.1). The same pattern for the APB and APL occurred in the notes and exercises. Beyond the main effect of thumb-rest positions, there were significant interactions for the thumb stabilizers between thumb-rest position and notes, and thumb-rest position and exercises. Before these interactions are presented, a brief summary of the performance of the APB, APL, and FDI on the notes and exercises will be presented.

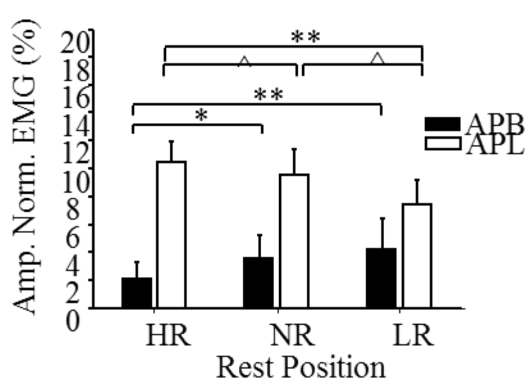

Figure 7.1 Mean (±SE) amplitude normalized EMG for APL and APB calculated across subjects for each rest position. Horizontal lines indicated significant differences revealed by Tukey post-hoc. *p<0.05, **p<0.01, ^p<0.001

7.4.1.2 Main effect of Notes

There was a significant main effect of notes for all eight muscles (see Table 7.2, Figure 7.2) shows means for the eight muscles across all subjects for each note. The APB and FDI were closely grouped together in their pattern of activity for each note. The APL, which holds the thumb up against the thumb-rest to support the instrument, was much more variable in its response to the different notes as seen in the spikes of activity.

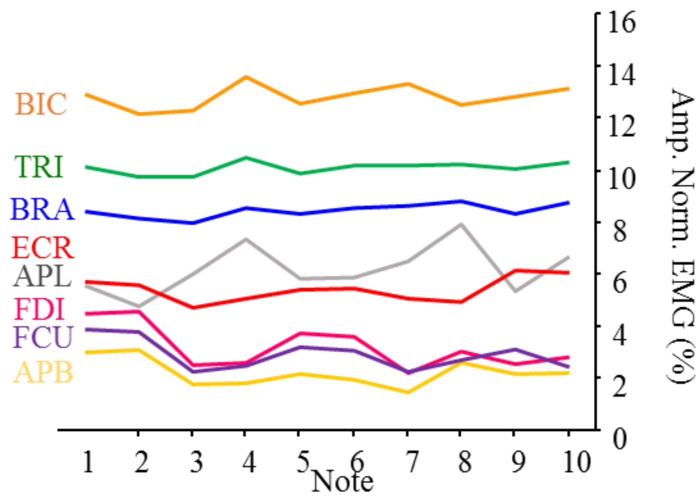

Figure 7.2 Mean amplitude normalized EMG muscle activity for all muscles calculated across all subjects and notes.

The APL and FDI had significant differences between note 4, which has no fingerings pressing holes or keys, and note 6, which has all fingers (but not register key) used to cover tone holes (see Figures 7.3 and 7.4).

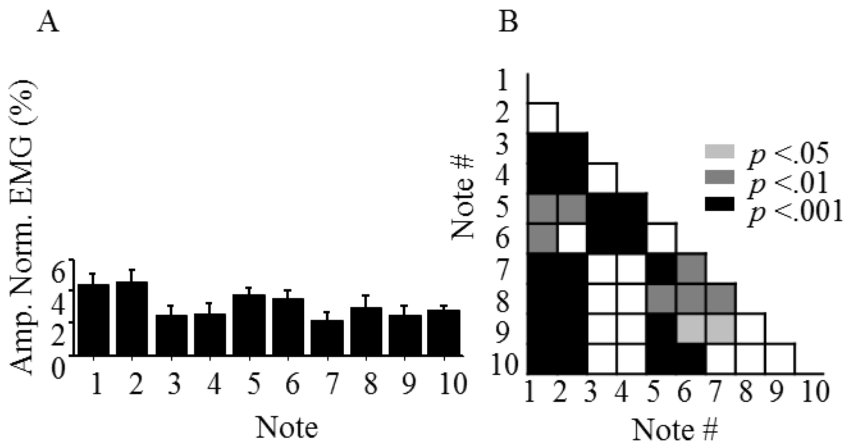

Figure 7.3 Main effect of Note on FDI. (A) Mean (±SE) amplitude normalized EMG for FDI calculated across subjects and rest positions for each held note. (B) Significant differences between notes for FDI muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

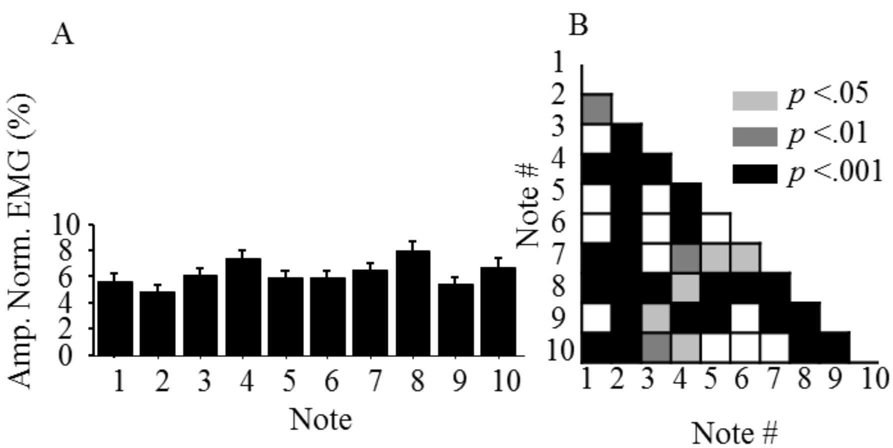

Figure 7.4 Main effect of Note on APL. (A) Mean (±SE) amplitude normalized EMG for APL calculated across subjects and rest positions for each held note. (B)Significant differences between notes for APL muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

The FDI and APB were similar in their activities to certain notes. They both had the highest levels of amplitude normalized EMG for notes 1 and 2 (E3 and B4 which use all fingers and the right pinky), and the lowest amplitude for note 7 (D4 which uses only the thumb, index, and middle fingers of the left hand) (see Figure 7.5). The APL almost had opposite activity: with

the highest percent activation for note 8 (C5 which uses just the thumb of the left hand) and the lowest percent activation for note 2 (B4) (see Figure 7.4).

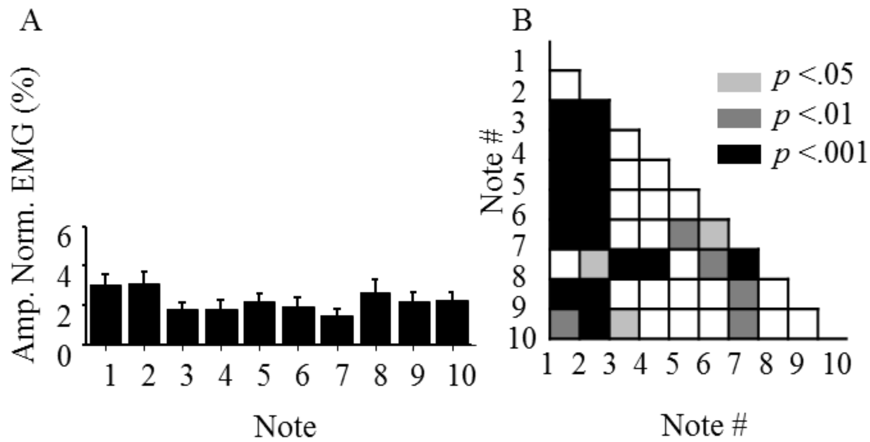

Figure 7.5 Main effect of Note on APB. (A) Mean (±SE) amplitude normalized EMG for APB calculated across subjects and rest positions for each held note. (B) Significant differences between notes for APB muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

Notes 1 and 2 require the right pinky to repeatedly press and release keys. In the APB and FDI, notes 1 and 2 were significantly different from all other notes with three exceptions (note 8 and 1 in the APB and notes 2 and 6 in the FDI), Figures 7.3 and 7.5. In the APL, note 2 was significantly different than all of the other notes.

Cross fingerings occur when fingers from both hands cover tone holes but leave uncovered tones holes between them, for example note 10 (Eb4 alternate fingering). The APB had significant differences between this cross fingered note and a non-cross-fingered note in the same register, note 7 (D4).

7.4.1.3 Main effects of Exercises

There was a significant main effect of exercise for all eight muscles, Table 7.3. The APB, FDI, and APL had wide ranges of EMG amplitude for the different exercises. The APB had the highest activation for exercises 1, 2, and 7 and the lowest activation for exercise 5 (see Figure

7.6). Exercises 1 and 2 required right hand pinky motion in the low register, and exercise 5 only required simple motion in the left hand.

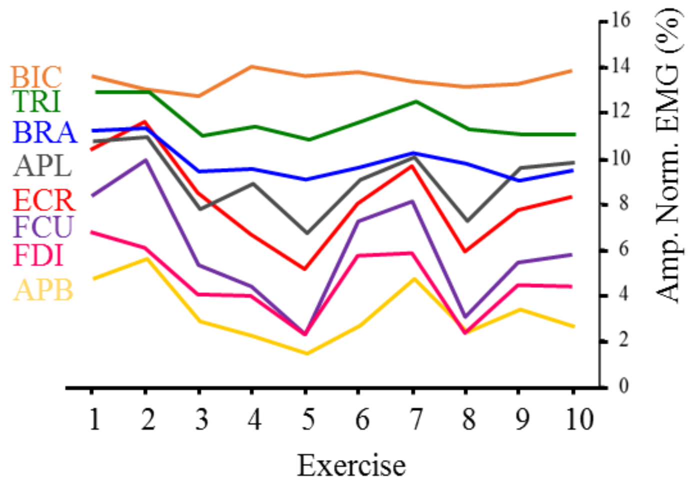

Figure 7.6 Mean amplitude normalized EMG for all muscles calculated across subjects and exercises.

The FDI shared similar patterns of activity in exercises as the APB, FDI (see Figure 7.6). Three distinct levels of EMG amplitude occurred for the FDI based on the involvement of the index finger in each exercise. Exercises 1, 2, 6, and 7 are quite high in activation and involve frequent changes with the index finger, exercises 3, 5, 9, and 10 constituted a middle range, and the exercises 5 and 8 were both quite low and involved no index finger use (see Figure 7.7).

The APL had a slightly different pattern of action than the APB because exercise 4 caused more activation than exercise 3 in the APL. Exercise 4 has leaps between registers, possibly causing more variability in the APL (see Figure 7.8).

Scales (exercises 9 and 10) were significantly different from the exercises that involved leaps and excessive pinky motion (exercises 1, 2, 6, 7, 8) in almost all muscles. See Figure 7.8 of the APL to see that all exercises except 7 were significantly different than exercises 9 and 10.

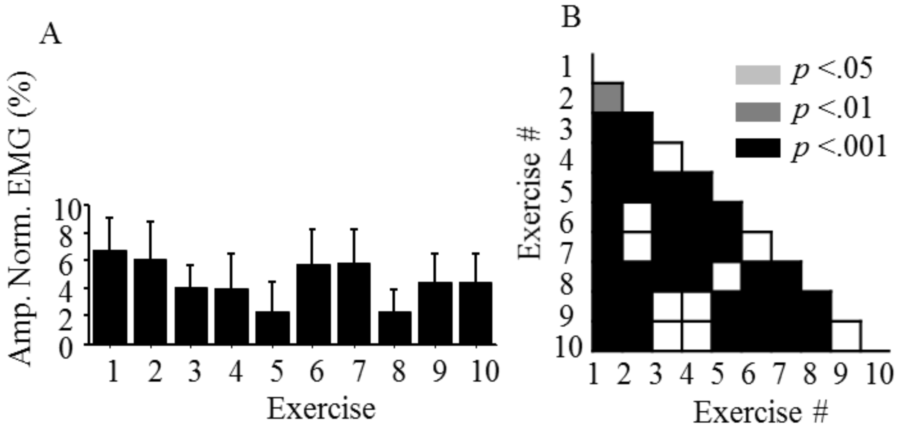

Figure 7.7 Main effect of Exercise on FDI. (A) Mean (±SE) amplitude normalized EMG for FDI calculated across subjects and exercises. (B) Significant differences between exercises for FDI muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

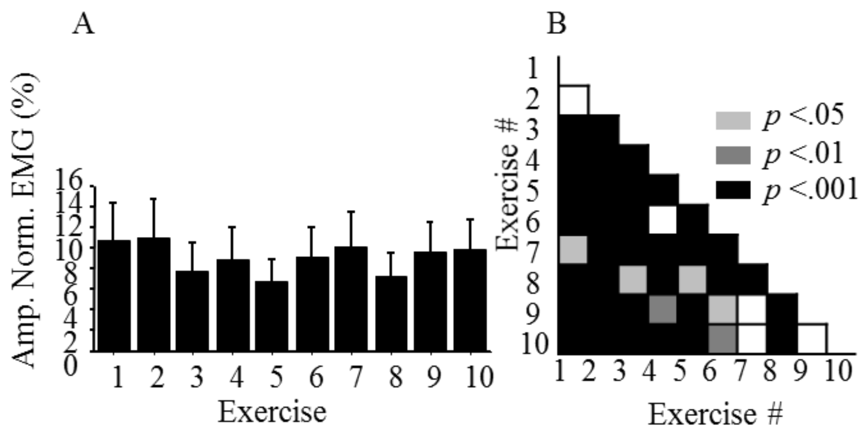

Figure 7.8 Main effect of Exercise on APL. (A) Mean (±SE) amplitude normalized EMG for APL calculated across subjects and exercises. (B) Significant differences between exercises for APL muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

7.4.1.4 Interaction: Position*Note

The APB had a significant main effect of position over all notes and exercises. When compared to each individual note, there was also a significant interaction between position and note in the APB. In 60% of the notes, the low thumb-rest position caused the highest level of

EMG amplitude for the APB. This dipped below the normal thumb-rest in note 4 and then crossed over the normal and high thumb-rest amplitude for notes 9 and 10 (see Figure 7.9). For notes 1-6, the high rest elicited the lowest APB activation.

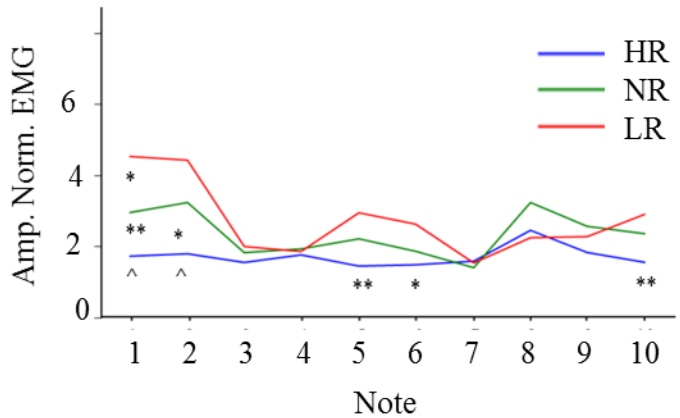

Figure 7.9 Mean amplitude normalized EMG in APB calculated across subjects and notes for position (HR, NR, LR). Asterisks indicate significant differences between rest positions on the same exercise in Tukey post-hoc; asterisks placed below the lowest line indicate a significant difference between the topmost and bottom line. *p<0.05, **p<0.01, ^p<0.001 (*p<0.05, **p<0.01, ^p<0.001) in Tukey post-hoc test.

In the APB on notes 1, 2, 5, 6 and 10, there were significant differences between the three rest positions (see Figure 7.9). These are important because they show the notes on which the three rest positions were *more* different than the other notes. The low rest was significantly higher for notes 1, 2, 5 and 6. These notes require all fingers to cover tone holes, and in the case of notes 1 and 2, for the right pinky to depress a key (see Figure 7.9).

7.4.1.5 Interaction: Position*Exercise

There was a significant interaction of position and exercise in the APB, APL and FDI, Table 7.3. The APL was the most sensitive muscle to changes in thumb-rest position during the exercises. In the APL the high rest elicited the highest EMG amplitude, the normal rest was second, and the low rest created the lowest EMG amplitude. This was true for all exercises except exercises 2, in which EMG amplitude for the normal thumb-rest position rose above the

high thumb-rest position (see Figure 7.10). Every exercise except exercise 5 had significant differences between rest positions. This was most common between the high and low positions and between the normal and low position (see Figure 7.10).

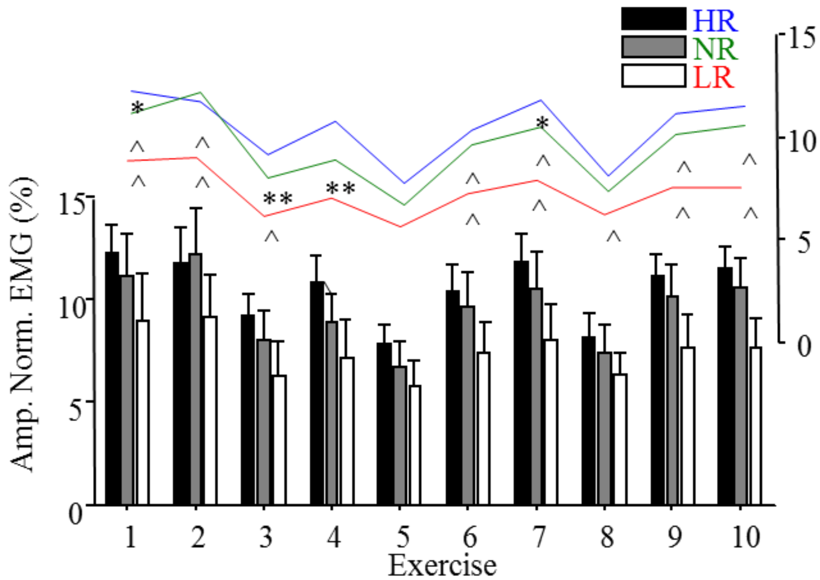

Figure 7.10 Mean (±SE) amplitude normalized EMG for APL calculated across subjects and exercises for rest position (lower bar plot). Upper line plot illustrates means for each rest position (colored lines) by each exercise (x-axis). Asterisks indicate significant differences between rest positions on the same exercise in Tukey post-hoc; asterisks placed below the lowest line indicate a significant difference between the topmost and bottom line. *p<0.05, **p<0.01, ^p<0.001

The FDI had a significant interaction between rest position and exercises (see Figure 7.11), Table O15 in Appendix O. Figure 7.11 shows the three positions were quite close in activation – with no position providing a consistently higher or lower result. In exercises 1 and 10, the FDI mimicked the APL: the high rest elicited the highest activation and the low rest elicited the lowest activation. The APB had an opposite reaction to the thumb-rest positions as the APL (see Figure 7.12). For nearly every exercise, the low rest elicited the highest APB EMG amplitude while the high rest was lowest. The APB had significant differences between activation levels for rest positions in exercises 1, 2 and 7 (see Figure 7.12) (Table O13 in Appendix O presents all results).

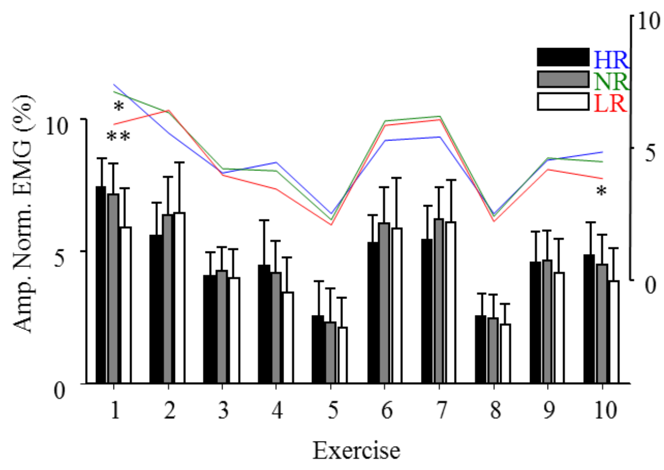

Figure 7.11 Mean (±SE) amplitude normalized EMG for FDI calculated across subjects and exercises for rest position (lower bar plot). Upper line plot illustrates means for each rest position (colored lines) by each exercise (x-axis). Asterisks indicate significant differences between rest positions on the same exercise in Tukey post-hoc; asterisks placed below the lowest line indicate a significant difference between the topmost and bottom line. *p<0.05, **p<0.01, ^p<0.001

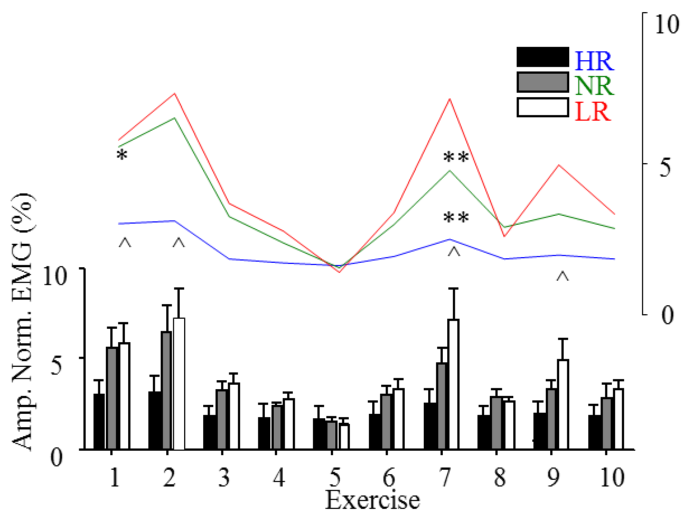

Figure 7.12 Mean (±SE) amplitude normalized EMG for APB calculated across subjects and exercises for rest position (lower bar plot). Upper line plot illustrates means for each rest position (colored lines) by each exercise (x-axis). Asterisks indicate significant differences between rest positions on the same exercise in Tukey post-hoc; asterisks placed below the lowest line indicate a significant difference between the topmost and bottom line. *p<0.05, **p<0.01, ^p<0.001

7.4.1.6 Main effect of Experience

The subjects were divided into two experience levels: students or professionals. There was a significant main effect of Experience for the APB in held notes (see Table 7.2). APB

amplitude is higher for student than the professionals (see Figure 7.13). There was no significant main effects of experience in the Exercises. While there was only one main effect of Experience level (APB), there were many instances of significant interactions of Experience and Note, or Experience and Exercise. There were no significant interactions between Experience and thumb-rest Position in the three thumb stabilizers. Below are the results for the thumb stabilizers.

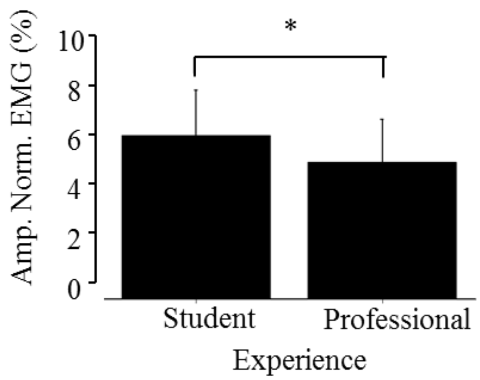

Figure 7.13 Mean (±SE) amplitude normalized EMG for APB calculated across subjects for both levels of experience. Asterisk indicates significant differences revealed by Tukey post-hoc. *p<0.05

There was a significant interaction between Experience and Note in the FDI. The students had consistently higher FDI amplitude than the professionals, with the exception of note 10, where there was no difference between groups. For notes 3 and 4, there was a significantly greater difference between students and professionals (see Figure 7.14).

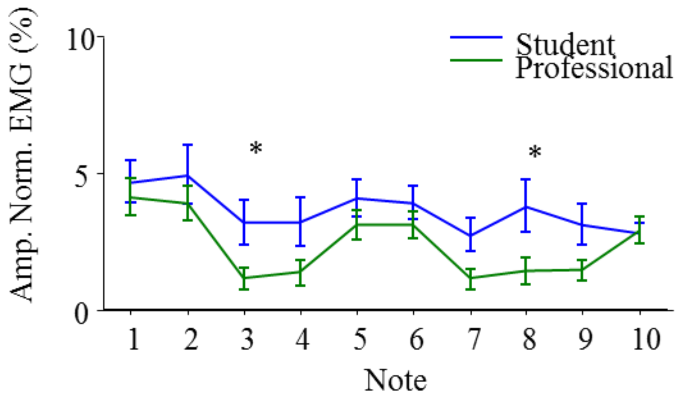

Figure 7.14 Mean (±SE) amplitude normalized EMG for FDI calculated across subjects and notes for both levels of experience. Asterisks indicate significant interactions between experience levels for certain notes as defined in Tukey post-hoc test. *p<0.05

There was a significant interaction between Experience and Exercise in the APL and FDI. In the APL, the students had consistently higher EMG amplitudes than the professionals (see Figure 7.15). This was also the case for the FDI (except exercise 1) (see Figure P8 in Appendix P). For the APL, the greatest difference between students and professionals was in exercise 2, which involves leaps with the right hand pinky, and exercise 4, which requires leaps between low and throat tone registers (see Figure 7.15).

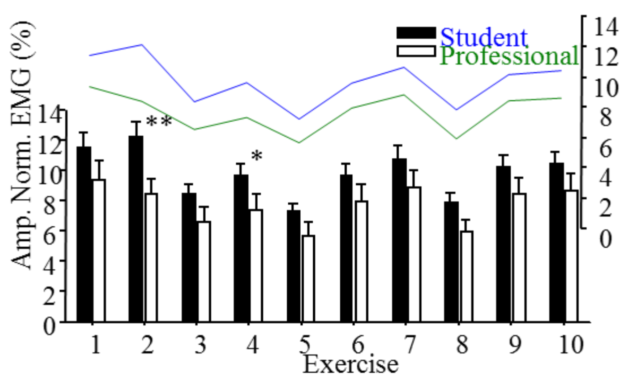

Figure 7.15 Mean (±SE) amplitude normalized EMG for APL calculated across subjects and exercises for experience level (lower bar plot). Upper line plot illustrates means for each experience level (colored lines) by each exercise (x-axis). Asterisks indicate significant differences between rest positions on the same exercise in Tukey post-hoc.*p<0.05, **p<0.01

7.4.1.7 Main effect of Size

There was no significant main effect of hand size during the notes or exercises for the thumb stabilizers (APB, APL and FDI; Tables 7.1 and 7.2). There was a significant interaction between Size and Note for the FDI and a significant interaction between Size and Exercise for the APB, APL, and FDI (Tables 7.1 and 7.2).

For FDI, the small hand group always had higher EMG amplitudes than the large hand group throughout the notes (see Figure 7.16). Table O2 in Appendix O shows that note 1 was significantly different than note 5 for the large hand size group but not the small hand size group, resulting in significant interaction between Size and Note.

Within the significant interaction between Size and Note in the FDI, notes 3, 4, 8 and 9 had differences between the two hand sizes that were significantly larger than the differences between other notes (see Figure 7.16). These four notes do not require the index finger to cover a tone hole or press a key.

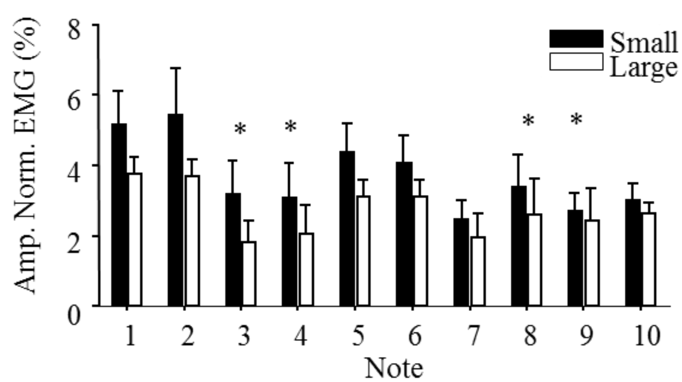

Figure 7.16 Mean (±SE) amplitude normalized EMG for FDI calculated across subjects and notes for hand size (small and large). Asterisks indicate statistically significant differences between hand size on the same note. *p<0.05

The APB, APL, and FDI each had significant interactions between Size and Exercise (see Table 7.3). In the APB, the small hands had higher EMG amplitude than the large hands for all

exercises except 5, 9 and 10 (see Figure 7.17). In the APL and FDI (and FCU), the small hand group almost exclusively had a higher level of amplitude than the large size hand group. The APL is representative of these muscles and is shown in Figure 7.18.

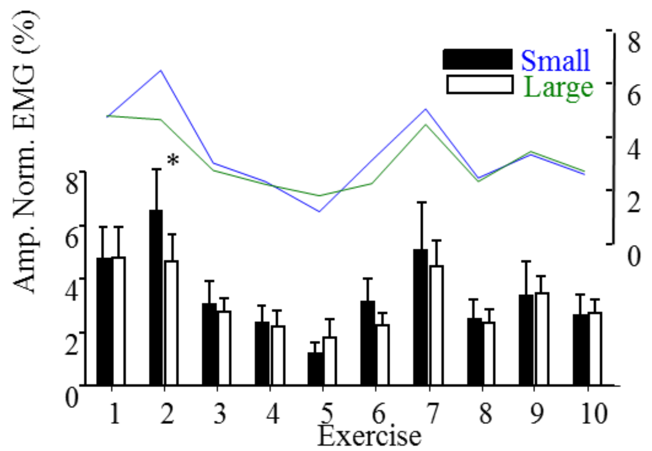

Figure 7.17 Mean (±SE) amplitude normalized EMG for APB calculated across subjects and exercises for hand size (lower bar plot). Upper line plot illustrates means for each hand size (colored lines) by each exercise (x-axis). Asterisks indicate significant differences between rest positions on the same exercise in Tukey post-hoc *p<0.05

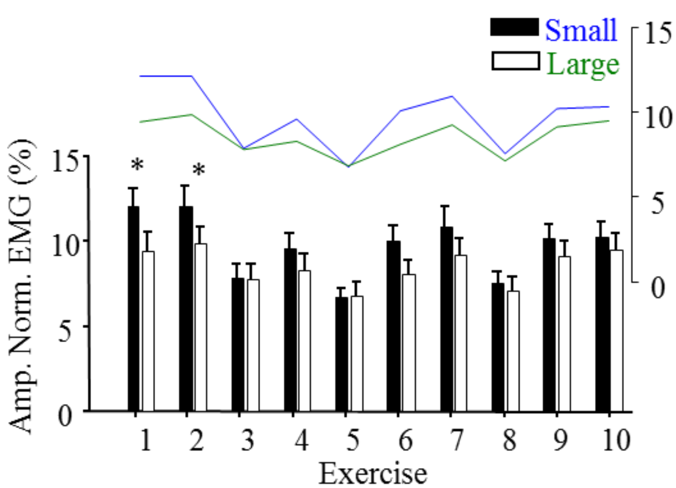

Figure 7.18. Mean (±SE) amplitude normalized EMG for APL calculated across subjects and exercises for hand size (lower bar plot). Upper line plot illustrates means for each hand size (colored lines) by each exercise (x-axis). Asterisks indicate significant differences between rest positions on the same exercise in Tukey post-hoc *p<0.05

7.4.2 Wrist Stabilizers: ECU and FCU

7.4.2.1 Main effects of Position and Experience

The ECR and FCU work in tandem to effect flexion and extension as well as radial and ulnar deviation. There was a significant main effect of thumb-rest position for the ECR and FCU. ECR was significantly higher in the low rest position, while the FCU was significantly higher for the high rest position (see Figure 7.19). The ECR and FCU had no significant interactions between the thumb-rest position and specific notes or exercises.

There were no significant main effects of Experience level for the wrist stabilizers (see Table 7.2 and 7.3). However, there were interactions between Experience and Note, Exercise, and Position. Therefore a brief review of the wrist stabilizers' performances in these areas follows here.

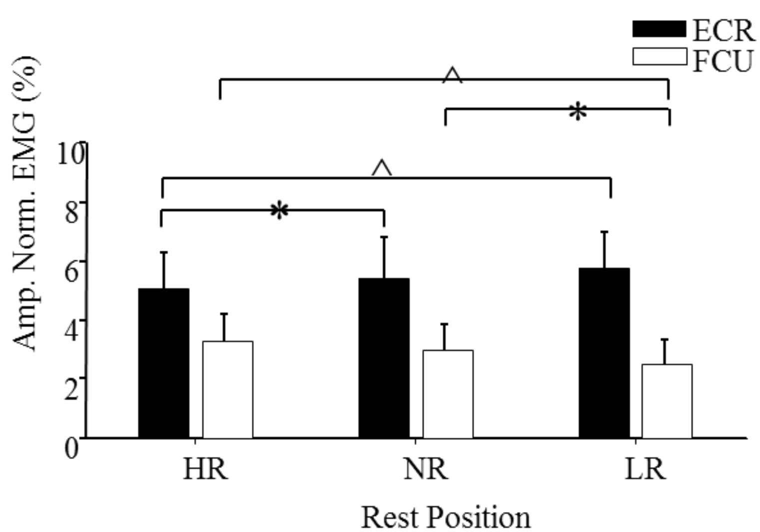

Figure 7.19. Mean (±SE) amplitude normalized EMG for ECR and FCU calculated across subjects for each rest position. Asterisks indicate significant differences revealed by Tukey post-hoc. *p<0.05, ^p<0.001

7.4.2.2 Main effect of Note

The FCU EMG amplitude was variable across notes, while the ECR was more consistent in amplitude across notes (see Figures 7.20 and 7.21).

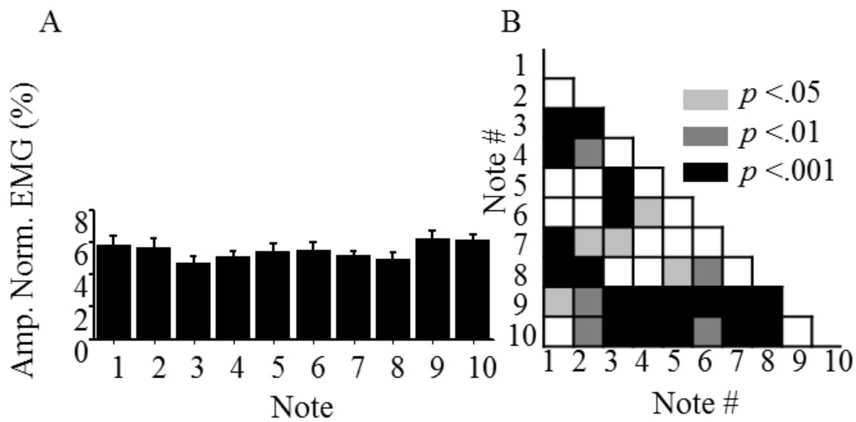

Figure 7.20 Main effect of Note on ECR. (A) Mean (±SE) amplitude normalized EMG for ECR calculated across subjects and rest positions for each held note. (B) Significant differences between notes for ECR muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

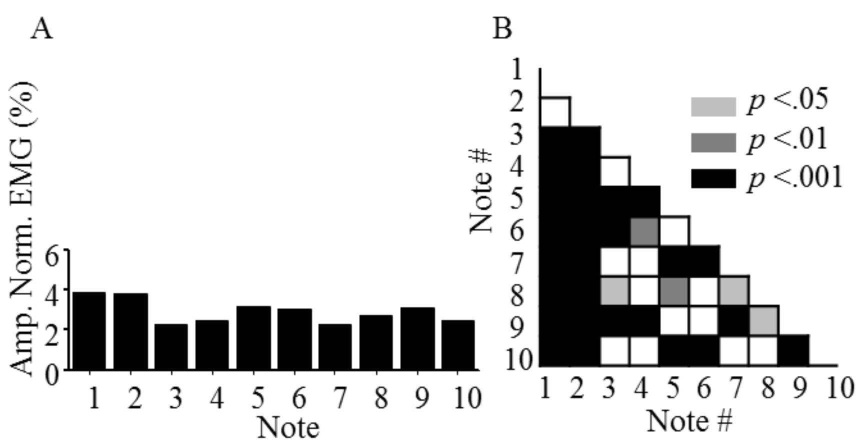

Figure 7.21 Main effect of Note on FCU. (A) Mean (±SE) amplitude normalized EMG for FCU calculated across subjects and rest positions for each held note. (B)Significant differences between notes for FCU muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

The FCU and ECR had relatively low levels of activation for notes 4 and 3 (and 7 in the ECR). These middle-low clarinet range notes require no finger, two left-hand fingers, and three left-hand fingers respectively. Furthermore, the ECR and FCU had significantly different performances between note 4 (no fingers) and note 6 (all fingers but not pinkies).

Notes 1 and 2 required all fingers and the right pinky. In the FCU these notes were significantly different from notes 3-10, but not from each other (see Figure 7.21). In the ECR, notes 1 and 2 were not as consistently different from the other notes as in the FCU. In particular, notes 1 and 2 were not different from notes 5 or 6, which are fingered the same as 1 and 2, but without the right-hand pinky. This helps isolate the FCU as a helper in the use of the right-hand pinky.

Note 10 is a cross-fingering that was significantly different from other low range notes in APB. The same significant pattern of activation occurred in the ECR.

7.4.2.3 Main effect of Exercise

There was a significant main effect of Exercises for the ECR and FCU (see Table 7.3b). The ECR and FCU both follow a pattern of EMG amplitude across exercises similar to the thumb stabilizers, although the amplitude differences between exercises was greater resulting in nearly every exercise being significantly different from each other (see Figures 7.22 and 7.23). This is a contrast for the ECR, which exhibited more steady levels of activations for the notes. Playing over the break by adding the right hand and right-hand pinky (exercise 7) was significantly different from all other exercises in the ECR and all except exercise 1 in the FCU.

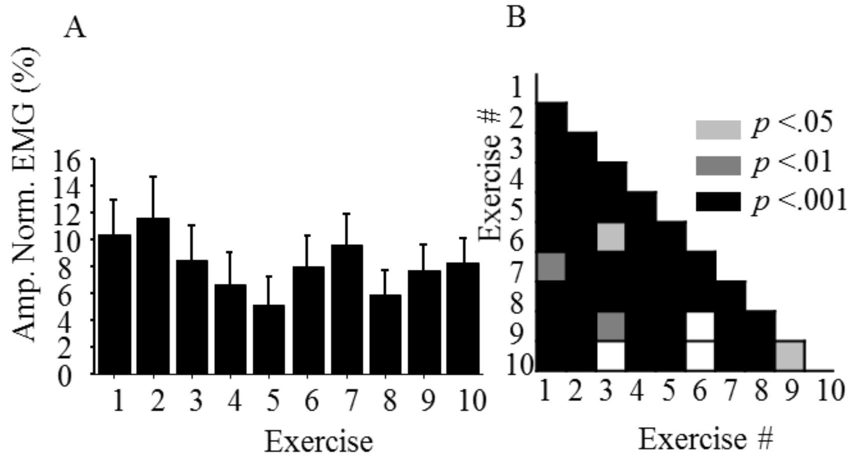

Figure 7.22 Main effect of Exercise on ECR. (A) Mean (±SE) amplitude normalized EMG for ECR calculated across subjects and exercises. (B) Significant differences between exercises for ECR muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

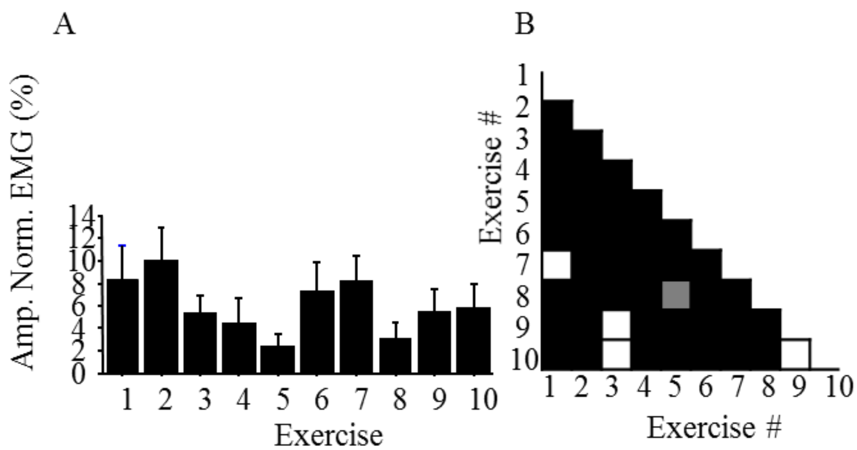

Figure 7.23 Main effect of Exercise on FCU. (A) Mean (±SE) amplitude normalized EMG for FCU calculated across subjects and exercises. (B) Significant differences between exercises for FCU muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

7.4.2.4 Interaction: Experience*Note

There was a significant interaction between Experience and Note for the ECR (see Table 7.2 and Figure 7.24). The students and professionals performed similarly to each other over the 10 notes, although the differences between notes were not consistent across groups. For example the professionals had a significant difference between note 1 and note 4 while the students did

not. Table O5 in Appendix O includes each of these interactions. There were no significant differences between experience levels on the same note.

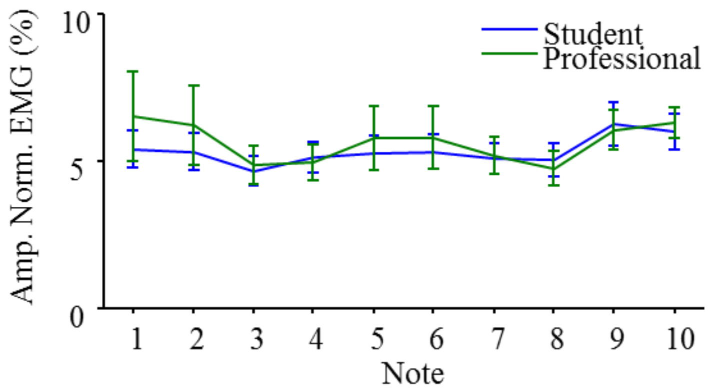

Figure 7.24 Mean (±SE) amplitude normalized EMG for ECR calculated across subjects and notes for both levels of experience.

7.4.2.5 Interaction: Experience*Exercise

There was a significant interaction between Experience and Exercise for FCU (see Table 7.3). FCU amplitude was consistently higher for students than professionals for all exercises (see Figure 7.25).The interaction was reflected by significantly larger differences between the students and professionals on exercise 2 and 6, which require the use of the pinkies.

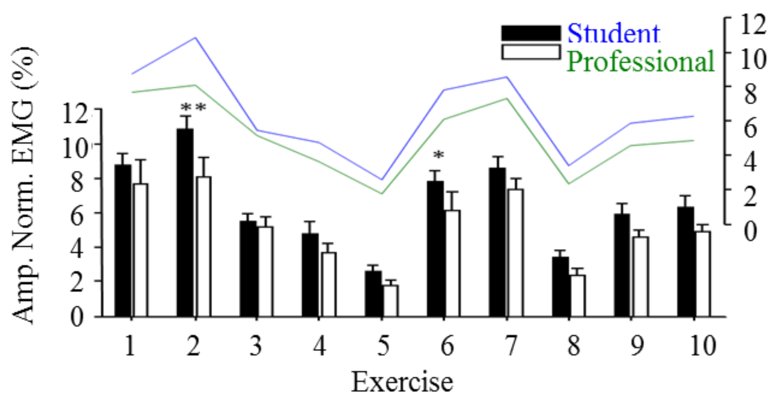

Figure 7.25 Mean (±SE) amplitude normalized EMG for FCU calculated across subjects and exercise for both levels of experience. Asterisks indicate significant interactions between experience level for certain exercises as defined in Tukey post-hoc test. *p<0.05 **p<.01

7.4.2.6 Interaction: Experience*Position

There was a significant interaction between Position and Experience in the wrist in the ECR (see Table 7.2). The professionals had the highest level of EMG amplitude for the normal thumb-rest and the lowest for the high thumb-rest (see Figure 7.26). The students also had the lowest level of EMG amplitude for the high thumb-rest but had the highest level of amplitude for the low thumb-rest.

7.4.2.7 Main effect of Size

The ECR and FCU did not have a significant main effect for hand size (see Tables 7.1 and 7.2). However, there were significant interactions between Size and Exercise for both the ECR and FCU (see Table 7.3). In both muscles, the small and large hand groups followed each other closely with only a couple exceptions (see Figures 7.27b). Exercise 1 was significantly different between the small and large hand size groups for both FCU and ECR. And in FCU, exercise 2 was also significantly different between the hand size groups.

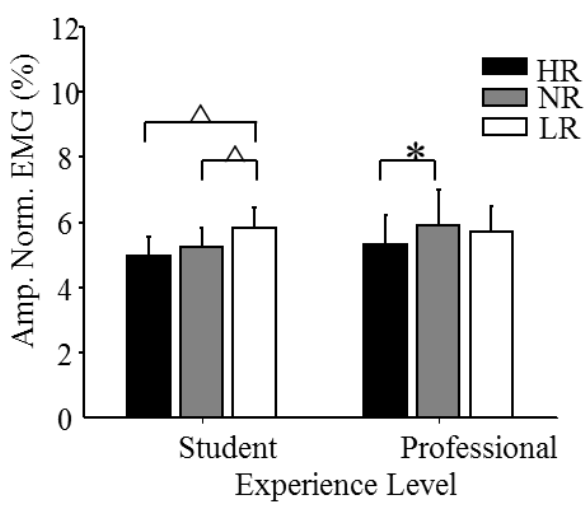

Figure 7.26 Mean (±SE) amplitude normalized EMG for ECR calculated across all subjects and exercises for thumb-rest position and experience level. Asterisks indicate significant interactions between experience level for certain thumb-rest positions as defined in Tukey post-hoc test. *p<0.05 ^p<0.001

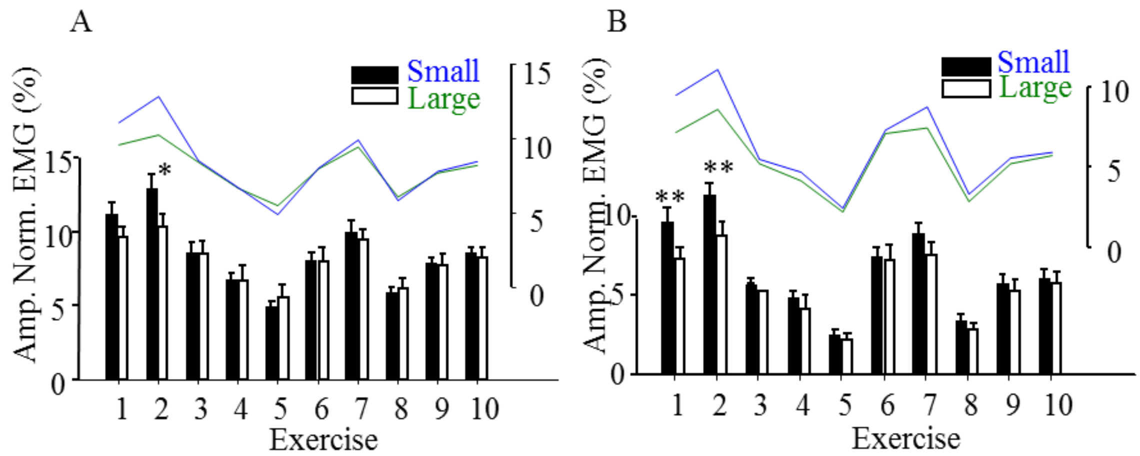

Figure 7.27 Mean (±SE) amplitude normalized EMG for (A) ECR and (B) FCU calculated across all subjects for hand size and exercise. Asterisks indicate significant interactions between hand size for certain exercises as defined in Tukey post-hoc test. *p<0.05, **p<0.01, ^p<0.001

7.4.3 Elbow and forearm stabilizers: TRI, BIC and BRA

7.4.3.1 Main effects of Position and Experience

There was a significant main effect of Position in the BIC in the notes (see Table 7.2). In the BIC, the high thumb-rest position elicited a significantly higher BIC amplitude than the low thumb-rest position (see Figure 7.28). There were no significant main effects of Position for the elbow stabilizers, nor significant interactions of thumb-rest position with Notes, Exercises, Size, or Experience (see Tables 7.1 and 7.2).

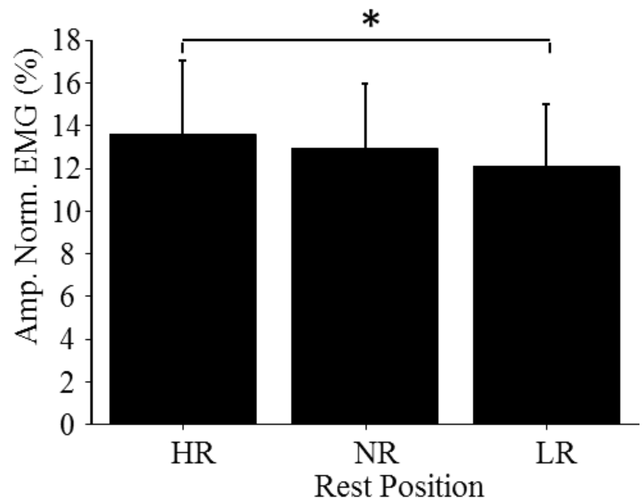

Figure 7.28 Main effect of Position on BIC. Mean (±SE) amplitude normalized EMG of BIC across all subjects and notes. Asterisk indicates significant interactions between rest positions as determined by Tukey post-hoc. *$p<0.05$

There were no significant main effects of Experience for the TRI, BIC, and BRA (see Tables 7.1 and 7.2). There were, however, significant interactions of Experience and Note in the TRI and Experience and Exercise in the BRA. Before these are introduced, a review of the TRI, BIC and BRA performances on the notes and exercises are presented.

7.4.3.2 Main effect of Note

There was a significant main effect of notes for the elbow stabilizers (see Table 7.1). The TRI, BIC and BRA exhibited consistency in activation level across most notes (see Figures 7.29, 7.30, 7.31). Because the BRA was so consistent, very few notes were significantly different from each other (see Figure 7.31). Note 3 which requires the use of the left-hand thumb and index finger, was significantly different from the rest of the notes (except for note 2) in the BRA. The TRI and BIC had the highest EMG amplitudes accompanied notes that involved few fingers (note 4) and the lowest amplitudes for notes that involved many fingers (notes 2 and 5; see Figures 7.29 and 7.30). In the BIC, note 4 was significantly different than all other notes except 7, and in the TRI, note 4 was significantly different than all other notes except 8 and 10.

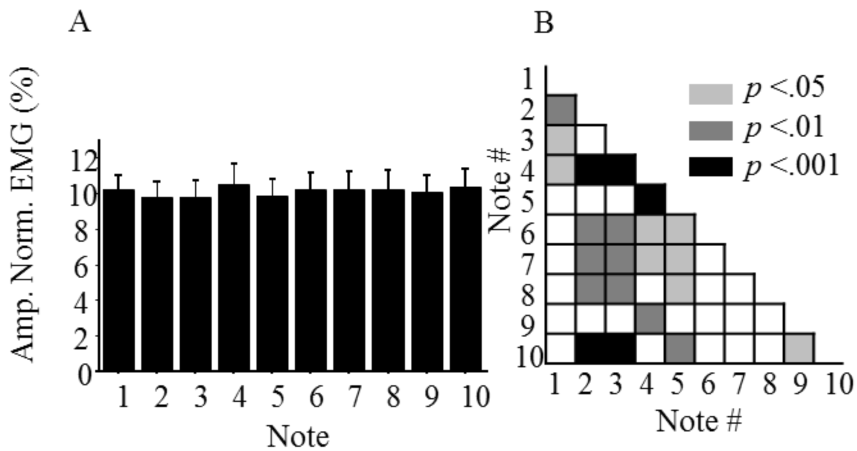

Figure 7.29 Main effect of Note on TRI. (A) Mean (±SE) amplitude normalized EMG for TRI calculated across subjects and rest positions for each held note. (B) Significant differences between notes for TRI muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

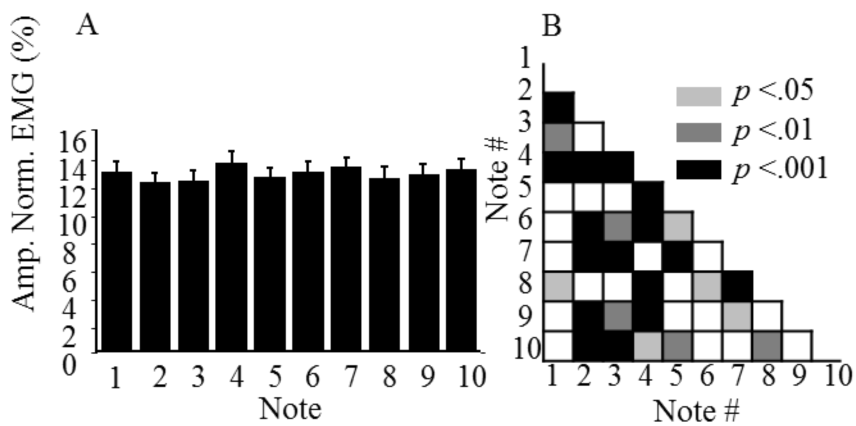

Figure 7.30 Main effect of Note on BIC. (A) Mean (±SE) amplitude normalized EMG for BIC calculated across subjects and rest positions for each held note. (B) Significant differences between notes for BIC muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

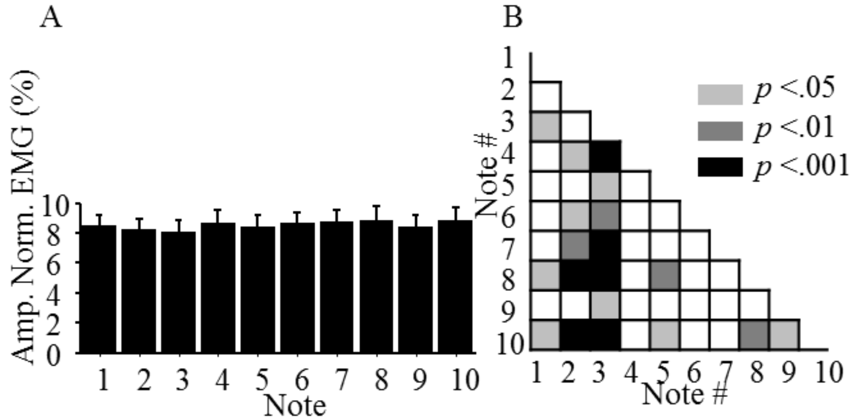

Figure 7.31 Main effect of Note on BRA. (A) Mean (±SE) amplitude normalized EMG for BRA calculated across subjects and rest positions for each held note. (B) Significant differences between notes for BRA muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

7.4.3.3 Main effect of Exercise

There was a significant main effect of Exercise on the elbow stabilizers (TRI, BIC and BRA) (see Table 7.3). The activation of the elbow stabilizers remained consistent across exercises. The TRI and BRA had higher EMG amplitudes for exercises 1, 2, and 7 than most of the other notes (see Figures 7.32 and 7.33). These three exercises require the use of the right hand pinky. Exercise 7 specifically isolated the element of playing over the break (adding the register key and all fingers). This exercise was significantly different from almost every other exercise in each of the eight muscles. For the BRA, exercise 7 was significantly different from all of the other exercises possibly because of the rotation needed in the forearm to go from low B3 to over the break B4 (see Figure 7.33). Furthermore, the exercises that did not involve the register key (3, 4, 5) were different than exercise 7 in the TRI and BRA (the BIC had only 3 and 4 significantly different than exercise 7).

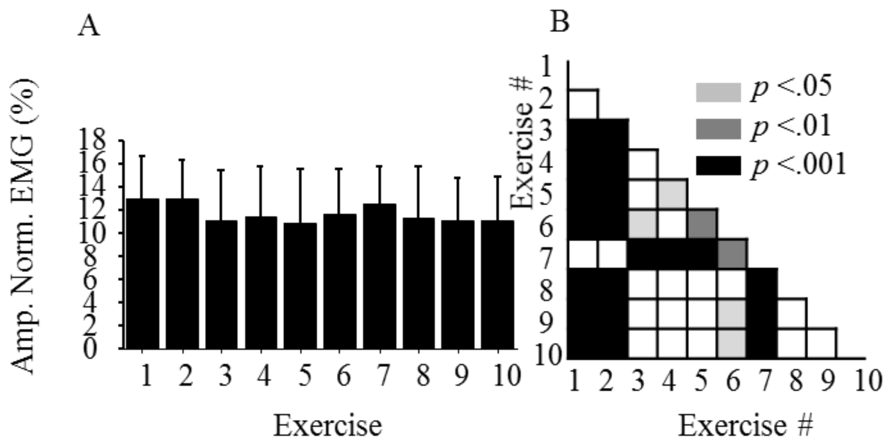

Figure 7.32 Main effect of Exercise on TRI. (A) Mean (±SE) amplitude normalized EMG for TRI calculated across subjects and rest positions for each exercise. (B) Significant differences between exercises for TRI muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

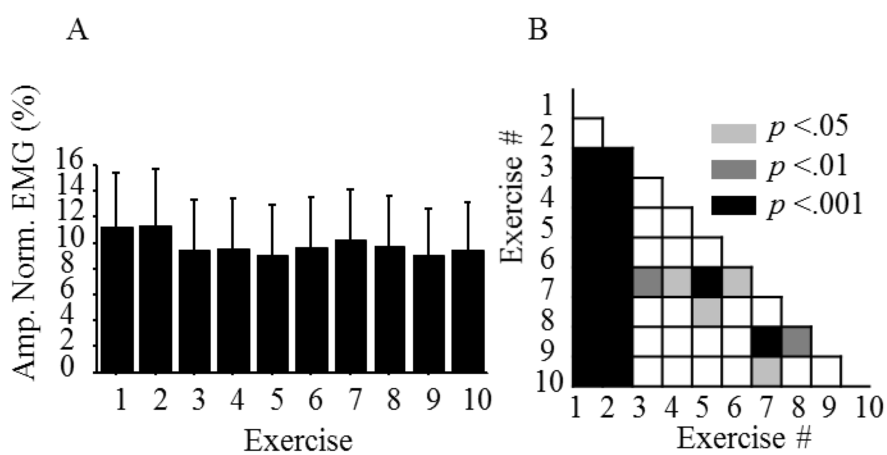

Figure 7.33 Main effect of Exercise on BRA. (A) Mean (±SE) amplitude normalized EMG for BRA calculated across subjects and rest positions for each exercise. (B) Significant differences between exercises for BRA muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

7.4.3.4 Interactions: Experience*Note and Experience*Exercise

The TRI had a significant interaction of experience level and notes (see Table 7.2). The TRI had parallel patterns of activity between the two experience levels, with the professionals always playing with a higher level of activation than the students (see Figure 7.34). The

professionals did have significant differences between notes 1 and 8 and 4 and 8, while the students did not; this causes a significant interaction. There were no significant differences between the students' and professionals' activation levels on the same note.

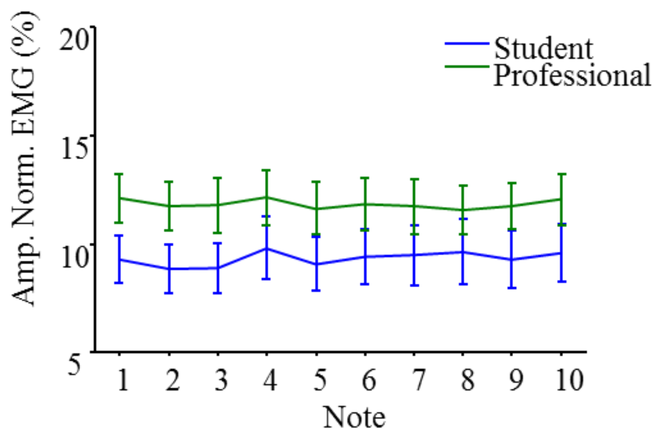

Figure 7.34 Mean (±SE) amplitude normalized EMG for TRI calculated across subjects and notes for both levels of experience.

The BRA had a significant interaction of experience level and exercise (see Figure 7.35). Amplitude was lower for the students than professionals on all exercises except exercise 2. Just like the TRI, the BRA had no significant differences between experience levels on the same note.

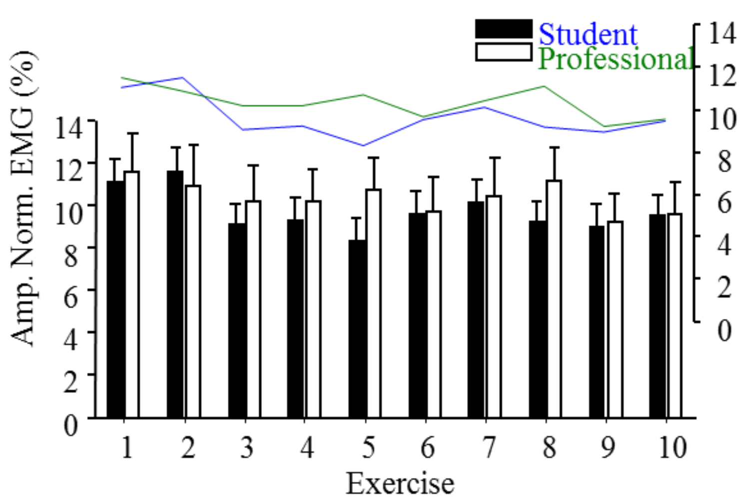

Figure 7.35 Mean (±SE) amplitude normalized EMG for BRA calculated across subjects and exercises for both levels of experience.

7.4.3.5 Main effect of Size and Interactions of Size*Exercise

Of the eight muscles in this study that were recorded, the TRI was the only muscle that had a significant main effect of Size for exercises (see Table 7.3, and Figure 7.36). The BIC and BRA had significant interactions between exercises within the same hand size group, and were very closely intertwined (see Figure 7.37 and 7.38). In the BRA, the small hand group had higher EMG amplitudes for exercises 1, 2 and 6-10, but were lower than the large hand group for exercises 3-5, which all have a good deal of right hand motion (see Figure 7.38). In the BIC, the small and large hand groups were closely intertwined like the BRA, but the large hand group had higher BIC amplitudes for the majority of the exercises (see Figure 7.37).

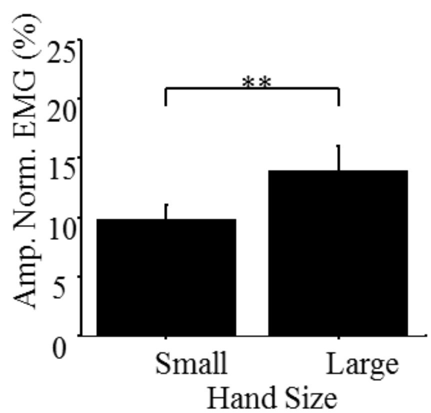

Figure 7.36 Mean (±SE) amplitude normalized EMG for TRI calculated across subjects, exercises, and thumb-rest positions for both levels of hand size. Asterisk indicates significant interactions between hand sizes as determined by Tukey post-hoc. **p<0.01

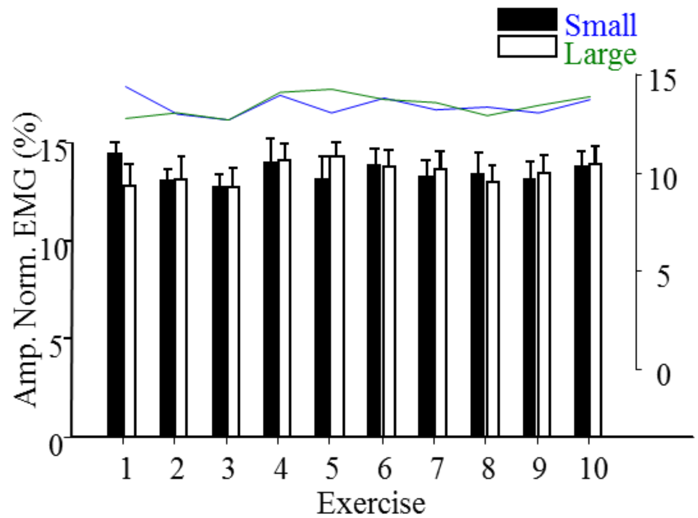

Figure 7.37 Mean (±SE) amplitude normalized EMG for BIC calculated across subjects, exercises and thumb-rest positions for both levels of hand size.

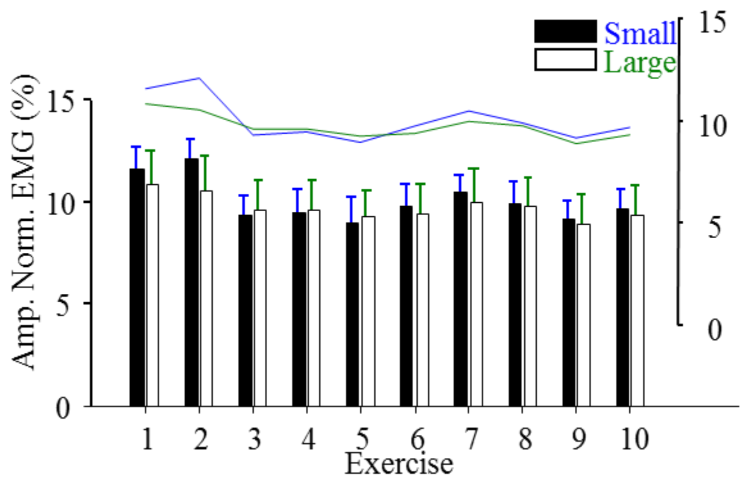

Figure 7.38 Mean (±SE) amplitude normalized EMG for BRA calculated across subjects, exercises and thumb-rest positions for both levels of hand size.

CHAPTER 8: DISCUSSION

8.1 Effect of thumb-rest position

The current study found that the BIC, APL, and FCU all decreased in activation as the thumb-rest is moved lower on the instrument. This could signal that the FCU helped create ulnar deviation at the wrist to help the APL extend the thumb up towards the high rest position, but did not do so in the low thumb-rest position. In contrast, the APB and ECR were both lowest in activation when the thumb-rest was highest. The ECR radially deviated the wrist and allowed for the APB to stretch the thumb downwards towards the lower rest.

The normal rest gave the best general balance of activation between the two thumb stabilizers (APB and APL) and the two wrist stabilizers (ECR and FCU). Therefore, a position that places the thumb between the index and middle finger likely serves as an acceptable position for most clarinet players. If a particular muscle group was implicated in a specific injury, the results presented here may offer injured players direction on how to alleviate strain by re-positioning their thumb-rest. For example if a player complained of pain in the region of their ECR portion of their forearm, a medical practitioner or teacher could advise the player to carefully experiment with placing their thumb-rest in a higher position on the instrument, where the ECR had a significantly lower activation among students and professionals.

Current data indicate that thumb-rest position can influence the activity of muscles in the right upper limb of clarinetists. This provides some response to the questions posed by Smutz et al. (1995) regarding the influence of modified thumb rests and the incidence rate of overuse injuries.[226] A long term study of clarinetists using modified thumb-rests may help draw

[226] Smutz et al., "Load on the Right Thumb of the Oboist," 95.

connections between the force data from the Smutz et al. study and the current EMG work about long term implications of modifying the support of woodwind instruments.

8.2 Effect of hand size

The effect of hand size on clarinet playing was another important focal point of this research project. It was hypothesized that hand size would influence the EMG amplitude for all exercises, notes and rest-positions. In the TRI, participants with large hands used a significantly higher level of muscle activity than participants with small hands (see Figure 7.36). This may reflect a difference in muscular strategy for supporting the instrument between participants of different hand sizes. Those with larger hands may recruit more proximal (close to the trunk) muscles, while small handed individuals may depend more on their distal (far from the trunk) muscles to stabilize the clarinet.

Every muscle except the TRI had a significant interaction between hand size and exercise (see Table 7.3). In the APB, APL, FCU, BIC and BRA, the small hand group always had a higher level of percent activation than the large size hand group. The ECR followed this pattern with minimal exceptions. The interactions between hand size and exercise reveals that small-handed players exhibited higher levels of muscle activation than large-handed players for certain activities. For small handed players, certain instrument modifications or support systems might help them reduce their need for extra muscle activity (see Chapter 10).

In the APB, FDI, and ECR, exercises that required right-hand pinky activity in the low register elicited especially high activation for small hand participants. The APL and FCU also had significantly higher amplitude for the small hand group for both exercises 1 and 2 which require all fingers and a right pinky key. These results demonstrated that the low register and pinky keys placed high demands on the thumb and wrist stabilizers. Pedagogues should take care

to help students with small hands master these playing tasks. Exercise 6, which required pinky motion between the right and left hands did not result in significant differences between hand size groups in the same muscles that had higher activations for exercises 1 and 2. This suggests that the engagement of the left hand pinky keys helped stabilize the instrument.

Rosario Mazzeo, clarinet pedagogue, suggests that beginners with small hands should begin on Eb piccolo clarinet to help create healthy thumb positioning.[227] Our results revealed that for certain exercises, this would be sound advice. A smaller instrument for beginning students could help reduce the stretching and degree of rotation that needs to be completed by muscles like the BRA and ECR. For medical practitioners, these data may support a higher likelihood of injury for small-handed players. This EMG research complements the findings of Harger (2012) that hand size influenced joint angles for clarinet players.[228] In this case, small handed participants consistently recruited more mean muscle activity to accomplish the same clarinet tasks as large handed participants.

8.3 Effect of Experience level

There was only a significant main effect of experience level within the APB, Table 7.2 Across all notes and thumb-rest positions, the student participants performed with a higher level of APB amplitude than the professionals. Students without total mastery of the instrument may try to grip harder by activating their APB in an attempt to stabilize the clarinet. There was no significant interaction between experience level and thumb-rest position, meaning that the students consistently performed with higher activation across all thumb-rest positions. This implies that the main effect was not due to larger acute changes to thumb-rest position in the

[227] Rosario Mazzeo, "Mazzeo Musings Series Ii No.25," *The Clarinet*, 19(1) Nov/Dec1991.
[228] Harger.

student participants. The pedagogical recommendation to "stay relaxed"[229] may only be achievable for the APB once the students have built their technique to be more fluid and familiar. More research about the interaction of the APB with the clarinet could help unravel these differences. It is possible that the APB is developed with the extra training and practice that professionals complete. Furthermore, an investigation of strengthening and stretching exercises on the APB may be informative for clarinetists.

The APL, FDI, BRA and FCU each had a significant interaction between Experience and Exercise. The APL's involvement in stabilizing the thumb made it prone to activities that displace the balance of the instrument from extra fingers on the instrument or changing notes in quick succession. In the APL, the students had consistently higher levels of muscle activation than the professionals, especially in exercises which demanded leaps with the pinky and between registers (exercises 1, 2, 4 and 10). The high activation of FCU in students during exercises that required the pinkies (2, 6) supports the hypothesis that the FCU helps the hand stretch downwards towards the pinky keys in a controlled manner. The student group had greater EMG amplitude when navigating large leaps on the instrument and utilizing the pinky to control four keys on the right side. These are advanced technical aspects of clarinet playing and are demanding on the wrist flexors. Teachers may use this information to guide their beginning students to less taxing activities to acclimate the hands to the task of playing clarinet. Scalar passages that move by step and limited pinky use are recommended for very early beginners. Then, teachers may introduce pinky key motion and large leaps on the instrument carefully, while helping the students retain the concept of upper arm support.

[229] Pino, 74.

The TRI had a significant interaction between Experience and Note. For all ten notes, the professionals had a higher level of muscle activation than the students. This was unexpected because the students had so consistently performed at a higher level of muscle activity for the exercises. More experienced players seem to use a slightly different strategy when holding steady notes than student players. They utilize their TRI more, a larger muscle that stabilizes the elbow.

There was a significant interaction between experience level and thumb-rest position on the performance of all notes in the ECR muscle, Table 7.2. For students, the high thumb-rest position had the lowest activation, and the low thumb-rest position had the highest activation (see Figure 7.26). The professionals also had the lowest activation of the ECR for the high thumb-rest; however, they had the highest activation for the normal thumb-rest position. The pattern of students and professionals in the ECR for the thumb-rest position was opposite that of the other muscles. Professionals may use their wrist extensors more to stabilize the wrist but the students use a different muscular strategy. Maintaining a relatively neutral wrist position is a difficult task for young students, and there may be different approaches (efficient or not) to achieving it that would cause lower levels of ECR activation. For the professionals, these results may indicate why the wrist extensors are a common site of pain for woodwind players.[230]

8.4 Effect of Notes and Exercises

8.4.1 Notes

All eight muscles had significant main effects of note and exercises. Most simply, this means that different tasks of clarinet playing created dramatic differences in the muscle activity of these eight muscles. This information helps enrich our understanding of the task of clarinet

[230] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 234.

playing. This is a measure of performance on notes and exercises across all thumb-rest positions, experience levels, and hand size.

The TRI, BIC, APL, FDI, ECR and FCU all had significant differences between the note that had all fingers open (note 4, G4) and the note that that had all fingers down (no register or pinkies) (note 6, G3). This indicated that the balance between these six muscles that stabilize the arm, wrist, and parts of the thumb changes slightly when the digits are placed on the instrument. As fingers are placed on the instrument, they exert forces along the length of the clarinet. This subtly changes the way in which players use their upper limb to steady the instrument. While some of the muscles had similar patterns of activity across the notes, others did not, meaning that the balance of the muscle activity does not stay consistent the entire time while playing.

When the pinkies are used, special activity levels in the FCU, APB, FDI, and APL were observed. The patterns of FCU, APB, FDI, and APL to notes 1 and 2 (with right hand pinkies) are unique among the 10 notes, make intuitive sense. As the right pinky extends to press the pinky key, the FCU must help create small ulnar deviation to help the pinky reach its target. The APB and FDI stabilize the thumb, and must work to keep the thumb stable as the wrist deviates and the palm stretches to reach the pinky keys.

The BIC, APB, and APL were significantly different between notes 4 (Bb4, throat tone) and 8 (C5). Both notes are fingered with just the left hand thumb and first finger. This information highlights the importance of the APB and APL as the balancers of the instrument when no right hand fingers are helping hold the instrument. The APL was primarily responsible for holding the thumb up against the thumb-rest of the clarinet, probably causing this heightened sensitivity between changes in notes and exercises. The high activation of the APL on note 4 and

low activation on note 8 reveals that as other fingers grasp the instrument, the APL is able to reduce its activation level.

Adding the register key with the left thumb exerts a force on the clarinet that is similar to the APB pushing against the side of the clarinet. This addition is exemplified in notes 1-2 (with pinkies) and 5-6 (without pinkies). The addition of the register key only impacted the TRI and BIC. The APL was influenced by the switch from note 1 to 2, with pinkies. TRI and BIC had lower activations for 2 than 1, and were lower for 5 than 6. This means that when the pinkies were involved, adding the register key accompanied a reduction in APL activation, but when the pinkies were not involved, adding the register key accompanied and increase in APL activation.

The one cross fingering that was included in the study (note 10) caused significant differences in the APB and ECR. This pair had similar activation patterns for the thumb-rest positions.

The results of the muscles on the different notes indicate that even the simple tasks of sustaining notes can cause very different activation patterns across the upper limb. While some muscles obviously work in conjunction with each other and follow similar patterns of activation, others have more complex relationships of similarities and differences based on task demands. It would be impossible to limit clarinet players to particular notes, but this information could be useful in rehabilitating a player that has already been injured and must slowly return to playing. Notes that place less demand on some of the right upper limb might include those without pinkies or notes in the left hand.

8.4.2 Exercises

One of the hardest tasks for beginning clarinetists to master is to play notes in the clarion register.[231] This involves "crossing the break" where the player goes to a B4 and must use all finger, pinkies, and the register key. Crossing the break into the clarion register is difficult because of the demands on all 10 fingers as well as the increased resistance of air pressure as the clarinet begins to overblow an interval of a 12th (19 half steps).[232] Exercise 7 in this project required participants to cross this break repeatedly. The rotation needed to bring the right-hand pinky to the key and also cover the tone holes of the lower joint accompanied elevated activity for the BRA which helps pronate and supinate the forearm. Furthermore, the exercises that did not involve the register key (3, 4, 5) were different than exercise 7 in all of the muscles. The difficulty that clarinet players have with crossing "the break" is highlighted by the current data.

The FDI, ECR, and FCU had low activation levels for exercises 9 and 10 which are both scales. When selecting a gentle warm up routine recommended by medical professionals,[233] clarinetists may choose to play scales as a relatively low impact exercise for their wrist stabilizers. The FDI, ECR and FCU had significantly different activations for the scales (exercises 9 and 10) and exercise 5. Exercise 5 only requires scalar movement in the left hand, so the muscles of the right upper limb and hand were free to set enough tension to hold the clarinet and then remain stable. This implies that the wrist stabilizers had a difference between the lower register (as in exercise 5) and the multiple registers of the scales.

Overall, the notes and exercises that require the use of the right hand pinky were associated with higher levels of muscle activation. Our results indicate that stabilizing the hand

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[231] Chodacki, Interview by Young, 2014.
[232] Chodacki, Interview by Young, 2014.
[233] Paull, 110.

as it reaches for the pinky keys is a difficult task and may be a potential source of overexertion in the wrist and forearm stabilizers. Repairmen can move the pinky keys slightly closer to the right hand, which might alleviate strain in the BRA, ECR and FCU. This might be of particular interest to players with smaller hands as they would have to stretch more to reach the pinky keys, and had a higher level of activation in all exercises in the ECR and FCU already.

8.5 Extensors

The wrist extensors are a common spot for tenderness in medical exams of injured musicians.[234] The ECR served as the primary measure of wrist extensors in this study. The APL group includes the abductor pollicis longus as well as the extensor pollicis brevis, and so also serves in an extensor role for the thumb. Medical expert Dr. Alice Brandfonbrener describes:

> Although most musicians are conditioned at least in terms of playing their instrument, all are subject to fatigue over time. With such fatigue comes shortening of the flexors with resultant increased stress on the weaker extensors that frequently bear the brunt of musicians' arm problems.[235]

The normal thumb-rest position gave the best general balance of activation for all four muscles and likely serves as a decent solution for most players. But the results of this study could be valuable for treating clarinetists that complain of fatigue or pain in certain areas. For example, if a clarinetist complains of pain near their ECR and APB regions, clarinet teachers and doctors may recommend moving the thumb-rest slightly higher where their activation was lower. If a patient complains of discomfort in the FCU and APL regions, a doctor might recommend moving the thumb-rest slightly lower. Unfortunately most overuse pain is described as "general discomfort," so future studies involving clarinetists with histories of injury would be helpful for this topic. Chesky et al. (2000) results of a study on neck strap force showed that elastic neck

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[234] McIlwain.
[235] Brandfonbrener, "Musculoskeletal Problems of Instrumental Musicians," 234.

straps could reduce axial force on clarinet players' thumbs.[236] The use of an elastic neck strap may help alleviate discomfort in the APL and ECR regions of the forearm which were so sensitive to changes in clarinet tasks during the current study.

The experience by note interaction revealed that performance of notes in the ECR was closely intertwined between the professionals and students (see Figure 7.24). For this muscle, information regarding hand size provides a clearer picture of what influences the ECR. Figure 8.1 shows that the larger hand group always had a higher level of activation in their ECR than the small hand group did. This suggests that players with larger hands use a different muscular strategy for supporting the instrument that relies more heavily on the wrist extensors.

This study highlighted that each muscle has strengths and weaknesses for the task of playing clarinet. The goal is to maximize the strengths of as many muscles as possible, without risking the health of the others.

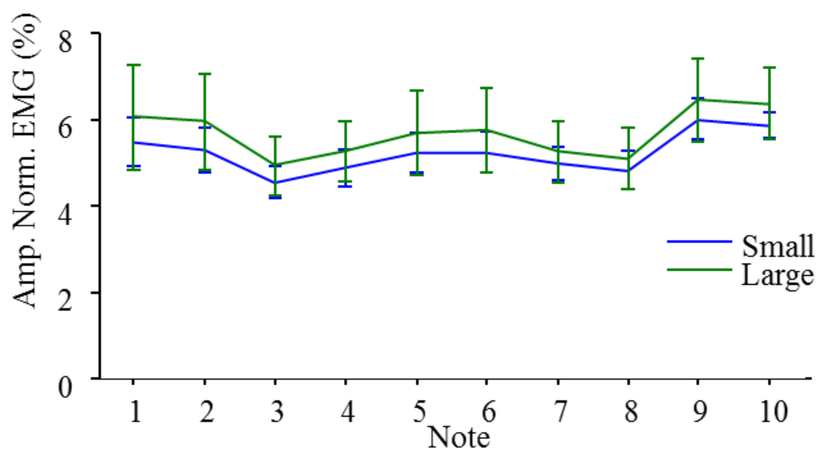

Figure 8.1. Mean (±SE) normalized amplitude EMG of ECR calculated across all subjects and notes for hand size.

[236] Chesky et al., "Effect of Elastic Neck Strap on Right Thumb Force and Force Angle During Clarinet Performance."

8.6 Final comments

In 1986, Fry predicted that overuse injury began as extended strain on the intrinsic muscles that "move metacarpophalangeal joints and spread the fingers" but that proximal muscles may also be involved.[237] The current research demonstrated that proximal muscles such as the wrist and elbow stabilizers are considerably influenced by changes in playing the clarinet. The ideal thumb-rest position varies by each muscle, creating an environment in which certain muscles will always be more strained than others.

The amount of significant differences of activation within each muscle for the notes and exercises was slightly unexpected. The results emphasized the true variety in task demands that playing the clarinet presents to the player. Ultimately, the clarinet acts like a long, complicated lever being acted on by the many potential combinations of fingers on the instrument. These fingers each exert varying levels of force which need to be mediated by the thumb, wrist and arm as well as the mouth. With the current thumb-rest model, it appears that the task of clarinet playing could not be achieved without variations in muscle activity. This variation within each muscle serves a protective role for musicians. Completely static muscle holds can cause injury,[238] and alternations of muscle activation allows for small periods of rest to avoid injury. There are other alternative thumb-rest models that could be investigated with further research to look for degrees of variation in the supportive muscles. Furthermore, modifying the instrument to move tone holes, keys, or alter the weight of the instrument by changing materials or dimensions could alter this muscular result. An underlying goal of this research beyond the thumb-rest position and hand size was to gain a better understanding of the task. The results successfully bring us closer to that goal and provide room for future research.

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[237] Fry, "Overuse Syndrome of the Upper Limb in Musicians," 36.
[238] Putz-Anderson et al., 5b-1.

CHAPTER 9: PEDAGOGY OF SUPPORTING THE CLARINET

9.1 Four common pedagogy principles

Modern musicians interact with many professionals: teachers, ensemble directors, chamber coaches, and theory and history professors. If a musician is injured, that circle of experts expands to include physical therapists, doctors, holistic healers, and even surgeons. Long before an injury occurs, a musician's primary contact for advice on the body is a lesson teacher or private instructor. Thousands of these pedagogues work throughout the world and have their own subjective experiences, beliefs, and traditions that guide their teaching.

The goal of clarinetists is to use the thumb-rest in a way that avoids injury, maximizes comfort, and promotes facile technical playing. Rosario Mazzeo wrote in *The Clarinet* journal, "A good position should remove all tension from the other fingers of the right hand. They must be free to be very glib and positive. Any tensing of the thumb invariably causes a sympathetic tensing of the four action fingers."[239] The current research shows that muscles that control the thumb must be engaged to complete the task of clarinet playing (see Figure 7.1 for APB and APL). We did not explore the changes to extensors and flexors of the digits and compare them to thumb control, which would be a wonderful avenue of research for the future.

The results of the current study have many implications for instructors of the clarinet. The entire upper limb showed adjustments in muscle activity based on task demands. Therefore, it should be considered as an entire system that functions together to achieve clarinet playing. Each teacher has particular methods for proper technique, but central guidelines have become popularized through oral tradition and print materials. Some clarinet pedagogues have published their views in books or the International Clarinet Association (ICA) trade journal, *The Clarinet*.

[239] Mazzeo, 8.

This chapter reviews some of the most common pedagogical principles regarding clarinet support, and frames each principle within the current research study.

9.1.1 First principle: "Stay relaxed"

Clarinet pedagogues emphasize that the arms and hands should remain as free of tension as possible.[240] This principle assumes that minimizing muscular tension throughout the upper limb will improve agility in the intrinsic and extrinsic muscles that move the fingers. In his book on hand and finger development, Larry Guy provided a picture of Daniel Bonade with the caption: "This photo of Daniel Bonade's fingers gives one an idea of their relaxation….Bonade attributed his outstanding technique in part to his relaxed finger position."[241]

In behavioral research, *arousal* means your state of attention, including muscular tension. Arousal is a factor that influences reaction time. In the case of clarinetists, a faster reaction time would create quicker, more efficient movement of the fingers towards the tone holes and keys. Reaction time is fastest with an intermediate level of arousal, and deteriorates when subjects are either too relaxed or too tense.[242] The multitendoned design of human fingers also lends biomechanical support for the goal of reducing unnecessary muscle tension. It would be inefficient to try to move one finger if one of the tendons attaching to that finger were too tense and working in opposition to the goal of movement. Therefore, the recommendation to "stay relaxed" is appropriate for most of the muscles that require fast reaction time and agility. These muscles include the extrinsic finger (digit) extensors and flexors.

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[240] Carmine Campione, *Campione on Clarinet: A Complete Guide to Clarinet Playing and Instruction* (Fairfield: John Ten-Ten Publishing, 2001); Pino; Keith Stein, *The Art of Clarinet Playing* (Miami, FL: Summy-Birchard Inc., 1958); Guy.
[241] Guy, 99.
[242] D.E. Broadbent, *Decision and Stress* (London: Academic Press, 1971); G.L. Freeman, "The Facilitative and Inhibitory Effects of Muscular Tension Upon Performance.," *American Jounral of Psychology* 26, (1933).

The weakest aspect of the "stay relaxed" pedagogical standby is its lack of instruction on how to use the muscles of the hand and arm to hold the clarinet. If no muscles are actively contracting, the clarinet would fall from the limp hands of the player onto the floor. The current research study shows that a complete system of muscle activation is involved in playing the clarinet. More realistic instructions for players would include: *reduced muscle tension, no over-exerting,* or *minimal muscle force.* Each alternative label reflects the balance between muscular tension and relaxation required to support the instrument with minimal unnecessary tension. More experienced players had slightly different muscular strategies for holding the instrument, especially with a higher activation of the *triceps brachii* (TRI) than the students. It may help students to envision engaging their elbow support rather than just "relax."

9.1.2 Second principle: "Round fingers"

The next pedagogical principle is to use *rounded fingers.* This occurs when tendons stabilize the joints of the finger (interphalangeal or IP joints) in order to flex and extend the entire finger as a single curved unit. The primary motion occurs at the metacarpophalangeal joint (the knuckle or MCP). The two IP joints are expected to stay firm: they should not collapse, "flatten out" or "lock at the knuckles" when pushing against the instrument.[243] Some believe that this motion will lift fingers directly above keys and require "less" muscular work.[244] [245]

To encourage rounded finger position, teachers sometimes advise students to imagine holding a tennis ball.[246] Famous pedagogue Robert Marcellus used the tennis ball analogy to encourage his students to round their fingers. He wrote, "The fingers should be gently

[243] Pino, 67.
[244] Guy, 55.
[245] Michele Gingras, *Clarinet Secrets: 52 Performance Strategies for the Advanced Clarinetist* (Lanham, Maryland: Scarecrow Press, Inc., 2004), 36.
[246] Stein.

curved…there is so much architectural strength in a curved finger…the fingers can be strong without pressure or tension."[247]

The origin of this pedagogical principle is not known. It assumes that a curved posture (position) of the finger – neither fully extended nor flexed – will be simpler and require less muscular work to move. The curved position does not necessarily reduce the total muscular work because the IP joints must be held fixed to maintain the posture. Theories of motor control address the idea of moving multiple muscles in one simple combined motion. To move as a single fixed unit, the muscles of a finger must act as a synergy, or a pattern of co-activation of muscle signals.[248] Synergies may occur when a single neural command moves a set of muscles, or when a pattern is learned so that multiple neural signals fire together to create the same result.[249] It has not been determined which category this motor task would fit best.

Some also believe that keeping curved fingers helps protect the natural bone arches in the hand, to potentially limit nerve entrapments. One medical doctor writes that maintaining curved fingers may benefit players by reducing tendon rubbing that is associated with carpal tunnel syndrome and other inflammatory conditions.[250]

Using rounded fingers to play clarinet is not always standard. In an 1824 second edition tutor, J.G.H. Backofen recommends "a flat placement of the finger tips on the finger holes"[251] (see Figure 9.1).

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[247] Kimberly Cole Luevano, "The Historical Performer: Robert Marcellus, Part 2," *The Clarinet*, March 2013.
[248] Nikolai Bernstein proposed the existence of muscle synergies as a neural strategy of simplifying the control of multiple degrees of freedom (Bernstein N. (1967)). The Coordination and Regulation of Movements. Pergamon Press. New York. OCLC 301528509). Degrees of freedom are the number of parameters within a mechanical system that can vary independently. These may include joints, muscles, etc.
[249] E. J. Weiss and M. Flanders, "Muscular and Postural Synergies of the Human Hand," *Journal of Neurophysiology* 92, (2004): 525.
[250] Rosset i Llobet, 36.
[251] Rice, "The Development of the Clarinet as Depicted in Austro-German Instruction Source, 1732-1892," 97.


die Finger dürfen nur ganz unmerklich gebogen seyn, ungefähr so:

(ja nicht so:

wie ich in einigen Clarinettschulen gefunden habe), damit die Mitte des vordersten Glieds des Fingers und nicht die Spitze desselben das Loch bedecke.

Eben so wird auch der Daumen der linken Hand ganz gerade, nehmlich so:

und nicht so:

Figure 9.1 Backofen's 1824 *Anweisung Zur Clarinette* which recommends (on the left) that players use flat finger tips to cover tone holes rather than curved.[252]

Michelle Zukofsky, current principal clarinetist with Los Angeles Philharmonic, has played on an Oehler (German) system clarinet for many years. She uses the flat-fingered technique described by Backofen with much success.[253] Dr. Rice writes, "With good breath control she achieves a beautiful legato coupled with an elegant tone quality."[254] Most French-system clarinet players use curved fingers, while some German-system clarinet players still utilize the flat finger technique that was used in the 19th century.

Because the instrument shape is fixed, altering the posture of the fingers by rounding or straightening consequently changes the space between the index finger and thumb (See Section 9.2 for more on this change). Our current research suggests that adjustments of the thumb would cause shifts in muscular response throughout the right upper limb. Our analysis took means of activity across subjects without taking into account slight changes in hand posture. Video data does exist of each subject, so this is another potential avenue for research. I suspect that using straightened fingers would require more involvement from the *abductor pollicis brevis* (APB)

[252] Rice, 2012, pg. 97.
[253] Rice, 2014.
[254] Rice, 2014.

and *first dorsal interosseous* (FDI) which stabilize the thumb position in relation to the palm. The *abductor pollicis longus* (APL) may also have more involvement depending on the thumb-rest position. Current pedagogical instructions on either rounding or straightening the fingers do not address how to hold the thumb, leaving players to experiment for themselves.

9.1.3 Third principle: "Only use the thumb"

Students are told to use *only* their thumb to support the instrument. This is based on the idea that movement will be inefficient if fingers are used for both supporting the instrument and covering tone holes. It is common for players of all skill levels to struggle with this. The index finger of the right hand is often braced under the right hand side keys to support the instrument. Pedagogue David Pino writes, "Sometimes students *feel* as though all nine fingers need to press harder to help support the instrument, or that the pinkies should try to brace the instrument to avoid dropping the instrument."[255] This problem is so prevalent that Larry Guy includes a special section for this problem in his book, *Hand and Finger Development for Clarinetists*: "Watch out for supporting clarinet under S1 key, pinching too much with left thumb and first finger, or pressing too much with the first finger… It may be a way of holding the instrument but with the detriment of making the fingers slow."[256]

This pedagogical principle is based on accurate assumptions: using fingers to support the instrument creates inefficiencies when they need to return to their duty of covering tone holes or keys. Such widespread warnings among pedagogues reflect how many players struggle with comfortably supporting the instrument with just their thumbs. The current research demonstrates that many muscles are engaged with the holding of the clarinet all the way up into the elbow stabilizers (and possibly beyond). When pedagogues tell their students "only use the thumb" they

[255] Pino, 139.
[256] Guy, 55.

minimize the role of the other supportive skeletal and muscular support throughout the upper arm. Students could benefit greatly from being taught how to perceive each independent action of the muscles that control the thumb, wrist and elbow. This could be achieved with simple exercises where the students wiggle their thumb in different planes and are shown where to palpate their muscles to feel each one working. In particular, it would be excellent to expose students to the importance of the *abductor pollicis brevis* (APB) and *abductor pollicis longus* (APL), which were both so sensitive to changes in thumb-rest position (see Figure 7.1), note (see Figure 7.2), exercise (see Figure 7.6), and experience level (see Figure 7.13).

9.1.4 Fourth principle: "Straight wrist"

Most teachers instruct their students to keep the wrist "neutral" or relaxed rather than bent.[257] [258] When beginning students hold the clarinet, their wrists often abduct or adduct in their attempt to support the instrument. Earl Thomas instructs clarinetists to play without "unduly bending the wrists" to avoid strain on the upper limb.[259] Furthermore, Pino writes: "Your fingers should come at the clarinet from about a right angle, but not quite. There should be a slightly upward angle leading from the fingers up the wrists and arms. Wrists should be comfortable but rather low."[260]

The position of the wrist inherently influences how clarinetists physically interact with their instrument. Medical studies on tapping tasks have supported this idea and their data suggested:

> Non-neutral wrist postures resulted in greater muscle stresses than the neutral (straight) wrist posture, and the stress in the extensor muscles were greater than the flexors in all conditions. Wrist extensors stress remained higher than 4.5 N/cm² and wrist flexor stress

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[257] In this case, bent would include any positions with excessive ulnar or radial deviation, and/or flexed or extended.
[258] Pino, 67.
[259] Earl Thomas, "Anatomical Essentials in Clarinet Hand Position," *The Clarinet*, 20(3) May/Jun1993, 18.
[260] Pino, 67.

> remained below 0.5 N/cm² during tapping. The sustained high motor unit recruitment of extensors suggests a greater risk than other muscles especially in flexed wrist posture. This study demonstrated from the perspective of internal tissue loading the importance of maintaining neutral wrist posture during keying activities.[261]

This research demonstrates what many clarinet teachers inherently suspect: a natural/neutral wrist best protects the flexor and extensor muscles.

The suggestion to keep a straight wrist lacks anatomical clarity. The balance of the wrist extensors and flexors are part of the current research which investigates the muscular work used to maintain a neutral wrist position. In a study of joint angles in clarinet players there was large variability in the thumb joint as well as the wrist joint.[262] The authors of this research suggested that they may be related because "the wrist angle guides thumb placement."[263] Video data from the current research study could be used to further investigate the influence of wrist angle on muscle activity during clarinet playing. Preliminary analysis of the video data revealed that wrist angle did sometimes change depending on thumb-rest positions and task demands (see Chapter 11 for future research).

The current research found that the wrist extensors had the lowest activity for the high thumb-rest and wrist flexors had the lowest activity in the low thumb-rest. The normal thumb-rest position, with the thumb between the index finger and middle finger, will likely serve most players best because it does not represent the extremes of either set of muscles. Students did have a significantly lower reaction in their wrist extensor to the high thumb-rest position (see Figure 7.26), so perhaps teachers can monitor this closely.

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[261] J. Qin, H. Chen, and J. T. Dennerlein, "Wrist Posture Affects Hand and Forearm Muscle Stress During Tapping," *Applied Ergonomics* 44, no. 6 (2013).
[262] Harger, 92.
[263] Harger, 92.

9.1.5 Conclusion

These four main principles earnestly guide players toward what pedagogues believe will prevent injury. Unfortunately, these concepts lack detailed information in anatomy or recommendations to accommodate individual differences. Furthermore, the topic of exactly how to place the thumb or conceptualize its use is lacking in the pedagogical literature. Naturally, different thumb/hand postures alter the location and way the thumb contacts the thumb-rest. It can lie anywhere along the length of the thumb, but most players place it between base of the nail bed and the thumb interphalangeal joint (IPJ). Children and adults have diverse hand sizes and shapes so they may inherently require different approaches to create a healthy support mechanism for the instrument. The variety in suggested thumb/hand posture reflects the dissonance within the pedagogical community about what is most healthy and efficient for clarinetists as beginners and for long term learning.

9.2 Pedagogy of index finger and thumb position

The four principles from section 3.1 are widely accepted among most clarinet pedagogues. In contrast, ideal position is taught in many different ways. Hand position deals with two components: the curve of the fingers, and the relationship between the thumb position and the index finger. There are many models for clarinet hand positions: the tennis-ball shape, C-shape, natural relaxed shape (found by letting hands hang by sides), and collapsed V-shape. Each teacher has their own variations on these recommendations and a small summary will follow.

Keith Stein and Larry Guy suggest that fingers should be curved as though holding a tennis ball.[264] This requires rounding the digits, maintaining the palmar arch of the hand, and rounding the thumb while it rotates in its *carpometacarpal joint* (CMC) joint (known as the

[264] Stein, 28-31. Guy, 12-16.

knuckle of the thumb), see page 58).[265] The C-shape hand position is promoted by Campione, in which he instructs all fingers to be rounded.[266] The C-Shape lends itself to more stretching of the thumb away from the rest of the palm in order to create a true curve. "Natural hand position" is promoted by both Thomas Ridenour and John Cipolla.[267] Each pedagogue has students drop their arms to their sides and then use the natural shape that the hand relaxes into. This causes mild curvature in the fingers and a straighter thumb than the tennis ball or C-shape model. The arches of the hand follow a natural arch, rather than being expanded with some of the intentionally curved models. A variation on the "natural hand position" is a collapsed V-Shape that Deborah Chodacki promotes.[268]

This model encourages players to use the *first dorsal interosseous* (FDI) muscle to bring the thumb close and as adjacent as possible to the index finger. With the thumb in this position, Chodacki believes there is a more stable thumb-fulcrum for the clarinet to balance on.[269] Generally, all of these models strive to create the same thing: injury-free playing.

Stephanie Harger, a doctoral student at the Arizona State University, conducted research on the topic of hand position. She used a CyberGlove® to measure joint angles within the hands of clarinetists and compared subjects' execution of pedagogical models to their actual playing. Harger summarized the pedagogical principles in this way:

> In summary, Bonade, Campione, Cipolla, Gingras, Guy, Klug, Pino, Ridenour, Stein, and Stubbins all recommend relaxed, soft fingers and natural, gentle, or tension-free hands as the most advantageous clarinet hand positions. Bonade, Campione, Cipolla, Gingras, Guy, Klug, Pino, Ridenour, and Stein agree that clarinet hand posture should have naturally curved fingers, while Bonade and Campione teach forming a "C" posture with

[265] For more information about the arches of the hand, please see Anatomy chapter.
[266] Harger, 32.
[267] Thomas Ridenour, *The Educator's Guide to the Clarinet: A Complete Guide to Teaching and Learning the Clarinet* (Denton, TX: Thomas Ridenour, 2000), 6; John Cipolla, "Clarinet Basics, Foundations for Clarinet Players," people.wku.edu/john.cipolla/ClarinetBasics.pdf (accessed September 10, 2014).
[268] Chodacki, Interview by Young, 2014.
[269] Chodacki, Interview by Young, 2014.

> the hands, and Guy and Stein suggest holding a tennis ball to find the correct arch of the fingers and palm. Campione, Guy, Pino, Ridenour, Stein, and Stubbins teach using the pulpy pad of the fingertips to close tone holes. Campione, Guy, Klug, Ridenour, Stein, and Stubbins say fingers should be kept close to the keys for efficient finger motion when playing clarinet.[270]

Harger made a strong argument for the need for a scientific model. She found that "subject right hand thumb placement and hand size significantly influence variations in index (first) finger flexion and ring [finger and] pinky abduction (spreading out from center finger)."[271] The tennis ball model diverged the least from actual playing postures, but that none of the pedagogical models were completely accurate.[272]

The current research study recorded questionnaire data from each participant regarding thumb posture (see Table N3, Appendix N). Subjects' descriptions of their own right-hand pedagogical model and right-hand position were inconsistent. More in depth interviews may have helped subjects report more details about their experiences with the thumb rest. Individually looking at each subject's data with these questionnaire answers for reference by be an avenue for further research.

9.3 Conclusion

There are many pedagogical principles that attempt to guide players towards injury free playing. Harger et al. (2012) found that none of the pedagogical models she tested accurately represented true playing positions for clarinet players. The process of improving pedagogical models must begin by discovering as much as possible about the task of clarinet playing. The current study indicates that the support of the clarinet involves the entire upper limb and is task dependent, so models should take into account this full-limb approach and allow for flexibility as

[270] Harger, 45.
[271] Harger, 87.
[272] Harger, 87.

task demands change. Students may not intuitively pay attention to the position of their elbows and wrists, but these joints and the muscles that move them are critical components of clarinet playing. The recruitment of these larger muscles is a strategy used by more experienced players and may help prevent injury in the smaller muscles that act on the thumb.

I hope that this research encourages pedagogues to reevaluate their own background and biases when it comes to teaching right hand support for clarinetists. It is an issue that can evolve over time as hand sizes and experience levels change, and pedagogues have the opportunity to gently guide their students towards a lifetime of healthy, comfortable playing.

CHAPTER 10: SUPPORT ALTERNATIVES FOR CLARINETISTS

There is a vast commercial market for clarinet support products today. Examples of these diverse products include neck straps and harnesses, telescopic pegs, and alternative thumb-rests that support the instrument. The popularity of these products reflects the widespread need among clarinetists for alternatives to the standard thumb-rest. Manufacturing companies claim their products will reduce discomfort and injury. One experiment has been conducted on elastic neck strap products,[273] but not all products have been experimentally investigated. This chapter will review the notable products currently available to clarinetists and provide commentary from the current study results when possible. It summarizes the state of the market at this time and explores the different ways inventors approach the issue of supporting the clarinet.

10.1 Neck straps

The basic principle of a neck strap is to transfer some of the instrument weight from the thumb to larger muscle groups such as the neck or back.

10.1.1 Traditional Neck Strap

A traditional neck strap is any device that attaches to the clarinet and wraps around the neck with a single length of material. Generally, these consist of a padded area for the neck and an adjustable loop of material that reaches down to attach to the clarinet. Companies create variations of this product by altering production materials and parameters such as length, padding, elasticity, and adjustability.

One large distinction among these products is their elasticity. D'Addario (and their woodwind-specific brand, Rico) offers a model that is adjustable in length, but has cords that attach to the instrument that are inelastic. This means that once a position is set, the instrument

[273] Chesky et al., "Effect of Elastic Neck Strap on Right Thumb Force and Force Angle During Clarinet Performance."

will be at a fixed length. The results of the current EMG study reflect the variety in muscle activity that is achieved by clarinet players as a result of their task demands. This appears to be an adaptive process that may help players avoid injury from excessive static loading. Neck straps that are inelastic may influence the ability of these muscles to change with the task demands and need further research.

Other companies such as BG and Yamaha have models of traditional neck straps that have elastic connections to the clarinet. This allows for more flexibility in position after the general length of the neck strap is set. Chesky et al. (2000) found that elastic neck straps reduced the upward (lateral) force on the clarinet but not the outward (radial/pulpar) force. Different muscles are used to create different forces from the thumb and hand. Outward force would be generated by intrinsic hand muscles such as the *flexor pollicis brevis, abductor pollicis brevis, opponens pollicis,* and *adductor pollicis*. Lateral force would be supported with muscles such as the *first dorsal interosseous* and *abductor pollicis longus*.

Another large distinction among these products is their level of padding for the neck. Claricord produces only one model of a thick single elastic band that both connects to the instrument and rests on the player's neck. In contrast, companies like Neotech, Leblanc, and Yamaha provide extra padding of foam and air pockets to provide extra comfort for players. These companies advertise the comfort of these products by using product names such as Neotech's "Pad-It Strap" ™.

10.1.2 Harness strap

Harness straps are more complex neck strap that give additional support beyond one strap on the neck. These are marketed towards saxophone players and bassoonists, but are occasionally used by clarinet players as well. One way that manufacturers provide more support

is by adding a thick collar-like yoke that then attaches to the instrument (BG Yoke strap, see Figure 10.1). The yoke circle around the neck is supposed to redistribute weight around the neck and back rather than on just one point. This can be further supported with suspender attachments to the musician's waist band (see Figure 10.1).

A different kind of harness hooks around the arms rather than the neck like the BG Saxophone harness (see Figure 10.2). This is supposed to shift strain to the muscles of the back rather than the cervical spine.

Figure 10.1 BG France Yoke strap with thick neck strap (left) and BG Modified Yolk strap with suspender supports (right) hind view.[274]

Figure 10.2 BG Harness neck strap with arm loops, front view.[275]

[274] "Bg France Products," http://www.bgfranckbichon.com/ (accessed April 8, 2014).
[275] http://www.bgfranckbichon.com/ (accessed April 8, 2014).__________, "Bg France Products."

Companies have also added belts worn on the waist to provide support. The Neotech *Super Harness* is a combination of a yoke, suspenders, and a waist buckle support. Most recently, the Vandoren (Saxophone Harness with Waist Strap) and Jazzlab (SaxHolder) companies have created products with exoskeleton-like supports. The Vandoren saxophone strap has a waist strap that is hooked onto plastic connecting pieces that attach down the back. It almost serves as a "hind" exoskeleton along the spine (see Figure 10.3).

Figure 10.3. Front (left) and rear (right) view of Vandoren Universal Harness. [276]

The Jazzlab's SaxHolder uses a counter weight measure to push against the stomach, Figure 10.4. The creators say that it is intended to distribute the weight of the instrument equally to both shoulders without any pressure on the neck.

The current EMG study demonstrates that muscles that stabilize the elbow are actively engaged when holding the clarinet and are influenced by factors such as hand size, thumb-rest position, and experience level. I strongly believe that this muscular involvement extends up into the shoulder and upper back. If this is the case, recruiting these larger muscles more by transferring some of the weight of the instrument to them through straps and harnesses may

[276] "Vandoren Products," http://www.vandoren-en.com/Universal-harness_a145.html (accessed September 5, 2014).

provide assistance to the smaller distal muscles towards the wrist and hand. Larger muscles would likely fatigue less with the weight of the instrument than the smaller muscles which have fewer motor units to generate activity. There is a risk associated with neck straps because it involves changing the clarinet task pretty drastically. Chesky et al. (2000) found that lateral forces were reduced, but not axial forces, meaning that the balance of the muscles near the hand and wrist had changed. Our data shows that muscles that create axial forces, *abductor pollicis brevis* (APB) in particular, have the least amount of activity in the high thumb rest position. It is possible that lateral forces (and strain on muscles like the *abductor pollicis longus* (APL)) could be reduced with a neck strap, and the axial forces could be reduced by moving the thumb-rest position upward. Finding answers for this topic would further EMG and force data research.

Figure 10.4 Saxholder device with plastic shoulder mounting and counterbalance system.[277]

10.1.3 Neck strap modifications

In addition to the many neck straps available today, some inventors have created devices to alter the attachment point of neck straps. The Stephen Fox device provides a pad to place against the torso for pulpar (away from the body) support (See Figure 10.5). Online forums

[277] Zach Solitto, "Can a Saxophone Neck Strap Cure Neck Strain While Playing?," http://www.bestsaxophonewebsiteever.com/can-a-saxophone-neck-strap-cure-neck-strain-while-playing (accessed September 1, 2014).

contributions give mixed reviews about the comfort of this device. Some reviewers claim they became used to the pressure on their abdomens, others found this pressure unacceptable.[278] This device would reduce outward (radial, pulpar) force for muscles like the *abductor pollicis brevis* (APB). Because this muscle was so sensitive to factors such as task demands and experience level, it is logical that an inventor designed a product that could address that issue.

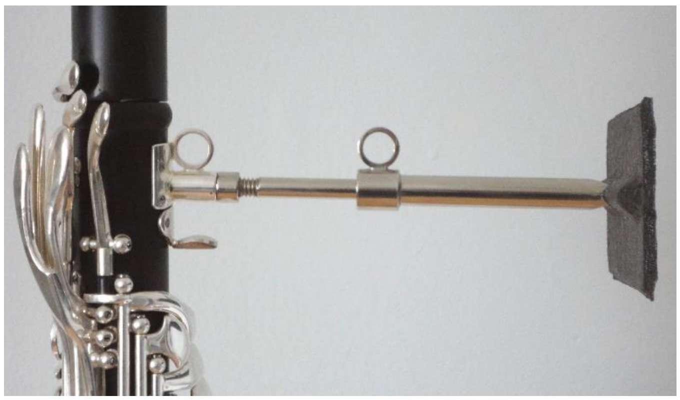

Figure 10.5 Stephen Fox Support Brace, side view.[279]

A similar creation called the “thumb solution” was created by clarinetist and otolarynologist, Heston L. Wilson.[280] With the help of a repairman, Wilson transformed a lyre (normally used for holding marching band music) into an extended attachment for a neck strap (See Figure 10.6). This product does not rest on the abdomen of the player, only changes the contact point for the instrument. The new attachment point for the neck strap would slightly change the forces exerted on the instrument, and for Wilson, this shift helped relieve his arm and thumb pain.

[278] Ken Shaw, "Au Revoir, Fhred," Woodwind.org http://test.woodwind.org/oboe/BBoard/read.html?f=1&i=378982&t=378982 (accessed September 2, 2012).
[279] Stephen Fox, "Stephen Fox Accessories," http://www.sfoxclarinets.com/Accessories.html (accessed August 10, 2014).
[280] Wilson L. Heston, "The Thumb-Solution," *The Clarinet*, 17(3) May/Jun1990, 40.

Figure 10.6 The “thumb-solution” neck strap attachment created by Heston L. Wilson.[281]

10.2 Pegs

Large string instrument like cellos and double basses use pegs to raise the instrument off the ground at a comfortable playing position. Woodwind and brass players have adopted this technique for their own instruments.

The FHRED (Finger and Hand Retraining Ergonomic Device) is a telescopic arm that supports the clarinet on a player’s chair. It is made of metal and attaches onto a ring on the thumb-rest of clarinets or oboes. On some instruments, this ring is already on the thumb-rest, but it can be quickly added by a repairman if it is not. The FHRED device extends from this attachment point between the performer’s legs to a rubber foot on the seat of a chair.

The FHRED transfers the clarinet’s weight to a point off of the musician’s body, which is a major benefit for most users. The device stays at a fixed length while playing, with no flexibility once it is set. Quodiblet, the company that created this product, also created a small accessory for the FHRED called the SAMI. The SAMI clips to a waistband or belt and uses the FHRED to transfer the weight of the instrument to this point. This addition allow users to this

[281] Heston, 40.

peg method while standing, increasing the possibilities for this device. These peg-based devices may be a great option for some people looking to reduce the weight their thumbs have to bear. Brass players including euphonium and trombone players have also adopted this approach with products such as Ergobrass and Ergobone.[282]

The Quodlibet Company closed (in roughly 2010) and is no longer selling the FHRED or SAMI devices on their former website. Another company, RDG Woodwinds has created a similar product (see Figure 10.7).

Figure 10.7 RDG Woodwinds BHOB peg support product based on the FHRED device. White arrow indicates peg that can extend to a player's seat.[283]

Peg-like products serve the players' needs by reducing upward (lateral) force that the upper limb has to exert on the clarinet. Based on our current results, this product may benefit the *abductor pollicis longus* (APL), *brachioradialis* (BRA), and *biceps brachii* (BIC) in their support of the instrument. A benefit of this product over neck straps is that that weight of the instrument is transferred to an external object rather than other locations on the body. It may potentially limit movement, which is a natural part of the clarinet task demands without any support systems. The

[282]Jouko Antere, "Ergo Brass Support System," http://www.ergobrass.com/trb/eng/eng_trb_etusivu.html (accessed September 10, 2014).

[283] __________, "Kickstand "Bhob" for Clarinet (Long)," RDG Woodwinds https://www.rdgwoodwinds.com/kickstand-bhob-clarinet-long-p-12593.html (accessed November 1, 2014).

collective system of upper arm support may be at risk if the balance of the muscles is shifted so greatly.

10.3 Alternative thumb-rests

To go beyond neck straps and pegs, inventors have found ways to alter the thumb-rest itself. The section will review four different interpretations of the thumb-rest: the Kooiman thumb-rests, the Ridenour Thumb Saddle, the All-Thumbs-Rest, and the Ergo Woodwind Comfortplayer (EWC).

10.3.1 Contact point: Kooiman brand

Ton Kooiman invents products focused on the ergonomics of woodwind playing. The primary goal of his clarinet products is to move the point of contact of the thumb-rest with the body. The Etude3 is a revised thumb-rest model that fits both clarinet and oboes, and the Maestro2 is an updated version of his original clarinet thumb-rest (See Figures 10.7 and 10.8). Both models attach to the lower joint of the instrument via an interlocking slide mechanism and drilled plate on the body of the instrument. Four structural components are shared by the Etude3 and Maestro2:

1. The fleshy pad of the thumb touches a concave surface on the drilled plate, rather than the clarinet body.
2. The thumb is positioned higher on the instrument to create opposition between the thumb and index finger
3. The point of contact that exerts the weight of the clarinet is moved away from the tip of the thumb and towards the proximal phalanx of the thumb.
4. The plate attachment of these products adds width to the body of the clarinet, expanding the space between the index finger and thumb.

A unique quality of these thumb-rests is the redistribution of the clarinet's weight to a different point on the thumb. The Etude3 achieves this with a curved hook surface and the Maestro2 achieves this with an adjustable padded arm, Figures 10.8 and 10.9.

The Etude3 has a new adjustable height component in the hook that rests on the top of the thumb which adds variability for different hand shapes, Figure 10.9. The Maestro2 has a larger, two part arm that attaches to the plate on the clarinet and the thumb. It has a metal joint between the two points to change the direction of the force vectors acting on the thumb, Figure 10.8.

Figure 10.8 The Kooiman Maestro2 thumb-rest rear view (left) and top view (right).[284]

[284] Ton Kooiman, "Ton Kooiman Products," http://www.tonkooiman.com/index.php/products (accessed August 10, 2014).

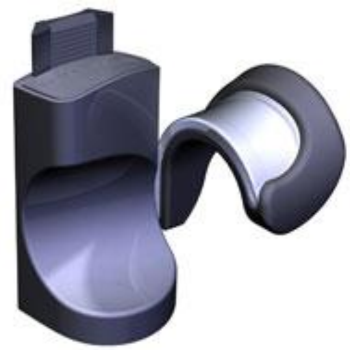

Figure 10.9 The Kooiman Etude3 thumb-rest, rear-side view.[285]

The Kooiman website claims their products encourage players to actively use their thumb – rather than let the weight of the instrument "hang in the tendons." Our current research strongly supports this idea, that supporting the clarinet is an active process engaging numerous muscles. The Ton Kooiman website also claims:

> The Etude, Maestro and Oboe make it possible to move the pressure point of the thumb-rest to the first phalanx of the thumb to the space between the two joints. The lever momentum is much smaller at this point so the thumb can support the weight more easily.[286]

This statement reflects an accurate understanding of how forces act on simple levers; however, biomechanical systems are more complex. Pearlman et al.'s (2004) cadaver study confirmed that fundamental thumb-tip force output vectors are nonlinear to the tendon tension input vectors. The research team predicted that it is "not realistic to assume in biomechanical models that thumb-tip force vectors scale linearly with tendon tensions, and that… the thumb may act as a 'floating digit' affected by load-dependent trapezium motion."[287] Goehler et al. (2010) found that linear models could explain the endpoint force of the thumb created by intrinsic muscles in load

[285] Kooiman,
[286] Kooiman,
[287] J.L. Pearlman, Roach, S.S., Valero-Cuevas, F.J., "The Fundamental Thumb-Tip Force Vectors Produced by the Muscles of the Thumb," *Journal of Orthopedic Research* 22, no. 2 (2004): 306.

bearing situations, but that these forces were highly dependent on thumb postures.[288] If the thumb changed postures and had different loading conditions, nonlinear thumb tip forces were seen. For clarinetists, this means that they would need a consistent loading condition and thumb posture for the Kooiman to deliver linearly predicted changes in force. Our research demonstrates that consistent loading conditions do not occur when playing the clarinet due to the forces exerted by the other digits on the instrument. This contradiction creates an opportunity for future research on this product.

10.3.2 Width: Ridenour Thumb Saddle

Another approach in thumb-rest modifications is to increase the clarinet's width. Tom Ridenour, former professor at Wesleyan College, achieves this with his Thumb Saddle product. This plastic addition attaches to any clarinet by sliding over the existing thumb-rest. The Thumb Saddle extends down along the body of the lower joint, widening the distance between the thumb and fingers by about 9 mm (see Figure 10.10 (left)). Ted Ridenour, son of the founder, reports that some users find strips of adhesive foam to place under the Thumb Saddle to make the distance of the thumb away from the clarinet even greater.[289] It is 19.5 mm from side to side, and 32.5 mm long.[290] This only adjusts the vertical position of the thumb-rest by a millimeter or less.

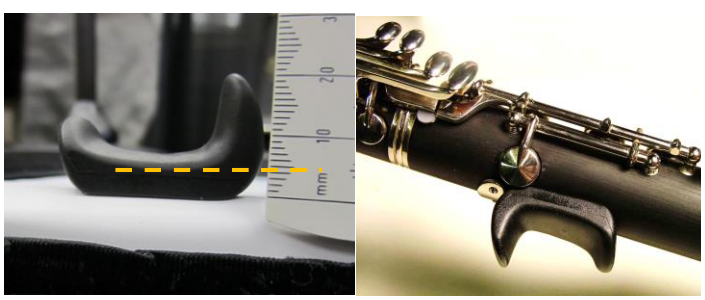

Figure 10.10 Ridenour Thumb Saddle, alone, left and on a clarinet, right.

[288] C.M. Goehler, Murray, W.M., "The Sensitivity of Endpoint Forces Produced by the Extrinsic Muscles of the Thumb to Posture," *Journal of Biomechanics* 43, no. 8 (2010): 1553.
[289] Ted Ridenour, "Ridenour Thumb Saddle Research," Email message to author, May 16, 2014.
[290] Ridenour, May 16, 2014.

The Ridenour website promotes the product as a way to reduce hand tension:

> Unlike adjustable thumb-rests which displace the thumb to the degree it throws the hand out of balance, The Ridenour Thumb Saddle eliminates the "pinch" tension between the thumb and fingers by simply opening the hand up. The increased openness promotes the needed relaxation without throwing the thumb and fingers out of balance.[291]

This statement from the Ridenour Company has not been explored with research, yet anecdotes from the creator and customers claim that it provides pain relief for some users. EMG research would be a wonderful avenue for explore the effects of changing instrument width on the supportive muscles of the upper limb. There were some differences in muscle activity between large and small handed participants by particular exercises. Only the *triceps brachii* (TRI) had a significant main effect of hand size, indicating that over the course of all thumb-rest positions, notes, and exercises the muscles that control the hand were not significantly different between the different hand size groups. In general, small handed participants had higher levels of activation during the exercises than large handed participants. Making the instrument wider may not be a healthy strategy for those with small hands.

In the book, *The Musician's Body*, the author writes that woodwind players have a tendency to shorten the distance between the index finger and thumb of the right hand in an attempt to achieve solid and stable support for the instrument.[292] The author of this book recommends widening this space with products such as the Ridenour Clarinet Thumb Saddle.

10.3.3 Surface area: All Thumbs REST

Kate Eakin, a former sufferer of tendonitis, invented a thumb-rest alternative called the All Thumbs REST (Relief from the Exertion of Sore Tendons). This device attaches to the

[291] Ted Ridenour, "Thumb Saddle," http://www.ridenourclarinetproducts.com/Thumb.htm (accessed August 10, 2014).
[292] Rosset i Llobet, 49.

bottom a thumb-rest of oboes, English horns, or clarinets with self-adhesive Velcro®. One side of the rest has a firm plastic coating, and the other is padded with foam cushioning for the thumb. At 50 mm long, 20 mm wide, and 7.94 mm (5/16”) thick, the All Thumbs REST significantly increases the potential contact area of the thumb-rest on the thumb beyond the traditional rest, Figure 4.11. This larger rest can be attached in a variety of angles to the body of the clarinet to allow for customization by the player. Figure 10.11 shows an overhead view of how a user would interact with the All Thumbs REST. Product descriptions claim the larger surface area “distributes the weight of your instrument across your arm, rather than putting pressure on a single point.”[293]

Figure 10.11 All Thumbs REST product attached to a clarinet.[294]

The large surface area and flexibility in mounting on the instrument with different angles provides many opportunities for customization with the All Thumbs REST. It is possible that more variations in thumb postures (rounded vs. straight) could be accommodated with this device. Current EMG research shows that there is a natural variation in muscle activity as clarinetists perform different tasks. This product may help provide more immediate options for

[293] Kate Eakin, "All Thumbs Rest Research," Email message to author, May 12, 2014.
[294] Eakin, May 12, 2014.

thumb position changes as the clarinetist plays. The All Thumbs REST alters the vertical thumb position on the instrument through its 7.94 mm width (before compression takes place). For about $20, the All Thumbs REST provides an inexpensive, temporary alteration that may help players alter their point of contact with the instrument.

10.3.4 Lower barrier: Ergo Woodwind Comfortplayer (EWC)

The Ergo Woodwind Comfortplayer (EWC) is an alternative thumb-rest attachment that provides a new gripping surface for clarinetists.[295] Belgian clarinetist and EWC creator, Peter Merckx, created this thumb-rest addition to increase stability in balancing the clarinet.[296] A flat silver-plated alloy plate is placed below the thumb-rest with an adhesive patch, then an adjustable pyramidal-shaped block is screwed into the plate. The plate changes the curved surface of the clarinet to a flat surface for the thumb to push against, Figure 10.12. The pyramidal block provides a bottom barrier for the thumb – preventing the thumb from slipping down the instrument, and giving it a solid object to push against while supporting the instrument.[297]

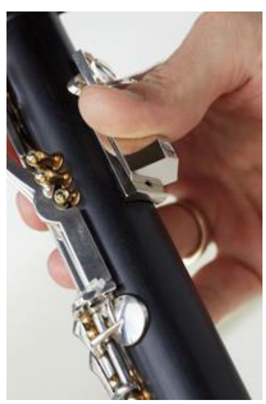

Figure 10.12 Ergo Woodwind Comfortplayer (EWC) made by the MyPM Company, hind view.[298]

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[295] This product is also sometimes called the "Thumb-Fix."
[296] MyPM, "Mypm International," http://www.mypminternational.com/ENG/home%20eng.html (accessed September 10, 2014).
[297] Stephan Vermeersch, "Product Review: Ergo Woodwind Comfort Player "Ewc"," *The Clarinet*, 41(2) 2014.
[298] Stephan Vermeersch, "Product Review: Ergo Woodwind Comfort Player "Ewc"," The Clarinet, 41(2) 2014.

The base plate slightly widens the diameter of the clarinet by a few millimeters. The lower block component essentially helps pin the thumb against the thumb-rest to anchor the hand in that position. Reviews from players claim that the EWC device gives more “stability, playing comfort and flexibility.”[299] They say they have achieved “freedom of technique that was previously absent,” after using the EWC.[300] The website of the EWC claims that the product can relieve “RSI (repetitive strain injury), tendonitis, lateral epicondylitis and could help prevent focal dystonia.”[301] These statements have not been verified by any published research.

The current research shows that some natural variability in the muscles occurs while playing the clarinet. The EWC product promotes both stability and flexibility; perhaps the perceived stability of having a firmer grip with the thumb muscles helps players relax their other forearm muscles. Again, EMG research would be a wonderful method for investigating the influence of this alternative thumb-rest product.

10.3.5 Conclusion

The Kooiman thumb-rests, Ridenour Thumb Saddle, All Thumbs REST, and Ergo Woodwind Comfortplayer products offer very different solutions for supporting the clarinet. With the Kooiman devices, the point of contact is moved towards the proximal portion of the thumb and the thumb is moved to a higher position on the instrument; the Ridenour device adds width to the clarinet body; the All Thumbs REST primarily increases surface area for the thumb; and the Ergo Woodwind Comfortplayer provides a bottom barrier to secure the thumb in the traditional thumb-rest.

[299] Stephan Vermeersch, "Product Review: Ergo Woodwind Comfort Player "Ewc"," The Clarinet, 41(2) 2014.
[300] Julia Heinen, "Pm," Email message to author, August 28, 2014.
[301] MyPM,

10.4 Other consideration: cushions

Any additions made to the thumb-rest area can have a potential effect on thumb position. While not a support device, a common addition to the right thumb area are thumb-rest cushions. Cushions designed for clarinet use are made from various types of plastic, foam, or rubber. They range in thickness from almost paper thin to nearly 5 cm. Some individuals use whatever household materials are available such as rubber tubing, foam, and even pencil cushions. For certain players, cushion products reduce skin discomfort.

Excess pliability in the surface that contacts the thumb may undermine a stable grip on the instrument.[302] This idea might have some validity: in physical therapy and athletic training, pliable surfaces are used to challenge postural muscles and strengthen them through increased work.[303] For clarinetists, the thumb-rests that come with the clarinets are generally quite narrow and any small instability introduced by a cushioned surface may not cause a significant disadvantage for experienced players. In fact, it may challenge the different muscles to stabilize the thumb more. This concept has not been experimentally tested, but could be another area of interest for future researchers.

4.5 Conclusion

The abundance of products for clarinet support reflects a need within the clarinet community. With all the companies of these products promoting "the solution," clarinetists need help discovering the fundamental basics of clarinet support so they can make their own informed decisions. There is a need for accurate data to guide our education policies for clarinet players and further research studies are needed. For teachers, it is important to remember that each player is anatomically unique and that one product may not work for everyone. As players grow

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[302]Chodacki, Interview by Young, 2014.

[303] Personal experience

in size and experience, their muscular activity changes and they may need different support solutions as they change. The subject of instrument support should be revisited consistently to promote awareness and foster playing habits which allow for natural development of healthy technique.

CHAPTER 11: FUTURE RESEARCH AND OUTLOOK

This work represents the first EMG analysis of clarinet playing. We evaluated the effect of thumb-rest position, playing experience and hand size within the context of clarinet biomechanics. Given that this was the first study of its kind, many future directions could be inspired from this work. Some further analysis could be conducted on the existing data found in this experiment which will be described and potential future experiments will be discussed.

11.1 Limitations of the current study

A limitation of the current study was the number of EMG channels at our disposal. This experiment used 8 EMG sensors for our research. If more channels were available this study, would have included the right hand abductor digiti minimi which moves the pinky, muscles that stabilize the shoulder and scapula, and left forearm muscles. Future research including these locations may further illuminate the body's system for the static hold of a clarinet. While we were happy with the recruitment of 20 subjects for this study, it would be even better to have a larger sample size of clarinetists.

11.2 Existing data

11.2.1 Video data

In the Methods section of this document, two cameras were described. These videos captured data that could be used in the future to further augment the EMG data. Video data were loaded into Kinovea software for analysis. Some basic preparation of the video data was completed, but not analyzed. The top camera was used to find joint angles in each of the participants' hands in the three different rest positions. After calibrating distances with the reference wooden dowel, lines were drawn between the video marker dots on the thumb CMC and MCP joints, and the thumb CMC and index MCP joints. The angles and distances were

calculated between the three dots. See Figure 11.1 for an example of Subject 13 playing with the normal rest position. The left is the wooden dowel reference, in red are the line lengths, and in yellow is the joint angle.

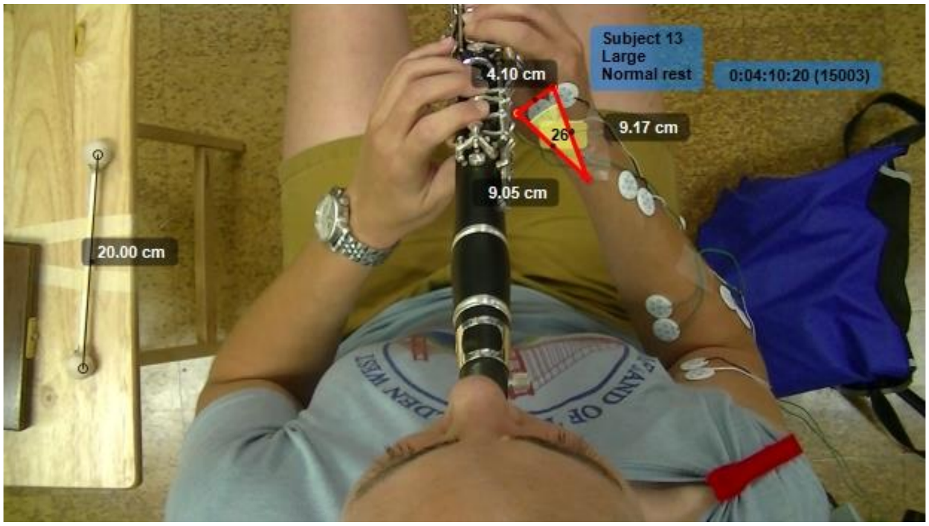

Figure 11.1 Angle image of subject 13 playing with the normal rest position.

Kinovea software exported these line and angle values into excel spreadsheets. These angles could be plotted by hand size to visually compare the grip styles of different participants. These data could also be used as a component of ANOVA analyses to explore if the hand angles and muscular activity were at all related.

The side camera could be used in a similar way to calculate degree of elbow flexion and wrist abduction.

11.2.2 EMG data

The current EMG recordings of exercise performances can be further analyzed with burst analysis. Some preliminary work was done to align each exercise's five trials with a cross-correlation algorithm created in MATLAB. Muscle bursts can be identified by establishing thresholds and selecting times that the muscles exceed those thresholds. A threshold could be

established by taking the mean muscle activity from a simple held note, and then calculating one or more standard deviations away from that mean.

In this study, we did not control for tempo within each trial, because we wanted to avoid constraining the players. We also did not have the capability of recording audio information on the clarinet with midi-like materials that some electronic pianos have. Even the most accomplished professional clarinet players had some inconsistencies of tempos, making averaging across all trials for bursts more difficult.

Burst analysis has the potential to show how muscles interact during the course of an exercise. During data collection, some of these patterns were visible to the naked eye. For example, in some exercises, the FDI would alternate bursts with the APB, and in other instances in would alternate with the APL. These extra details could provide interesting depth of analysis to the current research.

11.3 Future research

Future variations on this clarinet study would ideally combine the motion-tracking CyberGlove® from Harger (2012) and force measuring cells from the Smutz et al. (1995) and Chesky (2000) studies. Some of the force data could be gleaned from the EMG readings. Muscles that exert a pulpar force include the FDI and ABP and the muscles that exert lateral force on the thumb-rest would be ECR, FCU, and APL.

Goehler et al. (2010) demonstrated in a cadaver study that thumb postures are important for determining if endpoint forces created by intrinsic muscles in static loading situations will be linear or not.[304] As they describe in their work, experimentally controlling for exact thumb posture is difficult due to the small size of the thumb and its complexity. Future research on

[304] Goehler, "The Sensitivity of Endpoint Forces Produced by the Extrinsic Muscles of the Thumb to Posture," 1553.

thumb endpoint forces could be applied specifically to the alternative thumb-rest solutions such as the Ton Kooiman products, Ridenour Thumb Saddle, All Thumbs REST, and EWC. This could be investigated with load cells which measure force such as the 67-N load cells from Sensotec, Inc. that were used in Smutz et al.[305] This research could also be conducted on players using the regular thumb-rest style but with different thumb postures that are described in the pedagogy of clarinetists. The C-shape, V-shape, tennis ball, etc., would all likely cause different force outputs from the intrinsic and extrinsic hand muscles.

While the effects of neck straps on axial and radial forces on the thumb in clarinet players has been investigated, the effects of neck straps on the neck and back muscles have not been investigated. This is an excellent opportunity to use EMG recording for this application to investigate how the body of a clarinetist reacts to a shift in the weight of the instrument.

All of the subjects in the current study were healthy controls and future studies could incorporate comparisons between those with past or current injuries and healthy players. Ideally, a combination of EMG, force, and motion measurements could be combined to investigate treatment of clarinet players with injuries. Medical professionals that work at performing arts clinics throughout the world may be willing to participate with their patients in studies on the effects of different treatments on rehabilitation.

11.4 Summary and outlook

Based on the results of this study, no specific guidelines for thumb-rest position for clarinetists can be established at this time. This first exploration into using EMG recordings was successful in gaining a deeper understanding of the task demands. Some results confirmed our expectations, while others surprised us. For example, certain muscles responded well to a low

[305] Smutz et al., "Load on the Right Thumb of the Oboist," 95.

thumb-rest position in some situations, even beyond that of the traditional thumb-rest. Furthermore, this research did highlight some information about hand size and task demands that could be useful for pedagogues. These results may guide clarinet players towards alterations for their instruments to accommodate their own unique discomforts.

Research projects on the muscle activation of clarinet players have the potential to serve both the clarinet community and the community of researchers aiming to improve biomechanical models of the human hand and upper limb. Clarinet playing is a complex task that involves both static support of a weight and intricate finger motions that result from extensive training. Musicians are excellent resources for researchers exploring the effects of extensive practice and the mechanical mastery of fine motor tasks. In the future, deeper understandings of clarinet playing may have applications in surgery, therapy, and prosthetics.

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APPENDIX A: IRB ACTION ON PROTOCOL APPROVAL REQUEST

ACTION ON PROTOCOL APPROVAL REQUEST

LSU
Institutional Review Board
Dr. Robert Mathews, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Sara Winges
Kinesiology

FROM: Robert C. Mathews
Chair, Institutional Review Board

DATE: March 24, 2014
RE: **IRB#** 3344
TITLE: Patterns of muscle activity in hand movements

New Protocol/Modification/Continuation: Modification

Brief Modification Description: Adding Sarah Robert and Kathryn Young to project. Adding questionnaire. Adding language to consent form.

Review type: Full ____ Expedited __X__ **Review date:** 3/25/2014

Risk Factor: Minimal ___X___ Uncertain ______ Greater Than Minimal_______

Approved___X____ **Disapproved** ___________

Approval Date: 3/25/2014 **Approval Expiration Date:** 12/10/2014

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 50

Protocol Matches Scope of Work in Grant proposal: (if applicable) _______

By: Robert C. Mathews, Chairman ____________________

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

APPENDIX B: IRB APPROVAL OF INFORMED CONSENT FORM

LSU | College of Human Sciences & Education
School of Kinesiology

STUDY APPROVED BY:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
130 David Boyd Hall
225-578-8692 / www.lsu.edu/irb
Approval Expires: 12/10/2014

INFORMED CONSENT FORM

1. **Study Title:** Patterns of muscle activity in hand movements

2. **Performance Site:** School of Kinesiology laboratories, Louisiana State University and A&M College

3. **Investigators:** The following investigator is available for questions about this study,
M-F, 8:00 a.m. - 4:30 pm
Dr. Sara A. Winges 225-578-5960

4. **Purpose of the Study:** to better understand the complex multi-muscle patterns used to produce hand movements.

5. **Participant Inclusion:** Participants will be comprised of adults between the ages 18 and 65 who do not report neurological or psychological conditions.

6. **Participant Exclusion:** Women cannot be pregnant.

6. **Number of Participants:** 50.

7. **Study Procedures:** Informed consent and a history of training in skilled hand movements and hand injuries/problems will be taken. Devices will be attached to the surface of your arm and hand to record the activity of your muscles and several reflective markers may be placed and taped (medical tape to help prevent skin reactions) over segments of the upper and lower limbs, and the trunk to monitor body movements while participants are sitting or standing. A band may be placed around two fingers so they move together.

8. **Benefits:** As a volunteer from the college community you may earn extra credit for research participation. Otherwise there are no other direct benefits for you.

9. **Risks/Discomforts:** There is no known risk to the subject beyond those that occur in daily activity. Every effort will be made to maintain your safety. Every effort will be made to maintain confidentiality of your records. Files will be kept in secure cabinets to which only the investigators have access.

10. **Right to Refuse:** Subjects may choose not to participate or to withdraw from the study at any time without penalty or loss of any benefit to which they might otherwise be entitled.

11. **Privacy:** The LSU Institutional Review Board (which oversees university research with human participants) may inspect and/or copy the study records. Results of the study may be published, but no names or identifying information will be included in the publication. Other than as set forth above, subject identity will remain confidential unless disclosure is legally compelled.

12. **Signatures:** The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about Participants' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of the consent form.

Subject Signature: ______________________________ Date: ______________

APPENDIX C: IRB HUMAN SUBJECTS TRAINING CERTIFICATE FOR K. YOUNG

Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that **Kathryn Young** successfully completed the NIH Web-based training course "Protecting Human Research Participants".

Date of completion: 01/26/2014

Certification Number: 1367206

APPENDIX D: EXPERIMENT INFORMED CONSENT FORM

LSU | College of Human Sciences & Education School of Kinesiology

INFORMED CONSENT FORM

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APPENDIX D: CONSENT FORM CONTINUED

11. **Privacy:** The LSU Institutional Review Board (which oversees university research with human participants) may inspect and/or copy the study records. Results of the study may be published, but no names or identifying information will be included in the publication. Other than as set forth above, subject identity will remain confidential unless disclosure is legally compelled.

12. **Signatures:** The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about Participants' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of the consent form.

Subject Signature: ______________________________________ Date: __________________

APPENDIX E: CLARINET EMG PROTOCOL SHEET

Before participant gets there, place cameras on stands, determine which order the participant will play their high/low/medium positions, chair in correct position, and ensure EMG/computer set up is on and ready.

1. Questionnaire – Confirm that it was previously completed online
2. Participant Arrives/Prep
    a. Consent Form
        i. Place 4 digit subject code on consent form & subject number
        ii. Place 4 digit code on all forms that will be used to collect data for this subject with date
    b. Fill in Data Collection Form
        i. Measure arm length from shoulder to finger tip
        ii. Hand measurements:
            1. Trace hand fully extended
            2. Trace hand with just thumb extended
            3. Measure directly on hand width to confirm.
            4. Ensure subject number is on each page
3. Briefly describe the experiment to the participant and explain the process of placing the visual markers and sensors on their arm.

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4. Allow subject to get out their mouthpiece/reed and place it on the clarinet on a stand.
5. Clean subject's right arm with alcohol swabs.
6. Place visual markers on arm with Blue Magic Marker
    1. Thumb CMC
    2. Index CMC
    3. Distal Radius/Scaphoid (Along radial collateral ligament)
    4. Distal end of Ulna
    5. Medial epicondyle of humerus
    6. Proximal end of Radius

APPENDIX E: CONTINUED

7. Deltoid (near head of humerus)
8. Fifth Digit CMC

7. Place EMG sensors on 8 locations + reference. Palpate arm to verify muscle location.

Muscle Target for Sensor	Abbreviation	EMG Channel	Muscle function
Triceps brachii	TRI	1	Forearm extension, stabilize elbow joint
Biceps brachii	BIC	2	Forearm flexion, wrist stabilization
Abductor pollicis brevis	APB	3	Thumb opposition, flexion
Abductor pollicis longus /Extensor pollicis brevis	APL/EPB	4	Thumb reposition, extension
First Dorsal Interosseous	FDI	5	Flexes, radially abducts and pronates index MCP joint; radially adducts the thumb basal joint
Extensor Carpi radialis	ECR	6	Wrist extensor and stabilizer
Brachioradialis	BR	7	Forearm flexion
Flexor carpi ulnaris	FCU	8	Wrist flexor and stabilizer

8. Test each EMG channel for the appropriate muscle with the following tests:
   a. Triceps brachii – *push against experimenter to extend forearm.*
   b. Abductor pollicis brevis – *oppose thumb across palm, extend downwards*
   c. Abductor pollicis longus/Extensor pollicis brevis – *reoppose thumb, extend upwards.*
   d. First Dorsal Interosseous – *move index finger towards and away from thumb*
   e. Extensor Carpi radialis – *in pronated position, flex and extend hand towards ceiling and then floor. Should also be active during rotation of the forearm at the wrist/elbow axis.*
   f. Flexor carpi ulnaris – *in pronated position, flex and extend hand towards ceiling and then floor.*
   g. Biceps brachii – long head – *flex and extend forearm.*

   h. Brachioradialis - *Should also be active during rotation of the forearm at the wrist/elbow axis. Should be silent during wrist flexion/extension.*

9. Situate participant in seat and set up wires so they do not obstruct the camera or movement.
10. Turn on cameras and press record on each.
11. Read Instruction to participant:

> " *Thank you for participating in this experiment. We will be taking recordings from your skin to help us understand how your muscles are engaged for different tasks at three different thumb-rest positions. There will be three large blocks for each position that will consist of held notes, exercises, scales, and the held notes again. Before each section we'll tell you to begin, and give you a metronome click to try and encourage you to play at a certain, steady tempo. Then we will pause for a few minutes to take a break, reset the cameras, swab the clarinet, and adjust the clarinet to the next position.*
>
> *We would like you to try to play as normally as you can and sit as calmly as you can in the chair. If you can keep the clarinet at a nice neutral position without lifting it as you play that is ideal. Please play the fingerings that are listed above each note, and do not use any resonance fingerings even if they are your default. And finally, please don't support the bell of the clarinet on your knees or thighs; I'll help remind you."*

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12. PRE-HOLD measurement for 3 seconds

13. Ask them if they are ready to begin the first Block and proceed
    - Give Metronome count as needed
      a. Hold 1 – (3 seconds x 10 notes x 2 trial)
      b. Exercises – (6 seconds x 8 exercises x 5 trials)
      c. Scales – (8 seconds x 2 scales x 5 trials)
      d. Hold 2 – (3 seconds x 10 notes x 2 trial)
14. 5 Minute Break
      a. Swab clarinet
      b. Adjust the Clarinet to next position
      c. Check sensor attachments

APPENDIX E: CONTINUED

   d. Press stop on Cameras and then record again to start a new video

15. Ask them if they are ready to begin second Block and proceed
    - Give Metronome count as needed
        a. Hold 1 – (3 seconds x 10 notes x 2 trial)
        b. Exercises – (6 seconds x 8 exercises x 5 trials)
        c. Scales – (8 seconds x 2 scales x 5 trials)
        d. Hold 2 – (3 seconds x 10 notes x 2 trial)
16. 5 Minute Break #2
        a. Swab clarinet
        b. Adjust the Clarinet to next position
        c. Check sensor attachments
        d. Press stop on Cameras and then record again to start a new video
17. Ask them if they are ready to begin third Block and proceed.
    - Give Metronome count as needed
        a. Hold 1 – (3 seconds x 10 notes x 2 trial)
        b. Exercises – (6 seconds x 8 exercises x 5 trials)
        c. Scales – (8 seconds x 2 scales x 5 trials)
        d. Hold 2 – (3 seconds x 10 notes x 2 trial)
18. Prepare Participant to Leave:
        a. Remove EMG sensors
        b. Ask Questions and record on data sheet
        c. Stop video recorders
        d. Wipe off arms

APPENDIX F: DATA COLLECTION FORM

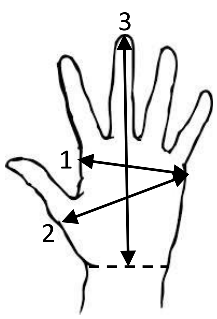
Subject Number__________ Date collected _____

Questionnaire code__________ Completed Questionnaire? _________

Sex ______ Age ______ Height ______ Arm Length (shoulder to fingertip) ______

Notes on sensor placement process:

Hand tracing / Measurements:



1 _______________

2 _______________

3 _______________

APPENDIX F: CONTINUED

Block 1: Thumb high _____ Thumb medium _______ Thumb low _____

Hold 1 – (3 seconds x 10 notes x 1 trial) –

	Trial 1
1H1	
2H1	
3H1	
4H1	
5H1	
6H1	
7H1	
8H1	
9H1	
10H1	

Exercises – (6 seconds x 8 exercises x 5 trials)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1E.					
2E					
3E					
4E					
5E					
6E					
7E					
8E					

Scales – (8 seconds x 3 scales x 5 trials)

Scale	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1S					
2S					

Hold 2 – (3 seconds x 10 notes x 1 trial)

	Trial 1
1H2	
2H2	
3H2	
4H2	
5H2	
6H2	
7H2	
8H2	
9H2	
10H2	

APPENDIX F: CONTINUED

Block 2: Thumb high _____ Thumb medium _______ Thumb low _____

Hold 1 – (3 seconds x 10 notes x 1 trial) –

	Trial 1
1H1	
2H1	
3H1	
4H1	
5H1	
6H1	
7H1	
8H1	
9H1	
10H1	

Exercises – (6 seconds x 8 exercises x 5 trials)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1E.					
2E					
3E					
4E					
5E					
6E					
7E					
8E					

Scales – (8 seconds x 3 scales x 5 trials)

Scale	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1S					
2S					

Hold 2 – (3 seconds x 10 notes x 1 trial)

	Trial 1
1H2	
2H2	
3H2	
4H2	
5H2	
6H2	
7H2	
8H2	
9H2	
10H2	

APPENDIX F: CONTINUED

Block 3: Thumb high _____ Thumb medium _______ Thumb low _____

Hold 1 – (3 seconds x 10 notes x 1 trial) –

	Trial 1
1H1	
2H1	
3H1	
4H1	
5H1	
6H1	
7H1	
8H1	
9H1	
10H1	

Exercises – (6 seconds x 8 exercises x 5 trials)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1E.					
2E					
3E					
4E					
5E					
6E					
7E					
8E					

Scales – (8 seconds x 3 scales x 5 trials)

Scale	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1S					
2S					

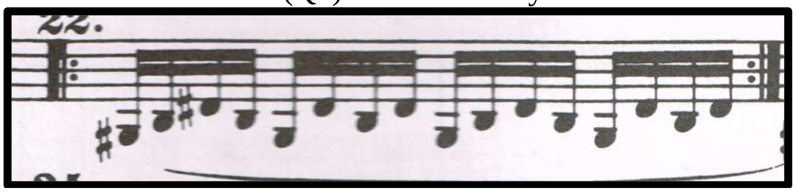
Hold 2 – (3 seconds x 10 notes x 1 trial)

	Trial 1
1H2	
2H2	
3H2	
4H2	
5H2	
6H2	
7H2	
8H2	
9H2	
10H2	

APPENDIX G: PLAYING EXAMPLE SHEET

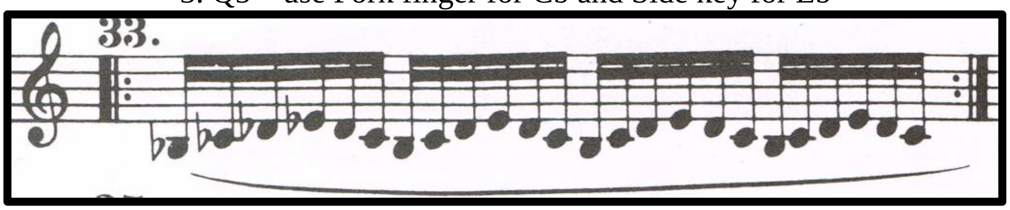
Finger Exercises

1. (Q3) – use Side Key

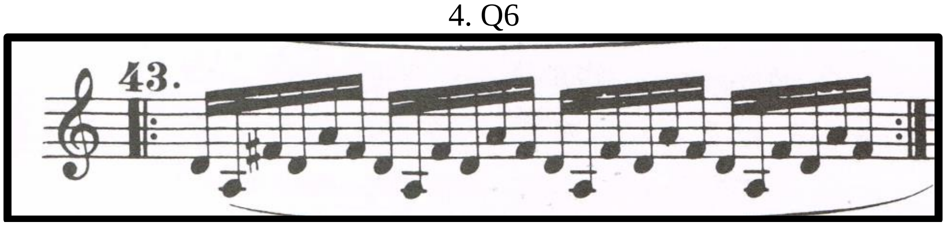


2. Q4 – use Right E

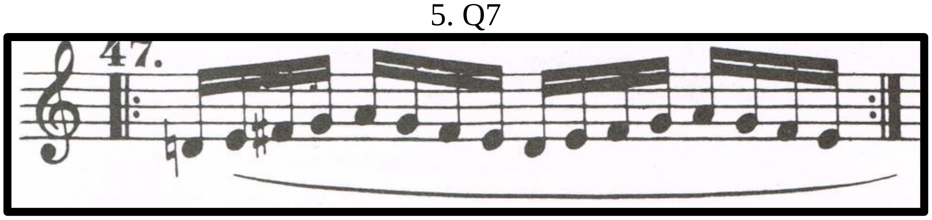
3. Q5 – use Fork finger for Cb and Side key for Eb



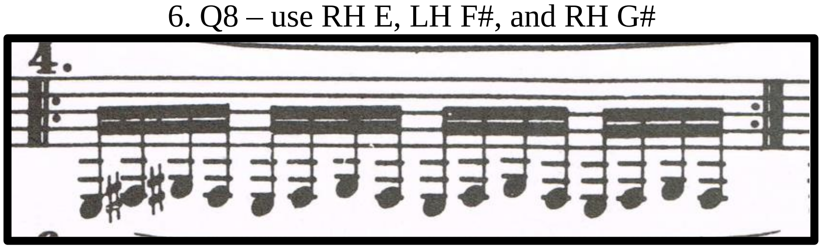
4. Q6



5. Q7



6. Q8 – use RH E, LH F#, and RH G#



APPENDIX G: CONTINUED

7. Q9 – Use right hand B and C

8. Q10 – Notice the Bb in the key signature – use Side Key high Bb please and no resonance fingerings

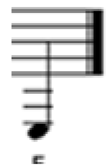
Scales

1. F Major – 2 octaves

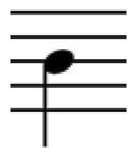
2. Chromatic scale – play as 16th notes.

APPENDIX G: CONTINUED
Individual Note Holds – For PreHold and PostHold

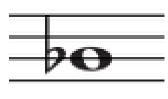
1. Low E – Right Hand Fingering



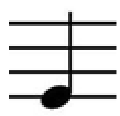
2. Staff B – Right Hand Fingering



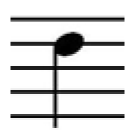
3. Staff Bb – no resonance fingers



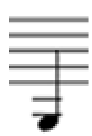
4. Open G – no resonance fingerings



5. Staff D

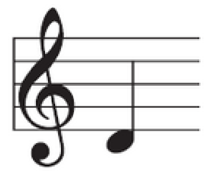


6. G below the staff

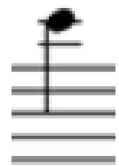


APPENDIX G: CONTINUED

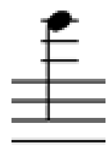
7. D below the staff



8. C above the staff



9. E above the staff - use right hand pinky resonance



10. Eb – use F1 or 1 and 1 fingering

APPENDIX H: QUESTIONNAIRE FORM

This Questionnaire was made available online through Google Document Forms at this location:

https://docs.google.com/forms/d/1idO96aeot1RTap0JtJAhhn4ZOjOMUSftT5e1nl8UAdk/viewform?usp=send_form

Subject Number ________________________

<u>Background Clarinet Information</u>

1. Sex ___________
2. Current Age_____
3. Years playing clarinet ________
4. What hand do you write with? _________
5. Hours of practice/day on average _________
6. How many days a week do you practice? __________
7. Do you practice at the same time every day? ______________Explain
8. Do you teach? ________ How many hours/week _________?
9. Do you play when you teach? ________
10. When practicing your heaviest, how many hours a day do you practice? _____________
11. Do you take breaks when you practice? _______
    a. If you do take breaks, how frequent are they?
    b. If you do take breaks, how long do they last?
12. Do you have a warm up regimen? , please describe

13. How many hours of rehearsal do you have, how many days a week? ____________
14. Do you stretch before you play? ___________ During? ____________ After? __________
15. Did you learn these stretches from a specific person or discipline?
16. Do you stretch in the middle of playing sessions?
17. Do you stretch after playing sessions?
18. What brand of clarinets do you play on?
19. Which embouchure style do you use?
20. What brand and model mouthpiece do you use?
21. What type of reeds do you normally use? List homemade or commercial, brand, strength, etc.

<u>Clarinet Support Questions</u>

22. Do you use any supports like neck straps, harnesses or chair mounts? If so, what kind?
23. Do you like or dislike neck straps? Explain.
24. What kind of thumb-rest do you have? Moveable_________ Fixed ________
25. Have you had your thumb-rest adjusted? If you have had your thumb-rest adjusted, please describe these adjustments below.
26. Have you ever tried brands of alternative thumb-rests such as Kooiman? Please describe

<u>Upper limb questions</u>

27. Have you ever been diagnosed with a pain/overuse disorder by a doctor? ___________

APPENDIX H: CONTINUED

28. If you have been diagnosed with a pain or overuse problem, please describe what led to that diagnosis in as much detail as possible
29. Do you ever experience discomfort or pain while you are playing? Explain
30. If you have discomfort would you describe it as one of the following? Check all that apply

Sharp pain
Dull discomfort
Electrical/Buzzing
Aching
Pinching
Other:

31. What do you do to help any discomfort from playing in the moment? Check all that apply:

Nothing
Use Neck Strap
Rest clarinet on knees
Pain/Inflammation medication
Stop Playing
Other:

32. What have you done outside the practice room to manage any discomfort you get from playing? Check all that apply, explain each and also add your own approaches in the provided space:

Yoga
Meditative Arts
Physician
Orthopedist
Neurologist
Other specialist
Rest
Hypnosis
Non-prescribed medication
Prescribed medication
No Treatment
Application of Heat
Application of Ice
Physical Therapy
Acupuncture
Braces or splints
Surgeon
Structured muscle strengthening
Osteopathic manipulation
Aerobic exercise
Chiropractic manipulation
Injections
Anaerobic Exercise
No treatment
Psychological counseling

APPENDIX H: CONTINUED

Massage Therapy
Alexander Technique
Taubman Method
Other:

Please explain any of your choices in the previous questions regarding treatments you may have tried.*required

(List based on 1988 Fishbein reports of ICSOM study)

33. How would you describe your own right hand position?
34. Do you model your right hand position after any of these pedagogical models?
    C-grip _______ Tennis ball _________
    Other (describe please) ___________________________

35. Have you tried different hand positions throughout your career? To what effect?

Other activity questions

36. Do you play other instruments? _________________ Which? _________________
37. Do you participate in athletic activities? __________ Which? _________________
38. Did you participate in athletic activities in the past? _____________________
39. Do any of your daily activities involve moving your fingers rapidly or lifting heavy objects? _________
40. Explain____
41. How many hours a day do you spend on the computer typing?
42. Do you text frequently on your mobile phone? How much?
43. Do you have a job that requires that you frequently use your arms?
44. Please add any pertinent information that you would like to include.

APPENDIX I: FINGERING CHARTS FOR SOPRANO CLARINET

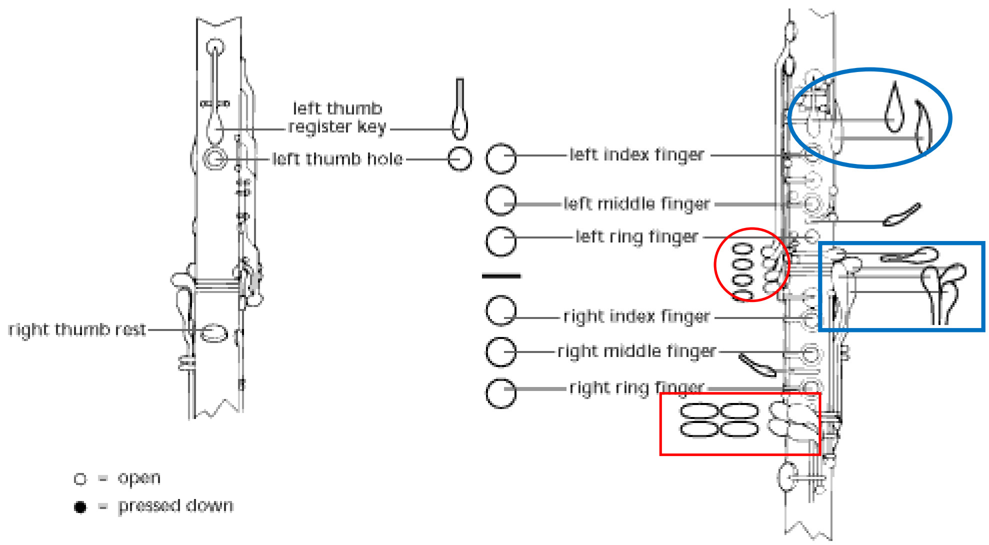


Figure I1 This diagram shows the fingers that cover each tone hole on the clarinet. The keys in the red circle are controlled by the right index finger, the keys in the red square are controlled by the right pinky. Keys in the blue circle are controlled by the left index finger and the keys in the blue square are controlled by the left pinky.[306]

[306] Lincoln Center for the Arts Website "Fingering Charts: Clarinet" (http://www2.milwaukee.k12.wi.us/lcmsa/Music_Theater/Band/Fingering_Charts/clarinet.gif)

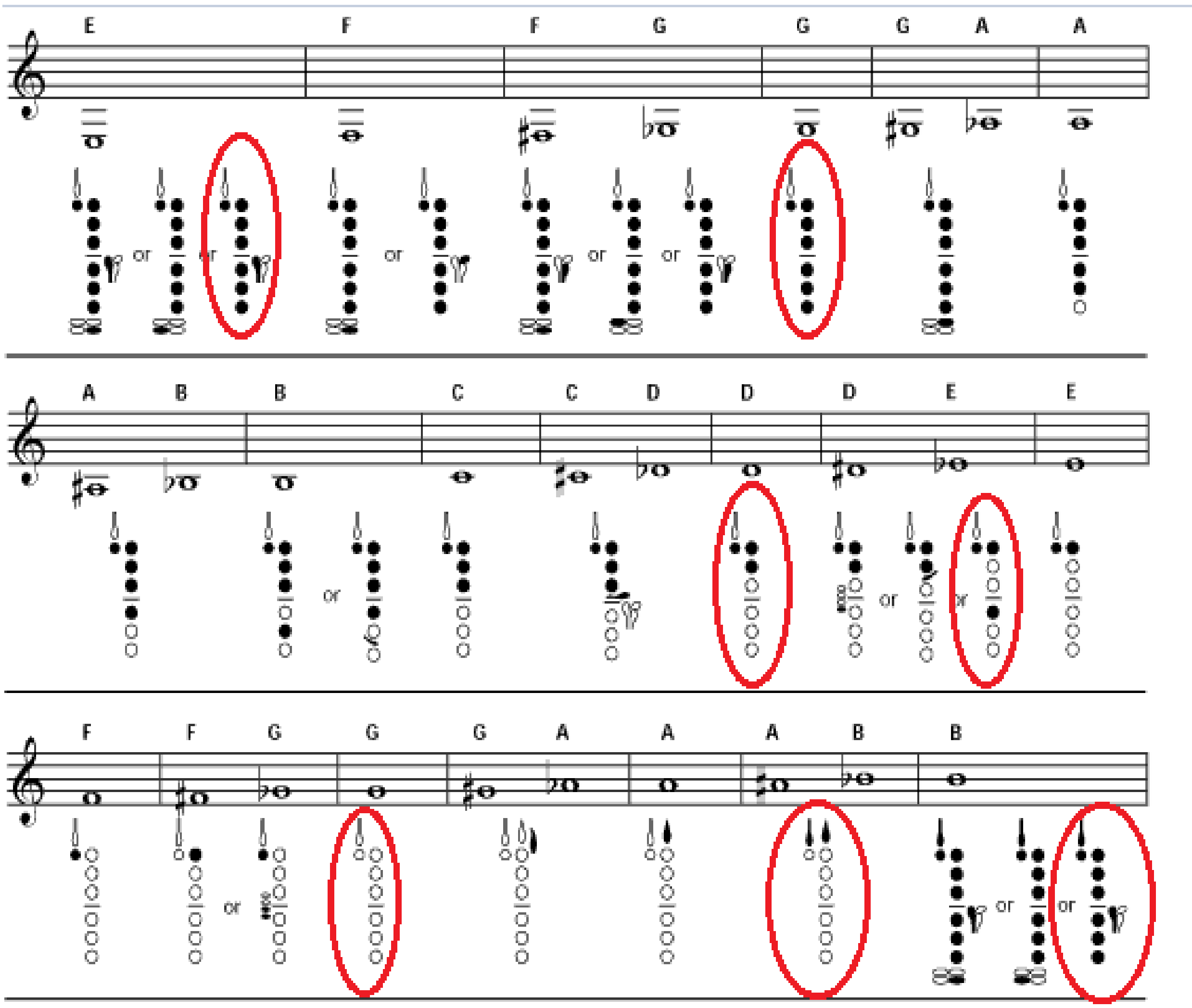


Figure I2 Fingerings for clarinet low E through staff B. Notes that were used as holds in the experiment are circled. Blackened holes indicate a finger is pressing down on it.[307]

[307] __________, "Fingering Charts: Clarinet," Lincoln Center for the Arts http://www2.milwaukee.k12.wi.us/lcmsa/Music_Theater/Band/Fingering_Charts/clarinet.gif (accessed August 14, 2014).

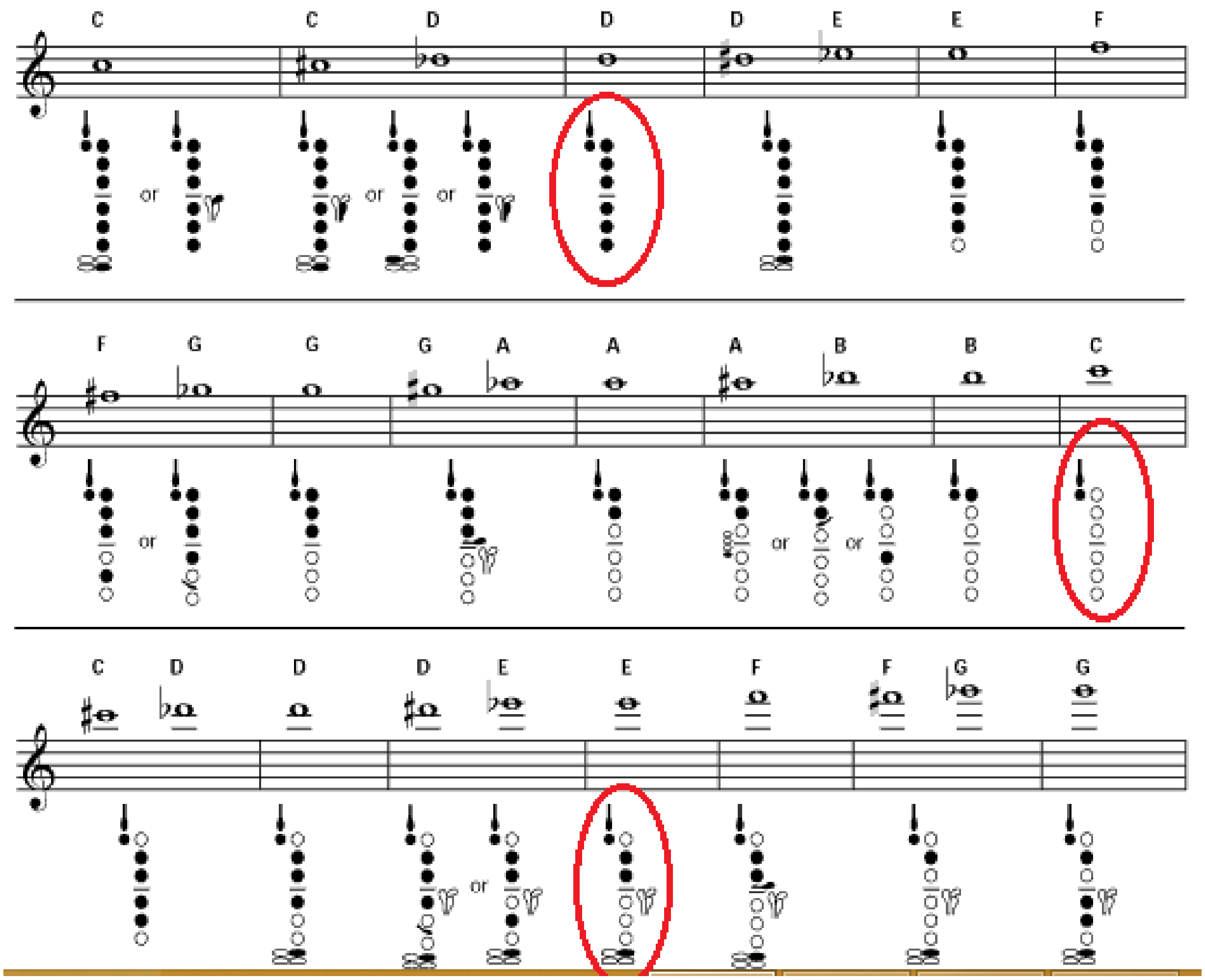


Figure I3 Fingerings for clarinet notes staff C through altissimo G. Notes that were used as holds in the experiment are circled. Blackened holes indicate a finger is pressing down on it.[308]

[308] __________, "Fingering Charts: Clarinet."

APPENDIX J: OCTAVE DESIGNATIONS

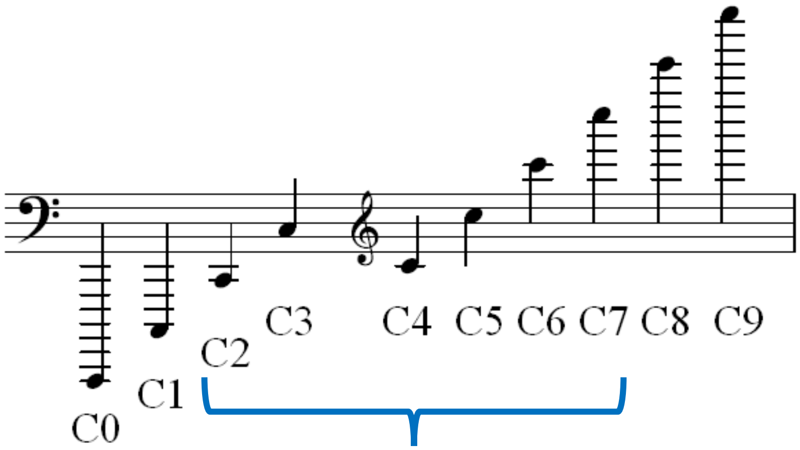
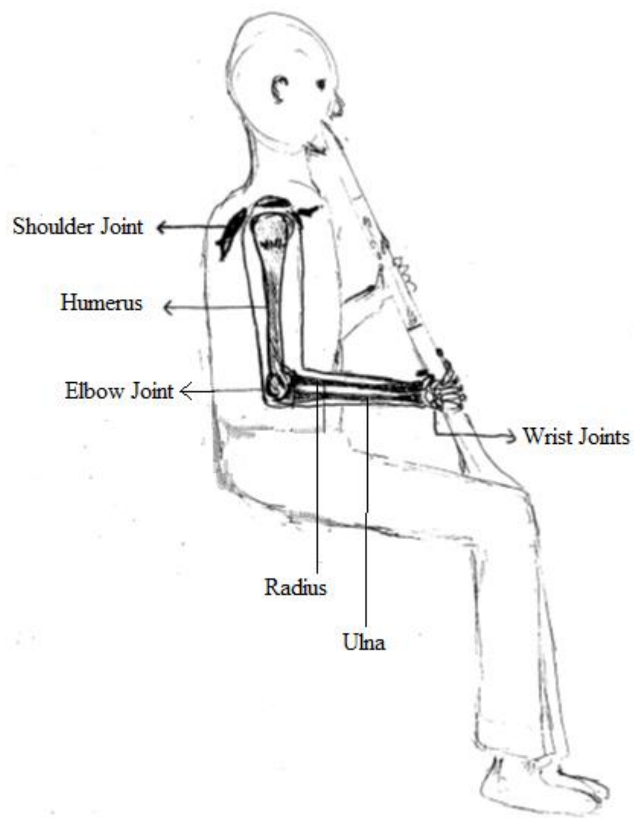


Figure J1 Labels for range in different octaves.[309] The Range of the Clarinet is from E3 to about G6 shown by bracket (some players work to achieve upwards of C7).

[309] __________, "Fingering Charts: Clarinet."

APPENDIX K: DRAWING OF SKELETAL STRUCTURE OF UPPER LIMB



APPENDIX L: ANATOMY TABLES

Table L1 Extrinsic muscles that act on the pollex:

Muscles	Classification	Origin	Insertion	Innervation	Action
Flexor pollicis longus	Deep anterior	anterior surface of radius and interosseous membrane between radius and ulna	the base of the distal phalanx	median nerve	Flexes distal phalanx at interphalangeal joint. (this has a different origin point as the rest of the fingers which are served by the flexor digitorum longus)
Abductor pollicis longus	Deep posterior	posterior surface of middle of radius, ulna, and interosseous membrane	first metacarpal	deep radial nerve	Abducts and extends the pollex at the carpometacarpal joint; also abducts hand at wrist
Extensor pollicis brevis	Deep posterior	posterior surface of middle of radius and interosseous membrane	inserts on the base of the proximal phalanx of the pollex	deep radial nerve	extends the proximal phalanx of the pollex at the metacarpophalangeal joint; first metacarpal of pollex at carpometacarpal joint, and hand at wrist
Extensor pollicis longus	Deep posterior	posterior surface of middle of ulna and interosseous membrane	base of distal phalanx of the pollex	deep radial nerve	extends the distal phalanx of the pollex at interphalangeal joint; first metacarpal of pollex at carpometacarpal joint and abducts hand at wrist joint

APPENDIX L: CONTINUED

Table L2 Six intrinsic muscles that act on the pollex.

Muscle	Classification	Origin	Insertion	Innervation	Action
Abductor pollicis brevis	Thenar/lateral aspect	flexor retinaculum, scaphoid, and trapezium	lateral side of proximal phalanx of the pollex	median nerve	abducts the pollex at the carpometacarpal joint (clarinet position)
Opponens pollicis	Thenar/lateral aspect	flexor retinaculum and trapezium	lateral side of first metacarpal	median nerve	pollex in the carpometacarpal joint so it can reach across the palm to meet any finger (oppositional movement)
Flexor pollicis brevis	Thenar/lateral aspect	flexor retinaculum, trapezium, capitate, and trapezoid	lateral side of the proximal phalanx of pollex	median and ulnar nerves	Flexes the pollex at the carpometacarpal and metacarpophalangeal joints (bending pollex as if you are rounding it).
Adductor pollicis	Thenar/lateral aspect	oblique and lateral heads that originate at the metacarpals	medial side of the proximal phalanx of pollex by a tendon	ulnar nerve	Adducts the pollex at the carpometacarpal and metacarpophalangeal joints (brings pollex back to straight).
Palmar interossei	Intermediate/ mid-palmar muscles	side of the shafts of metacarpals of all digits	sides of bases of proximal phalanges (on all except the middle one)	ulnar nerve	Creates an interconnected network of support within the hand. adducts and flexes each finger and except the middle finger at metacarpophalangeal joints and extend these fingers at interphalangeal joints
First dorsal interossei		adjacent sides of the metacarpals	proximal phalanx of each finger	the deep branch of the ulnar nerve	extends the pollex at the interphalangeal joints

APPENDIX L: CONTINUED

Table L3 Muscles that act on the forearm.

Muscle	Classific-ation	Origin	Insertion	Innervation	Actions
Biceps brachii	Flexor	Long head originates on tubercle above glenoid cavity and short head originates on coracoid process of scapula	Long and short head both insert on the radial tuberosity of the radius and bicipital aponeurosis	Musculocutaneous nerve	Flexes the forearm at the elbow joint, supinates forearm at radioulnar joints, and flexes arm at shoulder joint.
Brachialis	Flexor	distal anterior surface of the humerus	crosses the elbow joint, and inserts on the ulnar tuberosity and coronoid process of the ulna	musculocutaneous and radial nerves	Forearm at the elbow joint
Brachio-radialis	Flexor	lateral border of the distal end of humerus	inserts on superior to styloid process of radius	Radial nerve	Brachioradialis flexes the forearm at the elbow joint, supinates and pronates forearm at radioulnar joints to neutral position
Triceps brachii	Extensor	Long head on infraglenoid tubercle, lateral head on the lateral and posterior surface of the humerus, and the medial head on posterior surface of the humerus	olecranon of the ulna	Radial	Extends the forearm at the elbow joint and extends arm at the shoulder joint
Anconeus	Extensor	lateral epicondyle of humerus	olecranon and superior portion of shaft of ulna	Radial	Extends the forearm at the elbow joint

APPENDIX L: CONTINUED

Table L4 Flexors of the wrist

Muscle	Classification	Origin	Insertion	Innervation	Action
Flexor carpi radialis	Superficial anterior	medial epicondyle of humerus	second and third metacarpals	Median	Muscle flexes and abducts (radial deviation) hand at wrist joint
Palmaris longus	Superficial anterior	medial epicondyle of the humerus	flexor retinaculum and palmar aponeurosis (in the center of the palm)	Median	Weakly flexes the hand at the wrist joint
Flexor carpi ulnaris	Superficial anterior	medial epicondyle of the humerus	pisiform, hamate, and base of the fifth metacarpal	Ulnar	Flexes and adducts (ulnar deviation) hand at wrist joint
Flexor digitorum superficialis	Superficial anterior	medial epicondyle of the humerus, coronoid process of ulna, and a ridge along the lateral margin of anterior surface of radius	middle phalanx of each finger	median	Flexes the middle phalanx of each finger at the proximal interphalangeal joint, proximal phalanx of each finger at metacarpophalangeal joint, and hand at wrist joint
Flexor digitorum profundus	Deep anterior	Anterior medial surface of the body of the ulna	Inserts of base of distal phalanx of each digit	Median and ulna	Flexes distal and middle phalanges of each finger at interphalangeal joints, proximal phalanx of each finger at metacarpophalangeal joint, and hand at wrist joint

APPENDIX L: CONTINUED

Table L5 Extensors of the Wrist

Muscle	Classification	Origin	Insertion	Innervation	Action
Extensor carpi radialis ¬longus	Superficial posterior	lateral supracondylar ridge of the humerus	second metacarpal	Radial	Extends and abducts the hand at the wrist joint (radial deviation)
Extensor carpi radialis brevis	Superficial posterior	lateral epicondyle of the humerus	third metacarpal	Radial	Extends and abducts (radial deviation) the hand at the wrist joint
Extensor digitorum	Superficial posterior	lateral epicondyle of the humerus	distal and middle phalanges of each finger	Radial	Extends the distal and middle phalanges of each finger at the interphalangeal joints, proximal phalanx of each finger at the metacarpophalangeal joint, and extends the hand at the wrist joint.
Extensor digiti minimi	Superficial posterior	lateral epicondyle of humerus	tendon of extensor digitorum on fifth phalanx	deep radial nerve	Extends the proximal phalanx of the little finger at the metacarpophalangeal joint and extends the hand at the wrist joint
Extensor carpi ulnaris	Superficial posterior	lateral epicondyle of humerus and posterior border of the ulna	fifth metacarpal	deep radial nerve	Extends and adducts (ulnar deviation) the hand at the wrist joint.
Abductor pollicis longus	Deep posterior	posterior surface of the middle of radius, ulna and interosseous membrane	the first metacarpal	deep radial nerve	Abduct and extend the thumb at the carpometacarpal joint and abducts hand at the wrist joint.

Muscle	Classification	Origin	Insertion	Innervation	Action
Extensor pollicis brevis	Deep posterior	posterior surface of the middle of the radius and interosseous membrane	base of the proximal phalanx of the thumb	deep radial nerve	extends the proximal phalanx of the pollex at the metacarpophalangeal joint, first metacarpal of the thumb at the carpometacarpal joint and the hand at the wrist
Extensor pollicis longus	Deep posterior	the posterior surface of middle of ulna and interosseous membrane	base of distal phalanx of the pollex	deep radial nerve	extends the distal phalanx of the pollex at interphalangeal joint; first metacarpal of pollex at carpometacarpal joint and abducts hand at wrist joint
Extensor indicis	Deep posterior	posterior surface of the ulna	tendon of extensor digitorum of index finger	deep radial nerve	muscle extends the distal and middle phalanges of index finger at interphalangeal joints, proximal phalanx of index finger at the metacarpophalangeal joint, and the hand at the wrist joint

Table L6 Connective Tissue of the elbow joint.

Connective tissue	Description
Articular capsule	The anterior part of the articular capsule covers the anterior parts of the elbow joint, from the radial and coronoid fossae of the humerus to the coronoid process of the ulna and the annular ligament of the radius. The posterior part extends form the capitulum, olecranon fossa, and lateral epicondyle of the humerus to the annular ligament of the radius, the olecranon of the ulna, and the ulna posterior to the radial notch. This structure essentially creates the under foundation for the joint.
Ulnar collateral ligament	This is a dense triangular shaped ligament that connects the medial epicondyle of the humerus to the coronoid process and olecranon of the ulna. The ulnar collateral ligament can be found on the medial (inner towards abdomen) part of the elbow. Part of this ligament helps to make the socket for the trochlea of the humerus slightly deeper.

Connective tissue	Description
Radial collateral ligament	This is another dense triangular shaped ligament that connects the lateral epicondyle of the humerus to the annular ligament of the radius and the radial notch of the ulna. The radial collateral ligament can be found on the later (or outside) part of the elbow and essentially mirrors the ulnar collateral ligament in shape and function.
Annular ligament of the radius	Another strong band of connective tissue that encircles the head of the radius and serves as an attachment point for other ligaments of the elbow. This ligament holds the head of the radius in the radial notch of the ulna

Table L7 Innervation of the wrist

Nerve	Connections
Ulnar nerve	Flexor carpi ulnaris, ulnar half of the flexor digitorum profundus, and most muscles of the hand skin of medial side of hand, little finger, and medial half of ring finger. C8-T1
Radial nerve	Extensor muscles of forearm, triceps brachii, anconeus, skin of posterior arm and forearm, lateral two-thirds of dorsum of hand, and fingers over proximal and middle phalanges.
Median nerve	Flexors of forearm, except flexor carpi ulnaris, the ulnar half of the flexor digitorum profundus, and some muscles of the hand.

APPENDIX L: CONTINUED

Table L8 muscles that rotate the forearm.

Muscle	Origin	Insertion	Innervation	Action
Pronator teres	medial epicondyle of humerus and coronoid process of ulna	midlateral surface of the radius	Median	Pronates the forearm at the radioulnar joints and weakly flexes forearm at the elbow joint.
Pronator quadratus	distal portion of shaft of ulna	distal portion of shaft of radius	median	pronates the forearm at the radioulnar joints
Supinator	lateral epicondyle of the humerus and ridge near radial notch of the ulna	lateral surface of the proximal one-third of radius	Deep radial nerve	supinates the forearm at the radioulnar joint and is innervated by the deep radial nerve

Table L9 Muscles that act on the shoulder

Movement	Muscles
Move scapula and girdle	*subclavius, pectoralis minor, serratus anterior, trapezius, levator scapulae, thromboid major, rhomboid minor*
Move the humerus	*pectoralis major, latissimus dorsi, deltoid, subscapularis, supraspinatus, infraspinatus, teres major, teres minor, coracobrachialis*

APPENDIX M: ANATOMY IMAGES OF FOREARM AND HAND

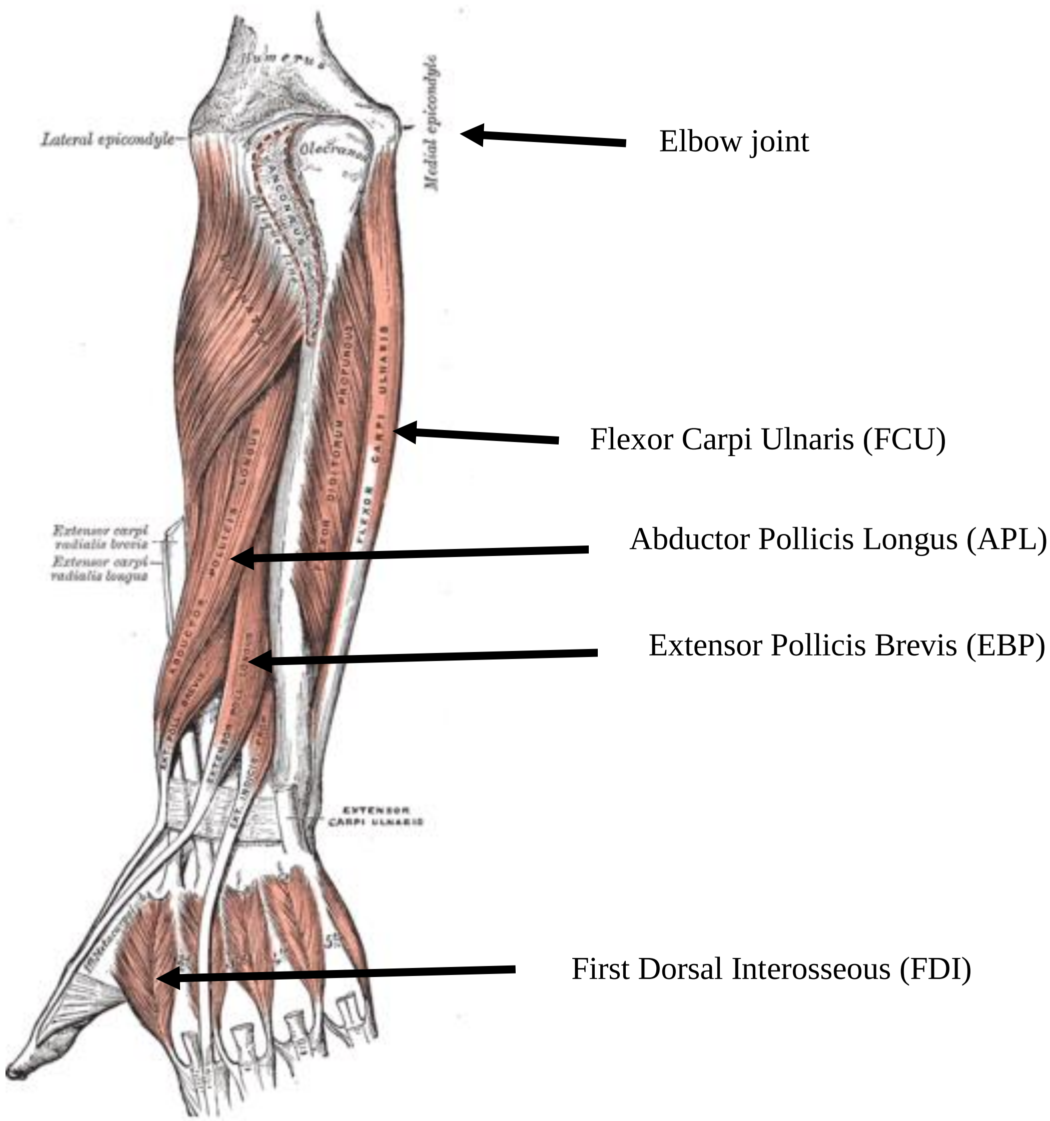


Figure M1 Deep forearm muscles of the left arm. Posterior view. Including FDI, EBP, APL, FCU and ECU.[310]

[310] Gray, 419.

APPENDIX M: CONTINUED

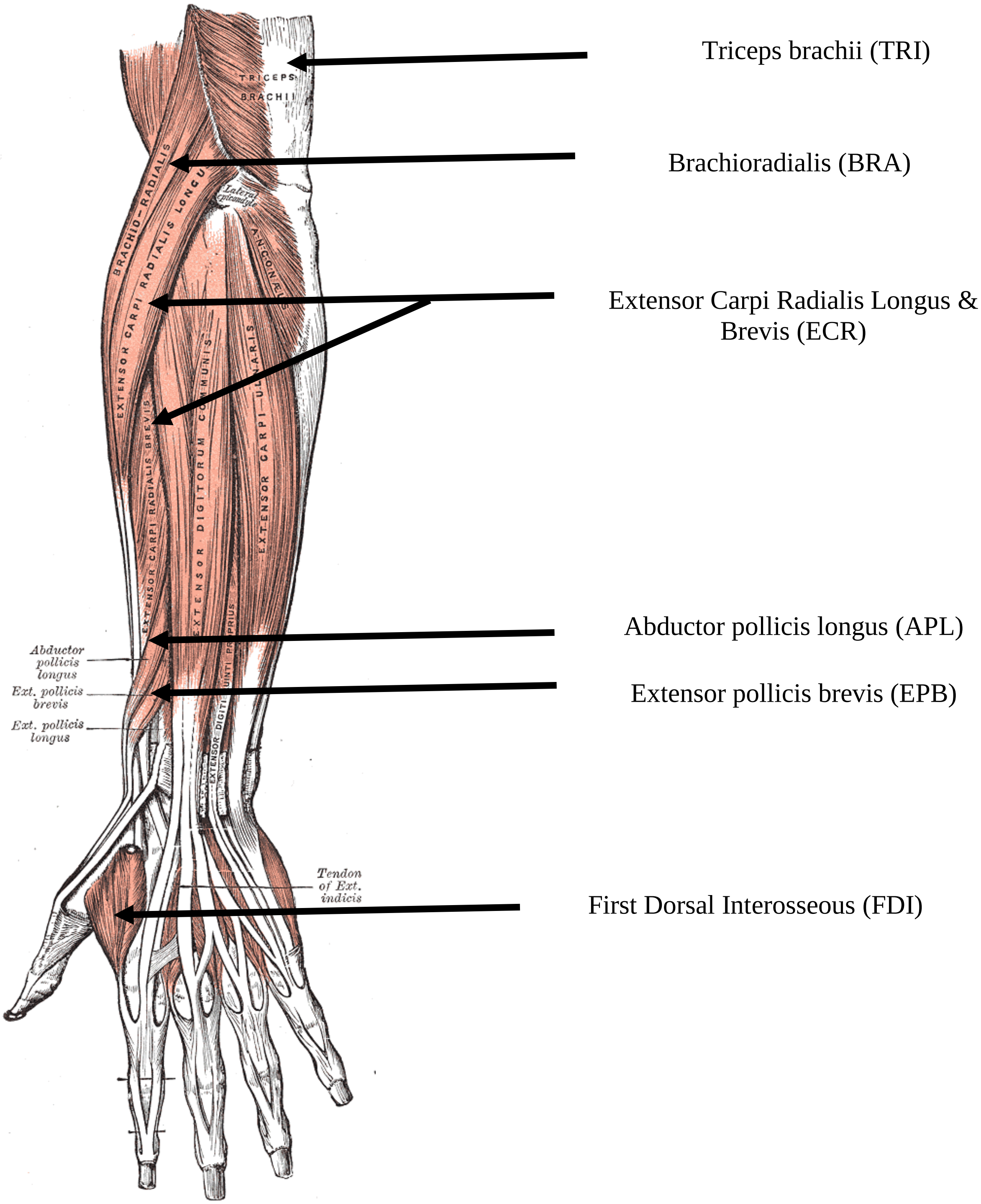


Figure M2 Superficial muscles of the forearm. Posterior View. Includes TRI, BRA, ECR, APL, EPB, FDI[311]

[311] Gray, 418.

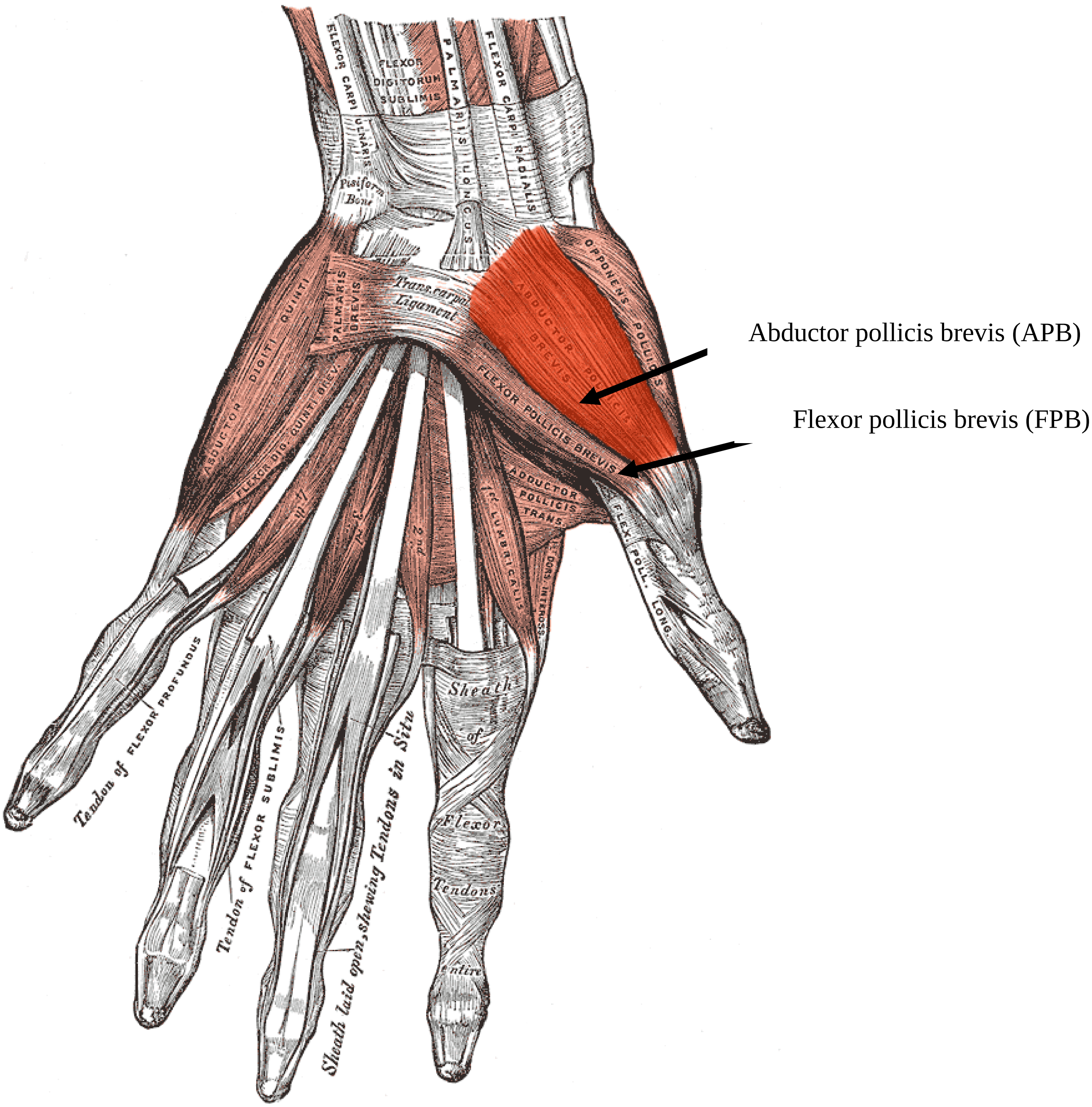


Figure M3 anterior view of left hand showing APB and FPB. [312]

[312] Gray, 463.

APPENDIX N: SUBJECT INFORMATION

Table N1 Height, arm and hand measurements for subjects. Asterisk (*) denotes large hand group.

Subject	Height	Arm length	Hand width	Palm diagonal	Hand length
1	6'2"	77	9.25	12.75	20*
2	5'1"	60	8	16	15.5
3	5'8.5"	75.5	8	11	18.75*
4	6'2"	74	9	11.5	19.75*
5	5'1"	59	8.25	10	16
6	4'11"	63.5	8.5	10.5	15.5
7	6'	76.5	9	11.5	19.5*
8	5'9"	68.5	8	10.5	18*
9	5'8"	66.5	8.75	12	19*
10	6'2"	79	9.5	11.5	20.5*
11	5'7"	65	8.75	10.6	17.5
12	5'11'	75.5	9	11	19*
13	5'9"	71.5	8.5	9.8	17.5
14	5'10'	70	8	10.3	17.4
15	5'3"	62.3	9	10.2	16.5
16	5'	61.5	7.5	9.5	16.5
17	5'1/2"	60.5	8.5	10.5	16.5
18	5'1"	63.5	7.5	9.5	16.5
19	5'10"	71.5	9.5	11.75	18*
20	5'7"	65.5	7.25	10	16.5

APPENDIX N: CONTINUED

Table N2 Questionnaire-reported pain information for all subjects.

Subject	Sex	Age	Injury Diagnosis	Discomfort or pain?	If you have discomfort would you describe it as one of the following?	What do you do to help any discomfort when playing?	Management of discomfort outside playing?
1	M	29	none	Sometimes	Sharp pain, Dull discomfort, Pinching	Use Neck Strap, Rest clarinet on knees, medication	Physician, Rest, Heat, Ice, Physical Therapy, Aerobic exercise, Alexander Technique
2	F	20	none	Sometimes	Dull discomfort, Aching	Stop Playing	No Treatment
3	F	20	none	Sometimes	Dull discomfort, Aching	Use Neck Strap, Rest clarinet on knees, Stop Playing	Rest, Alexander Technique
4	M	23	none	Sometimes	Sharp pain, Dull discomfort, Aching, Pinching	Rest clarinet on knees, Stop Playing	Massage Therapy
5	F	20	none	Sometimes	Dull discomfort	Rest clarinet on knees	Rest
6	F	25	none	Sometimes	Aching, Pinching	Rest clarinet on knees	No Treatment
7	M	24	none	Sometimes	Aching	Rest clarinet on knees, massage the joint	Yoga, Rest, Non-prescribed medication, Application of Ice, Acupuncture
8	F	21	none	Sometimes	Aching	Use Neck Strap	Rest
9	M	32	none	Sometimes	Sharp pain, Dull discomfort, Aching	Use Neck Strap, Rest clarinet on knees	Rest, Non-prescribed medication

Subject	Sex	Age	Injury Diagnosis	Discomfort or pain?	If you have discomfort would you describe it as one of the following?	What do you do to help any discomfort when playing?	Management of discomfort outside playing?
10	M	23	none	Sometimes	Aching	Use Neck Strap, Quickly stretch	Yoga, Rest
11	F	23	Overuse injury: arm, and shoulder.	Sometimes	Sharp pain, Dull discomfort	Rest clarinet on knees, Stop Playing	Physician, Rest, Application of Ice, Braces or splints, Alexander Technique
12	M	19	none	Sometimes	Dull discomfort	Use Neck Strap, Rest clarinet on knees	Rest, Alexander Technique
13	F	29	none	Sometimes	Sharp pain, Pinching	Rest clarinet on knees, Stop Playing	Rest, Aerobic exercise, Alexander Technique
14	F	40	none	Sometimes	Numbness/tingling	Rest clarinet on knees, Stop Playing	Yoga
15	F	30	Pinched C5 nerve	Sometimes	Electrical/Buzzing	Stop Playing	Neurologist, Rest, Non-prescribed medication, Massage Therapy
16	F	20	none	Sometimes	Dull discomfort	Rest clarinet on knees, Stop Playing	Rest, No Treatment
17	F	20	none	Sometimes	Dull discomfort	Use Neck Strap, Stop Playing	Yoga, Rest, Application of Heat, Application of Ice
18	F	26	None	Always	Sharp pain, Aching, Pinching	Stop Playing	Rest, Structured muscle strengthening
19	M	20	None	Sometimes	Dull discomfort	Stop Playing	Rest
20	F	60	Rotator cuff tear in shoulder from tennis.	Sometimes	Dull discomfort, Aching	Pain/Inflammation medication, Stop Playing	Yoga, Physician, Rest, Non-prescribed medication, Application of Ice, Physical Therapy, Acupuncture, Osteopathic manipulation, Massage Therapy

APPENDIX N: CONTINUED

Table N3 Hand position information for Subjects

Subject	Sex	Right hand Model	Describe right hand position	Thumb-rest Type
1	M	Tennis ball Grip	My right-hand digits are rounded with my thumb pointing down, bend at the upper-most joint in order to support the instrument.	Adjustable
2	F	i don't know	I don't know how to answer this question.	Fixed
3	F	C-Grip	Hitchhiker thumb and I use my thumb as a fulcrum for the clarinet or balance on.	Adjustable
4	M	C-Grip	Slightly grabby but working to get my right hand and wrist under the clarinet more.	Adjustable
5	F	C-Grip	Like a "c" shape.	Adjustable
6	F	U-grip	Relaxed, sometimes my first finger is curved too much	Adjustable
7	M	C-Grip	I am currently in the process of figuring out what hand position works best for me. I have found success in moving the point of contact with my right thumb close to my fingernail. I find that this allows my right pinky to move more freely and causes less muscle/joint pain in my thumb.	Adjustable
8	F	C-Grip	Sometimes stiff, but shaped like a slightly flattened "C" wrapping around the clarinet.	Adjustable
9	M	C-Grip	Normal C-shape	Adjustable
10	M	Curved	Comfortable and natural.	Adjustable
11	F	Relaxed hand at your side	Relaxed, as if I just pick my hand up in resting position. Sometimes my pinky flattens out.	Adjustable
12	M	C-Grip	Generally good, sometimes a little wild in my over-flexing of the right hand fingers.	Adjustable

Subject	Sex	Right hand Model	Describe right hand position	Thumb-rest Type
13	F	C-Grip, Tennis ball Grip	I try to keep my hand and fingers gently and naturally curved, as if I am holding a tennis ball. My thumb is double jointed, so I have had trouble keeping it straight. Usually, if I don't think about it, my thumb bends at the first joint (the joint closest to the tip of my thumb) and the joint rests against the back of the clarinet, holding most of the weight of the clarinet. I try to keep my fingers as close to the keys as possible at all times, and avoid straightening my fingers to hit the side keys.	Adjustable
14	F	C-Grip	Backwards c with curved knuckles	Fixed
15	F	C-Grip	Big C with fingers in continuous movement. Keeping pinky on a base position on Low F.	Adjustable
16	F	C-Grip	I try to keep it in the shape of a C	Adjustable
17	F	Tennis ball Grip, No	Right thumb holding clarinet with thumb-rest and the other fingers gently placed above the key holes.	Adjustable
18	F	C-Grip, Tennis ball Grip	Painful no matter what I do....	Adjustable
19	M	C-Grip	Shaped like a mixture of a C and a V.	Adjustable
20	F	Gentle curve in fingers	My thumb forms a 'V' shape with the side of my hand (index finger). Direction of wrist is heading in and down.	Fixed

APPENDIX O: SIGNIFICANT INTERACTIONS TABLES

Position*Note

Table O1 Significant interaction of position by note in APB, p values provided for signficiant differences between the two levels in the interaction.

Position 1	Note 1	Position 2	Note 2	P
HR	1	NR	1	0.0165
HR	1	NR	2	0.0034
HR	1	NR	8	0.0034
HR	1	LR	1	<.0001
HR	1	LR	2	<.0001
HR	1	LR	5	0.0203
HR	1	LR	10	0.0223
HR	2	NR	1	0.0237
HR	2	NR	2	0.0053
HR	2	NR	8	0.0053
HR	2	LR	1	<.0001
HR	2	LR	2	<.0001
HR	2	LR	5	0.0289
HR	2	LR	10	0.0318
HR	3	HR	8	0.0302
HR	3	NR	1	0.0064
HR	3	NR	2	0.0011
HR	3	NR	8	0.0011
HR	3	NR	9	0.0474
HR	3	LR	1	<.0001
HR	3	LR	2	<.0001
HR	3	LR	5	0.008
HR	3	LR	6	0.0413
HR	3	LR	10	0.0089
HR	4	NR	1	0.0185
HR	4	NR	2	0.004
HR	4	NR	8	0.004
HR	4	LR	1	<.0001

HR	4	LR	2	<.0001
HR	4	LR	5	0.0227
HR	4	LR	10	0.0251
HR	5	HR	8	0.0179
HR	5	NR	1	0.0039
HR	5	NR	2	0.0007
HR	5	NR	8	0.0007
HR	5	NR	9	0.032
HR	5	LR	1	<.0001
HR	5	LR	2	<.0001
HR	5	LR	5	0.0049
HR	5	LR	6	0.0276
HR	5	LR	10	0.0055
HR	6	HR	8	0.0218
HR	6	NR	1	0.0047
HR	6	NR	2	0.0008
HR	6	NR	8	0.0008
HR	6	NR	9	0.0371
HR	6	LR	1	<.0001
HR	6	LR	2	<.0001
HR	6	LR	5	0.0059
HR	6	LR	6	0.0321
HR	6	LR	10	0.0066
HR	7	HR	8	0.0369
HR	7	NR	1	0.0077
HR	7	NR	2	0.0014
HR	7	NR	8	0.0014
HR	7	LR	1	<.0001
HR	7	LR	2	<.0001
HR	7	LR	5	0.0096
HR	7	LR	6	0.0481
HR	7	LR	10	0.0107
HR	8	HR	10	0.0334
HR	8	NR	7	0.0453
HR	8	LR	1	<.0001
HR	8	LR	2	0.0002
HR	9	NR	1	0.0303

HR	9	NR	2	0.007
HR	9	NR	8	0.007
HR	9	LR	1	<.0001
HR	9	LR	2	<.0001
HR	9	LR	5	0.0367
HR	9	LR	10	0.0402
HR	10	NR	1	0.007
HR	10	NR	2	0.0013
HR	10	NR	8	0.0013
HR	10	LR	1	<.0001
HR	10	LR	2	<.0001
HR	10	LR	5	0.0088
HR	10	LR	6	0.0446
HR	10	LR	10	0.0098
NR	1	NR	3	0.007
NR	1	NR	4	0.0157
NR	1	NR	6	0.0108
NR	1	NR	7	0.0002
NR	1	LR	1	0.0029
NR	1	LR	2	0.0063
NR	1	LR	4	0.0317
NR	1	LR	7	0.0064
NR	2	NR	3	0.0008
NR	2	NR	4	0.0021
NR	2	NR	5	0.0164
NR	2	NR	6	0.0013
NR	2	NR	7	<.0001
NR	2	NR	10	0.0342
NR	2	LR	1	0.0141
NR	2	LR	2	0.0276
NR	2	LR	3	0.0167
NR	2	LR	4	0.0074
NR	2	LR	7	0.0012
NR	3	NR	8	0.0008
NR	3	LR	1	<.0001
NR	3	LR	2	<.0001
NR	3	LR	5	0.0348

NR	3	LR	10	0.0381
NR	4	NR	8	0.0021
NR	4	LR	1	<.0001
NR	4	LR	2	<.0001
NR	5	NR	8	0.0164
NR	5	LR	1	<.0001
NR	5	LR	2	<.0001
NR	6	NR	8	0.0013
NR	6	LR	1	<.0001

Size*Note

Table O2 Significant interactions between hand size and note in FDI, p values provided for significant differences between the two levels in the interaction.

Hand Size 1	Note 1	Hand Size 2	Note 2	P value
Small	1	Small	3	0.0019
Small	1	Small	4	0.0029
Small	1	Small	6	0.0264
Small	1	Small	7	<.0001
Small	1	Small	9	0.0002
Small	1	Small	10	<.0001
Small	1	Large	3	0.0004
Small	1	Large	4	0.0005
Small	1	Large	5	0.0498
Small	1	Large	6	0.048
Small	1	Large	7	0.0004
Small	1	Large	8	0.0016
Small	1	Large	9	0.0009
Small	1	Large	10	0.0233
Small	2	Small	3	<.0001
Small	2	Small	4	<.0001
Small	2	Small	5	0.0121
Small	2	Small	6	0.0013

Small	2	Small	7	<.0001
Small	2	Small	8	0.0039
Small	2	Small	9	<.0001
Small	2	Small	10	<.0001
Small	2	Large	3	0.0001
Small	2	Large	4	0.0002
Small	2	Large	5	0.0191
Small	2	Large	6	0.0183
Small	2	Large	7	0.0001
Small	2	Large	8	0.0005
Small	2	Large	9	0.0003
Small	2	Large	10	0.0084
Small	3	Small	10	0.0082
Small	3	Large	3	0.0117
Small	3	Large	4	0.0154
Small	3	Large	7	0.0119
Small	3	Large	8	0.0419
Small	3	Large	9	0.0242
Small	4	Small	10	0.0057
Small	4	Large	3	0.0103
Small	4	Large	4	0.0135
Small	4	Large	7	0.0104
Small	4	Large	8	0.0373
Small	4	Large	9	0.0214
Small	5	Small	7	0.0009
Small	5	Small	9	0.0268
Small	5	Small	10	<.0001
Small	5	Large	3	0.0021
Small	5	Large	4	0.0028
Small	5	Large	7	0.0021
Small	5	Large	8	0.0085
Small	5	Large	9	0.0046

Small	6	Small	7	0.0091
Small	6	Small	10	0.0004
Small	6	Large	3	0.0045
Small	6	Large	4	0.006
Small	6	Large	7	0.0046
Small	6	Large	8	0.0176
Small	6	Large	9	0.0098
Small	7	Small	8	0.0034
Small	8	Large	3	0.0032
Small	8	Large	4	0.0043
Small	8	Large	7	0.0032
Small	8	Large	8	0.0126
Small	8	Large	9	0.0069
Small	9	Small	10	0.042
Small	9	Large	3	0.0218
Small	9	Large	4	0.0283
Small	9	Large	7	0.0221
Small	9	Large	9	0.0436
Large	1	Large	3	<.0001
Large	1	Large	4	<.0001
Large	1	Large	5	0.0264
Large	1	Large	6	0.0236
Large	1	Large	7	<.0001
Large	1	Large	8	<.0001
Large	1	Large	9	<.0001
Large	1	Large	10	0.0023
Large	2	Large	3	<.0001
Large	2	Large	4	<.0001
Large	2	Large	7	<.0001
Large	2	Large	8	<.0001
Large	2	Large	9	<.0001
Large	2	Large	10	0.008

Large	3	Large	5	<.0001
Large	3	Large	6	<.0001
Large	3	Large	10	<.0001
Large	4	Large	5	<.0001
Large	4	Large	6	<.0001
Large	4	Large	10	0.0002
Large	5	Large	7	<.0001
Large	5	Large	8	0.0005
Large	5	Large	9	<.0001
Large	6	Large	7	<.0001
Large	6	Large	8	0.0006
Large	6	Large	9	<.0001
Large	7	Large	10	<.0001
Large	8	Large	10	0.0083
Large	9	Large	10	0.0012
Large	9	Large	10	0.0012
Small	1	Small	3	0.0019

Experience * Note

Table O3 Significant interaction of experience and note in TRI, p values provided for significant differences between the two levels in the interaction.

Experience 1	Notes 1	Experience 2	Note 2	P
Student	2	Student	10	<.0001
Student	3	Student	4	<.0001
Student	3	Student	6	0.002
Student	3	Student	7	6E-04
Student	3	Student	8	<.0001
Student	3	Student	9	0.024
Student	3	Student	10	<.0001
Student	4	Student	5	<.0001
Student	4	Student	6	0.033
Student	4	Student	9	0.003
Student	5	Student	7	0.022

Student	5	Student	8	0.002
Student	5	Student	10	0.006
Student	8	Student	9	0.041
Professional	1	Professional	8	0.038
Professional	4	Professional	8	0.029

Table O4 Significant interaction of experience and note in FDI, p values provided for significant differences between the two levels in the interaction.

Experience 1	Note 1	Experience 2	Note 2	P
Student	1	Student	3	<.0001
Student	1	Student	4	<.0001
Student	1	Student	6	0.0185
Student	1	Student	7	<.0001
Student	1	Student	8	0.0082
Student	1	Student	9	<.0001
Student	1	Student	10	<.0001
Student	1	Professional	3	0.0014
Student	1	Professional	4	0.0023
Student	1	Professional	7	0.0013
Student	1	Professional	8	0.0025
Student	1	Professional	9	0.0029
Student	2	Student	3	<.0001
Student	2	Student	4	<.0001
Student	2	Student	5	0.0111
Student	2	Student	6	0.0015
Student	2	Student	7	<.0001
Student	2	Student	8	0.0005
Student	2	Student	9	<.0001
Student	2	Student	10	<.0001
Student	2	Professional	3	0.0007
Student	2	Professional	4	0.0011
Student	2	Professional	7	0.0006
Student	2	Professional	8	0.0013
Student	2	Professional	9	0.0014
Student	2	Professional	10	0.048
Student	3	Student	5	0.0054
Student	3	Student	6	0.0319
Student	3	Professional	3	0.0475

Student	3	Professional	7	0.0444
Student	4	Student	5	0.0068
Student	4	Student	6	0.0387
Student	4	Professional	3	0.045
Student	4	Professional	7	0.042
Student	5	Student	7	<.0001
Student	5	Student	9	0.0024
Student	5	Student	10	<.0001
Student	5	Professional	3	0.0057
Student	5	Professional	4	0.0091
Student	5	Professional	7	0.0053
Student	5	Professional	8	0.0102
Student	5	Professional	9	0.0115
Student	6	Student	7	0.0005
Student	6	Student	9	0.0167
Student	6	Student	10	0.001
Student	6	Professional	3	0.0096
Student	6	Professional	4	0.0151
Student	6	Professional	7	0.0089
Student	6	Professional	8	0.0168
Student	6	Professional	9	0.0188
Student	7	Student	8	0.0014
Student	8	Student	9	0.0354
Student	8	Student	10	0.0025
Student	8	Professional	3	0.012
Student	8	Professional	4	0.0188
Student	8	Professional	7	0.0112
Student	8	Professional	8	0.0209
Student	8	Professional	9	0.0234
Professional	1	Professional	3	<.0001
Professional	1	Professional	4	<.0001
Professional	1	Professional	5	0.0314
Professional	1	Professional	6	0.034
Professional	1	Professional	7	<.0001
Professional	1	Professional	8	<.0001
Professional	1	Professional	9	<.0001
Professional	1	Professional	10	0.011
Professional	2	Professional	3	<.0001
Professional	2	Professional	4	<.0001

Professional	2	Professional	7	<.0001
Professional	2	Professional	8	<.0001
Professional	2	Professional	9	<.0001
Professional	2	Professional	10	0.0429
Professional	3	Professional	5	<.0001
Professional	3	Professional	6	<.0001
Professional	3	Professional	10	0.0003
Professional	4	Professional	5	0.0003
Professional	4	Professional	6	0.0003
Professional	4	Professional	10	0.0013
Professional	5	Professional	7	<.0001
Professional	5	Professional	8	0.0004
Professional	5	Professional	9	0.0006
Professional	6	Professional	7	<.0001
Professional	6	Professional	8	0.0004
Professional	6	Professional	9	0.0006
Professional	7	Professional	10	0.0002
Professional	8	Professional	10	0.0017
Professional	9	Professional	10	0.0025

Table O5 Significant interaction of experience and note in ECR, p values provided for significant differences between the two levels in the interaction.

Experience 1	Note 1	Experience 2	Note 2	P
Student	1	Student	3	0.0011
Student	1	Student	9	0.0001
Student	1	Student	10	0.0085
Student	2	Student	3	0.0035
Student	2	Student	9	<.0001
Student	2	Student	10	0.0028
Student	3	Student	4	0.0426
Student	3	Student	5	0.0069
Student	3	Student	6	0.0037
Student	3	Student	9	<.0001
Student	3	Student	10	<.0001
Student	4	Student	9	<.0001
Student	4	Student	10	0.0001
Student	5	Student	9	<.0001
Student	5	Student	10	0.0013

Student	6	Student	9	<.0001
Student	6	Student	10	0.0027
Student	7	Student	9	<.0001
Student	7	Student	10	<.0001
Student	8	Student	9	<.0001
Student	8	Student	10	<.0001
Professional	1	Professional	3	<.0001
Professional	1	Professional	4	<.0001
Professional	1	Professional	5	0.0277
Professional	1	Professional	6	0.0327
Professional	1	Professional	7	<.0001
Professional	1	Professional	8	<.0001
Professional	2	Professional	3	<.0001
Professional	2	Professional	4	0.0001
Professional	2	Professional	7	0.0019
Professional	2	Professional	8	<.0001
Professional	3	Professional	5	0.0066
Professional	3	Professional	6	0.0054
Professional	3	Professional	9	0.0004
Professional	3	Professional	10	<.0001
Professional	4	Professional	5	0.012
Professional	4	Professional	6	0.0099
Professional	4	Professional	9	0.0008
Professional	4	Professional	10	<.0001
Professional	5	Professional	8	0.0021
Professional	6	Professional	8	0.0017
Professional	7	Professional	9	0.0079
Professional	7	Professional	10	0.0007
Professional	8	Professional	9	<.0001
Professional	8	Professional	10	<.0001

Size*Exercise

Table O6 Significant interaction of hand size and exercise in BIC, p values provided for significant differences between the two levels in the interaction.

Small	1	Small	5	0.0007
Small	1	Small	7	0.0024
Small	1	Small	8	0.008

Small	1	Small	9	0.0009
Small	2	Small	4	0.0133
Small	2	Small	6	0.039
Small	3	Small	4	0.0014
Small	3	Small	6	0.0052
Small	3	Small	10	0.008
Small	4	Small	7	0.0458
Small	4	Small	9	0.0227
Large	1	Large	4	0.0018
Large	1	Large	5	0.0005
Large	1	Large	6	0.0207
Large	1	Large	7	0.0426
Large	1	Large	10	0.0081
Large	2	Large	4	0.0187
Large	2	Large	5	0.0067
Large	3	Large	4	0.0012
Large	3	Large	5	0.0003
Large	3	Large	6	0.0149
Large	3	Large	7	0.0316
Large	3	Large	10	0.0056
Large	4	Large	8	0.0056
Large	5	Large	8	0.0017
Large	6	Large	8	0.0495
Large	8	Large	10	0.0214

Table O7 Significant interaction of hand size and exercise in APB, p values provided for significant differences between the two levels in the interaction.

Small	1	Small	2	0.0003
Small	1	Small	3	0.0003
Small	1	Small	4	<.0001
Small	1	Small	5	<.0001

Small	1	Small	6	0.0007
Small	1	Small	8	<.0001
Small	1	Small	9	0.0028
Small	1	Small	10	<.0001
Small	1	Large	3	0.0217
Small	1	Large	4	0.0048
Small	1	Large	5	0.0013
Small	1	Large	6	0.0056
Small	1	Large	8	0.0065
Small	1	Large	10	0.0206
Small	2	Small	3	<.0001
Small	2	Small	4	<.0001
Small	2	Small	5	<.0001
Small	2	Small	6	<.0001
Small	2	Small	7	0.0024
Small	2	Small	8	<.0001
Small	2	Small	9	<.0001
Small	2	Small	10	<.0001
Small	2	Large	1	0.0488
Small	2	Large	2	0.0336
Small	2	Large	3	<.0001
Small	2	Large	4	<.0001
Small	2	Large	5	<.0001
Small	2	Large	6	<.0001
Small	2	Large	7	0.0217
Small	2	Large	8	<.0001
Small	2	Large	9	0.0009
Small	2	Large	10	<.0001
Small	3	Small	5	0.0001
Small	3	Small	7	<.0001
Small	3	Large	1	0.0464

Small	4	Small	5	0.0194
Small	4	Small	7	<.0001
Small	4	Small	9	0.0291
Small	4	Large	1	0.0062
Small	4	Large	2	0.0095
Small	4	Large	7	0.0152
Small	5	Small	6	<.0001
Small	5	Small	7	<.0001
Small	5	Small	8	0.0069
Small	5	Small	9	<.0001
Small	5	Small	10	0.0034
Small	5	Large	1	0.0002
Small	5	Large	2	0.0003
Small	5	Large	7	0.0005
Small	5	Large	9	0.0122
Small	6	Small	7	<.0001
Small	7	Small	8	<.0001
Small	7	Small	9	0.0003
Small	7	Small	10	<.0001
Small	7	Large	3	0.0093
Small	7	Large	4	0.0019
Small	7	Large	5	0.0005
Small	7	Large	6	0.0022
Small	7	Large	8	0.0026
Small	7	Large	10	0.0088
Small	8	Large	1	0.0103
Small	8	Large	2	0.0157
Small	8	Large	7	0.0246
Small	10	Large	1	0.0143
Small	10	Large	2	0.0214
Small	10	Large	7	0.0332

Large	1	Large	3	<.0001
Large	1	Large	4	<.0001
Large	1	Large	5	<.0001
Large	1	Large	6	<.0001
Large	1	Large	8	<.0001
Large	1	Large	9	0.0074
Large	1	Large	10	<.0001
Large	2	Large	3	0.0002
Large	2	Large	4	<.0001
Large	2	Large	5	<.0001
Large	2	Large	6	<.0001
Large	2	Large	8	<.0001
Large	2	Large	9	0.0169
Large	2	Large	10	0.0001
Large	3	Large	7	0.0005
Large	4	Large	7	<.0001
Large	4	Large	9	0.0144
Large	5	Large	7	<.0001
Large	5	Large	9	0.0012
Large	6	Large	7	<.0001
Large	6	Large	9	0.0194
Large	7	Large	8	<.0001
Large	7	Large	9	0.0387
Large	7	Large	10	0.0005
Large	8	Large	9	0.025

Table O8 Significant interaction of hand size and exercise in APL, p values provided for significant differences between the two levels in the interaction.

Size 1	Exercise 1	Size 2	Exercise 2	P
Small	1	Small	3	<.0001
Small	1	Small	4	<.0001
Small	1	Small	5	<.0001

Small	1	Small	6	<.0001
Small	1	Small	7	0.0017
Small	1	Small	8	<.0001
Small	1	Small	9	<.0001
Small	1	Small	10	<.0001
Small	1	Large	1	0.0208
Small	1	Large	2	0.0458
Small	1	Large	3	0.0006
Small	1	Large	4	0.0016
Small	1	Large	5	<.0001
Small	1	Large	6	0.001
Small	1	Large	7	0.014
Small	1	Large	8	0.0001
Small	1	Large	9	0.0106
Small	1	Large	10	0.0228
Small	2	Small	3	<.0001
Small	2	Small	4	<.0001
Small	2	Small	5	<.0001
Small	2	Small	6	<.0001
Small	2	Small	7	0.0013
Small	2	Small	8	<.0001
Small	2	Small	9	<.0001
Small	2	Small	10	<.0001
Small	2	Large	1	0.0195
Small	2	Large	2	0.0431
Small	2	Large	3	0.0005
Small	2	Large	4	0.0015
Small	2	Large	5	<.0001
Small	2	Large	6	0.0009
Small	2	Large	7	0.0131
Small	2	Large	8	<.0001

Small	2	Large	9	0.0099
Small	2	Large	10	0.0214
Small	3	Small	4	<.0001
Small	3	Small	5	0.002
Small	3	Small	6	<.0001
Small	3	Small	7	<.0001
Small	3	Small	9	<.0001
Small	3	Small	10	<.0001
Small	4	Small	5	<.0001
Small	4	Small	7	0.0002
Small	4	Small	8	<.0001
Small	4	Small	10	0.0491
Small	4	Large	5	0.0156
Small	4	Large	8	0.0267
Small	5	Small	6	<.0001
Small	5	Small	7	<.0001
Small	5	Small	8	0.0316
Small	5	Small	9	<.0001
Small	5	Small	10	<.0001
Small	5	Large	1	0.0172
Small	5	Large	2	0.0074
Small	5	Large	7	0.0253
Small	5	Large	9	0.0331
Small	5	Large	10	0.0156
Small	6	Small	7	0.0191
Small	6	Small	8	<.0001
Small	6	Large	3	0.0431
Small	6	Large	5	0.0054
Small	6	Large	8	0.0095
Small	7	Small	8	<.0001
Small	7	Small	9	0.0379

Small	7	Large	3	0.0073
Small	7	Large	4	0.0202
Small	7	Large	5	0.0008
Small	7	Large	6	0.013
Small	7	Large	8	0.0014
Small	8	Small	9	<.0001
Small	8	Small	10	<.0001
Small	8	Large	2	0.0377
Small	9	Large	3	0.0356
Small	9	Large	5	0.0043
Small	9	Large	8	0.0077
Small	10	Large	3	0.0277
Small	10	Large	5	0.0033
Small	10	Large	6	0.0469
Small	10	Large	8	0.0058
Large	1	Large	3	<.0001
Large	1	Large	4	0.0026
Large	1	Large	5	<.0001
Large	1	Large	6	0.0004
Large	1	Large	8	<.0001
Large	2	Large	3	<.0001
Large	2	Large	4	<.0001
Large	2	Large	5	<.0001
Large	2	Large	6	<.0001
Large	2	Large	8	<.0001
Large	3	Large	5	0.0096
Large	3	Large	7	0.0002
Large	3	Large	9	0.0006
Large	3	Large	10	<.0001
Large	4	Large	5	0.0001
Large	4	Large	7	0.0116

Large	4	Large	8	0.0017
Large	4	Large	9	0.029
Large	4	Large	10	0.0017
Large	5	Large	6	0.0011
Large	5	Large	7	<.0001
Large	5	Large	9	<.0001
Large	5	Large	10	<.0001
Large	6	Large	7	0.0022
Large	6	Large	8	0.0092
Large	6	Large	9	0.0064
Large	6	Large	10	0.0002
Large	7	Large	8	<.0001
Large	8	Large	9	<.0001
Large	8	Large	10	<.0001

Table O9 Significant interaction of hand size and exercise in FDI, p values provided for significant differences between the two levels in the interaction.

Hand Size 1	Exercise 1	Hand Size 2	Exercise 2	P
Small	1	Small	8	<.0001
Small	1	Small	9	<.0001
Small	1	Small	10	<.0001
Small	1	Large	2	0.0164
Small	1	Large	3	0.0012
Small	1	Large	4	0.0004
Small	1	Large	5	<.0001
Small	1	Large	7	0.027
Small	1	Large	8	<.0001
Small	1	Large	9	0.0012
Small	1	Large	10	0.0016
Small	2	Small	3	<.0001

Small	2	Small	4	<.0001
Small	2	Small	5	<.0001
Small	2	Small	6	0.0015
Small	2	Small	8	<.0001
Small	2	Small	9	<.0001
Small	2	Small	10	<.0001
Small	2	Large	2	0.0147
Small	2	Large	3	0.001
Small	2	Large	4	0.0003
Small	2	Large	5	<.0001
Small	2	Large	6	0.0499
Small	2	Large	7	0.0243
Small	2	Large	8	<.0001
Small	2	Large	9	0.0011
Small	2	Large	10	0.0014
Small	3	Small	5	<.0001
Small	3	Small	6	<.0001
Small	3	Small	7	<.0001
Small	3	Small	8	<.0001
Small	3	Small	9	0.0462
Small	3	Large	1	0.0079
Small	3	Large	5	0.0119
Small	3	Large	8	0.0435
Small	4	Small	5	<.0001
Small	4	Small	6	<.0001
Small	4	Small	7	<.0001
Small	4	Small	8	<.0001
Small	4	Large	1	0.014
Small	4	Large	5	0.0067
Small	4	Large	8	0.0258
Small	5	Small	6	<.0001

Small	5	Small	7	<.0001
Small	5	Small	9	<.0001
Small	5	Small	10	<.0001
Small	5	Large	1	0.0001
Small	5	Large	2	0.0107
Small	5	Large	6	0.0028
Small	5	Large	7	0.0063
Small	6	Small	8	<.0001
Small	6	Small	9	0.0004
Small	6	Small	10	<.0001
Small	6	Large	3	0.0254
Small	6	Large	4	0.0093
Small	6	Large	5	<.0001
Small	6	Large	8	0.0002
Small	6	Large	9	0.0267
Small	6	Large	10	0.034
Small	7	Small	8	<.0001
Small	7	Small	9	<.0001
Small	7	Small	10	<.0001
Small	7	Large	3	0.0054
Small	7	Large	4	0.0018
Small	7	Large	5	<.0001
Small	7	Large	8	<.0001
Small	7	Large	9	0.0057
Small	7	Large	10	0.0075
Small	8	Small	9	<.0001
Small	8	Small	10	<.0001
Small	8	Large	1	<.0001
Small	8	Large	2	0.005
Small	8	Large	6	0.0013
Small	8	Large	7	0.0029

Small	8	Large	10	0.0448
Small	9	Large	5	0.0016
Small	9	Large	8	0.0065
Small	10	Large	1	0.0317
Small	10	Large	5	0.0027
Small	10	Large	8	0.0112
Large	1	Large	2	<.0001
Large	1	Large	3	<.0001
Large	1	Large	4	<.0001
Large	1	Large	5	<.0001
Large	1	Large	6	0.0044
Large	1	Large	7	0.0003
Large	1	Large	8	<.0001
Large	1	Large	9	<.0001
Large	1	Large	10	<.0001
Large	2	Large	3	0.0137
Large	2	Large	4	0.0006
Large	2	Large	5	<.0001
Large	2	Large	8	<.0001
Large	2	Large	9	0.0157
Large	2	Large	10	0.0303
Large	3	Large	5	<.0001
Large	3	Large	6	0.0002
Large	3	Large	7	0.0031
Large	3	Large	8	<.0001
Large	4	Large	5	<.0001
Large	4	Large	6	<.0001
Large	4	Large	7	<.0001
Large	4	Large	8	0.0002
Large	5	Large	6	<.0001
Large	5	Large	7	<.0001

Large	5	Large	9	<.0001
Large	5	Large	10	<.0001
Large	6	Large	8	<.0001
Large	6	Large	9	0.0002
Large	6	Large	10	0.0006
Large	7	Large	8	<.0001
Large	7	Large	9	0.0036
Large	7	Large	10	0.0077
Large	8	Large	9	<.0001
Large	8	Large	10	<.0001

Table O10 Significant interaction of hand size and exercise in ECR, p values provided for significant differences between the two levels in the interaction.

Hand size 1	Exercise 1	Hand size 2	Exercise 2	P
Small	1	Small	2	<.0001
Small	1	Small	3	<.0001
Small	1	Small	4	<.0001
Small	1	Small	5	<.0001
Small	1	Small	6	<.0001
Small	1	Small	7	0.0001
Small	1	Small	8	<.0001
Small	1	Small	9	<.0001
Small	1	Small	10	<.0001
Small	1	Large	3	0.0123
Small	1	Large	4	0.0002
Small	1	Large	5	<.0001
Small	1	Large	6	0.0042
Small	1	Large	8	<.0001
Small	1	Large	9	0.0022
Small	1	Large	10	0.0075
Small	2	Small	3	<.0001

Small	2	Small	4	<.0001
Small	2	Small	5	<.0001
Small	2	Small	6	<.0001
Small	2	Small	7	<.0001
Small	2	Small	8	<.0001
Small	2	Small	9	<.0001
Small	2	Small	10	<.0001
Small	2	Large	1	0.0032
Small	2	Large	2	0.0164
Small	2	Large	3	0.0002
Small	2	Large	4	<.0001
Small	2	Large	5	<.0001
Small	2	Large	6	<.0001
Small	2	Large	7	0.0023
Small	2	Large	8	<.0001
Small	2	Large	9	<.0001
Small	2	Large	10	0.0001
Small	3	Small	4	<.0001
Small	3	Small	5	<.0001
Small	3	Small	7	<.0001
Small	3	Small	8	<.0001
Small	3	Small	9	0.0198
Small	3	Large	5	0.0054
Small	3	Large	8	0.0201
Small	4	Small	5	<.0001
Small	4	Small	6	<.0001
Small	4	Small	7	<.0001
Small	4	Small	8	0.0026
Small	4	Small	9	0.0004
Small	4	Small	10	<.0001
Small	4	Large	1	0.0072

Small	4	Large	2	0.0014
Small	4	Large	7	0.01
Small	5	Small	6	<.0001
Small	5	Small	7	<.0001
Small	5	Small	8	0.0033
Small	5	Small	9	<.0001
Small	5	Small	10	<.0001
Small	5	Large	1	<.0001
Small	5	Large	2	<.0001
Small	5	Large	3	0.0014
Small	5	Large	6	0.0043
Small	5	Large	7	0.0001
Small	5	Large	9	0.008
Small	5	Large	10	0.0023
Small	6	Small	7	<.0001
Small	6	Small	8	<.0001
Small	6	Large	2	0.0295
Small	6	Large	5	0.0173
Small	7	Small	8	<.0001
Small	7	Small	9	<.0001
Small	7	Small	10	<.0001
Small	7	Large	4	0.0035
Small	7	Large	5	0.0002
Small	7	Large	8	0.0008
Small	7	Large	9	0.0358
Small	8	Small	9	<.0001
Small	8	Small	10	<.0001
Small	8	Large	1	0.0008
Small	8	Large	2	0.0001
Small	8	Large	3	0.0122
Small	8	Large	6	0.0341

Small	8	Large	7	0.0011
Small	8	Large	10	0.0198
Small	9	Small	10	0.0494
Small	9	Large	2	0.0181
Small	9	Large	5	0.0282
Small	10	Large	5	0.0071
Small	10	Large	8	0.0259
Large	1	Large	2	0.0332
Large	1	Large	3	0.0004
Large	1	Large	4	<.0001
Large	1	Large	5	<.0001
Large	1	Large	6	<.0001
Large	1	Large	8	<.0001
Large	1	Large	9	<.0001
Large	1	Large	10	<.0001
Large	2	Large	3	<.0001
Large	2	Large	4	<.0001
Large	2	Large	5	<.0001
Large	2	Large	6	<.0001
Large	2	Large	7	0.0103
Large	2	Large	8	<.0001
Large	2	Large	9	<.0001
Large	2	Large	10	<.0001
Large	3	Large	4	<.0001
Large	3	Large	5	<.0001
Large	3	Large	7	0.0018
Large	3	Large	8	<.0001
Large	3	Large	9	0.026
Large	4	Large	5	0.0004
Large	4	Large	6	<.0001
Large	4	Large	7	<.0001

Large	4	Large	9	0.0019
Large	4	Large	10	<.0001
Large	5	Large	6	<.0001
Large	5	Large	7	<.0001
Large	5	Large	9	<.0001
Large	5	Large	10	<.0001
Large	6	Large	7	<.0001
Large	6	Large	8	<.0001
Large	7	Large	8	<.0001
Large	7	Large	9	<.0001
Large	7	Large	10	0.0002
Large	8	Large	9	<.0001
Large	8	Large	10	<.0001

Table O11 Significant interaction of hand size and exercise in BRA, p values provided for significant differences between the two levels in the interaction.

Size 1	Exercise 1	Size 2	Exercise 2	P
Small	1	Small	3	<.0001
Small	1	Small	4	<.0001
Small	1	Small	5	<.0001
Small	1	Small	6	<.0001
Small	1	Small	7	0.0048
Small	1	Small	8	<.0001
Small	1	Small	9	<.0001
Small	1	Small	10	<.0001
Small	2	Small	3	<.0001
Small	2	Small	4	<.0001
Small	2	Small	5	<.0001
Small	2	Small	6	<.0001
Small	2	Small	7	<.0001

Small	2	Small	8	<.0001
Small	2	Small	9	<.0001
Small	2	Small	10	<.0001
Small	3	Small	7	0.0027
Small	4	Small	7	0.0119
Small	5	Small	6	0.0347
Small	5	Small	7	0.0001
Small	5	Small	8	0.0199
Small	7	Small	9	0.001
Small	7	Small	10	0.0439
Large	1	Large	3	0.0031
Large	1	Large	4	0.004
Large	1	Large	5	0.0002
Large	1	Large	6	0.0006
Large	1	Large	7	0.0433
Large	1	Large	8	0.0101
Large	1	Large	9	<.0001
Large	1	Large	10	0.0003
Large	2	Large	3	0.0245
Large	2	Large	4	0.0296
Large	2	Large	5	0.0023
Large	2	Large	6	0.0067
Large	2	Large	9	<.0001
Large	2	Large	10	0.0034
Large	7	Large	9	0.0089
Large	8	Large	9	0.039

Table O12 Significant interaction of hand size and exercise in FCU, p values provided for significant differences between the two levels in the interaction.

Size 1	Exercise 1	Size 2	Exercise 2	P

Small	1	Small	2	<.0001
Small	1	Small	3	<.0001
Small	1	Small	4	<.0001
Small	1	Small	5	<.0001
Small	1	Small	6	<.0001
Small	1	Small	8	<.0001
Small	1	Small	9	<.0001
Small	1	Small	10	<.0001
Small	1	Large	1	0.0063
Small	1	Large	3	<.0001
Small	1	Large	4	<.0001
Small	1	Large	5	<.0001
Small	1	Large	6	0.0051
Small	1	Large	7	0.0152
Small	1	Large	8	<.0001
Small	1	Large	9	<.0001
Small	1	Large	10	<.0001
Small	2	Small	3	<.0001
Small	2	Small	4	<.0001
Small	2	Small	5	<.0001
Small	2	Small	6	<.0001
Small	2	Small	7	<.0001
Small	2	Small	8	<.0001
Small	2	Small	9	<.0001
Small	2	Small	10	<.0001
Small	2	Large	1	<.0001
Small	2	Large	2	0.0035
Small	2	Large	3	<.0001
Small	2	Large	4	<.0001
Small	2	Large	5	<.0001
Small	2	Large	6	<.0001

Small	2	Large	7	<.0001
Small	2	Large	8	<.0001
Small	2	Large	9	<.0001
Small	2	Large	10	<.0001
Small	3	Small	4	0.0247
Small	3	Small	5	<.0001
Small	3	Small	6	<.0001
Small	3	Small	7	<.0001
Small	3	Small	8	<.0001
Small	3	Large	1	0.0392
Small	3	Large	2	0.0004
Small	3	Large	5	0.0002
Small	3	Large	6	0.0472
Small	3	Large	7	0.0172
Small	3	Large	8	0.0018
Small	4	Small	5	<.0001
Small	4	Small	6	<.0001
Small	4	Small	7	<.0001
Small	4	Small	8	0.0003
Small	4	Small	9	0.0112
Small	4	Small	10	0.0006
Small	4	Large	1	0.0032
Small	4	Large	2	<.0001
Small	4	Large	5	0.0035
Small	4	Large	6	0.004
Small	4	Large	7	0.0012
Small	4	Large	8	0.0244
Small	5	Small	6	<.0001
Small	5	Small	7	<.0001
Small	5	Small	8	0.0199
Small	5	Small	9	<.0001

Small	5	Small	10	<.0001
Small	5	Large	1	<.0001
Small	5	Large	2	<.0001
Small	5	Large	3	0.0015
Small	5	Large	4	0.0451
Small	5	Large	6	<.0001
Small	5	Large	7	<.0001
Small	5	Large	9	0.0013
Small	5	Large	10	0.0003
Small	6	Small	7	0.0001
Small	6	Small	8	<.0001
Small	6	Small	9	<.0001
Small	6	Small	10	0.0001
Small	6	Large	3	0.0102
Small	6	Large	4	0.0003
Small	6	Large	5	<.0001
Small	6	Large	8	<.0001
Small	6	Large	9	0.0112
Small	6	Large	10	0.0431
Small	7	Small	8	<.0001
Small	7	Small	9	<.0001
Small	7	Small	10	<.0001
Small	7	Large	3	<.0001
Small	7	Large	4	<.0001
Small	7	Large	5	<.0001
Small	7	Large	6	0.0422
Small	7	Large	8	<.0001
Small	7	Large	9	0.0001
Small	7	Large	10	0.0005
Small	8	Small	9	<.0001
Small	8	Small	10	<.0001

Small	8	Large	1	<.0001
Small	8	Large	2	<.0001
Small	8	Large	3	0.0221
Small	8	Large	6	<.0001
Small	8	Large	7	<.0001
Small	8	Large	9	0.0202
Small	8	Large	10	0.0049
Small	9	Large	2	0.0005
Small	9	Large	5	0.0002
Small	9	Large	7	0.0236
Small	9	Large	8	0.0013
Small	10	Large	2	0.0017
Small	10	Large	4	0.025
Small	10	Large	5	<.0001
Small	10	Large	8	0.0004
Large	1	Large	2	0.0002
Large	1	Large	3	<.0001
Large	1	Large	4	<.0001
Large	1	Large	5	<.0001
Large	1	Large	8	<.0001
Large	1	Large	9	<.0001
Large	1	Large	10	0.0002
Large	2	Large	3	<.0001
Large	2	Large	4	<.0001
Large	2	Large	5	<.0001
Large	2	Large	6	<.0001
Large	2	Large	7	0.0024
Large	2	Large	8	<.0001
Large	2	Large	9	<.0001
Large	2	Large	10	<.0001
Large	3	Large	4	0.0043

Large	3	Large	5	<.0001
Large	3	Large	6	<.0001
Large	3	Large	7	<.0001
Large	3	Large	8	<.0001
Large	4	Large	5	<.0001
Large	4	Large	6	<.0001
Large	4	Large	7	<.0001
Large	4	Large	8	0.001
Large	4	Large	9	0.0033
Large	4	Large	10	<.0001
Large	5	Large	6	<.0001
Large	5	Large	7	<.0001
Large	5	Large	9	<.0001
Large	5	Large	10	<.0001
Large	6	Large	8	<.0001
Large	6	Large	9	<.0001
Large	6	Large	10	0.0003
Large	7	Large	8	<.0001
Large	7	Large	9	<.0001
Large	7	Large	10	<.0001
Large	8	Large	9	<.0001
Large	8	Large	10	<.0001

Position* Exercise

Table O13 Significant interaction of thumb-rest position (position) and exercise in APB, p values provided for significant differences between the two levels in the interaction.

Position 1	Exercise 1	Position 2	Exercise 2	P
HR	1	HR	4	0.0315
HR	1	HR	5	0.0217
HR	1	HR	8	0.0442

HR	1	NR	1	0.002
HR	1	NR	2	<.0001
HR	1	NR	7	0.0338
HR	1	LR	1	0.0009
HR	1	LR	2	<.0001
HR	2	NR	2	<.0001
HR	2	LR	9	0.0243
HR	3	NR	2	<.0001
HR	4	NR	1	<.0001
HR	4	NR	2	<.0001
HR	4	NR	9	0.0499
HR	5	LR	1	<.0001
HR	5	LR	6	0.0418
HR	5	LR	7	<.0001
HR	5	LR	9	<.0001
HR	6	NR	1	<.0001
HR	6	NR	2	<.0001
HR	6	NR	7	0.0006
HR	6	LR	1	<.0001
HR	6	LR	7	<.0001
HR	6	LR	9	0.0003
HR	7	NR	1	0.0002
HR	7	NR	7	0.0064
HR	7	LR	1	<.0001
HR	7	LR	2	<.0001
HR	7	LR	7	<.0001
HR	7	LR	9	0.0037
HR	8	NR	1	<.0001
HR	8	NR	2	<.0001
HR	8	NR	7	0.0004
HR	8	LR	1	<.0001

HR	8	LR	2	<.0001
HR	8	LR	3	0.0262
HR	8	LR	7	<.0001
HR	8	LR	9	0.0002
HR	9	NR	1	<.0001
HR	9	NR	2	<.0001
HR	9	NR	7	0.0008
HR	9	LR	1	<.0001
HR	9	LR	2	<.0001
HR	9	LR	3	0.043
HR	9	LR	7	<.0001
HR	9	LR	9	0.0004
HR	10	NR	1	<.0001
HR	10	NR	2	<.0001
HR	10	NR	7	0.0005
HR	10	LR	1	<.0001
HR	10	LR	2	<.0001
HR	10	LR	3	0.0291
HR	10	LR	7	<.0001
HR	10	LR	9	0.0003
NR	1	NR	3	<.0001
NR	1	NR	4	<.0001
NR	1	NR	5	<.0001
NR	1	NR	6	<.0001
NR	1	NR	8	<.0001
NR	1	NR	9	0.0002
NR	1	NR	10	<.0001
NR	1	LR	2	0.0403
NR	1	LR	3	0.0185
NR	1	LR	4	0.0006
NR	1	LR	5	<.0001

NR	1	LR	6	0.0061
NR	1	LR	8	0.0003
NR	1	LR	10	0.0061
NR	2	NR	3	<.0001
NR	2	NR	4	<.0001
NR	2	NR	5	<.0001
NR	2	NR	6	<.0001
NR	2	NR	7	0.0045
NR	2	NR	8	<.0001
NR	2	NR	9	<.0001
NR	2	NR	10	<.0001
NR	2	LR	3	0.0007
NR	2	LR	4	<.0001
NR	2	LR	5	<.0001
NR	2	LR	6	0.0002
NR	2	LR	8	<.0001
NR	2	LR	10	0.0002
NR	3	NR	5	0.0044
NR	3	NR	7	0.0107
NR	3	LR	1	0.002
NR	3	LR	2	<.0001
NR	3	LR	5	0.0252
NR	3	LR	7	<.0001
NR	3	LR	9	0.0405
NR	4	NR	7	<.0001
NR	4	LR	1	<.0001
NR	4	LR	2	<.0001
NR	4	LR	7	<.0001
NR	4	LR	9	0.0021
NR	5	NR	6	0.0172
NR	5	NR	7	<.0001

NR	5	NR	8	0.0252
NR	5	NR	9	0.0025
NR	5	NR	10	0.0269
NR	5	LR	1	<.0001
NR	5	LR	2	<.0001
NR	5	LR	3	0.0101
NR	5	LR	6	0.029
NR	5	LR	7	<.0001
NR	5	LR	9	<.0001
NR	5	LR	10	0.029
NR	6	NR	7	0.0025
NR	6	LR	1	0.0006
NR	6	LR	2	<.0001
NR	6	LR	7	<.0001
NR	6	LR	9	0.017
NR	7	NR	8	0.0016
NR	7	NR	9	0.0175
NR	7	NR	10	0.0014
NR	7	LR	2	0.0026
NR	7	LR	4	0.0136
NR	7	LR	5	<.0001
NR	7	LR	7	0.0047
NR	7	LR	8	0.0078
NR	8	LR	1	0.0004
NR	8	LR	2	<.0001
NR	8	LR	7	<.0001
NR	8	LR	9	0.0128
NR	9	LR	1	0.0031
NR	9	LR	2	<.0001
NR	9	LR	5	0.018
NR	9	LR	7	<.0001

NR	10	LR	1	0.0004
NR	10	LR	2	<.0001
NR	10	LR	7	<.0001
NR	10	LR	9	0.0122
LR	1	LR	2	0.0144
LR	1	LR	3	0.0004
LR	1	LR	4	<.0001
LR	1	LR	5	<.0001
LR	1	LR	6	<.0001
LR	1	LR	7	0.029
LR	1	LR	8	<.0001
LR	1	LR	10	<.0001
LR	2	LR	3	<.0001
LR	2	LR	4	<.0001
LR	2	LR	5	<.0001
LR	2	LR	6	<.0001
LR	2	LR	8	<.0001
LR	2	LR	9	<.0001
LR	2	LR	10	<.0001
LR	3	LR	5	0.0002
LR	3	LR	7	<.0001
LR	3	LR	9	0.0341
LR	4	LR	5	0.0255
LR	4	LR	7	<.0001
LR	4	LR	9	0.0003
LR	5	LR	6	0.0014
LR	5	LR	7	<.0001
LR	5	LR	9	<.0001
LR	5	LR	10	0.0014
LR	6	LR	7	<.0001
LR	6	LR	9	0.0078

LR	7	LR	8	<.0001
LR	7	LR	9	0.0003
LR	7	LR	10	<.0001
LR	8	LR	9	0.0001
LR	9	LR	10	0.0078

Table O14 Significant interaction of thumb-rest position (position) and exercise in APL, p values provided for significant differences between the two levels in the interaction.

Position 1	Exercise 1	Position 2	Exercise 2	P
HR	1	HR	3	<.0001
HR	1	HR	4	0.0021
HR	1	HR	5	<.0001
HR	1	HR	6	<.0001
HR	1	HR	8	<.0001
HR	1	HR	9	0.016
HR	1	NR	1	0.0451
HR	1	NR	3	<.0001
HR	1	NR	4	<.0001
HR	1	NR	5	<.0001
HR	1	NR	6	<.0001
HR	1	NR	7	0.0015
HR	1	NR	8	<.0001
HR	1	NR	9	0.0001
HR	1	NR	10	0.002
HR	1	LR	1	<.0001
HR	1	LR	2	<.0001
HR	1	LR	3	<.0001
HR	1	LR	4	<.0001
HR	1	LR	5	<.0001
HR	1	LR	6	<.0001
HR	1	LR	7	<.0001

HR	1	LR	8	<.0001
HR	1	LR	9	<.0001
HR	1	LR	10	<.0001
HR	2	HR	3	<.0001
HR	2	HR	5	<.0001
HR	2	HR	6	0.0033
HR	2	HR	8	<.0001
HR	2	NR	3	<.0001
HR	2	NR	4	<.0001
HR	2	NR	5	<.0001
HR	2	NR	6	0.0001
HR	2	NR	7	0.0281
HR	2	NR	8	<.0001
HR	2	NR	9	0.0047
HR	2	LR	1	<.0001
HR	2	LR	2	<.0001
HR	3	HR	6	0.0124
HR	3	HR	8	0.0285
HR	3	HR	9	<.0001
HR	3	NR	1	0.0004
HR	3	LR	3	<.0001
HR	3	LR	4	0.0002
HR	3	LR	5	<.0001
HR	3	LR	6	0.0007
HR	3	LR	7	0.0235
HR	3	LR	8	<.0001
HR	4	HR	7	0.0285
HR	4	NR	2	0.0148
HR	4	LR	2	0.0013
HR	4	LR	5	<.0001
HR	4	LR	6	<.0001

HR	4	LR	10	<.0001
HR	5	HR	6	<.0001
HR	5	HR	7	<.0001
HR	5	HR	10	<.0001
HR	5	NR	6	0.0017
HR	5	LR	8	0.005
HR	6	NR	4	0.0063
HR	6	LR	3	<.0001
HR	6	LR	4	<.0001
HR	6	LR	5	<.0001
HR	6	LR	6	<.0001
HR	6	LR	8	<.0001
HR	7	HR	8	<.0001
HR	7	NR	3	<.0001
HR	7	NR	7	0.0146
HR	7	NR	9	0.0021
HR	7	LR	1	<.0001
HR	7	LR	2	<.0001
HR	7	LR	3	<.0001
HR	7	LR	5	<.0001
HR	7	LR	6	<.0001
HR	7	LR	7	<.0001
HR	7	LR	8	<.0001
HR	7	LR	9	<.0001
HR	7	LR	10	<.0001
HR	8	HR	10	<.0001
HR	8	NR	1	<.0001
HR	8	NR	2	<.0001
HR	8	NR	5	0.007
HR	8	NR	6	0.0122
HR	8	NR	9	0.0004

HR	8	NR	10	<.0001
HR	8	LR	3	0.0006
HR	8	LR	5	<.0001
HR	8	LR	8	0.0006
HR	9	NR	3	<.0001
HR	9	NR	4	<.0001
HR	9	NR	5	<.0001
HR	9	NR	6	0.0043
HR	9	NR	8	<.0001
HR	9	LR	1	<.0001
HR	9	LR	2	0.0002
HR	9	LR	3	<.0001
HR	9	LR	4	<.0001
HR	9	LR	5	<.0001
HR	9	LR	6	<.0001
HR	9	LR	7	<.0001
HR	9	LR	8	<.0001
HR	9	LR	9	<.0001
HR	9	LR	10	<.0001
HR	10	NR	3	<.0001
HR	10	NR	4	<.0001
HR	10	NR	5	<.0001
HR	10	NR	6	0.0004
HR	10	NR	8	<.0001
HR	10	NR	9	0.0122
HR	10	LR	1	<.0001
HR	10	LR	2	<.0001
HR	10	LR	3	<.0001
HR	10	LR	4	<.0001
HR	10	LR	5	<.0001
HR	10	LR	6	<.0001

HR	10	LR	7	<.0001
HR	10	LR	8	<.0001
HR	10	LR	9	<.0001
HR	10	LR	10	<.0001
NR	1	NR	2	0.0262
NR	1	NR	3	<.0001
NR	1	NR	4	<.0001
NR	1	NR	5	<.0001
NR	1	NR	6	0.0006
NR	1	NR	8	<.0001
NR	1	NR	9	0.0282
NR	1	LR	1	<.0001
NR	1	LR	2	0.0002
NR	1	LR	3	<.0001
NR	1	LR	4	<.0001
NR	1	LR	5	<.0001
NR	1	LR	6	<.0001
NR	1	LR	7	<.0001
NR	1	LR	8	<.0001
NR	1	LR	9	<.0001
NR	1	LR	10	<.0001
NR	2	NR	3	<.0001
NR	2	NR	4	<.0001
NR	2	NR	5	<.0001
NR	2	NR	6	<.0001
NR	2	NR	7	0.0003
NR	2	NR	8	<.0001
NR	2	NR	9	<.0001
NR	2	NR	10	0.0004
NR	2	LR	1	<.0001
NR	2	LR	2	<.0001

NR	2	LR	3	<.0001
NR	2	LR	4	<.0001
NR	2	LR	5	<.0001
NR	2	LR	6	<.0001
NR	2	LR	7	<.0001
NR	2	LR	8	<.0001
NR	2	LR	9	<.0001
NR	2	LR	10	<.0001
NR	3	NR	5	0.0049
NR	3	NR	6	0.0007
NR	3	NR	7	<.0001
NR	3	NR	9	<.0001
NR	3	NR	10	<.0001
NR	3	LR	3	0.002
NR	3	LR	5	<.0001
NR	3	LR	8	0.0019
NR	4	NR	5	<.0001
NR	4	NR	7	0.0003
NR	4	NR	8	0.0017
NR	4	NR	9	0.0047
NR	4	NR	10	0.0002
NR	4	LR	3	<.0001
NR	4	LR	4	0.0019
NR	4	LR	5	<.0001
NR	4	LR	6	0.0054
NR	4	LR	8	<.0001
NR	4	LR	9	0.0323
NR	4	LR	10	0.0266
NR	5	NR	6	<.0001
NR	5	NR	7	<.0001
NR	5	NR	9	<.0001

NR	5	NR	10	<.0001
NR	5	LR	1	<.0001
NR	5	LR	2	<.0001
NR	5	LR	7	0.0233
NR	6	NR	7	0.0439
NR	6	NR	8	<.0001
NR	6	NR	10	0.0338
NR	6	LR	3	<.0001
NR	6	LR	4	<.0001
NR	6	LR	5	<.0001
NR	6	LR	6	<.0001
NR	6	LR	7	0.0034
NR	6	LR	8	<.0001
NR	6	LR	9	0.0006
NR	6	LR	10	0.0004
NR	7	NR	8	<.0001
NR	7	LR	1	0.0036
NR	7	LR	2	0.0091
NR	7	LR	3	<.0001
NR	7	LR	4	<.0001
NR	7	LR	5	<.0001
NR	7	LR	6	<.0001
NR	7	LR	7	<.0001
NR	7	LR	8	<.0001
NR	7	LR	9	<.0001
NR	7	LR	10	<.0001
NR	8	NR	9	<.0001
NR	8	NR	10	<.0001
NR	8	LR	1	0.0066
NR	8	LR	2	0.0025
NR	8	LR	3	0.0447

NR	8	LR	5	0.0031
NR	8	LR	8	0.0432
NR	9	LR	1	0.0228
NR	9	LR	2	0.0484
NR	9	LR	3	<.0001
NR	9	LR	4	<.0001
NR	9	LR	5	<.0001
NR	9	LR	6	<.0001
NR	9	LR	7	<.0001
NR	9	LR	8	<.0001
NR	9	LR	9	<.0001
NR	9	LR	10	<.0001
NR	10	LR	1	0.0027
NR	10	LR	2	0.007
NR	10	LR	3	<.0001
NR	10	LR	4	<.0001
NR	10	LR	5	<.0001
NR	10	LR	6	<.0001
NR	10	LR	7	<.0001
NR	10	LR	8	<.0001
NR	10	LR	9	<.0001
NR	10	LR	10	<.0001
LR	1	LR	3	<.0001
LR	1	LR	4	0.0001
LR	1	LR	5	<.0001
LR	1	LR	6	0.0006
LR	1	LR	7	0.0409
LR	1	LR	8	<.0001
LR	1	LR	9	0.0078
LR	1	LR	10	0.0059
LR	2	LR	3	<.0001

LR	2	LR	4	<.0001
LR	2	LR	5	<.0001
LR	2	LR	6	0.0002
LR	2	LR	7	0.016
LR	2	LR	8	<.0001
LR	2	LR	9	0.0025
LR	2	LR	10	0.0018
LR	3	LR	6	0.0269
LR	3	LR	7	0.0003
LR	3	LR	9	0.0029
LR	3	LR	10	0.0038
LR	4	LR	5	0.003
LR	5	LR	6	0.0008
LR	5	LR	7	<.0001
LR	5	LR	9	<.0001
LR	5	LR	10	<.0001
LR	6	LR	8	0.0257
LR	7	LR	8	0.0003
LR	8	LR	9	0.0027
LR	8	LR	10	0.0036

Table O15 Significant interaction of thumb-rest position (position) and exercise in FDI, p values provided for significant differences between the two levels in the interaction.

Position 1	Exercise 1	Position 2	Exercise 2	P
HR	1	HR	3	<.0001
HR	1	HR	4	<.0001
HR	1	HR	5	<.0001
HR	1	HR	7	<.0001
HR	1	HR	8	<.0001
HR	1	HR	9	<.0001
HR	1	HR	10	<.0001

HR	1	NR	2	0.029
HR	1	NR	3	<.0001
HR	1	NR	4	<.0001
HR	1	NR	5	<.0001
HR	1	NR	6	0.0071
HR	1	NR	7	0.0173
HR	1	NR	8	<.0001
HR	1	NR	9	<.0001
HR	1	LR	1	0.0025
HR	1	LR	2	0.0364
HR	1	LR	3	<.0001
HR	1	LR	5	<.0001
HR	1	LR	6	0.0023
HR	1	LR	7	0.007
HR	1	LR	8	<.0001
HR	1	LR	9	<.0001
HR	1	LR	10	<.0001
HR	2	HR	3	0.001
HR	2	HR	4	0.0136
HR	2	HR	5	<.0001
HR	2	HR	8	<.0001
HR	2	HR	9	0.0231
HR	2	NR	1	0.0019
HR	2	NR	3	0.0108
HR	2	NR	10	0.0438
HR	2	LR	3	0.0019
HR	2	LR	4	<.0001
HR	2	LR	5	<.0001
HR	2	LR	9	0.008
HR	3	HR	6	0.005
HR	3	NR	2	<.0001

HR	3	NR	5	0.0005
HR	3	NR	6	0.0001
HR	3	NR	7	<.0001
HR	3	NR	8	0.0012
HR	3	LR	2	<.0001
HR	3	LR	8	0.0003
HR	4	HR	7	0.0325
HR	4	HR	8	<.0001
HR	4	NR	2	0.0003
HR	4	NR	5	<.0001
HR	4	NR	6	0.0018
HR	4	NR	7	0.0006
HR	4	LR	1	0.0051
HR	4	LR	2	0.0002
HR	4	LR	5	<.0001
HR	4	LR	6	0.0056
HR	4	LR	7	0.0018
HR	4	LR	8	<.0001
HR	5	HR	6	<.0001
HR	5	HR	10	<.0001
HR	5	NR	1	<.0001
HR	5	NR	4	0.0011
HR	5	NR	10	<.0001
HR	5	LR	3	0.0041
HR	5	LR	6	<.0001
HR	5	LR	10	0.0078
HR	6	NR	3	0.0331
HR	6	NR	4	0.0221
HR	6	NR	5	<.0001
HR	6	NR	8	<.0001
HR	6	LR	2	0.0417

HR	6	LR	3	0.0072
HR	6	LR	8	<.0001
HR	6	LR	10	0.0038
HR	7	HR	8	<.0001
HR	7	NR	3	0.0234
HR	7	NR	4	0.0153
HR	7	NR	5	<.0001
HR	7	LR	3	0.0048
HR	7	LR	5	<.0001
HR	7	LR	8	<.0001
HR	7	LR	9	0.0178
HR	7	LR	10	0.0025
HR	8	HR	9	<.0001
HR	8	HR	10	<.0001
HR	8	NR	6	<.0001
HR	8	NR	7	<.0001
HR	8	NR	9	<.0001
HR	8	NR	10	0.0001
HR	8	LR	1	<.0001
HR	8	LR	2	<.0001
HR	8	LR	3	0.005
HR	8	LR	6	<.0001
HR	8	LR	7	<.0001
HR	8	LR	9	0.0011
HR	8	LR	10	0.0093
HR	9	NR	1	<.0001
HR	9	NR	2	0.0005
HR	9	NR	5	<.0001
HR	9	NR	6	0.0031
HR	9	NR	7	0.0011
HR	9	NR	8	<.0001

HR	9	LR	1	0.0085
HR	9	LR	2	0.0004
HR	9	LR	4	0.028
HR	9	LR	5	<.0001
HR	9	LR	6	0.0093
HR	9	LR	7	0.0031
HR	9	LR	8	<.0001
HR	10	NR	1	<.0001
HR	10	NR	2	0.0041
HR	10	NR	5	<.0001
HR	10	NR	6	0.0179
HR	10	NR	7	0.0074
HR	10	NR	8	<.0001
HR	10	LR	1	0.042
HR	10	LR	2	0.0031
HR	10	LR	4	0.0052
HR	10	LR	5	<.0001
HR	10	LR	6	0.0451
HR	10	LR	7	0.0183
HR	10	LR	8	<.0001
HR	10	LR	10	0.049
NR	1	NR	3	<.0001
NR	1	NR	4	<.0001
NR	1	NR	5	<.0001
NR	1	NR	6	0.0147
NR	1	NR	7	0.0378
NR	1	NR	8	<.0001
NR	1	NR	9	<.0001
NR	1	NR	10	<.0001
NR	1	LR	1	0.0144
NR	1	LR	3	<.0001

NR	1	LR	4	<.0001
NR	1	LR	5	<.0001
NR	1	LR	6	0.0133
NR	1	LR	7	0.0339
NR	1	LR	8	<.0001
NR	1	LR	9	<.0001
NR	1	LR	10	<.0001
NR	2	NR	3	<.0001
NR	2	NR	4	<.0001
NR	2	NR	5	<.0001
NR	2	NR	8	<.0001
NR	2	NR	9	0.0001
NR	2	NR	10	<.0001
NR	2	LR	3	<.0001
NR	2	LR	4	<.0001
NR	2	LR	5	<.0001
NR	2	LR	8	<.0001
NR	2	LR	9	<.0001
NR	2	LR	10	<.0001
NR	3	NR	5	<.0001
NR	3	NR	6	<.0001
NR	3	NR	7	<.0001
NR	3	NR	8	<.0001
NR	3	LR	1	0.0013
NR	3	LR	2	<.0001
NR	3	LR	5	<.0001
NR	3	LR	6	0.0015
NR	3	LR	7	0.0004
NR	3	LR	8	<.0001
NR	4	NR	5	<.0001
NR	4	NR	6	<.0001

NR	4	NR	7	<.0001
NR	4	NR	8	<.0001
NR	4	LR	1	0.0008
NR	4	LR	2	<.0001
NR	4	LR	5	<.0001
NR	4	LR	6	0.0009
NR	4	LR	7	0.0002
NR	4	LR	8	0.0002
NR	5	NR	6	<.0001
NR	5	NR	7	<.0001
NR	5	NR	9	<.0001
NR	5	NR	10	<.0001
NR	5	LR	1	<.0001
NR	5	LR	2	<.0001
NR	5	LR	3	0.0011
NR	5	LR	4	0.0259
NR	5	LR	6	<.0001
NR	5	LR	7	<.0001
NR	5	LR	9	0.0002
NR	5	LR	10	0.0023
NR	6	NR	8	<.0001
NR	6	NR	9	0.0012
NR	6	NR	10	0.0005
NR	6	LR	3	<.0001
NR	6	LR	4	<.0001
NR	6	LR	5	<.0001
NR	6	LR	8	<.0001
NR	6	LR	9	0.0003
NR	6	LR	10	<.0001
NR	7	NR	8	<.0001
NR	7	NR	9	0.0003

NR	7	NR	10	0.0001
NR	7	LR	3	<.0001
NR	7	LR	4	<.0001
NR	7	LR	5	<.0001
NR	7	LR	8	<.0001
NR	7	LR	9	<.0001
NR	7	LR	10	<.0001
NR	8	NR	9	<.0001
NR	8	NR	10	<.0001
NR	8	LR	1	<.0001
NR	8	LR	2	<.0001
NR	8	LR	3	0.0029
NR	8	LR	6	<.0001
NR	8	LR	7	<.0001
NR	8	LR	9	0.0006
NR	8	LR	10	0.0056
NR	9	LR	1	0.0138
NR	9	LR	2	0.0007
NR	9	LR	4	0.018
NR	9	LR	5	<.0001
NR	9	LR	6	0.015
NR	9	LR	7	0.0054
NR	9	LR	8	<.0001
NR	10	LR	1	0.0074
NR	10	LR	2	0.0003
NR	10	LR	4	0.0316
NR	10	LR	5	<.0001
NR	10	LR	6	0.0081
NR	10	LR	7	0.0027
NR	10	LR	8	<.0001
LR	1	LR	3	<.0001

LR	1	LR	4	<.0001
LR	1	LR	5	<.0001
LR	1	LR	8	<.0001
LR	1	LR	9	0.0001
LR	1	LR	10	<.0001
LR	2	LR	3	<.0001
LR	2	LR	4	<.0001
LR	2	LR	5	<.0001
LR	2	LR	8	<.0001
LR	2	LR	9	<.0001
LR	2	LR	10	<.0001
LR	3	LR	5	<.0001
LR	3	LR	6	<.0001
LR	3	LR	7	<.0001
LR	3	LR	8	<.0001
LR	4	LR	5	0.0021
LR	4	LR	6	<.0001
LR	4	LR	7	<.0001
LR	4	LR	8	0.0067
LR	5	LR	6	<.0001
LR	5	LR	7	<.0001
LR	5	LR	9	<.0001
LR	5	LR	10	<.0001
LR	6	LR	8	<.0001
LR	6	LR	9	0.0001
LR	6	LR	10	<.0001
LR	7	LR	8	<.0001
LR	7	LR	9	<.0001
LR	7	LR	10	<.0001
LR	8	LR	9	<.0001
LR	8	LR	10	0.0003

Experience* Exercise

Table O16 Significant interaction of experience level and exercise in APL, p values provided for significant differences between the two levels in the interaction.

Experience 1	Exercise 1	Experience 2	Exercise 2	P
Student	1	Student	2	0.0253
Student	1	Student	3	<.0001
Student	1	Student	4	<.0001
Student	1	Student	5	<.0001
Student	1	Student	6	<.0001
Student	1	Student	7	0.0196
Student	1	Student	8	<.0001
Student	1	Student	9	0.0001
Student	1	Student	10	0.0025
Student	1	Professional	2	0.0087
Student	1	Professional	3	0.0001
Student	1	Professional	4	0.0008
Student	1	Professional	5	<.0001
Student	1	Professional	6	0.0033
Student	1	Professional	7	0.0212
Student	1	Professional	8	<.0001
Student	1	Professional	9	0.0095
Student	1	Professional	10	0.0138
Student	2	Student	3	<.0001
Student	2	Student	4	<.0001
Student	2	Student	5	<.0001
Student	2	Student	6	<.0001
Student	2	Student	7	<.0001
Student	2	Student	8	<.0001
Student	2	Student	9	<.0001

Student	2	Student	10	<.0001
Student	2	Professional	1	0.0138
Student	2	Professional	2	0.0017
Student	2	Professional	3	<.0001
Student	2	Professional	4	0.0001
Student	2	Professional	5	<.0001
Student	2	Professional	6	0.0006
Student	2	Professional	7	0.0044
Student	2	Professional	8	<.0001
Student	2	Professional	9	0.0018
Student	2	Professional	10	0.0027
Student	3	Student	4	0.0001
Student	3	Student	5	0.0005
Student	3	Student	6	0.0002
Student	3	Student	7	<.0001
Student	3	Student	9	<.0001
Student	3	Student	10	<.0001
Student	3	Professional	5	0.0172
Student	3	Professional	8	0.0318
Student	4	Student	5	<.0001
Student	4	Student	7	0.0018
Student	4	Student	8	<.0001
Student	4	Student	10	0.0152
Student	4	Professional	3	0.0073
Student	4	Professional	4	0.04
Student	4	Professional	5	0.001
Student	4	Professional	8	0.002
Student	5	Student	6	<.0001
Student	5	Student	7	<.0001
Student	5	Student	9	<.0001
Student	5	Student	10	<.0001

Student	6	Student	7	0.0011
Student	6	Student	8	<.0001
Student	6	Student	10	0.0098
Student	6	Professional	3	0.0082
Student	6	Professional	4	0.0442
Student	6	Professional	5	0.0011
Student	6	Professional	8	0.0023
Student	7	Student	8	<.0001
Student	7	Professional	2	0.0426
Student	7	Professional	3	0.0007
Student	7	Professional	4	0.0046
Student	7	Professional	5	<.0001
Student	7	Professional	6	0.0175
Student	7	Professional	8	0.0002
Student	7	Professional	9	0.0457
Student	8	Student	9	<.0001
Student	8	Student	10	<.0001
Student	8	Professional	5	0.0475
Student	9	Professional	3	0.0022
Student	9	Professional	4	0.0136
Student	9	Professional	5	0.0003
Student	9	Professional	6	0.0474
Student	9	Professional	8	0.0006
Student	10	Professional	3	0.0012
Student	10	Professional	4	0.0076
Student	10	Professional	5	0.0002
Student	10	Professional	6	0.028
Student	10	Professional	8	0.0003
Professional	1	Professional	3	<.0001
Professional	1	Professional	4	<.0001
Professional	1	Professional	5	<.0001

Professional	1	Professional	6	0.0042
Professional	1	Professional	8	<.0001
Professional	2	Professional	3	0.0001
Professional	2	Professional	4	0.0285
Professional	2	Professional	5	<.0001
Professional	2	Professional	8	<.0001
Professional	3	Professional	6	0.0031
Professional	3	Professional	7	<.0001
Professional	3	Professional	9	<.0001
Professional	3	Professional	10	<.0001
Professional	4	Professional	5	0.0005
Professional	4	Professional	7	0.0023
Professional	4	Professional	8	0.004
Professional	4	Professional	9	0.0235
Professional	4	Professional	10	0.0086
Professional	5	Professional	6	<.0001
Professional	5	Professional	7	<.0001
Professional	5	Professional	9	<.0001
Professional	5	Professional	10	<.0001
Professional	6	Professional	8	<.0001
Professional	7	Professional	8	<.0001
Professional	8	Professional	9	<.0001
Professional	8	Professional	10	<.0001

Table O17 Significant interaction of experience level and exercise in FDI, p values provided for significant differences between the two levels in the interaction.

Experience 1	Exercise 1	Experience 2	Exercise 2	P
Student	1	Student	3	<.0001
Student	1	Student	4	<.0001
Student	1	Student	5	<.0001

Student	1	Student	6	0.003
Student	1	Student	8	<.0001
Student	1	Student	9	<.0001
Student	1	Student	10	<.0001
Student	1	Professional	3	0.007
Student	1	Professional	4	5E-04
Student	1	Professional	5	<.0001
Student	1	Professional	8	<.0001
Student	1	Professional	9	0.002
Student	1	Professional	10	0.004
Student	2	Student	3	<.0001
Student	2	Student	4	<.0001
Student	2	Student	5	<.0001
Student	2	Student	8	<.0001
Student	2	Student	9	<.0001
Student	2	Student	10	<.0001
Student	2	Professional	3	0.017
Student	2	Professional	4	0.001
Student	2	Professional	5	<.0001
Student	2	Professional	8	<.0001
Student	2	Professional	9	0.006
Student	2	Professional	10	0.01
Student	3	Student	5	<.0001
Student	3	Student	6	<.0001
Student	3	Student	7	<.0001
Student	3	Student	8	<.0001
Student	3	Student	9	0.018
Student	3	Professional	1	0.003
Student	3	Professional	5	0.003
Student	3	Professional	8	0.021
Student	4	Student	5	<.0001

Student	4	Student	6	<.0001
Student	4	Student	7	<.0001
Student	4	Student	8	<.0001
Student	4	Professional	1	0.007
Student	4	Professional	5	0.001
Student	4	Professional	8	0.009
Student	5	Student	6	<.0001
Student	5	Student	7	<.0001
Student	5	Student	9	<.0001
Student	5	Student	10	<.0001
Student	5	Professional	1	<.0001
Student	5	Professional	2	0.005
Student	5	Professional	6	0.004
Student	5	Professional	7	0.026
Student	6	Student	8	<.0001
Student	6	Student	9	0.002
Student	6	Student	10	3E-04
Student	6	Professional	4	0.007
Student	6	Professional	5	<.0001
Student	6	Professional	8	2E-04
Student	6	Professional	9	0.027
Student	6	Professional	10	0.047
Student	7	Student	8	<.0001
Student	7	Student	9	<.0001
Student	7	Student	10	<.0001
Student	7	Professional	3	0.018
Student	7	Professional	4	0.001
Student	7	Professional	5	<.0001
Student	7	Professional	8	<.0001
Student	7	Professional	9	0.006
Student	7	Professional	10	0.011

Student	8	Student	9	<.0001
Student	8	Student	10	<.0001
Student	8	Professional	1	<.0001
Student	8	Professional	2	0.003
Student	8	Professional	6	0.002
Student	8	Professional	7	0.015
Student	9	Professional	1	0.019
Student	9	Professional	5	3E-04
Student	9	Professional	8	0.003
Student	10	Professional	1	0.012
Student	10	Professional	5	6E-04
Student	10	Professional	8	0.005
Professional	1	Professional	2	0.001
Professional	1	Professional	3	<.0001
Professional	1	Professional	4	<.0001
Professional	1	Professional	5	<.0001
Professional	1	Professional	6	0.003
Professional	1	Professional	7	<.0001
Professional	1	Professional	8	<.0001
Professional	1	Professional	9	<.0001
Professional	1	Professional	10	<.0001
Professional	2	Professional	3	0.001
Professional	2	Professional	4	<.0001
Professional	2	Professional	5	<.0001
Professional	2	Professional	8	<.0001
Professional	2	Professional	9	<.0001
Professional	2	Professional	10	3E-04
Professional	3	Professional	4	0.035
Professional	3	Professional	5	<.0001
Professional	3	Professional	6	4E-04
Professional	3	Professional	8	<.0001

Professional	4	Professional	5	<.0001
Professional	4	Professional	6	<.0001
Professional	4	Professional	7	<.0001
Professional	4	Professional	8	0.007
Professional	5	Professional	6	<.0001
Professional	5	Professional	7	<.0001
Professional	5	Professional	9	<.0001
Professional	5	Professional	10	<.0001
Professional	6	Professional	8	<.0001
Professional	6	Professional	9	<.0001
Professional	6	Professional	10	<.0001
Professional	7	Professional	8	<.0001
Professional	7	Professional	9	0.005
Professional	7	Professional	10	0.02
Professional	8	Professional	9	<.0001
Professional	8	Professional	10	<.0001

Table O18 Significant interaction of experience level and exercise in BRA, p values provided for significant differences between the two levels in the interaction.

Experience 1	Exercise 1	Experience 2	Exercise 2	P
Student	1	Student	3	<.0001
Student	1	Student	4	<.0001
Student	1	Student	5	<.0001
Student	1	Student	6	<.0001
Student	1	Student	7	0.0068
Student	1	Student	8	<.0001
Student	1	Student	9	<.0001
Student	1	Student	10	<.0001
Student	2	Student	3	<.0001

Student	2	Student	4	<.0001
Student	2	Student	5	<.0001
Student	2	Student	6	<.0001
Student	2	Student	7	<.0001
Student	2	Student	8	<.0001
Student	2	Student	9	<.0001
Student	2	Student	10	<.0001
Student	3	Student	5	0.0274
Student	3	Student	7	0.0016
Student	4	Student	5	0.0078
Student	4	Student	7	0.0068
Student	5	Student	6	0.0004
Student	5	Student	7	<.0001
Student	5	Student	8	0.0124
Student	5	Student	10	0.0008
Student	7	Student	8	0.0042
Student	7	Student	9	0.0004
Student	7	Student	10	0.0452
Professional	1	Professional	3	0.0055
Professional	1	Professional	4	0.0067
Professional	1	Professional	6	0.0002
Professional	1	Professional	7	0.0224
Professional	1	Professional	9	<.0001
Professional	1	Professional	10	<.0001
Professional	2	Professional	6	0.0155
Professional	2	Professional	9	0.0008
Professional	2	Professional	10	0.0065
Professional	4	Professional	9	0.0485
Professional	5	Professional	6	0.0435
Professional	5	Professional	9	0.0031
Professional	5	Professional	10	0.0202

Professional	6	Professional	8	0.0037
Professional	7	Professional	9	0.0164
Professional	8	Professional	9	0.0001
Professional	8	Professional	10	0.0014

Table O19 Significant interaction of experience level and exercise in FCU, p values provided for significant differences between the two levels in the interaction.

Experience 1	Exercise 1	Experience 2	Exercise 2	P
Student	1	Student	2	<.0001
Student	1	Student	3	<.0001
Student	1	Student	4	<.0001
Student	1	Student	5	<.0001
Student	1	Student	6	0.0042
Student	1	Student	8	<.0001
Student	1	Student	9	<.0001
Student	1	Student	10	<.0001
Student	1	Professional	3	0.0001
Student	1	Professional	4	<.0001
Student	1	Professional	5	<.0001
Student	1	Professional	6	0.0031
Student	1	Professional	8	<.0001
Student	1	Professional	9	<.0001
Student	1	Professional	10	<.0001
Student	2	Student	3	<.0001
Student	2	Student	4	<.0001
Student	2	Student	5	<.0001
Student	2	Student	6	<.0001
Student	2	Student	7	<.0001
Student	2	Student	8	<.0001
Student	2	Student	9	<.0001
Student	2	Student	10	<.0001
Student	2	Professional	1	0.0006
Student	2	Professional	2	0.0023
Student	2	Professional	3	<.0001
Student	2	Professional	4	<.0001
Student	2	Professional	5	<.0001
Student	2	Professional	6	<.0001
Student	2	Professional	7	0.0002

Student	2	Professional	8	<.0001
Student	2	Professional	9	<.0001
Student	2	Professional	10	<.0001
Student	3	Student	4	0.0313
Student	3	Student	5	<.0001
Student	3	Student	6	<.0001
Student	3	Student	7	<.0001
Student	3	Student	8	<.0001
Student	3	Student	10	0.0143
Student	3	Professional	1	0.0105
Student	3	Professional	2	0.0029
Student	3	Professional	4	0.0368
Student	3	Professional	5	<.0001
Student	3	Professional	7	0.0295
Student	3	Professional	8	0.0007
Student	4	Student	5	<.0001
Student	4	Student	6	<.0001
Student	4	Student	7	<.0001
Student	4	Student	8	<.0001
Student	4	Student	9	0.0009
Student	4	Student	10	<.0001
Student	4	Professional	1	0.0011
Student	4	Professional	2	0.0003
Student	4	Professional	5	0.001
Student	4	Professional	7	0.0036
Student	4	Professional	8	0.0068
Student	5	Student	6	<.0001
Student	5	Student	7	<.0001
Student	5	Student	8	0.0137
Student	5	Student	9	<.0001
Student	5	Student	10	<.0001
Student	5	Professional	1	<.0001
Student	5	Professional	2	<.0001
Student	5	Professional	3	0.0037
Student	5	Professional	6	0.0002
Student	5	Professional	7	<.0001
Student	5	Professional	9	0.023
Student	5	Professional	10	0.0086
Student	6	Student	7	0.0205
Student	6	Student	8	<.0001
Student	6	Student	9	<.0001

Student	6	Student	10	<.0001
Student	6	Professional	3	0.0034
Student	6	Professional	4	<.0001
Student	6	Professional	5	<.0001
Student	6	Professional	6	0.0488
Student	6	Professional	8	<.0001
Student	6	Professional	9	0.0005
Student	6	Professional	10	0.0014
Student	7	Student	8	<.0001
Student	7	Student	9	<.0001
Student	7	Student	10	<.0001
Student	7	Professional	3	0.0003
Student	7	Professional	4	<.0001
Student	7	Professional	5	<.0001
Student	7	Professional	6	0.0055
Student	7	Professional	8	<.0001
Student	7	Professional	9	<.0001
Student	7	Professional	10	0.0001
Student	8	Student	9	<.0001
Student	8	Student	10	<.0001
Student	8	Professional	1	<.0001
Student	8	Professional	2	<.0001
Student	8	Professional	3	0.0398
Student	8	Professional	6	0.0026
Student	8	Professional	7	<.0001
Student	9	Professional	1	0.0318
Student	9	Professional	2	0.0095
Student	9	Professional	4	0.0124
Student	9	Professional	5	<.0001
Student	9	Professional	8	0.0002
Student	10	Professional	2	0.0317
Student	10	Professional	4	0.0034
Student	10	Professional	5	<.0001
Student	10	Professional	8	<.0001
Student	10	Professional	9	0.044
Professional	1	Professional	3	<.0001
Professional	1	Professional	4	<.0001
Professional	1	Professional	5	<.0001
Professional	1	Professional	6	0.0013
Professional	1	Professional	8	<.0001
Professional	1	Professional	9	<.0001

Professional	1	Professional	10	<.0001
Professional	2	Professional	3	<.0001
Professional	2	Professional	4	<.0001
Professional	2	Professional	5	<.0001
Professional	2	Professional	6	<.0001
Professional	2	Professional	8	<.0001
Professional	2	Professional	9	<.0001
Professional	2	Professional	10	<.0001
Professional	3	Professional	4	0.0022
Professional	3	Professional	5	<.0001
Professional	3	Professional	7	<.0001
Professional	3	Professional	8	<.0001
Professional	4	Professional	5	0.0001
Professional	4	Professional	6	<.0001
Professional	4	Professional	7	<.0001
Professional	4	Professional	8	0.0078
Professional	4	Professional	10	0.0125
Professional	5	Professional	6	<.0001
Professional	5	Professional	7	<.0001
Professional	5	Professional	9	<.0001
Professional	5	Professional	10	<.0001
Professional	6	Professional	7	0.0128
Professional	6	Professional	8	<.0001
Professional	6	Professional	9	0.0016
Professional	6	Professional	10	0.014
Professional	7	Professional	8	<.0001
Professional	7	Professional	9	<.0001
Professional	7	Professional	10	<.0001
Professional	8	Professional	9	<.0001
Professional	8	Professional	10	<.0001

Experience * Position, notes

Table O20 Significant interaction of experience level and position within the performance of notes in ECR, p values provided for significant differences between the two levels in the interaction.

Experience 1	Position 1	Experience 2	Position 2	P
1	1	1	3	0.0013

Position*Note

Table O21 Significant interaction of thumb-rest position (position) and note in APB, p values provided for significant differences between the two levels in the interaction.

Position 1	Note 1	Position 2	Note 2	P
HR	1	NR	1	0.0165
HR	1	NR	2	0.0034
HR	1	NR	8	0.0034
HR	1	LR	1	<.0001
HR	1	LR	2	<.0001
HR	1	LR	5	0.0203
HR	1	LR	10	0.0223
HR	2	NR	1	0.0237
HR	2	NR	2	0.0053
HR	2	NR	8	0.0053
HR	2	LR	1	<.0001
HR	2	LR	2	<.0001
HR	2	LR	5	0.0289
HR	2	LR	10	0.0318
HR	3	HR	8	0.0302
HR	3	NR	1	0.0064
HR	3	NR	2	0.0011
HR	3	NR	8	0.0011
HR	3	NR	9	0.0474
HR	3	LR	1	<.0001
HR	3	LR	2	<.0001
HR	3	LR	5	0.008
HR	3	LR	6	0.0413
HR	3	LR	10	0.0089
HR	4	NR	1	0.0185
HR	4	NR	2	0.004
HR	4	NR	8	0.004
HR	4	LR	1	<.0001
HR	4	LR	2	<.0001
HR	4	LR	5	0.0227
HR	4	LR	10	0.0251
HR	5	HR	8	0.0179
HR	5	NR	1	0.0039

HR	5	NR	2	0.0007
HR	5	NR	8	0.0007
HR	5	NR	9	0.032
HR	5	LR	1	<.0001
HR	5	LR	2	<.0001
HR	5	LR	5	0.0049
HR	5	LR	6	0.0276
HR	5	LR	10	0.0055
HR	6	HR	8	0.0218
HR	6	NR	1	0.0047
HR	6	NR	2	0.0008
HR	6	NR	8	0.0008
HR	6	NR	9	0.0371
HR	6	LR	1	<.0001
HR	6	LR	2	<.0001
HR	6	LR	5	0.0059
HR	6	LR	6	0.0321
HR	6	LR	10	0.0066
HR	7	HR	8	0.0369
HR	7	NR	1	0.0077
HR	7	NR	2	0.0014
HR	7	NR	8	0.0014
HR	7	LR	1	<.0001
HR	7	LR	2	<.0001
HR	7	LR	5	0.0096
HR	7	LR	6	0.0481
HR	7	LR	10	0.0107
HR	8	HR	10	0.0334
HR	8	NR	7	0.0453
HR	8	LR	1	<.0001
HR	8	LR	2	0.0002
HR	9	NR	1	0.0303
HR	9	NR	2	0.007
HR	9	NR	8	0.007
HR	9	LR	1	<.0001
HR	9	LR	2	<.0001
HR	9	LR	5	0.0367
HR	9	LR	10	0.0402
HR	10	LR	1	0.007

HR	10	LR	2	0.0013
HR	10	LR	8	0.0013
HR	10	LR	1	<.0001
HR	10	LR	2	<.0001
HR	10	LR	5	0.0088
HR	10	LR	6	0.0446
HR	10	LR	10	0.0098
NR	1	NR	3	0.007
NR	1	NR	4	0.0157
NR	1	NR	6	0.0108
NR	1	NR	7	0.0002
NR	1	LR	1	0.0029
NR	1	LR	2	0.0063
NR	1	LR	4	0.0317
NR	1	LR	7	0.0064
NR	2	NR	3	0.0008
NR	2	NR	4	0.0021
NR	2	NR	5	0.0164
NR	2	NR	6	0.0013
NR	2	NR	7	<.0001
NR	2	NR	10	0.0342
NR	2	LR	1	0.0141
NR	2	LR	2	0.0276
NR	2	LR	3	0.0167
NR	2	LR	4	0.0074
NR	2	LR	7	0.0012
NR	3	NR	8	0.0008
NR	3	LR	1	<.0001
NR	3	LR	2	<.0001
NR	3	LR	5	0.0348
NR	3	LR	10	0.0381
NR	4	NR	8	0.0021
NR	4	LR	1	<.0001
NR	4	LR	2	<.0001
NR	5	NR	8	0.0164
NR	5	LR	1	<.0001
NR	5	LR	2	<.0001
NR	6	NR	8	0.0013
NR	6	LR	1	<.0001

NR	6	LR	2	<.0001
NR	6	LR	5	0.0465
NR	7	NR	8	<.0001
NR	7	NR	9	0.0062
NR	7	NR	10	0.026
NR	7	LR	1	<.0001
NR	7	LR	2	<.0001
NR	7	LR	5	0.0039
NR	7	LR	6	0.0225
NR	7	LR	10	0.0043
NR	8	NR	10	0.0342
NR	8	LR	1	0.014
NR	8	LR	2	0.0276
NR	8	LR	3	0.0167
NR	8	LR	4	0.0074
NR	8	LR	7	0.0012
NR	9	LR	1	0.0002
NR	9	LR	2	0.0005
NR	9	LR	7	0.0477
NR	10	LR	1	<.0001
NR	10	LR	2	0.0001
LR	1	LR	3	<.0001
LR	1	LR	4	<.0001
LR	1	LR	5	0.0002
LR	1	LR	6	<.0001
LR	1	LR	7	<.0001
LR	1	LR	8	<.0001
LR	1	LR	9	<.0001
LR	1	LR	10	0.0001
LR	2	LR	3	<.0001
LR	2	LR	4	<.0001
LR	2	LR	5	0.0005
LR	2	LR	6	<.0001
LR	2	LR	7	<.0001
LR	2	LR	8	<.0001
LR	2	LR	9	<.0001
LR	2	LR	10	0.0004
LR	3	LR	5	0.0282
LR	3	LR	10	0.0317

LR	4	LR	5	0.0107
LR	4	LR	10	0.0122
LR	5	LR	7	0.0011
LR	6	LR	7	0.012
LR	7	LR	10	0.0013

Position*Exercise

Table O22 Significant interaction of thumb-rest position (position) and exercise in APB, p values provided for significant differences between the two levels in the interaction.

Position 1	Exercise 2	Position 2	Exercise 2	P
HR	1	HR	4	0.0315
HR	1	HR	5	0.0217
HR	1	HR	8	0.0442
HR	1	NR	1	0.002
HR	1	NR	2	<.0001
HR	1	NR	7	0.0338
HR	1	LR	1	0.0009
HR	1	LR	2	<.0001
HR	2	NR	2	<.0001
HR	2	LR	9	0.0243
HR	3	NR	2	<.0001
HR	4	NR	1	<.0001
HR	4	NR	2	<.0001
HR	4	NR	9	0.0499
HR	5	LR	1	<.0001
HR	5	LR	6	0.0418
HR	5	LR	7	<.0001
HR	5	LR	9	<.0001
HR	6	NR	1	<.0001
HR	6	NR	2	<.0001
HR	6	NR	7	0.0006

HR	6	LR	1	<.0001
HR	6	LR	7	<.0001
HR	6	LR	9	0.0003
HR	7	NR	1	0.0002
HR	7	NR	7	0.0064
HR	7	LR	1	<.0001
HR	7	LR	2	<.0001
HR	7	LR	7	<.0001
HR	7	LR	9	0.0037
HR	8	NR	1	<.0001
HR	8	NR	2	<.0001
HR	8	NR	7	0.0004
HR	8	LR	1	<.0001
HR	8	LR	2	<.0001
HR	8	LR	3	0.0262
HR	8	LR	7	<.0001
HR	8	LR	9	0.0002
HR	9	NR	1	<.0001
HR	9	NR	2	<.0001
HR	9	NR	7	0.0008
HR	9	LR	1	<.0001
HR	9	LR	2	<.0001
HR	9	LR	3	0.043
HR	9	LR	7	<.0001
HR	9	LR	9	0.0004
HR	10	NR	1	<.0001
HR	10	NR	2	<.0001
HR	10	NR	7	0.0005
HR	10	LR	1	<.0001
HR	10	LR	2	<.0001
HR	10	LR	3	0.0291

HR	10	LR	7	<.0001
HR	10	LR	9	0.0003
NR	1	NR	3	<.0001
NR	1	NR	4	<.0001
NR	1	NR	5	<.0001
NR	1	NR	6	<.0001
NR	1	NR	8	<.0001
NR	1	NR	9	0.0002
NR	1	NR	10	<.0001
NR	1	LR	2	0.0403
NR	1	LR	3	0.0185
NR	1	LR	4	0.0006
NR	1	LR	5	<.0001
NR	1	LR	6	0.0061
NR	1	LR	8	0.0003
NR	1	LR	10	0.0061
NR	2	NR	3	<.0001
NR	2	NR	4	<.0001
NR	2	NR	5	<.0001
NR	2	NR	6	<.0001
NR	2	NR	7	0.0045
NR	2	NR	8	<.0001
NR	2	NR	9	<.0001
NR	2	NR	10	<.0001
NR	2	LR	3	0.0007
NR	2	LR	4	<.0001
NR	2	LR	5	<.0001
NR	2	LR	6	0.0002
NR	2	LR	8	<.0001
NR	2	LR	10	0.0002
NR	3	NR	5	0.0044

NR	3	NR	7	0.0107
NR	3	LR	1	0.002
NR	3	LR	2	<.0001
NR	3	LR	5	0.0252
NR	3	LR	7	<.0001
NR	3	LR	9	0.0405
NR	4	NR	7	<.0001
NR	4	LR	1	<.0001
NR	4	LR	2	<.0001
NR	4	LR	7	<.0001
NR	4	LR	9	0.0021
NR	5	NR	6	0.0172
NR	5	NR	7	<.0001
NR	5	NR	8	0.0252
NR	5	NR	9	0.0025
NR	5	NR	10	0.0269
NR	5	LR	1	<.0001
NR	5	LR	2	<.0001
NR	5	LR	3	0.0101
NR	5	LR	6	0.029
NR	5	LR	7	<.0001
NR	5	LR	9	<.0001
NR	5	LR	10	0.029
NR	6	NR	7	0.0025
NR	6	LR	1	0.0006
NR	6	LR	2	<.0001
NR	6	LR	7	<.0001
NR	6	LR	9	0.017
NR	7	NR	8	0.0016
NR	7	NR	9	0.0175
NR	7	NR	10	0.0014

NR	7	LR	2	0.0026
NR	7	LR	4	0.0136
NR	7	LR	5	<.0001
NR	7	LR	7	0.0047
NR	7	LR	8	0.0078
NR	8	LR	1	0.0004
NR	8	LR	2	<.0001
NR	8	LR	7	<.0001
NR	8	LR	9	0.0128
NR	9	LR	1	0.0031
NR	9	LR	2	<.0001
NR	9	LR	5	0.018
NR	9	LR	7	<.0001
NR	10	LR	1	0.0004
NR	10	LR	2	<.0001
NR	10	LR	7	<.0001
NR	10	LR	9	0.0122
LR	1	LR	2	0.0144
LR	1	LR	3	0.0004
LR	1	LR	4	<.0001
LR	1	LR	5	<.0001
LR	1	LR	6	<.0001
LR	1	LR	7	0.029
LR	1	LR	8	<.0001
LR	1	LR	10	<.0001
LR	2	LR	3	<.0001
LR	2	LR	4	<.0001
LR	2	LR	5	<.0001
LR	2	LR	6	<.0001
LR	2	LR	8	<.0001
LR	2	LR	9	<.0001

LR	2	LR	10	<.0001
LR	3	LR	5	0.0002
LR	3	LR	7	<.0001
LR	3	LR	9	0.0341
LR	4	LR	5	0.0255
LR	4	LR	7	<.0001
LR	4	LR	9	0.0003
LR	5	LR	6	0.0014
LR	5	LR	7	<.0001
LR	5	LR	9	<.0001
LR	5	LR	10	0.0014
LR	6	LR	7	<.0001
LR	6	LR	9	0.0078
LR	7	LR	8	<.0001
LR	7	LR	9	0.0003
LR	7	LR	10	<.0001
LR	8	LR	9	0.0001
LR	9	LR	10	0.0078

Table O23 Significant interaction of thumb-rest position (position) and exercise in APL, p values provided for significant differences between the two levels in the interaction.

Position 1	Exercise 1	Position 2	Exercise 2	P
HR	1	HR	3	<.0001
HR	1	HR	4	0.0021
HR	1	HR	5	<.0001
HR	1	HR	6	<.0001
HR	1	HR	8	<.0001
HR	1	HR	9	0.016
HR	1	NR	1	0.0451
HR	1	NR	3	<.0001

HR	1	NR	4	<.0001
HR	1	NR	5	<.0001
HR	1	NR	6	<.0001
HR	1	NR	7	0.0015
HR	1	NR	8	<.0001
HR	1	NR	9	0.0001
HR	1	NR	10	0.002
HR	1	LR	1	<.0001
HR	1	LR	2	<.0001
HR	1	LR	3	<.0001
HR	1	LR	4	<.0001
HR	1	LR	5	<.0001
HR	1	LR	6	<.0001
HR	1	LR	7	<.0001
HR	1	LR	8	<.0001
HR	1	LR	9	<.0001
HR	1	LR	10	<.0001
HR	2	HR	3	<.0001
HR	2	HR	5	<.0001
HR	2	HR	6	0.0033
HR	2	HR	8	<.0001
HR	2	NR	3	<.0001
HR	2	NR	4	<.0001
HR	2	NR	5	<.0001
HR	2	NR	6	0.0001
HR	2	NR	7	0.0281
HR	2	NR	8	<.0001
HR	2	NR	9	0.0047
HR	2	LR	1	<.0001
HR	2	LR	2	<.0001
HR	3	HR	6	0.0124

HR	3	HR	8	0.0285
HR	3	HR	9	<.0001
HR	3	NR	1	0.0004
HR	3	LR	3	<.0001
HR	3	LR	4	0.0002
HR	3	LR	5	<.0001
HR	3	LR	6	0.0007
HR	3	LR	7	0.0235
HR	3	LR	8	<.0001
HR	4	HR	7	0.0285
HR	4	NR	2	0.0148
HR	4	LR	2	0.0013
HR	4	LR	5	<.0001
HR	4	LR	6	<.0001
HR	4	LR	10	<.0001
HR	5	HR	6	<.0001
HR	5	HR	7	<.0001
HR	5	HR	10	<.0001
HR	5	NR	6	0.0017
HR	5	LR	8	0.005
HR	6	NR	4	0.0063
HR	6	LR	3	<.0001
HR	6	LR	4	<.0001
HR	6	LR	5	<.0001
HR	6	LR	6	<.0001
HR	6	LR	8	<.0001
HR	7	HR	8	<.0001
HR	7	NR	3	<.0001
HR	7	NR	7	0.0146
HR	7	NR	9	0.0021
HR	7	LR	1	<.0001

HR	7	LR	2	<.0001
HR	7	LR	3	<.0001
HR	7	LR	5	<.0001
HR	7	LR	6	<.0001
HR	7	LR	7	<.0001
HR	7	LR	8	<.0001
HR	7	LR	9	<.0001
HR	7	LR	10	<.0001
HR	8	HR	10	<.0001
HR	8	NR	1	<.0001
HR	8	NR	2	<.0001
HR	8	NR	5	0.007
HR	8	NR	6	0.0122
HR	8	NR	9	0.0004
HR	8	NR	10	<.0001
HR	8	LR	3	0.0006
HR	8	LR	5	<.0001
HR	8	LR	8	0.0006
HR	9	NR	3	<.0001
HR	9	NR	4	<.0001
HR	9	NR	5	<.0001
HR	9	NR	6	0.0043
HR	9	NR	8	<.0001
HR	9	LR	1	<.0001
HR	9	LR	2	0.0002
HR	9	LR	3	<.0001
HR	9	LR	4	<.0001
HR	9	LR	5	<.0001
HR	9	LR	6	<.0001
HR	9	LR	7	<.0001
HR	9	LR	8	<.0001

HR	9	LR	9	<.0001
HR	9	LR	10	<.0001
HR	10	NR	3	<.0001
HR	10	NR	4	<.0001
HR	10	NR	5	<.0001
HR	10	NR	6	0.0004
HR	10	NR	8	<.0001
HR	10	NR	9	0.0122
HR	10	LR	1	<.0001
HR	10	LR	2	<.0001
HR	10	LR	3	<.0001
HR	10	LR	4	<.0001
HR	10	LR	5	<.0001
HR	10	LR	6	<.0001
HR	10	LR	7	<.0001
HR	10	LR	8	<.0001
HR	10	LR	9	<.0001
HR	10	LR	10	<.0001
NR	1	NR	2	0.0262
NR	1	NR	3	<.0001
NR	1	NR	4	<.0001
NR	1	NR	5	<.0001
NR	1	NR	6	0.0006
NR	1	NR	8	<.0001
NR	1	NR	9	0.0282
NR	1	LR	1	<.0001
NR	1	LR	2	0.0002
NR	1	LR	3	<.0001
NR	1	LR	4	<.0001
NR	1	LR	5	<.0001
NR	1	LR	6	<.0001

NR	1	LR	7	<.0001
NR	1	LR	8	<.0001
NR	1	LR	9	<.0001
NR	1	LR	10	<.0001
NR	2	NR	3	<.0001
NR	2	NR	4	<.0001
NR	2	NR	5	<.0001
NR	2	NR	6	<.0001
NR	2	NR	7	0.0003
NR	2	NR	8	<.0001
NR	2	NR	9	<.0001
NR	2	NR	10	0.0004
NR	2	LR	1	<.0001
NR	2	LR	2	<.0001
NR	2	LR	3	<.0001
NR	2	LR	4	<.0001
NR	2	LR	5	<.0001
NR	2	LR	6	<.0001
NR	2	LR	7	<.0001
NR	2	LR	8	<.0001
NR	2	LR	9	<.0001
NR	2	LR	10	<.0001
NR	3	NR	5	0.0049
NR	3	NR	6	0.0007
NR	3	NR	7	<.0001
NR	3	NR	9	<.0001
NR	3	NR	10	<.0001
NR	3	LR	3	0.002
NR	3	LR	5	<.0001
NR	3	LR	8	0.0019
NR	4	NR	5	<.0001

NR	4	NR	7	0.0003
NR	4	NR	8	0.0017
NR	4	NR	9	0.0047
NR	4	NR	10	0.0002
NR	4	LR	3	<.0001
NR	4	LR	4	0.0019
NR	4	LR	5	<.0001
NR	4	LR	6	0.0054
NR	4	LR	8	<.0001
NR	4	LR	9	0.0323
NR	4	LR	10	0.0266
NR	5	NR	6	<.0001
NR	5	NR	7	<.0001
NR	5	NR	9	<.0001
NR	5	NR	10	<.0001
NR	5	LR	1	<.0001
NR	5	LR	2	<.0001
NR	5	LR	7	0.0233
NR	6	NR	7	0.0439
NR	6	NR	8	<.0001
NR	6	NR	10	0.0338
NR	6	LR	3	<.0001
NR	6	LR	4	<.0001
NR	6	LR	5	<.0001
NR	6	LR	6	<.0001
NR	6	LR	7	0.0034
NR	6	LR	8	<.0001
NR	6	LR	9	0.0006
NR	6	LR	10	0.0004
NR	7	NR	8	<.0001
NR	7	LR	1	0.0036

NR	7	LR	2	0.0091
NR	7	LR	3	<.0001
NR	7	LR	4	<.0001
NR	7	LR	5	<.0001
NR	7	LR	6	<.0001
NR	7	LR	7	<.0001
NR	7	LR	8	<.0001
NR	7	LR	9	<.0001
NR	7	LR	10	<.0001
NR	8	NR	9	<.0001
NR	8	NR	10	<.0001
NR	8	LR	1	0.0066
NR	8	LR	2	0.0025
NR	8	LR	3	0.0447
NR	8	LR	5	0.0031
NR	8	LR	8	0.0432
NR	9	LR	1	0.0228
NR	9	LR	2	0.0484
NR	9	LR	3	<.0001
NR	9	LR	4	<.0001
NR	9	LR	5	<.0001
NR	9	LR	6	<.0001
NR	9	LR	7	<.0001
NR	9	LR	8	<.0001
NR	9	LR	9	<.0001
NR	9	LR	10	<.0001
NR	10	LR	1	0.0027
NR	10	LR	2	0.007
NR	10	LR	3	<.0001
NR	10	LR	4	<.0001
NR	10	LR	5	<.0001

NR	10	LR	6	<.0001
NR	10	LR	7	<.0001
NR	10	LR	8	<.0001
NR	10	LR	9	<.0001
NR	10	LR	10	<.0001
LR	1	LR	3	<.0001
LR	1	LR	4	0.0001
LR	1	LR	5	<.0001
LR	1	LR	6	0.0006
LR	1	LR	7	0.0409
LR	1	LR	8	<.0001
LR	1	LR	9	0.0078
LR	1	LR	10	0.0059
LR	2	LR	3	<.0001
LR	2	LR	4	<.0001
LR	2	LR	5	<.0001
LR	2	LR	6	0.0002
LR	2	LR	7	0.016
LR	2	LR	8	<.0001
LR	2	LR	9	0.0025
LR	2	LR	10	0.0018
LR	3	LR	6	0.0269
LR	3	LR	7	0.0003
LR	3	LR	9	0.0029
LR	3	LR	10	0.0038
LR	4	LR	5	0.003
LR	5	LR	6	0.0008
LR	5	LR	7	<.0001
LR	5	LR	9	<.0001
LR	5	LR	10	<.0001
LR	6	LR	8	0.0257

LR	7	LR	8	0.0003
LR	8	LR	9	0.0027
LR	8	LR	10	0.0036

APPENDIX P: DATA FIGURES

Rest Position

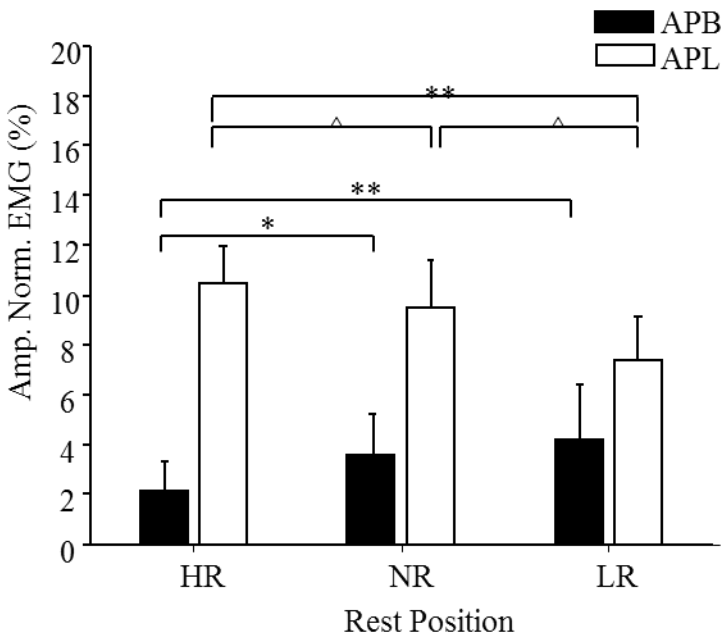


Figure P1 Mean (±SE) amplitude normalized EMG for APB and APL calculated across subjects and exercises for each rest position. Asterisks indicate significant differences between thumb-rest positions revealed by Tukey post-hoc. *p<0.05, **p<0.01, ^p<0.001

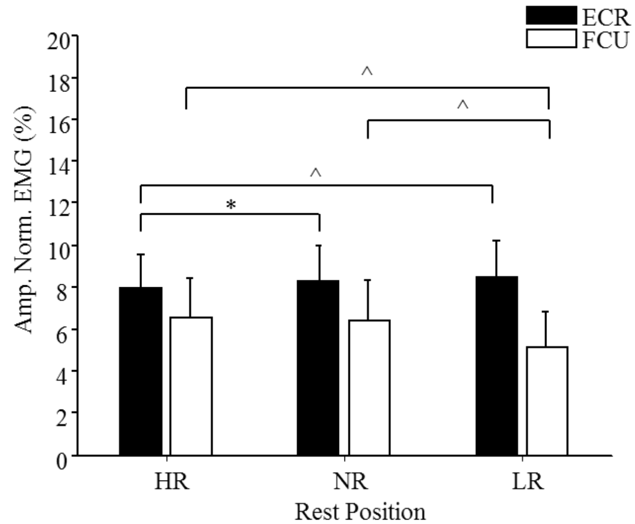


Figure P2 Mean (±SE) amplitude normalized EMG for ECR and FCU calculated across subjects and exercises for each thumb-rest position. Asterisks indicate significant differences between thumb-rest positions revealed by Tukey post-hoc. *p<0.05, **p<0.01, ^p<0.001

Exercise

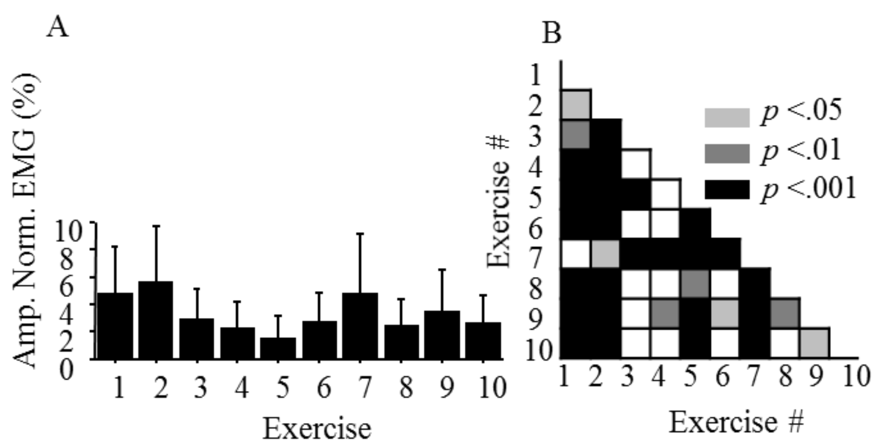


Figure P3 (A) Mean (±SE) amplitude normalized EMG for APB calculated across subjects and exercises. (B) Significant differences between exercises for APB muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels.

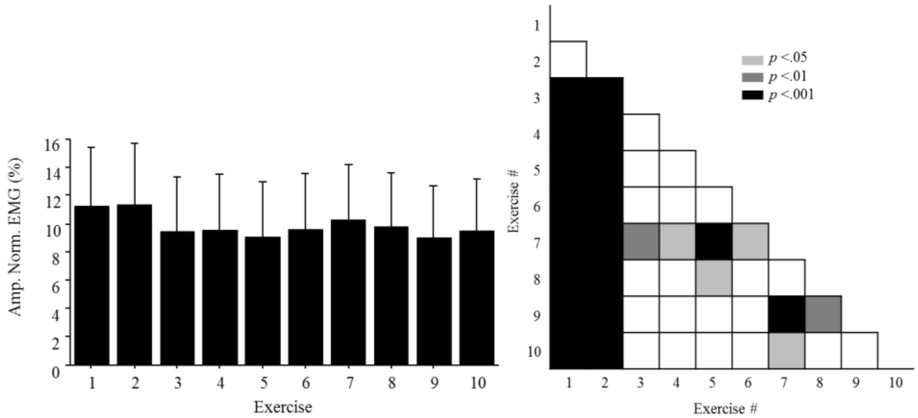


Figure P4 (A) Mean (±SE) amplitude normalized EMG for BRA calculated across subjects and exercises. (B) Significant differences between exercises for BRA muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

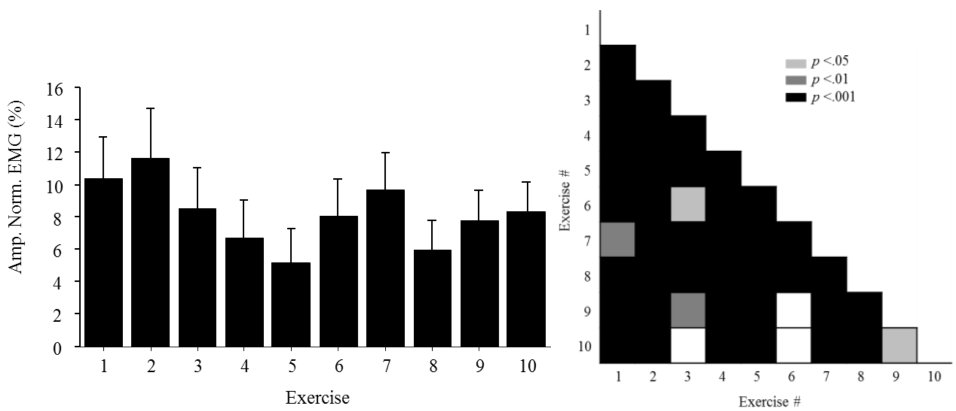


Figure P5 (A) Mean (±SE) amplitude normalized EMG for ECR calculated across subjects and exercises (B) Significant differences between exercises for ECR muscle activity across all subjects determined by Tukey post-hoc, color legend describes significance levels, white blocks are not significant.

Experience*Note

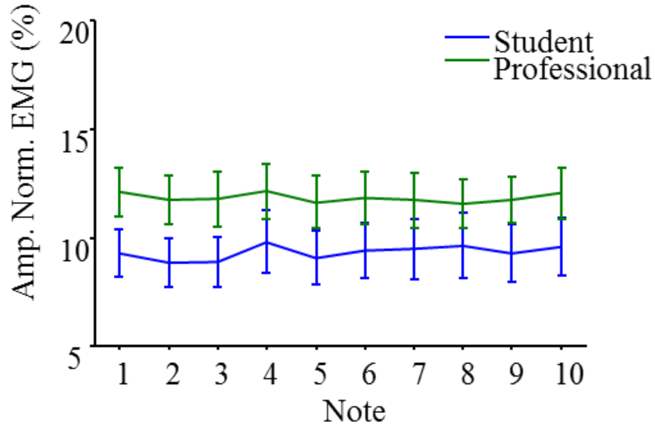


Figure P6 Mean (±SE) amplitude normalized EMG for TRI calculated across subjects for experience level and note.

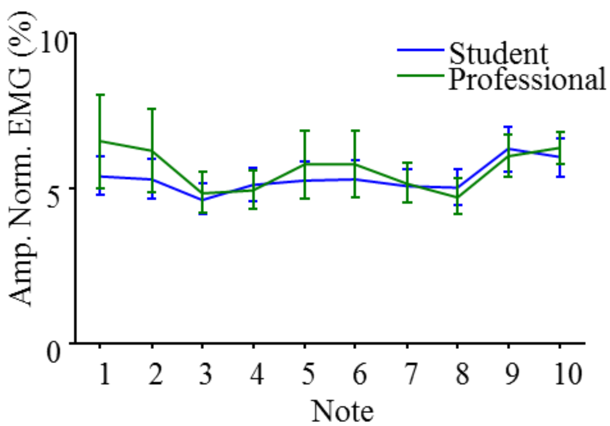


Figure P7 Mean (±SE) amplitude normalized EMG for ECR calculated across subjects for experience level and note

Experience*Exercise

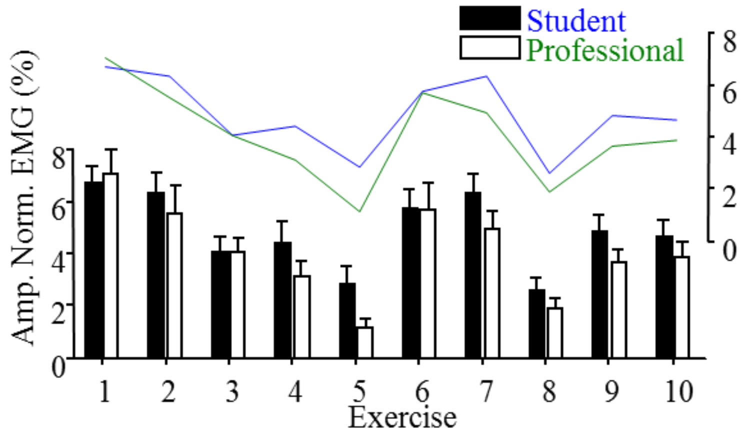


Figure P8 Mean (±SE) amplitude normalized EMG for FDI calculated across subjects and exercises for experience level (student, professional).

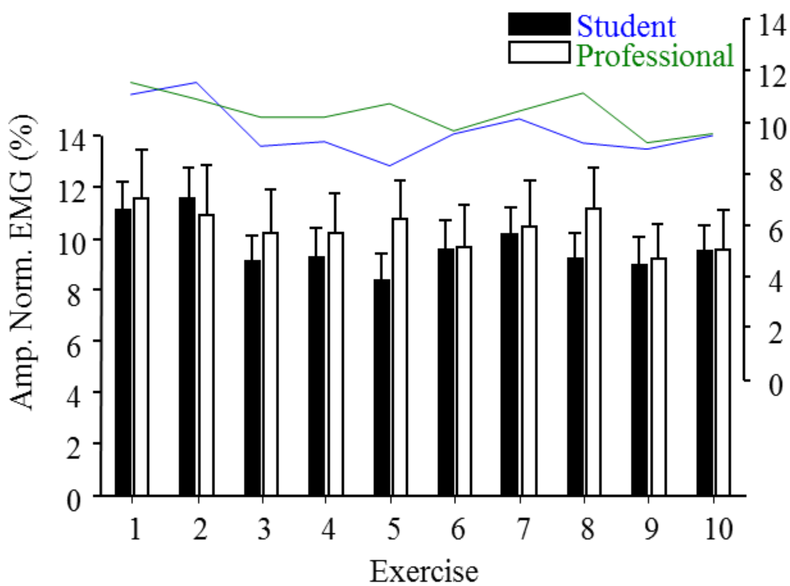


Figure P9 Mean (±SE) amplitude normalized EMG for BRA calculated across subjects and exercises for experience level (student, professional).

Size*Exercise

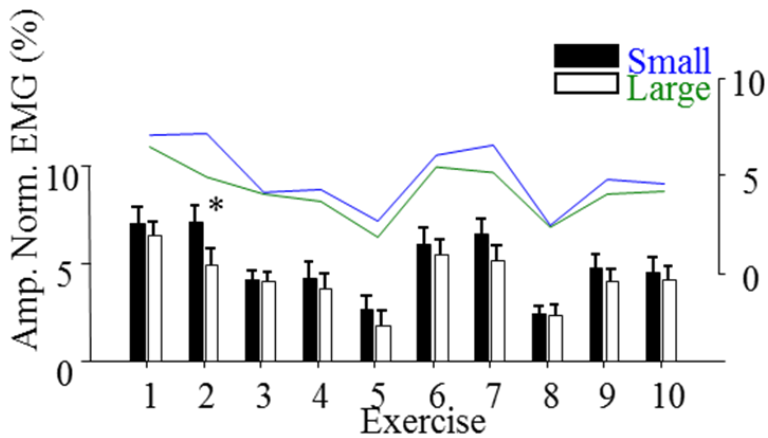


Figure P10. Mean (±SE) amplitude normalized EMG for APL calculated across subjects and exercises for hand size. Asterisks indicate significant differences between hand sizes on the same exercise in Tukey post-hoc. *p<0.05

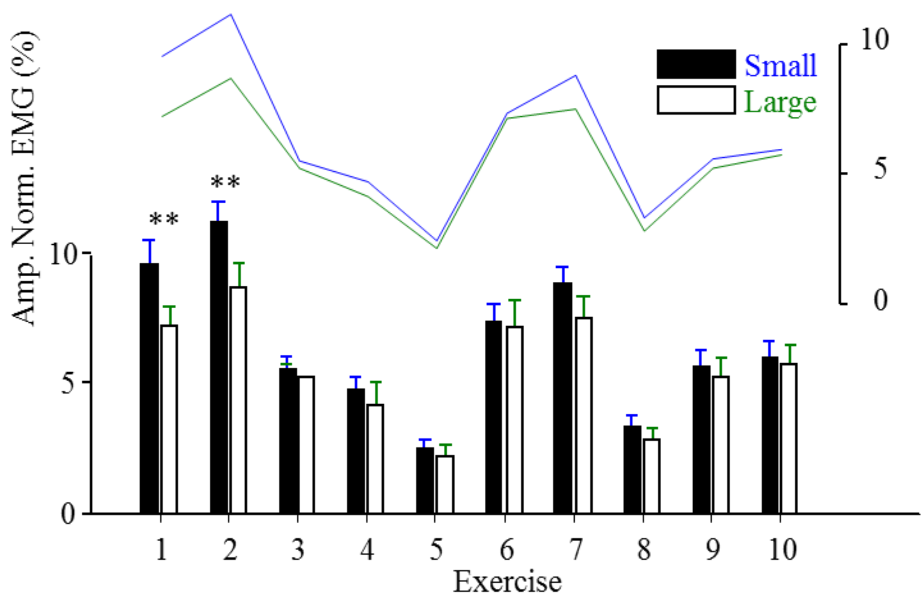


Figure P11 Mean (±SE) amplitude normalized EMG for FDI calculated across subjects and exercises for hand size. Asterisks indicates significant differences between hand size on the same exercise in Tukey post-hoc **p<0.01

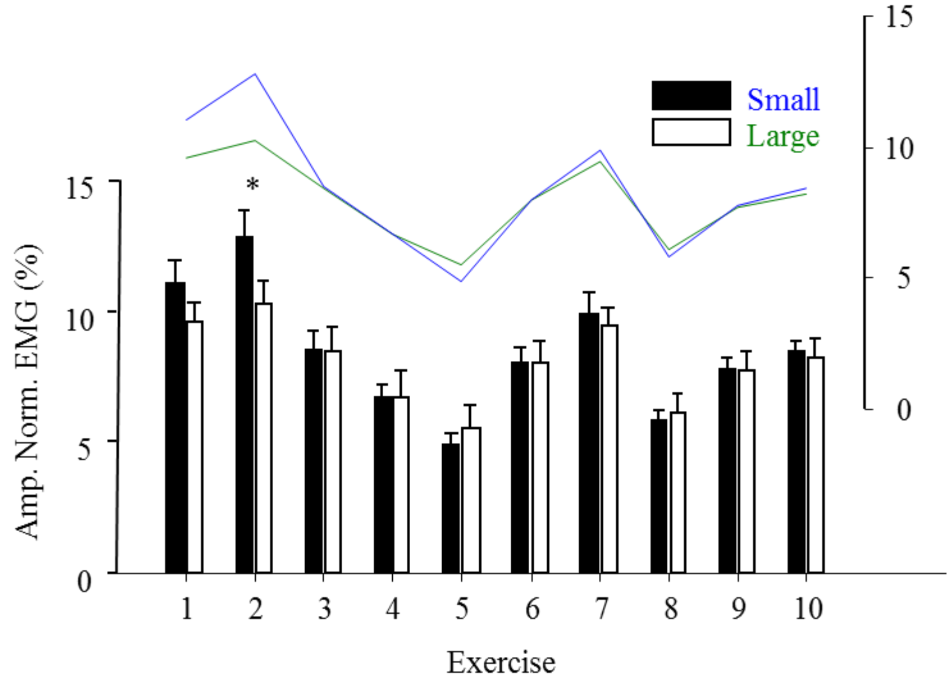


Figure P12 Mean (±SE) amplitude normalized EMG for ECR calculated across subjects and exercises for hand size. Asterisks indicates significant differences between hand size on the same exercise in Tukey post-hoc *p<0.05

APPENDIX Q: INTERNAL CONTROL OF ACUTE CHANGES

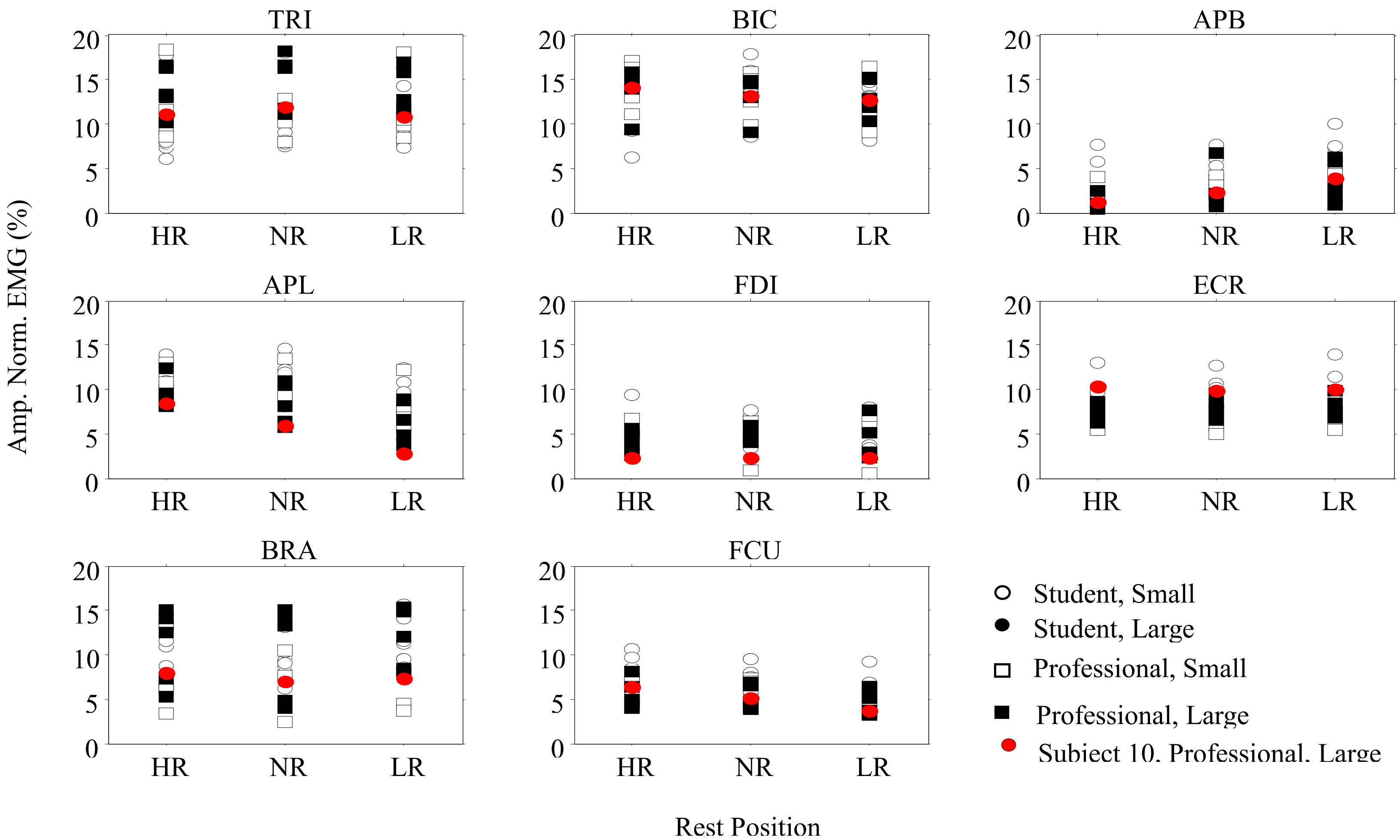


Figure Q1 Mean (±SE) amplitude normalized EMG for TRI, BIC, APB, APL, FDI, ECR, BRA, and FCU calculated across subjects and rest positions.

VITA

Kathryn Elise Young was born in 1987 to Peter and Cindy Young. She grew up with her younger sister, Becca, in Albany, New York. She is currently in her last semester of her Doctorate of Musical Arts degree, and expects to graduate December 19, 2014. She earned her Master of Music degree from LSU, Bachelor of Arts degree in Music and Brain and Cognitive Science from the University of Rochester and High School diploma from Bethlehem Central High School.

She is the Professor of Clarinet at the Louisiana College in Pineville, LA and also serves as Graduate Teaching Assistant for the Louisiana State University (LSU). Young works as a Bass, Eb, and soprano clarinetist with the Baton Rouge Symphony, Acadiana Symphony, and Opera Lousiane Company. She performs frequently in solo and chamber recitals each year. In addition to her positions at Louisiana College and LSU, she teaches private lessons at East Ascension High School, Grace Notes Music Studios, and her private home studio. She is a member of the International Clarinet Association, and served on the Artistic Organizing Committee for ClarinetFest 2014.