An Ultrasonographic Observation of Saxophonists' Tongue Positions

While Producing Front F Pitch Bends

by

Ryan C. Lemoine

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Graduate Supervisory Committee:

Joshua Gardner, Co-Chair
Christopher Creviston, Co-Chair
Sabine Feisst
Robert Spring

ARIZONA STATE UNIVERSITY

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ABSTRACT

Voicing, as it pertains to saxophone pedagogy, presents certain obstacles to both teachers and students simply because we cannot visually assess the internal mechanics of the vocal tract. The teacher is then left to instruct based on subjective "feel" which can lead to conflicting instruction, and in some cases, misinformation. In an effort to expand the understanding and pedagogical resources available, ten subjects—comprised of graduate-level and professional-level saxophonists—performed varied pitch bend tasks while their tongue motion was imaged ultrasonographically and recorded. Tongue range of motion was measured from midsagittal tongue contours extracted from the ultrasound data using a superimposed polar grid. The results indicate variations in how saxophonists shape their tongues in order to produce pitch bends from F6.

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CHAPTER 1

INTRODUCTION

Saxophone teachers address many concepts that may be difficult to convey to the student. Those topics pertaining to the internal mechanisms at work during saxophone performance may prove to be some of the most difficult to express. Exterior mechanisms, such as fingerings, posture, hand position, embouchure, etc., though not always necessarily simple topics to teach, afford us the advantage of clear visibility during performance, allowing the instructor to visually assess important information for determining the course of pedagogy. Contrary to observable technique, determining any tongue shape or articulation problems is reliant on indirect results or secondary observable phenomena, such as the sound quality produced or physical cues from the throat and mouth. This can prove quite frustrating for both the student and teacher, which has led to several studies designed to observe the vocal tract mechanics during performance to gain a better understanding of the internal mechanisms.

The current study wishes to provide a resource for saxophone pedagogy, to provide a visual aid for students and teacher when tackling the subject of vocal tract manipulation or voicing as well as to adapt an ultrasonography protocol for saxophone performance (Gardner, 2010). Further understanding of the tongue's motion during saxophone performance will improve upon the existing pedagogy. Pitch bends from the written F above the staff (hereafter referred to as F6) will be the primary focus of the current study. In order to discuss the topic, we must first understand the internal mechanisms that are in use.

Vocal Tract Anatomy

Mechanics within the oral cavity involved in vocal tract manipulation are a primary focus of this study; therefore, a brief anatomy introduction covering the oral cavity architecture is necessary. Many components of the oral cavity are involved in saxophone performance, including the tongue, palate, soft palate, and velum, along with the teeth, lips, and cheeks. For a more extensive overview of oral cavity physiology and function, please refer to Anatomy and Physiology for Speech, Language, and Hearing by Seikel, King, and Drumright (2005).

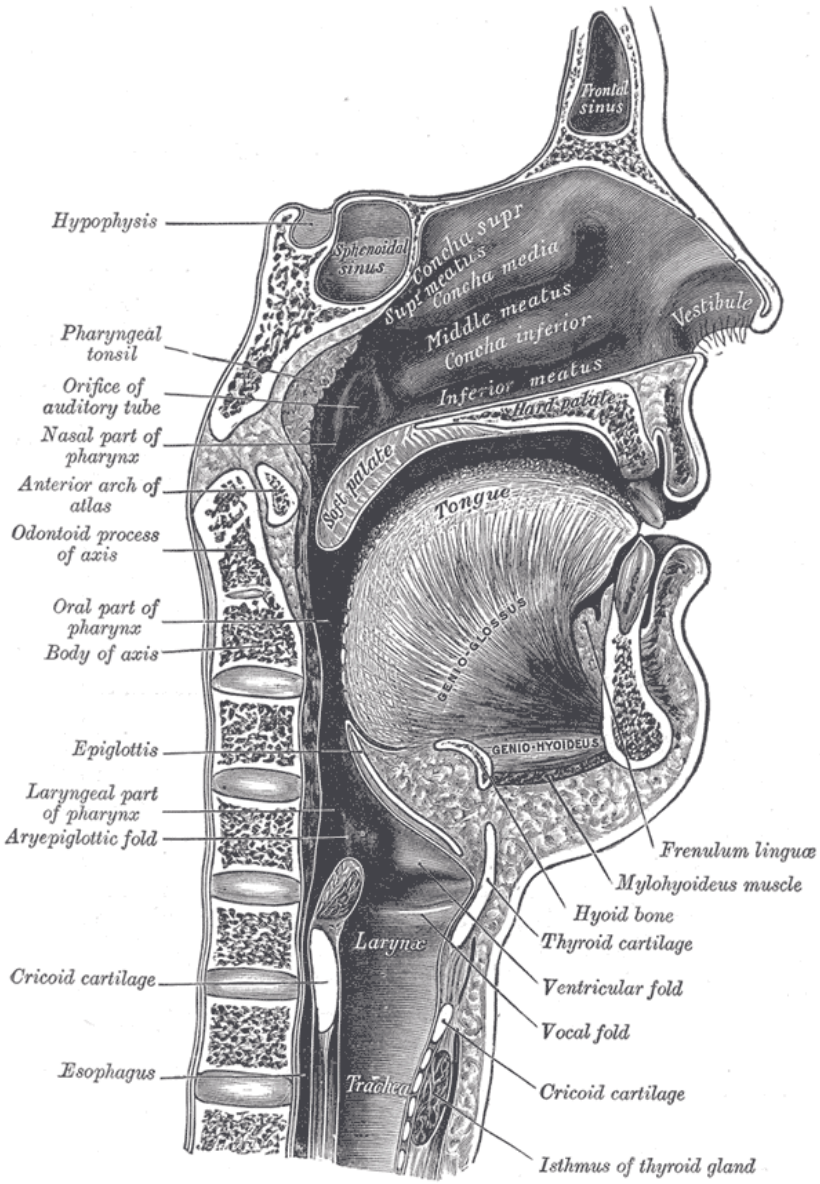
Tongue

The tongue, physically the largest mobile articulator, is largely involved during performance and speech (Seikel et al, 2005, p. 267). Rather than a singular muscle, the tongue is an organized set of intrinsic muscles controlling microstructure articulation being operated and positioned by extrinsic muscles (Seikel et al, 2005, p. 372-373). The tongue changes shape and position as muscles interact with one another without skeletal support—the tongue is a muscular hydrostat (Levine, 2005, p. 1). An example of a similar structure would be the trunk of an elephant. Even further, Levine et al (2005, p. 207-208) give a clearer explanation of the nature of tongue movement:

> Muscles can only shorten as a result of their own activation. To lengthen, a muscle must be acted upon by some force external to itself. In the case of the tongue, or any other muscular hydrostat, this force is created by the interaction of other muscles within the tongue with the incompressibility of the tongue. Thus, the control of the tongue depends on exploiting the dynamical interaction between the contraction of individual muscles and the incompressibility.

Four intrinsic muscles (Superior Longitudinal, Inferior Longitudinal, Transverse, and Vertical) control refined muscle movement, while five extrinsic muscles (Genioglossus, Hyoglossus, Styloglossus, Chondroglossus, and Palatoglossus) control large-scale motion (Seikel et al, 2005, p.372-374). The upper surface of the tongue is referred to as the dorsum (Seikel et al, 2005, p. 328-329). Dividing the tongue into left and right sections longitudinally is the median fibrous septum. The median fibrous septum also serves as an origin point for the system of operating muscles for the tongue (Seikel et al, 2005, p. 329).

Figure 1. Sagittal illustration of the vocal tract (Gray, 1918, plate 994).



Hard Palate

The hard palate is one of three immobile articulators—the other two being the teeth and alveolar ridge. All three of these articulators are major components to articulating speech phonemes. The hard palate is a boney structure that forms the upper barrier of the vocal tract and a divide between the nasal and oral cavities. The sloped structure leading to the hard palate from the front top teeth is called the alveolar ridge (Seikel et al, 2005, p. 268). The point where the hard palate transitions to the velum is the velar juncture, which is a point of reference later in this study.

Velum

The velum is most commonly referred to as the soft palate. Acting as another mobile articulator, the velum is a complex structure of soft tissue controlling access to the nasal cavity from the oral cavity (Seikel et al, 2005, p. 267). During non-nasal speech, the velum generally remains closed. The velum is closed for the duration of saxophone performance to allow the pressurized air to flow through the pharyngeal and oral cavities into the saxophone, with the exception of inhalation during the circular breathing process.

Ultrasound Imaging

Due to the nature of this study, some brief contextual knowledge of ultrasound technology is beneficial. The reader is directed to Hedrik, Hykes, and Starchman (2005), the text from which this section is derived, for further details.

Ultrasound is not a new technology for internal imaging. Bats, whales, as well as humans use the physical principles of ultrasound imaging—echolocation. The process involves the emission of focused sound waves, and using the timing of received sound wave reflections to identify and locate objects not directly visible.

Ultrasound technology involves the use of high frequency sound waves. These sound waves are created by the twisting of an array of piezoelectric crystals housed in the ultrasound transducer when a pulse of electrical current is applied to them. These crystals both transmit and receive sound waves. Sound waves react in a similar way as light waves in that they can reflect off the edge of an object in its path. Just as a light wave can give information about an object upon which it shines, sound waves also contribute information concerning an object's characteristics. The reflection from transmitted sound waves gives information regarding the reflecting object, mainly distance information along individual lines of sight relative to each crystal in the transducer. This distance information, along with some other properties, are used to produce an image.

The sounds waves pass through a given object until reaching an acoustic impedance mismatch, which causes the wave to reflect back to the transducer. Acoustic impedance is the product of a medium's density and the speed at which a sound wave will travel through that medium, or acoustic velocity. If a given medium and surrounding media have the same acoustic impedance, the sound will transfer from one medium to the other with little wave reflection. At an impedance mismatch, some of the sound is reflected back to transducer—the impedance difference will affect how much energy is reflected. It is this tissue heterogeneity that makes ultrasound imaging of soft tissue structures possible. The angle at which the sound waves arrive at the impedance mismatch affects the amount of reflection. At normal incidence (a 90 degree angle between sound wave and object surface), the sound wave will reflect directly back to the interface resulting in an optimal image. If the sound wave is directed at an angle other than 90 degrees to the object's surface, less sound is reflected back to the interface diminishing image clarity.

When imaging the tongue, an impedance mismatch is created between the tissue and air at the surface of the tongue. The sound waves reflect at this mismatch, providing information to create an image of the tongue surface. Because of this, when the tongue is pressed against the palatal bone, which occurs during swallowing, the reflection occurs where the tissue and bone contact.

Although ultrasound has proven to be an excellent method for imaging the tongue for quantitative and observational research, it is not without limitations. First, the submental window created by the hyoid and jaw bones affect how much of the tongue is visible. This window is reduced during saxophone performance by the forward motion of the hyoid bone as well as the front jaw bone. Another limitation concerning tongue imaging is that not all persons create clear images. There are many factors, none absolute, but generally young, thin, females produce higher quality images though poor images have been observed from young subjects and clear images from older subjects (Stone, 2005, p.462). Stone attributes these differences to the amount of fat in the tongue and possibly more moisture in the mouths of younger subjects. Although exact gender differences remain unclear, Stone discusses the smaller and smoother female tongue surface as a reason for clearer imaging (2005, p.462). Additionally, since the angle of incidence affects how much acoustic energy is reflected back to the transducer, steep tongue contours tend to produce poorer images than relatively flat contours.

Previous research exploring the musician's vocal tract and oral cavity during performance make use of various approaches such as fiber-optic (optical) and fluoroscopic (X-ray) imaging. Fiber-optic imaging provides clear color imaging of internal mechanisms that ultrasound cannot produce. A major limitation of fiber-optic imaging is that the scope must be inserted into the oral cavity through either the nasal cavity or the side of the musician's mouth. Both of these options inhibit the production of a realistic performance environment. Additionally, measurements are difficult to obtain since the scope position cannot be fixed relative to the structures being observed. Fluoroscopic research has also given great insight into the intraoral manipulation of voicing. Fluoroscopic imaging, while providing a clear image of internal structures, exposes the subject to ionizing X-ray radiation, which is a health risk. Fluoroscopy also produces two-dimensional images of three-dimensional objects, making measurements within a given plane difficult to obtain. Ultrasound is a safe and non-invasive method to observe the inner mechanisms of the oral cavity and vocal tract. The subject is exposed to little or no known health risks, and measurements can be taken with fixed reference to the subject’s cranium within a ~2 mm plane. These aspects make ultrasound a viable resource for tongue contour analysis.

CHAPTER 2

LITERATURE REVIEW

Saxophone performance involves both external and internal physical mechanisms. The external mechanisms include holding the instrument, general finger movement/technique, and embouchure placement, shape, and pressure. These elements are most readily associated with saxophone performance. Internal performance mechanisms include the tongue and mouth/vocal tract, lungs, diaphragm, and other muscles. Inhalation involves the lungs and diaphragm. *The Cambridge Companion to the Saxophone* (Horch, 1998, p. 77) covers the topic of inhalation by stating that the lungs are filled with air as a result of the diaphragm lowering in the chest cavity. Horch (1998, p. 77) describes exhalation as the reverse motion of the diaphragm, moving upward, then compressing the space in the chest cavity and lungs, forcing air out of the body and through the saxophone. Muscles can only actively shorten, and are not capable of an active reverse motion as described by Horch. Exhalation, pertaining to saxophone performance, involves an act of forced exhalation activated by the abdominal and intercostal muscles, accompanied by the relaxation of the diaphragm (Seikel et al, 2005, p. 34-35).

Another primary internal mechanism of saxophone performance is the tongue. The tongue has two different functions regarding saxophone performance: articulatory and non-articulatory. As an articulator, the tongue is placed against the vibrating reed to interrupt the sound being produced. Some extended techniques make use of the tongue as well. Flutter tongue requires the tongue to vibrate against the hard palate as air passes over it, similar to rolling an "r," thereby distorting the produced sound. The slap tongue technique involves the tongue creating a suction against the reed, which when released, produces a percussive sound as the reed is released by the tongue. Additionally, there are certain contributing elements toward the process of circular breathing, where the tongue and soft palate meet to isolate the oral and pharyngeal cavities, allowing the performer to inhale through the nose while maintaining outward airflow through the instrument.

The non-articulatory functions of the tongue are commonly referred to as *voicing* in the pedagogical literature. As defined by Donald Sinta (1992, p.2), "Voicing refers to an awareness and control of the muscles and soft flexible tissue in the oral cavity and vocal tract." The voicing technique strongly affects many facets of saxophone performance, as Sinta (1992, p.2) continues, "Playing the saxophone requires change in the configuration of our mouth, tongue, and throat which contributes directly to control over [saxophone] range, intonation, and dynamics." The altissimo range (highest register—third mode of vibration and higher) for saxophone refers to all notes produced above the natural range, or keyed range of the instrument. Frederick Westphal places less importance on voicing in his book, *Guide to Teaching Woodwinds*. Westphal (1990, p. 142) states, "A good tone is the product of all the elements involved in performance: the instrument, mouthpiece, reed, embouchure, and breath support." While these elements are certainly integral to good tone production on the saxophone, Westphal omits any mention of the internal mechanisms involved. Westphal (1990, p. 152) does mention the tongue's involvement in a later section addressing altissimo, mentioning that the tongue moves varying amounts, arching of the tongue controls air stream, and experimentation is necessary to achieve the altissimo range, though he never explicitly mentions the term *voicing*.

Paul Harvey (1995, p. 51) comments on tone production and throat and oral cavity shape for saxophone performance, stating "you get a good clarinet sound by blowing up to the pitch, thinking 'EEEEE'. On the saxophone you get the right sound by blowing DOWN to the pitch, thinking 'AWWWW' (as in the word 'awful,' N.B.

English Pronunciation).” Harvey does not reference the implementation of the voicing technique or give further detail for “blowing down” for saxophone performance or “blowing up” for clarinet performance elsewhere in the text. The reader can interpret Harvey by thinking of the /ah/ sound as an open oral cavity and /ee/ as a higher tongue or more closed position. Harvey’s comment is furthered by his association between throat positions to sounding pitch when operating the saxophone mouthpiece/reed alone, stating that proper throat position is indicated by the proper sounding pitch attained by playing the mouthpiece alone (Harvey, 1995, p. 51). Harvey’s use of vowel phonemes to attain desired oral cavity positioning is quite common in the field of saxophone pedagogy. Although comparing mouthpiece pitch can be a useful pedagogical tool to find a proper oral cavity shape, the current study will show that several tongue shapes are in fact relevant factors as well.

The voicing mechanism is essential for consistent control and flexibility of tone, intonation, and altissimo pitch production during saxophone performance. Spoken phonemes are often used to convey target tongue shapes/positions. It is well documented in speech research that certain phonemes produce certain tongue shapes. The teacher can use the shared language between the student and teacher to reference specific phonemes resulting in different tongue shape targets. The benefit of audible feedback for the teacher is confirmation that the student is accomplishing these targets. The notations to produce “a separate sign for each distinctive sound” found in speech, or phonemes, are a primary focus of the International Phonetic Association (IPA, 2005, p. 27). Each phoneme represents a distinct sound being produced by a specific placement of the vocal tract structures.

Figure 2. Vowel Chart created by International Phonetics Association.

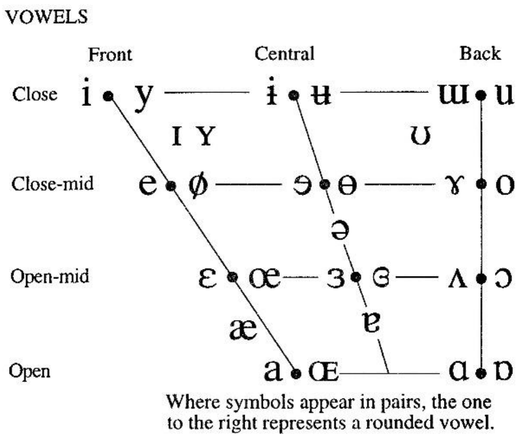


Figure 2 shows a vowel chart illustrating the constriction locations for different vowel sounds in the American English language (IPA, 2005, p.202). The reader can track the position of the vocal tract constriction, often created by the tongue, relative to the orientation described by the vowel chart. Since the tongue is a critical component in the voicing technique, specific phonemes are often referenced for certain performance outcomes. The shared language coupled with audible feedback allow vowel shapes to aid teachers to convey specific vocal tract manipulation mechanisms. Ladefoged (1996, p. 93) supports the process of output reference feedback by stating "The air in the vocal tract will vibrate in different ways when the vocal organs are in different positions." He continues along this topic by saying, "the way in which a body of air vibrates depends on its size and shape." (Ladefoged, 1996, p.93). This is not dissimilar to a Helmholtz resonator. Strong connections can be made between the descriptive imagery utilizing a common, shared language system between the teacher and student and an individual's physical interpretation of the vocal tract when teaching specific vocal tract manipulation.

Glissando and portamento refer to a continuous variation of the pitch from note to note and are the result of changing the acoustical properties of the vocal tract (Chen, 2009, p.1511). When using the vocal tract to produce a pitch bend, it is possible to lower the pitch by approximately one octave (further in some cases) from the higher registers where the resonant frequencies of the saxophone are weaker; though significant upward pitch change is not possible using this technique (Scavone, 2008, p. 2395-2396). Scavone (2008) speaks in terms of two main resonant cavities activated during performance: those of the vocal tract are considered "upstream" and those of the instrument are considered "downstream." It would seem that what we refer to as voicing is the acoustical phenomenon observed by Scavone—manipulation of the acoustic impedance of the vocal tract. A performer can create a strong enough resonance in the upstream corridor to override the fixed downstream bore configuration resonance to manipulate how the reed vibrates (Scavone, 2008, p. 2395-2396). Successful pitch and tone production in the upper registers rely on precise upstream resonance manipulation since bore resonances are weaker in the upper range of the instrument.

Saxophone pedagogy has addressed voicing skill development at varying levels of detail. The available pedagogy addressing this technique range from thinking of the sound /uur/ and "maintaining a large vacant area behind the teeth and in front of the tongue" (Lang, 1982, p. 3), to firming the embouchure more than normal and arching the tongue high in the mouth as if to be saying the syllable /ee/, as in the word "reed" (Luckey, 1998, p. 4). Westphal's text (1990) states:

> The position of the tongue is critical in the production of altissimo notes. Varying amounts of arching of the tongue varies the direction of the air stream to produce the tones….although some experimentation will be necessary to determine exact tongue positions. (p. 152)

Westphal here indicates that experimentation is needed when pursuing proper vocal tract position.

Many differing opinions exist on when a saxophonist should begin focusing on voicing and altissimo studies. Westphal (1990, p. 152) says that only advanced players who have a strong, flexible embouchure, and have mastered breath control, support, and the entire range up to F6 (written pitch) should attempt to study the altissimo range. Whereas Sinta (1992) mentions that advanced students will find frustration with the unfamiliar oral cavity manipulation, and that for this reason it is strongly recommended that voicing study should begin at an early age.

A majority of pedagogical materials examined in the present document cover the voicing concept beginning with the study and production of overtones and harmonics. Sigurd Rascher explores this methodology in his *Top Tones for Saxophone* method book. Rascher (1977) begins his text with the study of sustained tones, dynamic flexibility and uniformity of tone character, followed by "tone imagination," or the ability to hear and even sing the target pitches before attempting to produce them, therefore increasing the student's aural perception of the pitch. The vocal tract manipulation required to achieve overtones on the saxophone are similar to the configurations and structures utilized when producing altissimo tones as well as other voicing procedures including pitch bends.

Another pedagogical technique for teaching the voicing technique is the Front-F pitch bend exercise, sometimes referred to as the "Front-F Trick." Sinta (1992, p. 8) states, "This skill is often elusive for non-jazz saxophonists, but once acquired seems to be a significant skill in mastery of other voicing exercises." This skill/exercise/technique is the basis of the current study. This technique and method is mentioned only in Sinta's (1992, p. 8) publication, but has found a place in saxophone pedagogy. Mechanisms involved to produce the upstream acoustical conditions to control the frequency of the vibrating reed are likely similar, if not the same, as those produced by Front-F pitch bends and overtones during saxophone performance.

Several imaging studies have been conducted in an effort to better understand the internal systems at work during saxophone performance. Making use of fiber-optic technology, Matthew Patnode (1999) conducted a study determining if advanced-level saxophonists were able to characterize their tongue position while performing altissimo passages on the saxophone. Patnode concluded that while accurate altissimo tongue position could be determined when performing octave or large interval excerpts, the tongue motion was less clear during smaller chromatic intervals. The current study aims to help clarify some aspects of these smaller or gradual tongue motions, such as during chromatic altissimo passages as well as pitch bends.

Steven Jordheim (2009) and the Lawrence University Saxophone Studio completed a fiber-optic examination of the vocal tract during saxophone performance. Jordheim's intention was "To increase understanding of the involvement of the vocal mechanism in the performance of standard and extended saxophone techniques and to provide direction for future research" (Jordheim, 2009). Jordheim's project covered many facets of saxophone performance, including circular breathing, slap tonguing, double tonguing, altissimo production, and pitch bending. Videos and still images were produced from two internal view-points: 1) between the lips through the side of the performer's mouth; 2) trans-nasally directed down the performer's throat. The video available shows that the tongue is active during both pitch bends and altissimo playing, as well as other techniques covered. In the mouth video, the tongue rises upward and toward the posterior oral cavity during pitch bends. Little of the tongue can be seen during the pitch bend throat video. During the altissimo mouth video, the tongue seems to be moving similarly, moving toward the posterior oral cavity when producing higher altissimo tones, and forward for lower notes in the natural range. It is difficult to confirm this since the scope cannot be fixed relative to the cranium, and the limited view of the tongue.

Despite potential health risks due to exposure to X-rays, Raymond Wheeler (2003) performed a fluoroscopic study on himself while performing clarinet, saxophone, oboe, and bassoon. Videos of Wheeler's (2003) work were produced from 16mm motion picture images, later dubbed with sound. The videos included an extensive use of clarinet range and vocalization, as well as scaler patterns on the oboe, bassoon, and saxophone. Wheeler's video shows the tongue during both altissimo production on the clarinet, as well as pitch bending and pitch manipulation. The fluoroscopic method allows the viewer to observe how the tongue is manipulated to control the acoustical conditions of the oral cavity. The tongue shifts between further down the throat and more forward in the mouth as well as varying the width and shape of the throat. These manipulations and formations are likely the structural changes that produce the observed acoustical phenomena noted by Scavone and others during altissimo register production as well as pitch control, including pitch bends on clarinet as well as the saxophone.

One major limitation when teaching this skill is that the teacher nor the student has the ability to directly view the tongue or oral cavity that they are attempting to control. The teacher and student are reliant on the teacher's subjective description of *feel* when they produce the effect, and the student is asked to make the same connections from verbal commands as the teacher deems correct. This is often met with frustration for all involved. This study seeks to accomplish two goals: 1) to quantify tongue movement during controlled pitch bend tasks; 2) Measure the tongue range of motion and generalize the location of this motion between various pitch bend target pitches.

CHAPTER 3

METHODS AND PROCEDURES

Overview

This study seeks to observe and quantify tongue motion during descending and ascending pitch bends from F6 on the alto saxophone and measure the tongue's range of motion. This information will then be cross-referenced with current pedagogy literature.

Subjects/Equipment

Ten (10) subjects were selected from graduate students and professional saxophonists currently attending or had recently graduated from the Arizona State University School of Music who are proficient in voicing and glissandi production. These subjects included nine (9) male and one (1) female American saxophonists. Their ages ranged from 22-46 years old. Each saxophonist performed the study tasks first on their individual alto saxophone equipment and then again on control equipment; however, data from the control equipment were not used in the present study. Subject equipment included professional model Yamaha and Selmer alto saxophones and various facings/styles of Selmer mouthpieces with varying Vandoren or Rico reed strengths. Complete equipment lists can be found in Appendices A-J.

The performance tasks consisted of seven (7) individual tasks, including a single sustained tone, specific portamento target pitches, and producing a pitch bend as far down as possible. A printed copy of the performance tasks were provided for the recording session, and executed using a metronome set to 40 BPM. The metronome was used to help maintain data alignment for later comparative analysis. The slow tempo was chosen to avoid loss of data at the ultrasound frame rate (approximately 32 frames per second). The performance tasks used for the current study are included in Appendix N.

Data Collection and Processing

All ultrasound image data for this study were collected at the Performance Physiology Research Laboratory (PPR Lab) at the Arizona State University School of Music on February 13, 17, 19, 24, and May 14 of 2015. All data collection was under the supervision of the Performance Physiology Research Laboratory director Dr. Joshua Gardner and the current author. Equipment used:

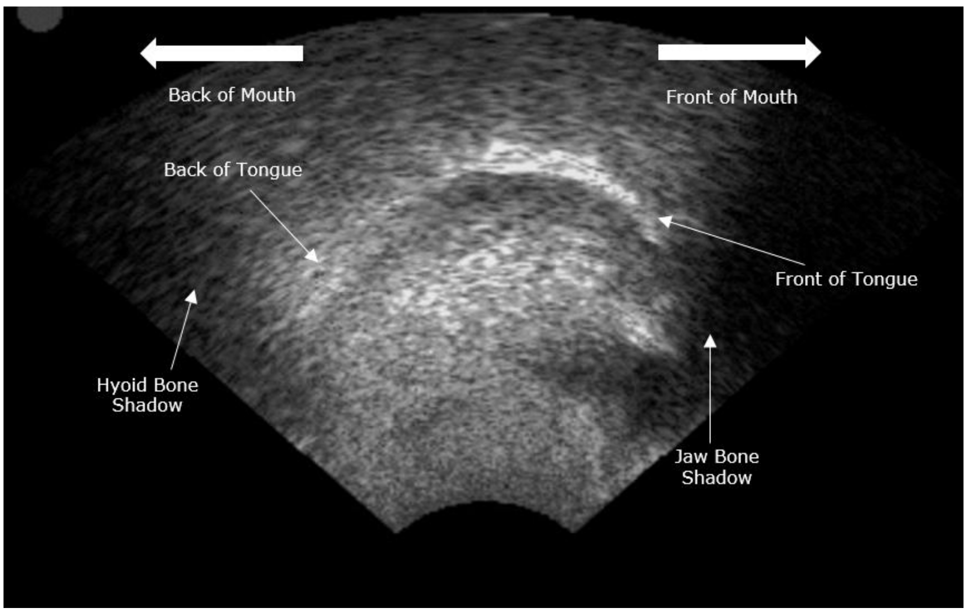
Equipment:

1. Articulate Instruments Ultrasound Stabilization Headset
2. Terason T3000 Ultrasound System
3. Earthworks M30 Measurement Microphone
4. Sound Devices USBPre2 Audio Interface/Preamp
5. Dr. Beat-66 Metronome
6. Software:
    a. MATLAB
    b. CAVITE
    c. UltraSpeech
    d. Ultramat
    e. ImageJ
    f. EdgeTrak
    g. Praat
    h. Quicktime 7
    i. Microsoft Excel 2013
    j. Adobe Premiere
    k. Microsoft Word 2013

A Terason T3000 Ultrasound System was used to capture midsagittal tongue images at approximately 32 scans per second while each subject performed the study tasks. An Articulate Instruments Ultrasound Stabilization Headset was used to fix the transducer relative to the subject's head. The stabilization headset has six different areas of adjustment to maximize stability and reduce movement-induced error. Prior to installation on the headset, the transducer was manually positioned under the chin for each subject by the lab director to find a general transducer position for optimal imaging and make adjustments to the US machine, including scan depth, focal point, gain, and sector width. Once the satisfactory angle and settings were determined, the stabilization headset was adjusted for each subject's cranium.

The field of view available from ultrasound imaging is limited by the hyoid bone (posterior) and jawbone (anterior), making accurate transducer placement of high importance in order to maximize the amount of tongue surface exposed to the ultrasound beam. When playing the saxophone, the hyoid bone moves forward and upward, which casts a shadow reducing how much of the tongue surface is exposed to the ultrasound beam, thus limiting the tongue surface that can be imaged.

Figure 3. Two-dimensional midsagittal ultrasound frame labeling areas of interest.



The tip of the tongue is obscured by the tissue/air interface at the floor of the mouth, thus further limiting what can be seen with this imaging modality. The head of each subject was jutted forward from their body to maximize the size of the submental "window" between the jaw and hyoid bone shadows. The ultrasound image in Figure 3 shows a single midsagittal tongue contour illustrating the limitations produced by both the hyoid bone and jaw bone as well as orienting the tongue contour in the oral cavity.

Once the transducer was attached to the headset, the subject was asked to perform a few swallows to make final adjustments and to collect palate trace contours used for quantitative measurements during the study. Each subject was supplied with a bottle of water to maintain moisture for quality imaging (Stone, 2005, p. 462). Each subject was then handed their personal saxophone equipment (set-up previously), and performed all seven performance tasks in succession. The set of performance tasks were not provided to the subjects in advance of the recording session. Subjects were positioned facing away from the ultrasound machine display during the data collection so they could not see what their tongues were doing. Viewing the ultrasound monitor may result in biased tongue movement. Subjects were allowed to repeat certain tasks if they were not satisfied. These are notated Task#b respectively. The data collection occurred over the course of multiple days, though each subject completed all given tasks in one session to maintain headset and transducer positioning. Each recording session lasted approximately 60 minutes.

During data collection, ultrasound images were recorded as bitmap image sequences along with mono, 16-bit audio sampled at 44.1 kHz using the UltraSpeech (Hueber et al, 2008) application. Using the Ultramat MATLAB toolkit (Hueber, 2013), ultrasound image sequences were compiled into uncompressed AVI files for each task. The toolkit also synchronizes the audio; however, the separate synchronized video and audio files were combined using QuickTime Pro due to a known issue with the toolkit. For the sake of file management, the uncompressed audio/video files were converted to a compressed MP4 format for reference and data size management. Since the audio is synchronized to the ultrasound data and the ultrasound framerate is known, the timing of specific acoustical events could be used to locate target ultrasound frames for analysis. A combination of video observation and the acoustical analysis software application, Praat (Boersma, 2001), were used to determine the three (3) target times (with the exception of Task 1). The target times were calculated based on when the initial F6, each task's target pitch, and return F6 sounded.

Target times for each task were then input into an Excel document to calculate a specific frame for each event. This calculation was accomplished by multiplying each subject's individual frame rate during the given task by the time of the sounding event, thereby generating a specific frame number for the event. Each output was rounded to the nearest whole number. This was repeated for each frame per each task per subject. Once the frame numbers were calculated, each audio-aligned video was saved as an image sequence extracted at the respective framerate.

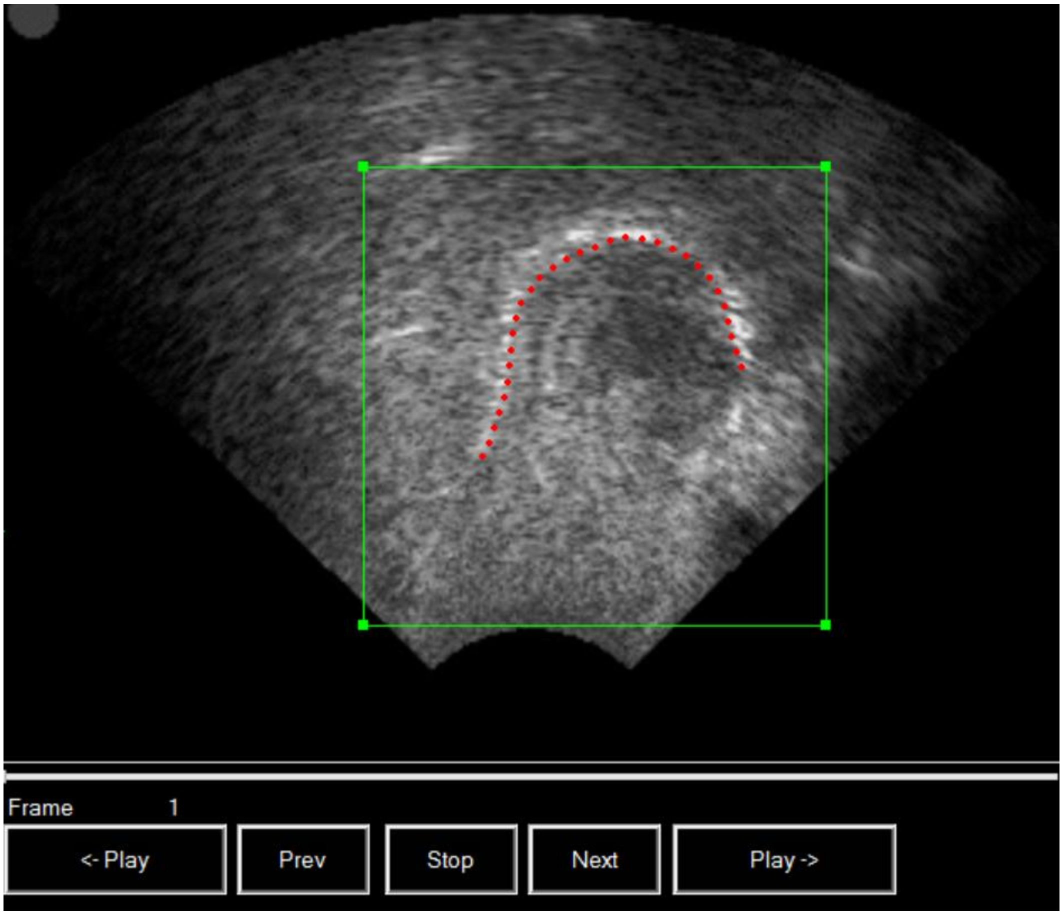
Selected individual frames were grouped by subject and task, and then imported into EdgeTrak, a semi-automatic edge detection system that can track the tongue's surface in two-dimensional ultrasound images (Li et al, 2005). The application requires the user to select several points along the tongue contour from which additional points are interpolated using image gradient information. The initial contour is then automatically copied to subsequent frames and optimized for the given contour. For further information on the contour detection and tracking system, see Li, Kambhamettu, and Stone, "Automatic Contour Tracking in Ultrasound Images," 2005.

Contours were tracked one task at a time, encompassing three frames per task. EdgeTrak requires the user to load a minimum of two frames in a sequence, so because Task 1 only consisted of one frame, one frame immediately before and immediately after the selected frame were added to create a sequence.

Once a task image sequence was loaded into EdgeTrak, several guidelines were set within the program. A region of interest (ROI) window was adjusted to include the entire tongue contour for the duration of the sequence. Once the ROI was selected, all images in the sequence were checked to confirm tongue position stayed within the ROI. At this point, the sequence was saved as a TS file to make future reference easier. This file includes ROI data, scaling mark locations, contour coordinates, and image directory information. Files were saved in the following format: [Subject Code]_task[#]_[sequence ###]. Once saved as a TS file, the image gradients for the sequence were calculated. Calculating image gradients is required for the edge-tracking algorithm to recognize and track contour changes accurately based on the imaged tongue surface. Traditionally, the first frame is used to provide a contour from which all following contours in the sequence are tracked. Due to the sequence containing only three frames each, and the second frame being considerably different from one and three, the Optimize Sequence function was not used. The Initiate by Click function allows the user to select three or more points along the tongue contour gradient, which are then used to automatically interpolate a previously set number of points (default is 33 pts).

During the optimization process, if points extended beyond the visible contour, they were manually deleted. Figure 4 is a screenshot of a midsagittal tongue contour in EdgeTrak. The red points, called snaxels, are transformed into coordinate points relative to the top of the image. Once all sequenced images contained optimized contours, the TS file was saved.

Figure 4. Single Ultrasound Frame in EdgeTrak.

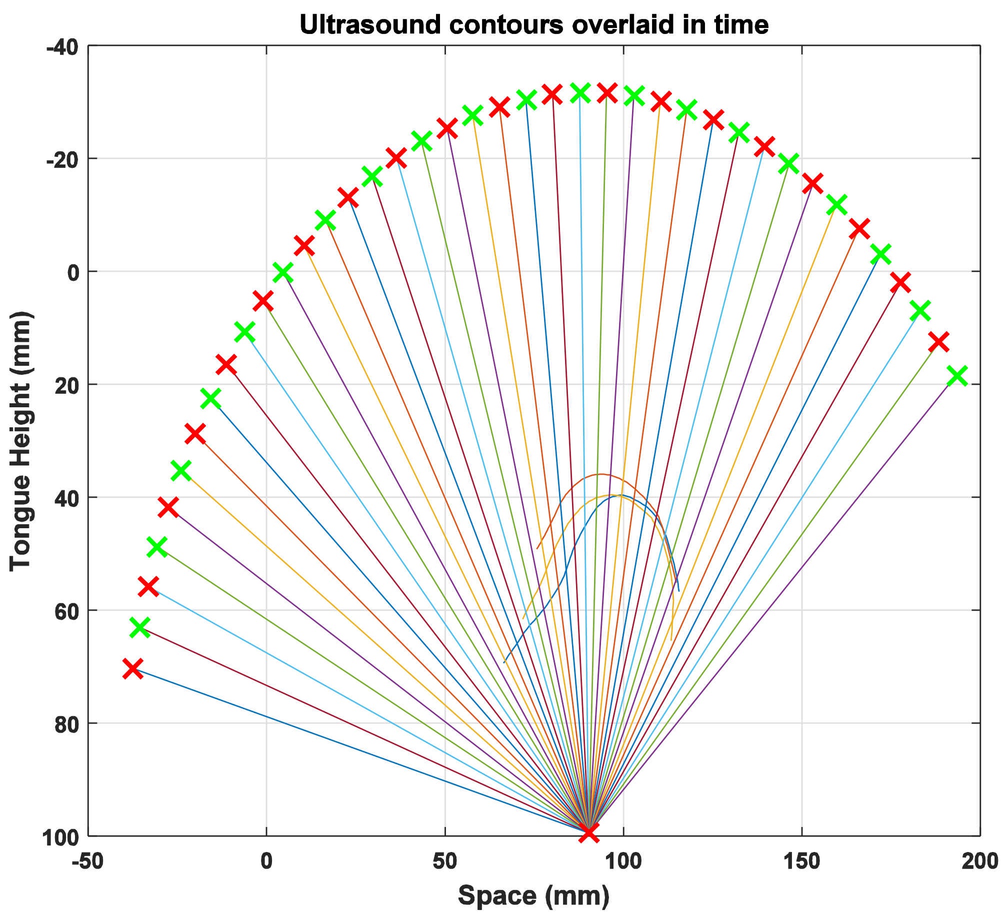


The saved TS files contain information pertaining to filename, region of interest settings, scaling factor information, as well as coordinates for each point per contour per frame sequence. The coordinates of each point are measured in pixels. In order for the measurements to be meaningful, the pixel measurements were converted into millimeter measurements. EdgeTrak allows the user to input a scaling factor when exporting contours as CON files. The scaling factor is a ratio of millimeters per pixel. Calculating this ratio involves measuring the number of pixels between centimeter scaling marks imprinted in the ultrasound images. The free image analysis application ImageJ (Rasband, 2009) was used to take measurements from the ultrasound images. Loading one image into ImageJ, it was enlarged using the zoom function, and oriented to the scaling marks previously mentioned. The measurement function was used, choosing two adjacent scaling marks, with the x coordinate constant. While zoomed in, there will be several pixels to choose from for positioning each scaling mark. The chosen pixel location along the x-axis was maintained for each point on each scaling mark. The distance between the two scaling points, positioned on the centimeter scaling marks, was measured in pixels thus calculating the number of pixels in one centimeter. From this measurement, the scaling factor of millimeters/pixel ratio can be calculated. For this study, the scaling factor was .24609217. UltraSpeech also provides pixel dimensions directly; however, they were measured manually for verification. Finally, the contours were extracted as a single CON file. When extracting the CON files, the scaling factor is used to convert pixel measurements to millimeters.

Once the contours had been extracted and converted to millimeters, a custom software application specifically designed for tongue analysis, CAVITE: Contour Analysis VIsualization TEchnique (Parthasarathy et al, 2004), was used for further analysis. The application allows the user to perform various analyses on tongue contour sequences. For this study, a polar grid was superimposed on the contours to measure range of motion along fixed polar spokes with an origin representing the approximate location of the transducer.

In order to configure the polar grid to cover the max and min x-values of all contours, all tongue contours were loaded into CAVITE and displayed together on a single two-dimensional grid. With all contours displayed, a single polar grid consisting of 40 spokes was created and saved. The far left and right spokes were positioned where they would not intersect with any tongue contours. As each task sequence was loaded into CAVITE, this universal polar grid was also loaded. The contour intersection coordinates for each spoke were saved per task.

Figure 5. Task 4 From Subject JDR02192015 With Superimposed Polar Grid.



Using the intersection coordinates along the polar spokes, range of motion (ROM) could be calculated by comparing coordinates between adjacent contours. Only spokes that intersected all three contours were used for ROM analysis. The ROM between contours one and two, and two and three were averaged, representing the average amount of tongue motion observed to and from the target pitch.

The oral cavity was divided into two segments using the position of the velar juncture. To calculate this point, palate contours were loaded with the polar grid to locate where the juncture lies along the grid. When tracing the palate, the velar juncture was used as a rigid dividing point. Spokes anterior to the juncture dictate the front segment; spokes posterior to the juncture dictate the back segment.

CHAPTER 4

RESULTS

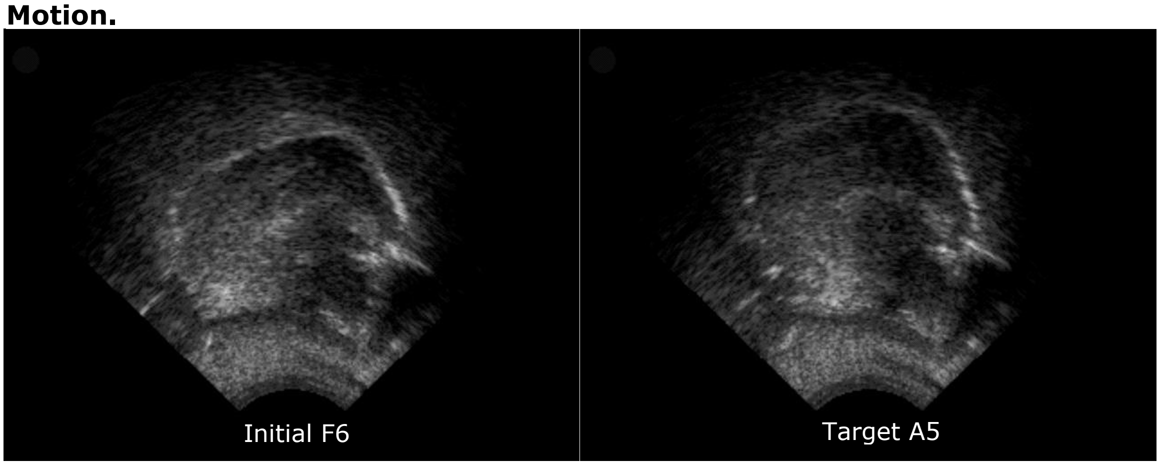
The current study contains several numerical analyses examining the front F pitch bend technique. This technique was successfully completed by all ten subjects possessing tongue contours of different shapes and sizes. First, tongue motion was quantified by extracting two-dimensional coordinates from midsagittal tongue contours. This was accomplished by selecting respective ultrasound frames of the tongue contours from the performance tasks and tracking and quantifying the tongue contours using EdgeTrak.

Second, the range of motion was calculated along each spoke, averaged, and compared from the initial F6 tongue contour moving towards the target pitch contour, as well as range of motion observed returning to the F6. Please refer to Tables 1-2 for a complete listing of tongue contour range of motion averages. Tables 3-6 display ROM for anterior and posterior oral cavity segments, respectively, and can be found in Appendix M.

Further, the oral cavity was divided into anterior and posterior regions. This was calculated not in reference to the contour itself, but rather by the position of the velar juncture relative to the polar grid. All points intersected by the polar spokes anterior to the velar juncture were considered anterior, while all polar spokes intersecting posterior to the juncture were categorized as posterior. The division of the oral cavity into two coronal segments is designed to describe, more specifically, where the majority of motion occurs within the oral cavity.

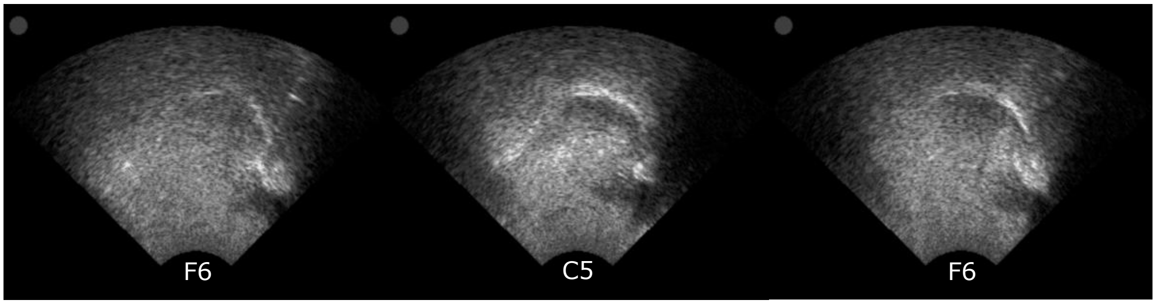
Upon quantifying the tongue contours, a considerable amount of tongue motion was observed to generate the pitch bend. The first visible tongue motion, shortly before the pitch moves from the initial F6, shows the posterior tongue contour rising and shifting back in the oral cavity. This motion is met with an overall rising and extending motion forward in the anterior and backward in the posterior of the contour with a majority of subjects. Figure 6 illustrates the raised tongue contour and expansion of the posterior tongue toward the rear of the oral cavity. Some subjects displayed less upward and forward motion, but all subjects demonstrated posterior tongue motion during the pitch bend performance tasks and reversed this motion to return to the initial pitch.

Figure 6. Two-dimensional Ultrasound Images Displaying Initial Contour Motion.



The seventh performance task (Appendix N) was unmetered and without a specified target note. The only directions given were for the subject to bend the F6 pitch as low as possible, and to return to F6 without an interruption of tone. One subject was able to bend the pitch more than one octave below the starting pitch. Subject EMB performed a pitch bend from F6 to C5 during Task 7b. As Figure 7 illustrates, the contour for the lowest pitch (C5) was extremely similar to that of the initial F6 contour. EMB task 7b did follow the typical pattern of the other subjects, but when crossing the F5 octave, the tongue position reverted towards the original position and contour displayed at F6.

Figure 7. Two-dimensional Tongue Contours From F6 to C5 and Returning to F6.



The next phase of analysis was to compare tongue range of motion. Range of motion was calculated using the coordinates generated by the established polar grid in CAVITE. Average ROM was calculated across all spokes intersecting contour pairs 1-2 and 2-3 (See Tables 1 and 2). Positive ROM values indicate motion away from the spoke origin; negative ROM values indicate motion toward the spoke origin. Note that the spoke origin was placed in the approximate position of the transducer; therefore, positive values signify motion away from the transducer and negative values demonstrate motion toward the transducer.

Table 1. Average Range of Motion Between Contours 1-2 for all Subjects.

Average Range of Motion: Contours 1-2						
	Task 2	Task 3	Task 4	Task 5	Task6	Task 7
CCB02242015	1.2	5.5	5.1	4.8	6.0	6.0
CLC02242015	-	8.6	6.6	5.6	9.2	8.8
DOM02172015	1.6	6.3	3.7	3.5	7.9	5.2
DSP05142015	2.6	*2.7	4.8	*5.3	5.1	6.4
EMB02132015	1.1	2.3	*2.5	3.1	5.2	**0.9
JDR02192015	2.1	1.4	4.8	3.1	*5.0	*7.2
PJM02242015	1.6	2.5	3.1	4.5	5.4	2.7
RCL02242015	3.1	4.9	2.1	7.0	7.1	7.3
SAD02132015	0.7	3.8	4.6	6.8	10.9	*12.4
TJF02172015	0.4	7.9	9.2	*11.3	12.4	11.1

Note: Task 1 is omitted because there is no ROM for a single contour.
**Notates the second attempt of task (Task #b).*
***Notates only task where subject pitch bend exceeded one octave.*

Table 2. Average Range of Motion Between Contours 2-3 for all Subjects.

Average Range of Motion: Contours 2-3						
	Task 2	Task 3	Task 4	Task 5	Task6	Task 7
CCB02242015	-0.7	-5.0	-4.3	-4.0	-4.9	-4.9
CLC02242015	-	-7.1	-5.8	-5.6	-6.1	-9.1
DOM02172015	-0.3	-4.9	1.1	-1.2	-5.3	-4.3
DSP05142015	-1.8	*-2.2	-3.8	*-3.7	-4.4	-5.4
EMB02132015	-1.8	-3.0	*-3.5	-3.3	-4.0	**0.5
JDR02192015	-0.3	-1.1	-3.3	-2.1	*-3.7	*-5.6
PJM02242015	-1.6	-2.7	-3.7	-5.0	-6.5	-1.6
RCL02242015	-0.1	-3.1	-1.7	-5.6	-5.1	-6.4
SAD02132015	-1.0	-2.5	-1.8	-3.8	-7.5	*-7.2
TJF02172015	-0.6	-6.0	-7.1	*-10.6	-7.3	-10.4

Note: Task 1 is omitted because there is no ROM for a single contour.
**Notates the second attempt of task (Task #b).*
***Notates only task where subject pitch bend exceeded one octave.*

Figure 8 takes the aforementioned average information and shows variations for a single task across all subjects. This allows for a discussion of contour motion differences between subjects for a given task. Interestingly, the majority of subjects had greater ROM approaching the target pitch than the return range of motion, as can be seen in Figure 8. A minority of thirteen occurrences display a larger, and in a single case equal, ROM between contours 2-3 than that of contours 1-2. Greater ROM between contours 2-3 were seen in two subjects, EMB and PJM, for tasks 2-5. One subject (PJM) exhibited a consistently greater ROM during contours 2-3 during all tasks, with the exception of Task_7.

Figure 8. Range of Motion Averaged for a Single Task Across all Subjects.

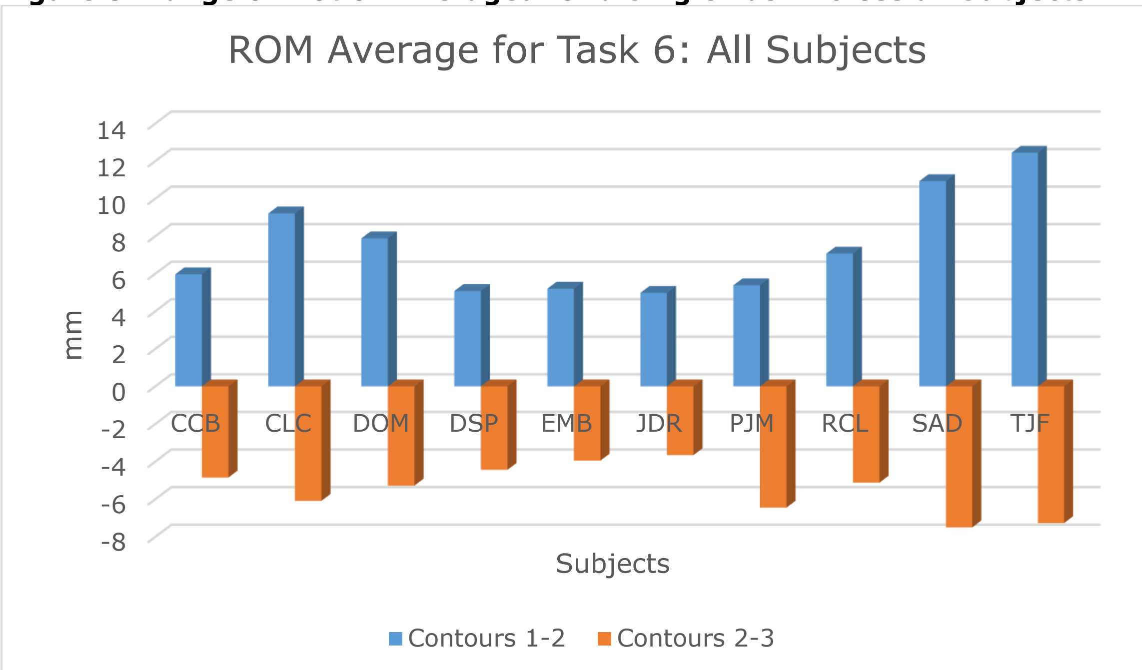
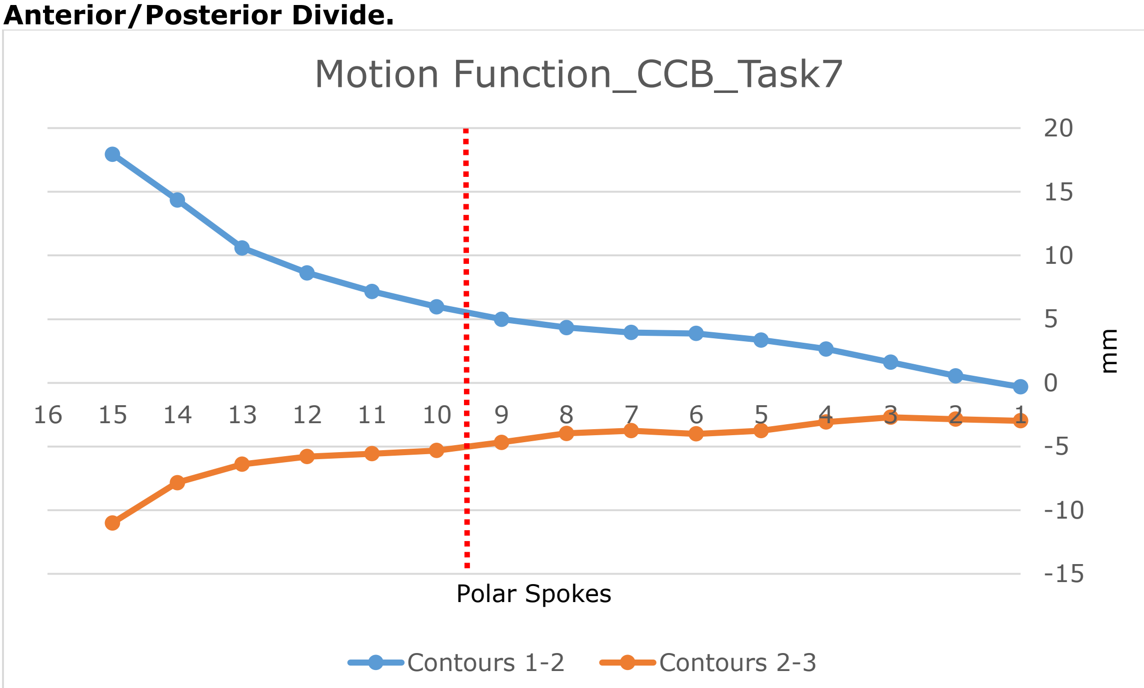
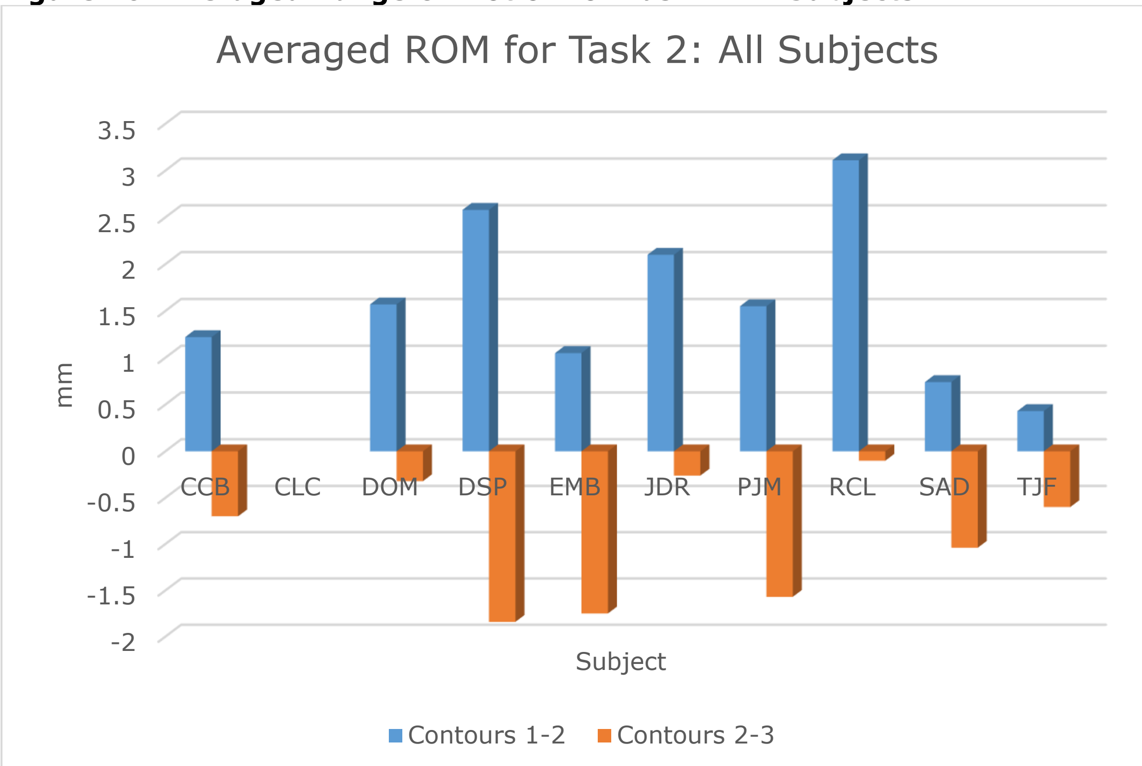


Figure 9. Averaged Range of Motion for Subject CCB Including Anterior/Posterior Divide.



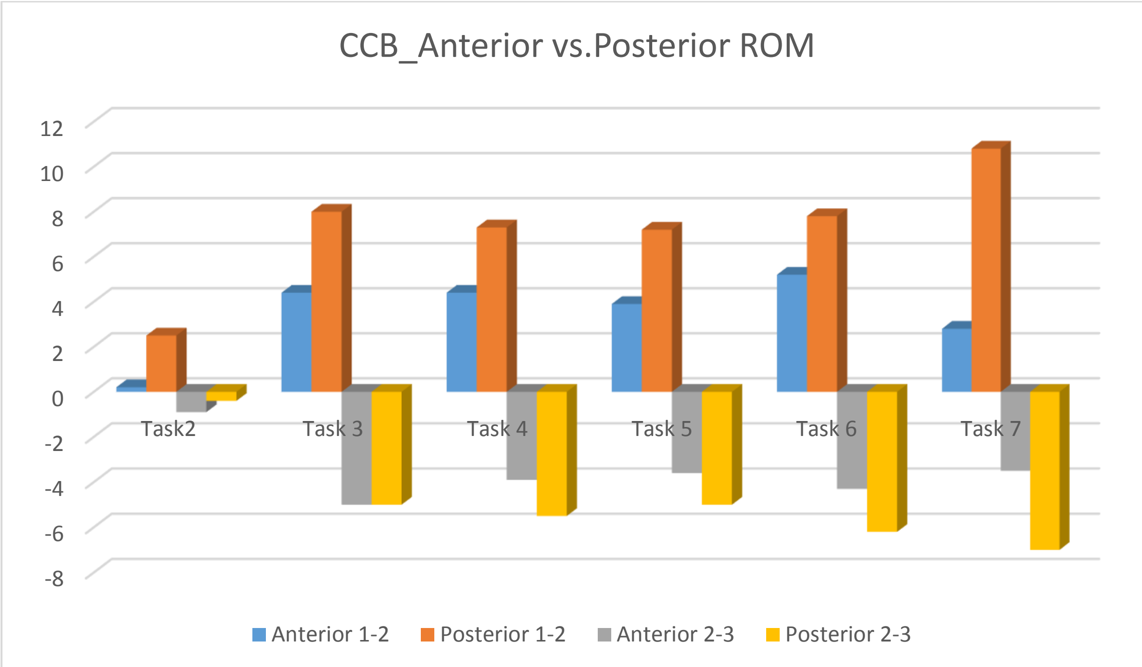
In contrast, Figure 10 represents data from Task 2 where four subjects averaged a greater ROM returning from contour 2 to contour 3. Task 2 is the only task to have more than two subjects with a greater ROM for contours 2-3.

Figure 10. Averaged Range Of Motion for Task 2: All Subjects.



Range of motion was also examined anterior and posterior to the velar juncture. As discussed earlier, the velar juncture is located where the hard and soft palate meet. Once this point was identified and marked on the polar grid for each subject, the polar spokes were labeled anterior or posterior depending on their position relative to the juncture. Figure 9 shows the tongue motion of subject CCB during a Task 7. The red dashed vertical line indicates where the velar juncture occurs relative to the spokes of the polar grid. The polar spoke coordinates could then be distinguished by the anterior (right) and posterior (left) of the oral cavity. With a fixed division for anterior and posterior segments per subject, the range of motion for each segment was then compared to establish a more clear assessment of where motion is occurring during the performance tasks. As can be seen in Figures 9 and 11, most motion occurs posterior to the velar juncture.

Figure 11. Range of Motion Comparing Anterior and Posterior Contour Areas.



CHAPTER 5

DISCUSSION

One of the objectives of this study was to quantify tongue motion during saxophone performance of Front-F pitch bends. The author also wanted to adapt a protocol for imaging the tongue during clarinet performance (Gardner, 2010) for saxophone performance. Additional analysis include calculation of range of motion during the performance tasks as well as range of motion specific to the anterior and posterior segments of the oral cavity, as defined by individual velar juncture locations.

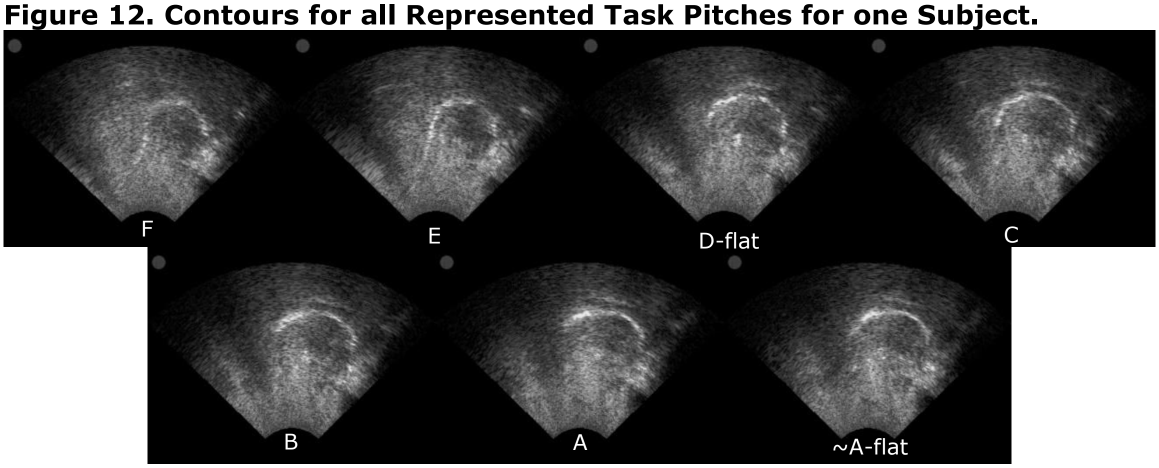
To quantify tongue motion for the tasks in question, midsagittal tongue contours were recorded with the transducer stabilized relative to the cranium and extracted from individual ultrasound images using EdgeTrak. By calculating a precise scaling factor converting pixels to millimeters, tongue and palate contour data could be measured using a meaningful unit.

As expected, the shapes of the tongue followed similar patterns of motion across all subjects with some variations. Though differences in shape and size across subjects exist, the general tongue contour motion is similar. It is important to remember that differences in tongue and oral cavity size may contribute to differences in tongue contour shape but general motion is similar. Additional potential factors may include allergies, native language, and whether or not a performer has their wisdom teeth. Any influence these factors may have is beyond the scope of this study, but worthy of future research.

The shape of the initial F6 tongue contour included a high posterior arch leading to a downward slope toward the anterior oral cavity. One of subject JDR's initial F6 contours presented a shape more similar to a bell curve, and during the pitch bend, the posterior tongue did not extend back in the oral cavity, but only raised, maintaining the original narrow curve shape. The shapes and sizes of tongues vary from person to person, which may be a contributing factor for slight differences in contour shape and size.

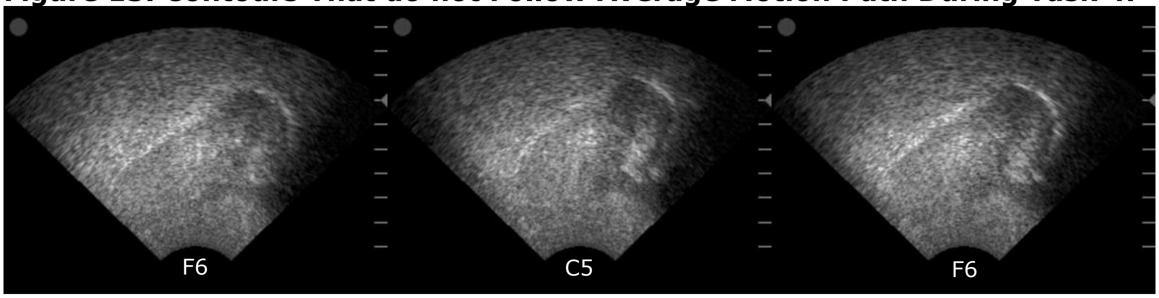
As the subject moved through the performance tasks, the target pitch progressed lower in range. As a result, the posterior contour extension backwards previously mentioned also progressed farther toward the posterior oral cavity. As the motion change in the posterior tongue became more dramatic, it was met with a slight anterior expansion forward as well.

Figure 12. Contours for all Represented Task Pitches for one Subject.



In Figure 12, the progression of expansion can be viewed across all tasks for one subject. Though during Task 7 the subject did not play a significantly lower pitch than during Task 6, a visible progression can be seen of the posterior tongue contour shifting backward in the oral cavity. Contrary to the motion visible in Figure 12, Figure 13 shows three contours from a subject’s performance of Task4. The contours do not follow the previously discussed posterior shift, but maintains the initial F6 contour only producing a shift up and forward to attain the target pitch. The only visual change is observed near the tongue root where the contour moves forward, which also contrasts to previous observations.

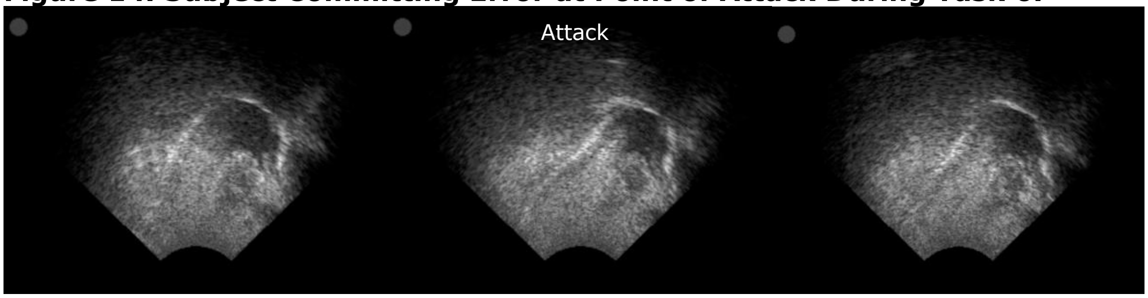
Figure 13. Contours That do not Follow Average Motion Path During Task 4.



Interestingly, during data collection, Task 3 (Target Pitch D-flat) presented issues with multiple subjects. When approaching the target pitch of D-flat, the sounding pitch was reluctant to stabilize at D-flat. The subjects' tongues moved slightly and the aural effect was one of resistance to the frequency. This deviation was present more so in the subjects using Selmer brand saxophones, but was not absent from subjects performing Yamaha brand saxophones. Due to the constant alternation and subtlety of the tongue contour instability, it would be difficult to represent visually using still images.

Subjects were allowed to re-perform tasks if they were not satisfied with the initial performance (notated in this study by the labeling 'Task_#b'). A benefit to the author when this occurred is the opportunity to observe differences in shape with less desirable results compared to those of a satisfactory performance, which then could afford us knowledge on avoiding such errors. Figure 14 displays a subject moving a considerable portion of the tongue root upon initiation of the F6, or the point of articulation. The three frames are immediately preceding the articulation, the contour at the point of articulation, and finally the return contour once the initial F6 of the task has sounded. The resulting error is an unstable articulation of the initial F6. This discrepancy implies that erroneous motion involving the posterior contour may result in distortion or lost control of pitch.

Figure 14. Subject Committing Error at Point of Attack During Task 6.



Studying tongue motion between extracted contours is an extension of quantifying tongue motion of pitch bends during saxophone performance. Gaining a greater knowledge concerning the amount of tongue motion and the specific changes and differences in tongue motion can help to resolve unknown internal aspects involved with saxophone performance. The extracted contours discussed previously were displayed on a single grid with a superimposed polar grid using the software CAVITE. Once polar radii coordinates (intersection points) were calculated for each intersecting contour, the difference between contours 1-2 and contours 2-3 was calculated. These data display the range of motion between all intersecting polar coordinates moving toward the target pitch, as well as ROM returning to F6. Because contours 1 and 3 are the same pitch, we expect the ROM between contours 2-3 to be a mirror of the ROM between contours 1-2. This is not the case for the majority of subjects tested. Most subjects moved their tongues more between F6 and the target pitch as opposed to returning from the target pitch back to F6. This is also evident by visually examining the sonograms. The contour upon return to F6 is wider and positioned more posteriorly in the oral cavity. There are also a few instances where the return ROM has a greater ROM than the ROM between contours 1-2.

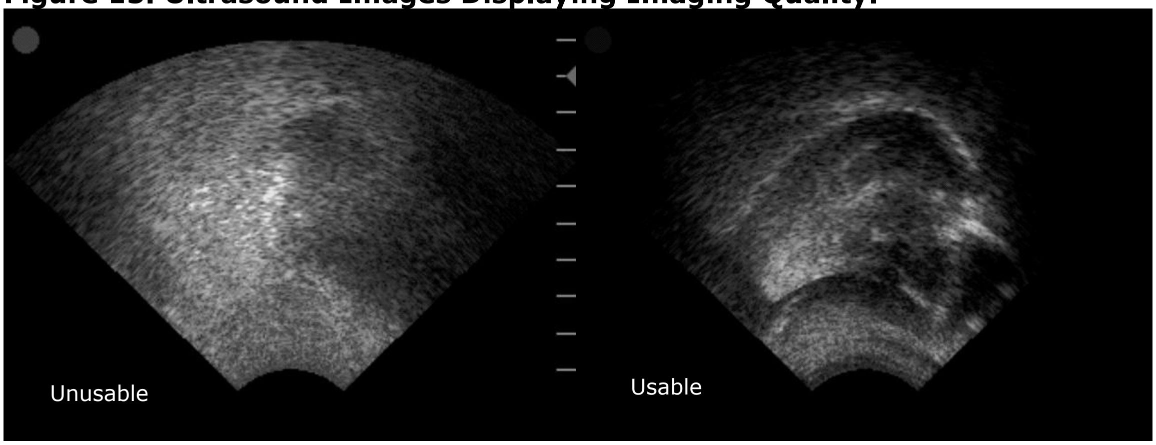
Most tongue motion occurred posterior to the velar juncture for most subjects. Across 59 task performances, eight showed greater ROM between contours 2-3 than 1-2, with one having equal average ROM. Looking more specifically at anterior and posterior areas of the oral cavity provides a more detailed description of motion. The ROM in the anterior segment of the oral cavity between contours 2-3 was greater than that of contours 1-2 for 31 tasks with two tasks measuring identical ROM. ROM in the posterior segment of the oral cavity for contours 2-3 was greater than that of contours 1-2 for only three tasks. These statistics suggest that a majority of the tongue contour motion being used for Front-F pitch bends is taking place posterior to the velar juncture and that the tongue tends to move more between the initial pitch and the target than the return to the initial pitch. The current data support Wheeler's (2003) research that during clarinet performance, the tongue's contour is active in the posterior oral cavity relative to the output of the instrument.

Limitations

Though ultrasound is an extremely safe and non-invasive method of internal observation, it does present the researcher with limitations. One preliminary detail requiring slight alteration from traditional saxophone performance for imaging purposes was determining the optimal submental position for the transducer. As mentioned previously, this required the subject to jut their head forward, which was different than the subject's posture during normal performance. Another notable factor was the pressure presented by the transducer against the throat. When the saxophonist produced a pitch bend, the exterior dimensions of the throat expanded, thus presenting pressure as it pressed against the transducer. This interruption, though minimal, presented a possible non-typical performance environment variable.

Though a majority of subjects imaged well, some data were unsuitable for analysis. As mentioned previously in the Ultrasound Imaging portion of this text, many factors influence image quality such as weight, sex, and gender. Routinely it has been observed that young females image best, and older males yield less favorable results, though this is not an unequivocal truth, as older subjects have produced quality images and younger subjects reveal less favorable results (Stone, 2005, p.462). In Figure 15, the two images displayed are both from older male subjects of differing body types.

Figure 15. Ultrasound Images Displaying Imaging Quality.



From these very different images, we can see how imaging quality can vary between subjects. The tongue contour is not discernable in the left image, and so cannot be substantiated. Another limiting factor of this study is the number of subjects. Testing a larger breadth of performers from different teachers or locations globally may yield different percentages.

CHAPTER 6

CONCLUSION

The findings of the current study may be relevant to saxophone instructors in a few different ways. For a visual aid, the videos that were produced for this study will be available through the current author's website (www.ryanclemoine.com). These may provide a useful tool for the student to unlock and increase the breadth of their understanding of vocal tract manipulation. Sometimes the word choice used by an instructor can evoke or conceptualize differently for different persons. Self-analysis plays an important role when studying these techniques, and it is very much a cumulative process of experimentation with vocal tract awareness and positions. The video data provide a concrete representation of what is happening, and thus bypasses the traditions of teaching by a subjective description of *feel*.

This study also clarifies where the majority of tongue motion is taking place. Voicing pedagogy can now be focused on the posterior tongue, but this should not exclude the anterior segment since motion in one area of the tongue may cause sympathetic motion in other parts. This could prove useful when instructing students on specific areas of the tongue, which in turn may help to generate new concepts for the student's perception and creativity, hopefully relieving some frustration and increasing efficiency. Conversely, the data also show that there can be some variation in tongue control while achieving the same result. The bulk of awareness should come from a mindful trial and error approach with less focus on a correct or incorrect verdict.

Exposure of the present materials should be at the discretion of the instructor—as an instructional aid, rather than a replacement for the instructor. These techniques utilize very fine muscle groups within the soft tissues of the oral cavity and should be addressed using healthy practice habits. The presence of the videos and data may guide the student to believe that each note must have a specific oral cavity shape or position, which may prove problematic. Since each person has a unique vocal tract configuration—tongue shape, volume, teeth position, palate shape, etc.—variation is to be expected.

Additional future research in the area of ultrasound imaging involving saxophone performance could prove to be beneficial for quantifying the internal structures and how they behave during performance. In doing this, the field of saxophone pedagogy would be exposed to increased clarity of pedagogical concepts as well as possibly a more succinct path for learning such procedures. A possible continuation of this study could be the addition of student subjects of varying skill levels, and observing how specific tasks may or may not yield differing outcomes across the subject groups. Another possible study to gain clarity of specific differences concerning vocal tract manipulation could be the combination of ultrasound with force sensing technology in an effort to determine a connection, if any, between the pressure exerted by the embouchure and the manipulation of the vocal tract (Low, 2014). Additional research regarding the tongue placement of younger players while both successfully and unsuccessfully producing tones in the palm key register could be pedagogically valuable.

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APPENDIX A

SUBJECT: CCB02242015

Personal Alto Saxophone Equipment:

Saxophone: Selmer Super Action 80 SERIE II

Neck: Yamaha C1 neck (solid silver)

Mouthpiece: Selmer S80 C*

Ligature: Rovner Versa (leather)

Reed: Vandoren Traditional 3.5

Wisdom Teeth: Wisdom Teeth Removed

Average Range of Motion Figures for Subject CCB: All Tasks

Figure 16. Average Range Of Motion for Subject CCB: Task 2.

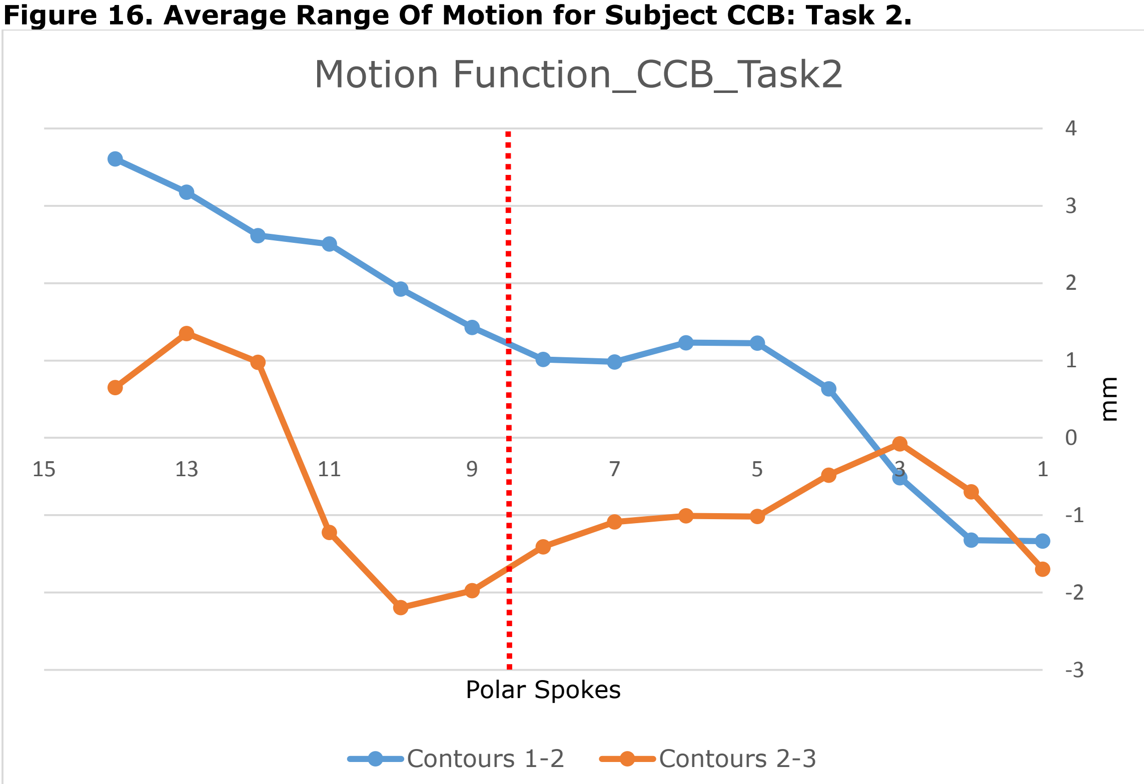


Figure 17. Average Range Of Motion for Subject CCB: Task 3.

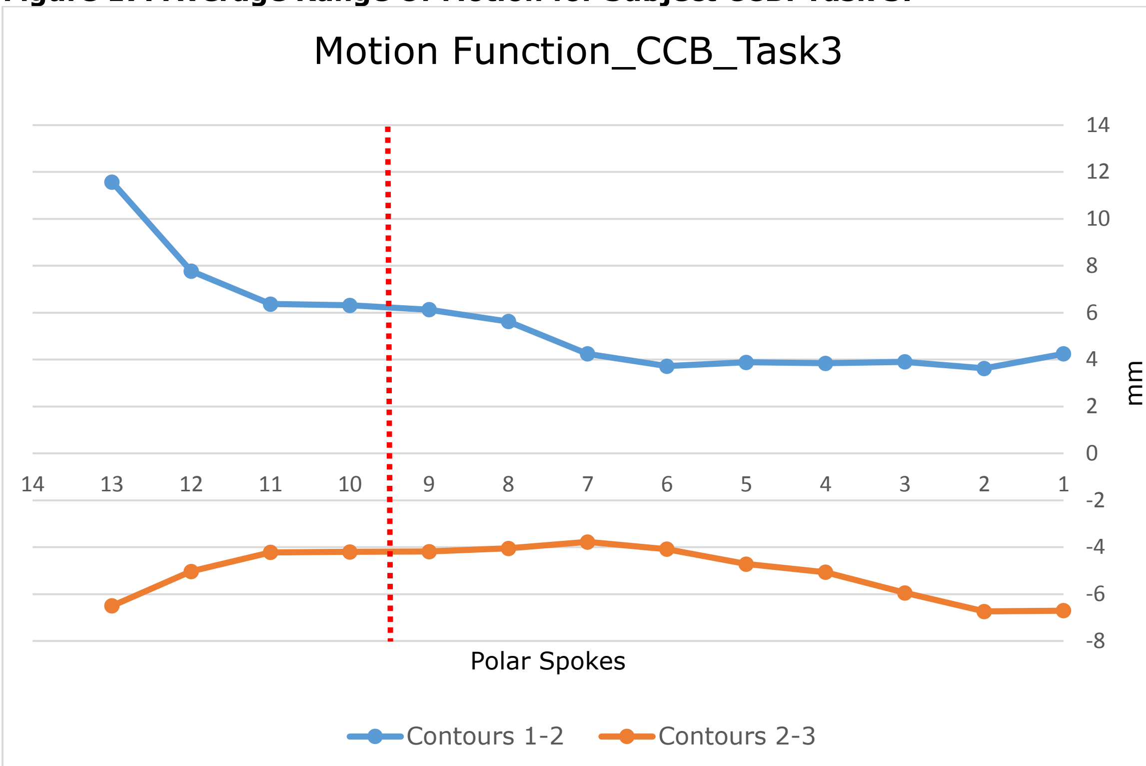


Figure 18. Average Range Of Motion for Subject CCB: Task 4.

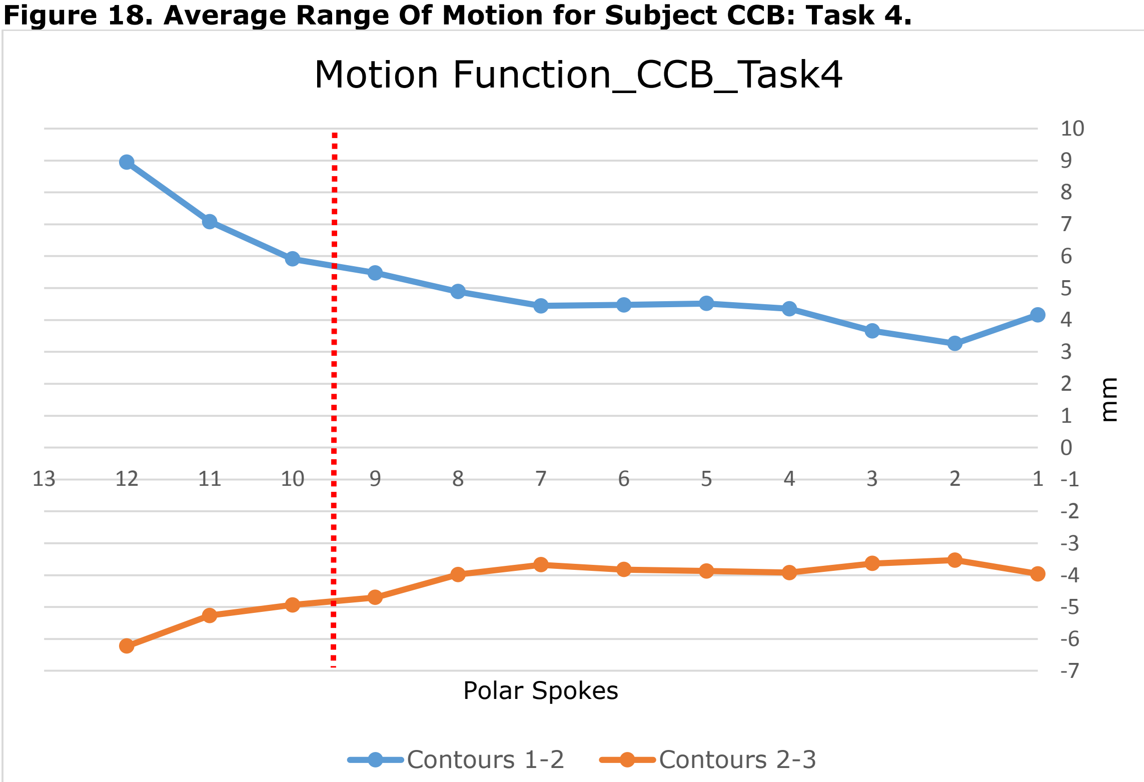


Figure 19. Average Range Of Motion for Subject CCB: Task 5.

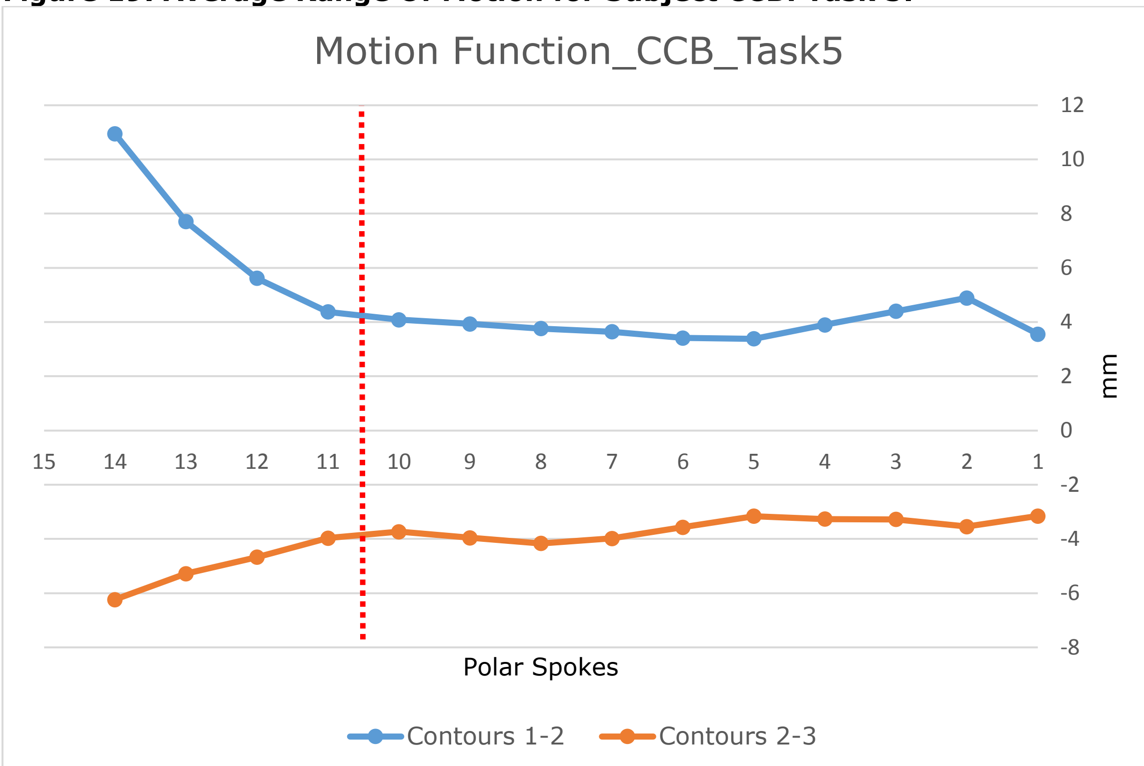


Figure 20. Average Range Of Motion for Subject CCB: Task 6.

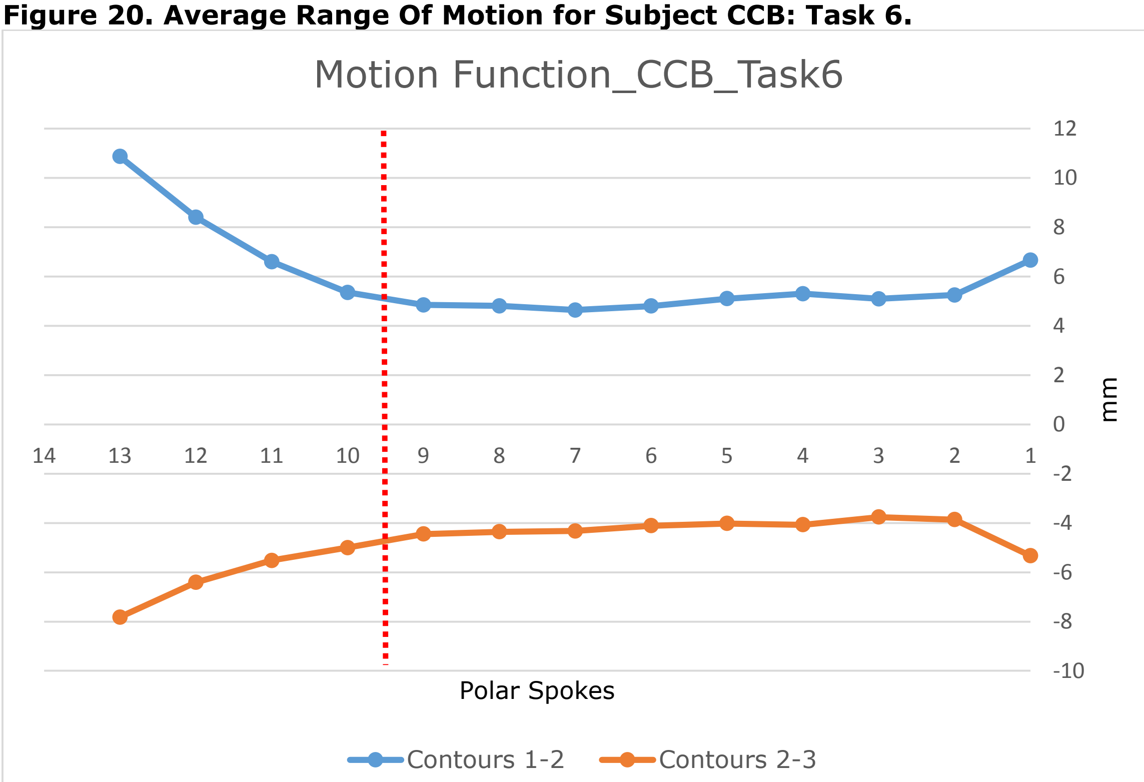
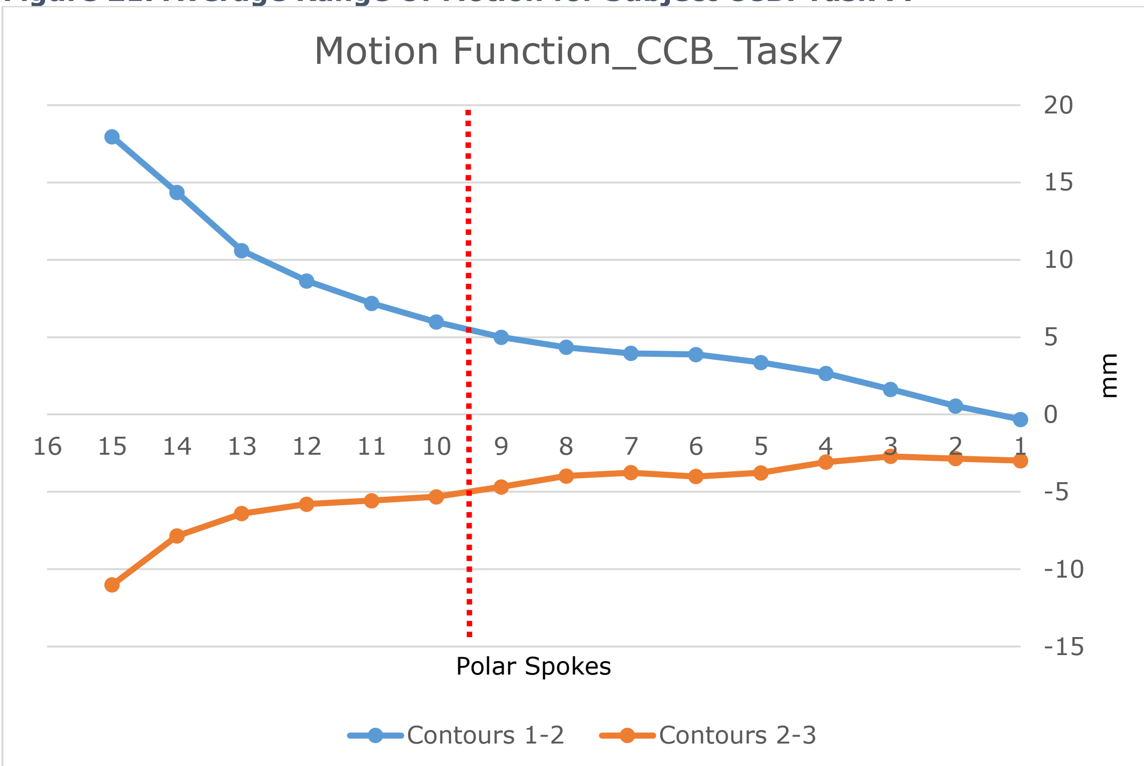


Figure 21. Average Range Of Motion for Subject CCB: Task 7.



APPENDIX B

SUBJECT: CLC02242015

Personal Alto Saxophone Equipment:

Saxophone: Yamaha Custom Z (gold plated)

Neck: Yamaha V1 (solid silver)

Mouthpiece: Selmer S80 C* (customized)

Ligature: Ishimori (solid silver)

Reed: Vandoren Traditional 3.5

Wisdom Teeth: Has Wisdom Teeth

Average Range of Motion Figures for Subject CLC: All Tasks

Figure 22. Average Range Of Motion for Subject CLC: Task 3.

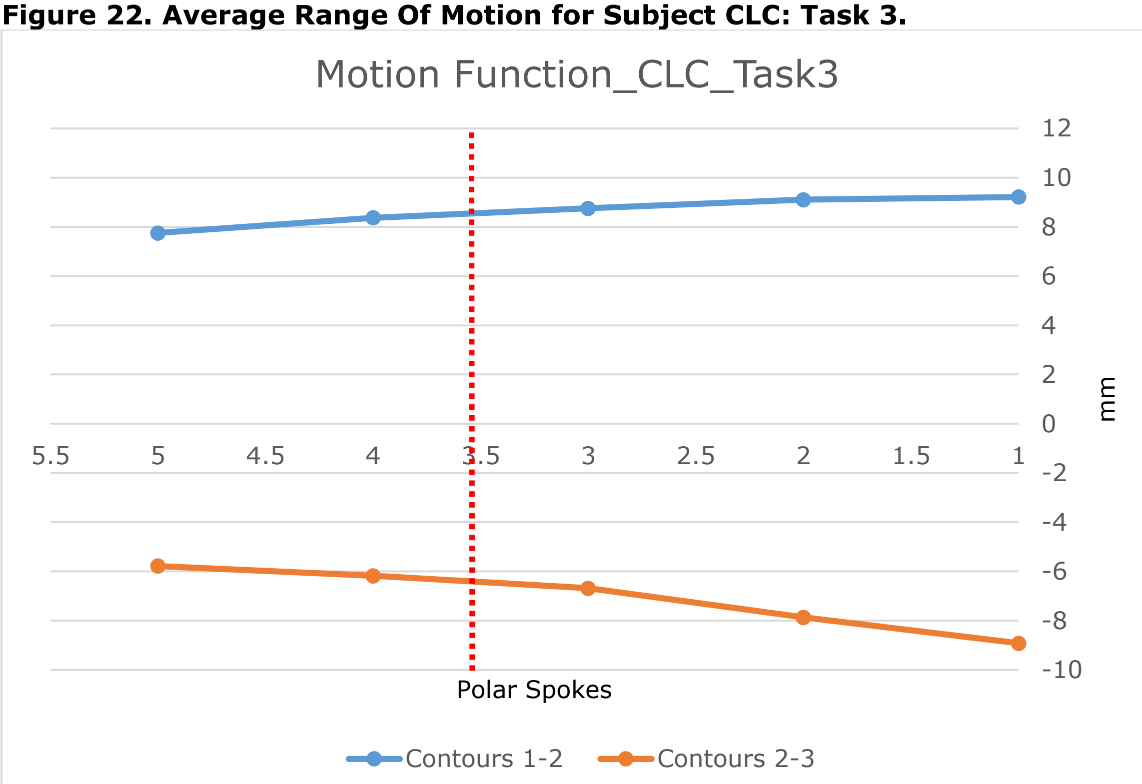


Figure 23. Average Range Of Motion for Subject CLC: Task 4.

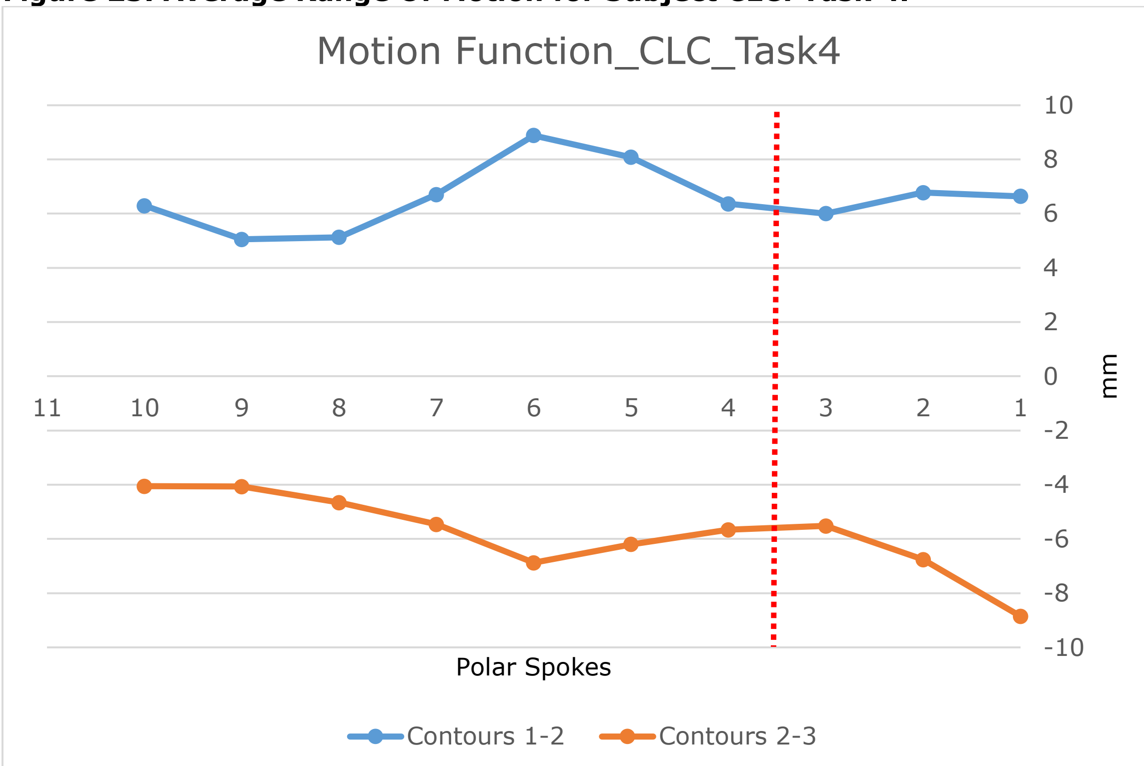


Figure 24. Average Range Of Motion for Subject CLC: Task 5.

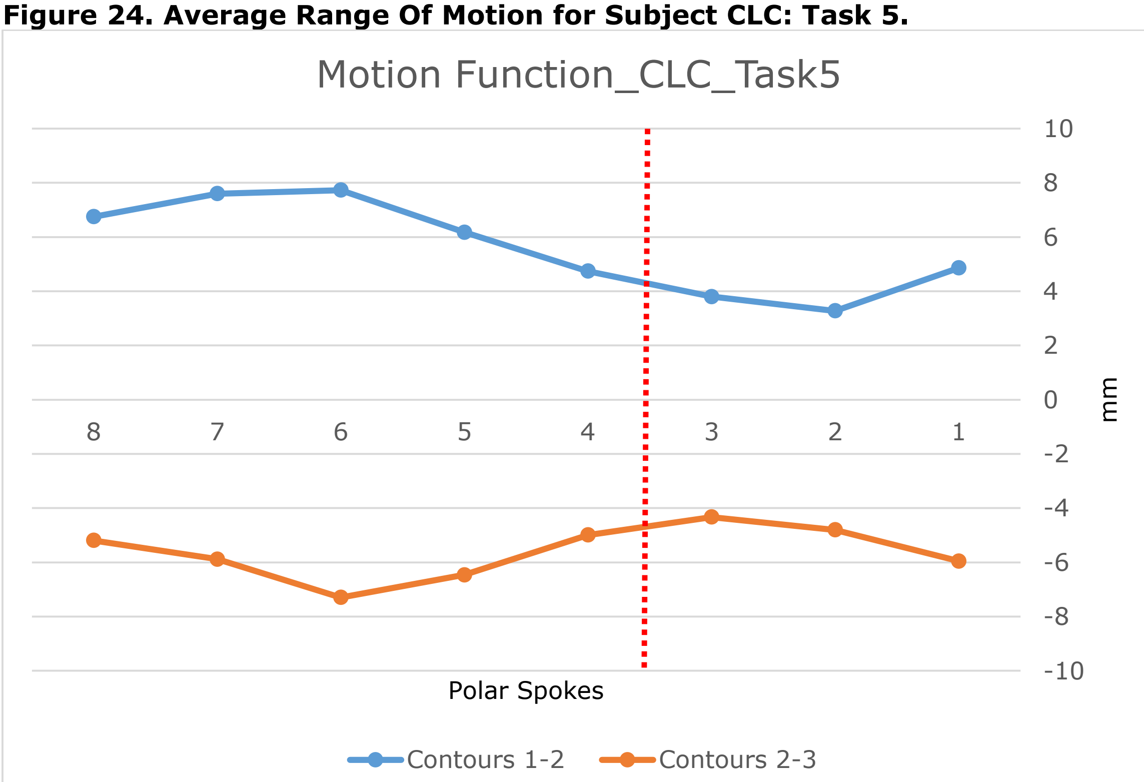


Figure 25. Average Range Of Motion for Subject CLC: Task 6.

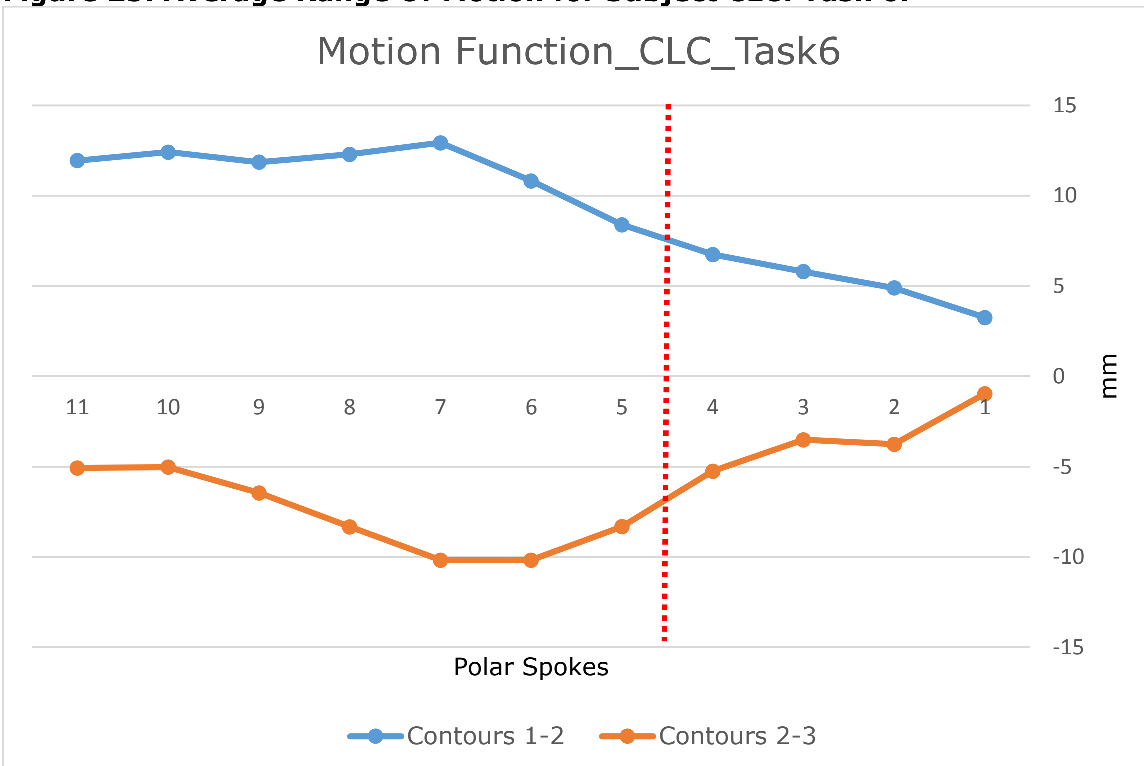
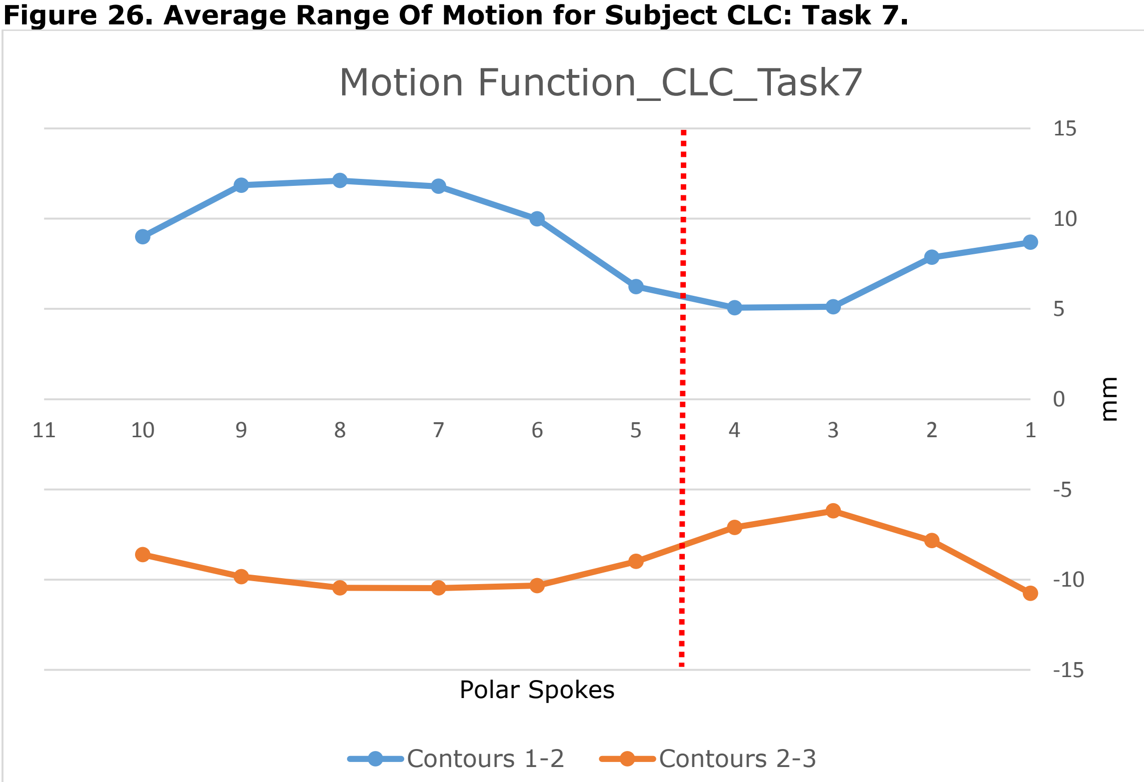


Figure 26. Average Range Of Motion for Subject CLC: Task 7.



APPENDIX C

SUBJECT: DOM02172015

Personal Alto Saxophone Equipment:

Saxophone: Selmer Paris Super Action 80 SERIE II (silver plated)

Neck: (stock neck)

Mouthpiece: Selmer S80 C**

Ligature: Selmer (stock inverted single screw)

Reed: Rico Reserve 3.5

Wisdom Teeth: Born Without Wisdom teeth

Average Range of Motion Figures for Subject CLC: All Tasks

Figure 27. Average Range Of Motion for Subject DOM: Task 2.

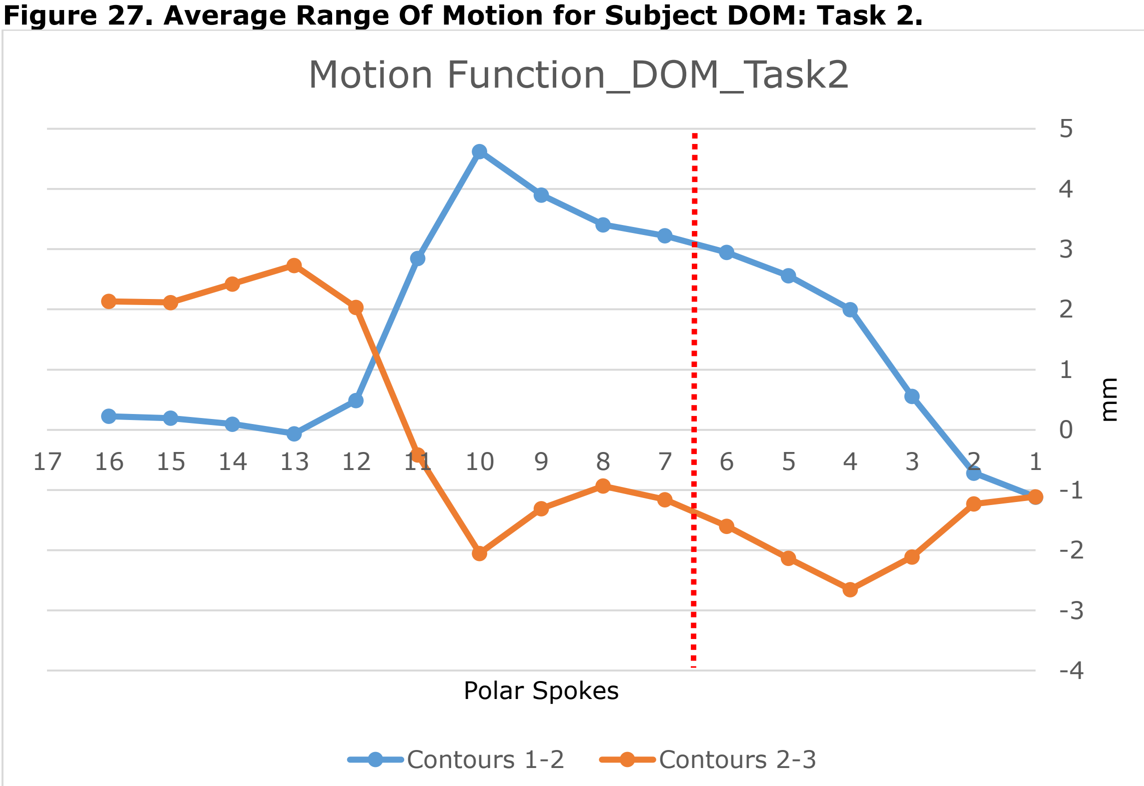


Figure 28. Average Range Of Motion for Subject DOM: Task 3.

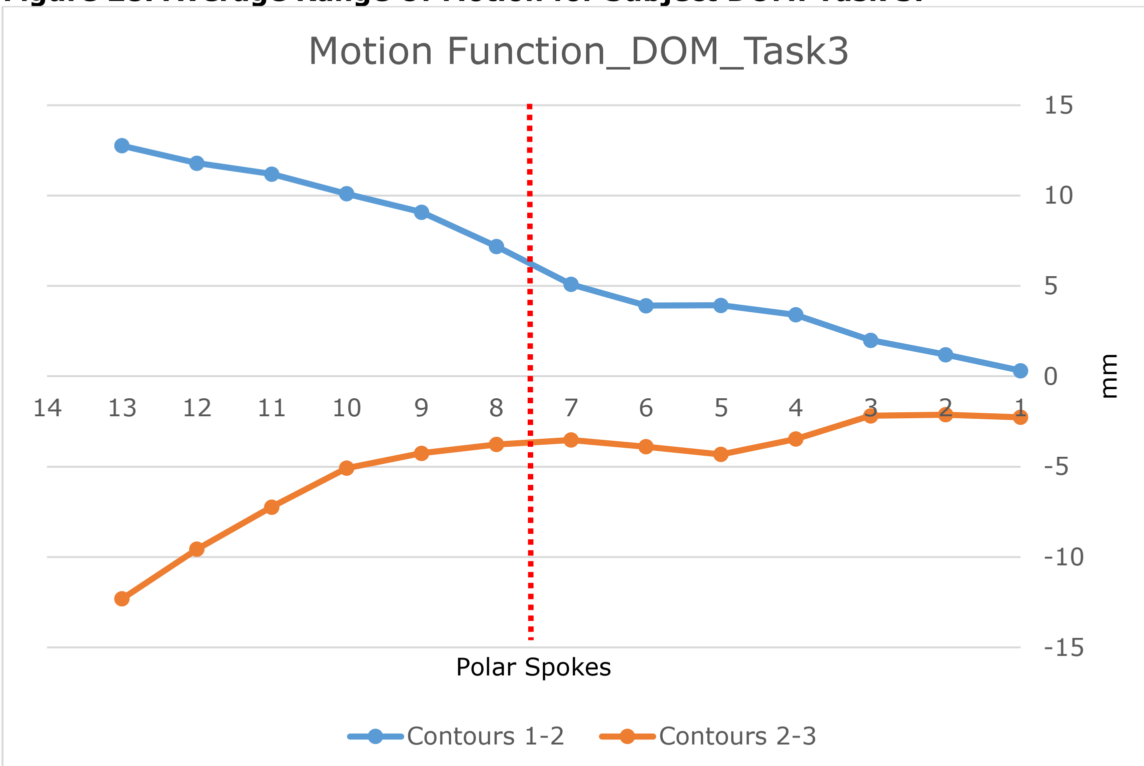


Figure 29. Average Range Of Motion for Subject DOM: Task 4.

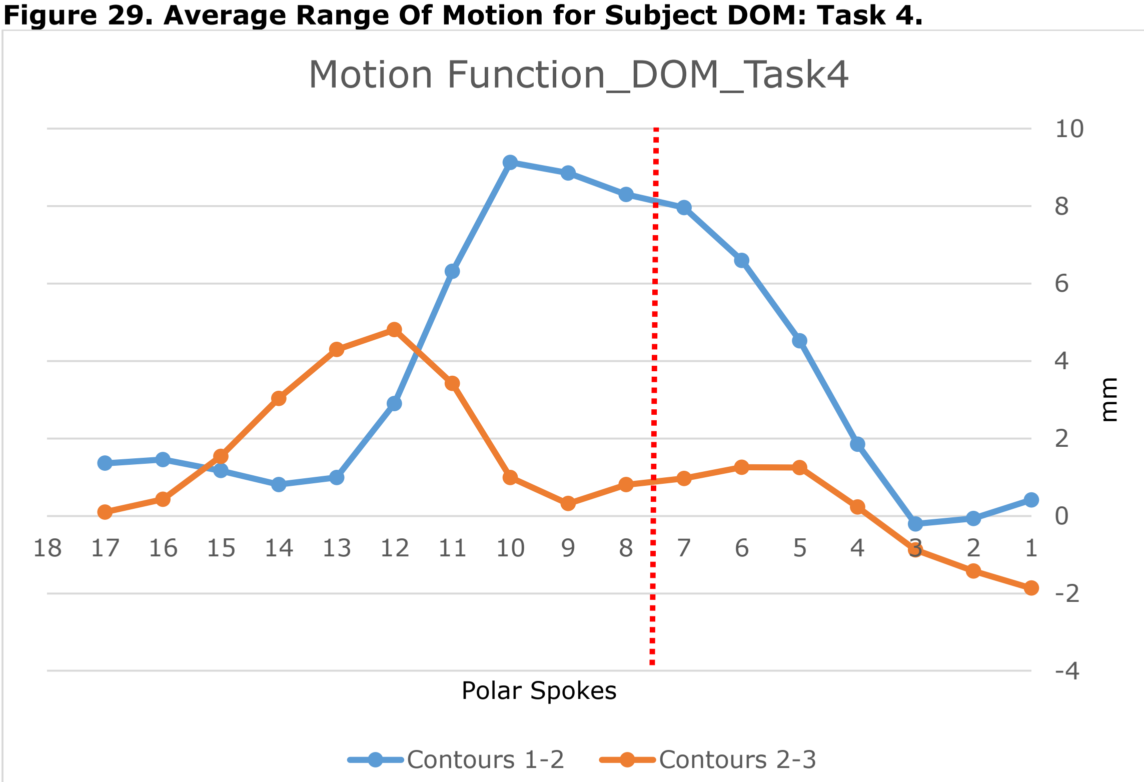


Figure 30. Average Range Of Motion for Subject DOM: Task 5.

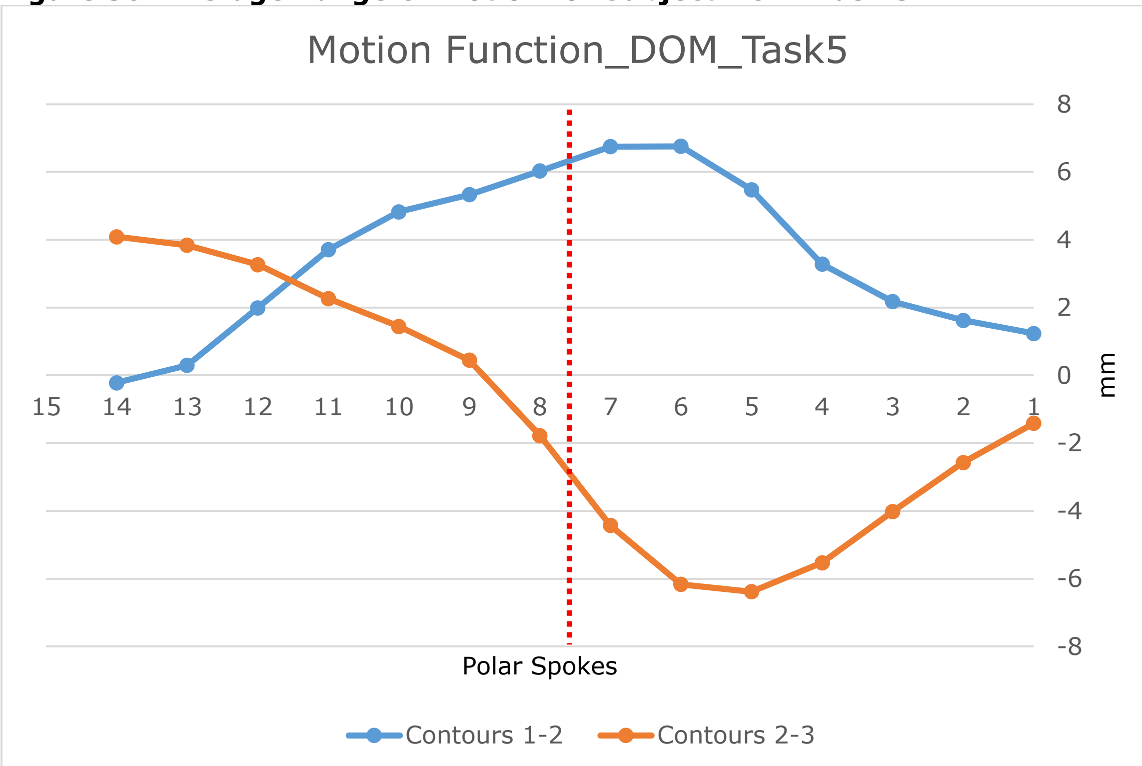


Figure 31. Average Range Of Motion for Subject DOM: Task 6.

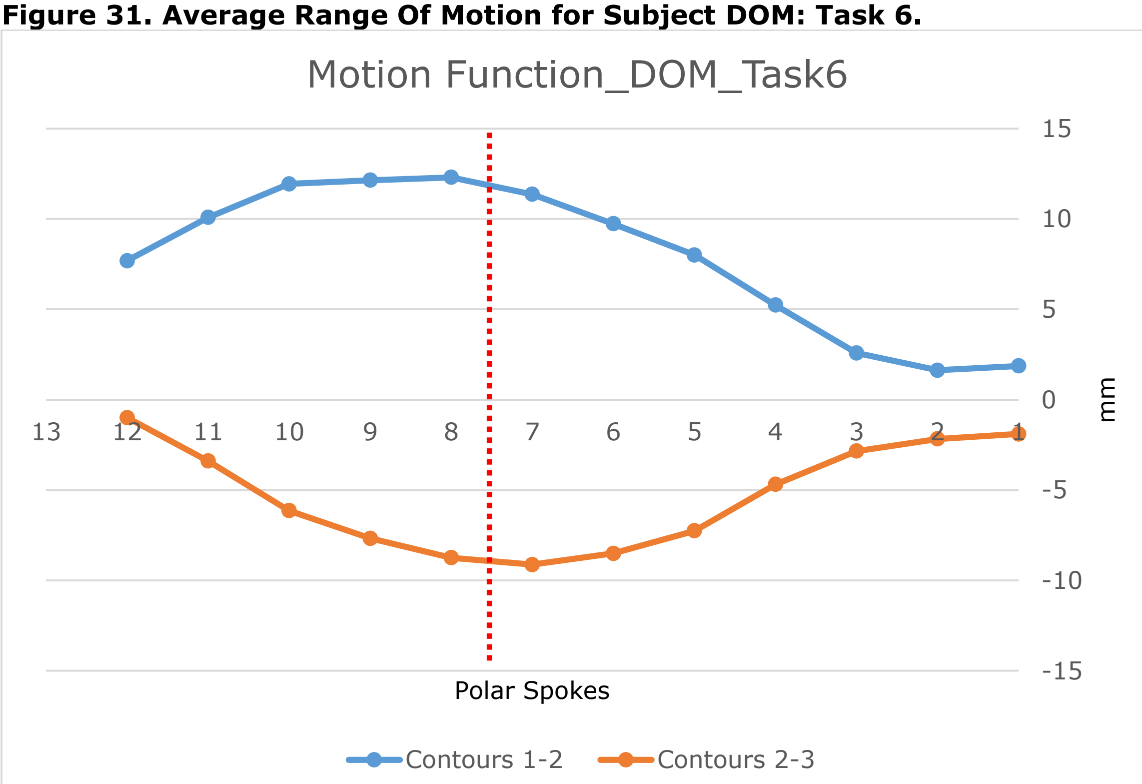
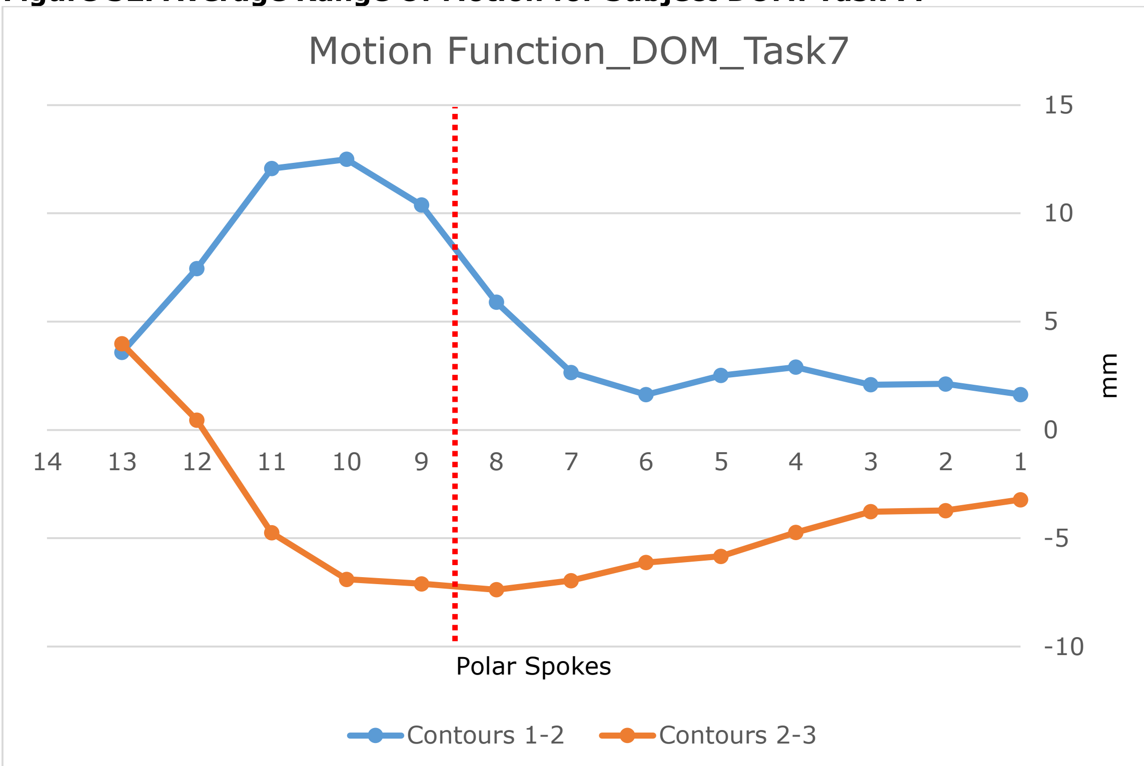


Figure 32. Average Range Of Motion for Subject DOM: Task 7.



APPENDIX D

SUBJECT: DSP05142015

Personal Alto Saxophone Equipment:

Saxophone: Selmer Paris Super Action 80 SERIE II

Neck: (stock neck)

Mouthpiece: Selmer S90/190 (refaced)

Ligature: Bob Scott

Reed: Vandoren Traditional 3

Wisdom Teeth: Wisdom Teeth Removed

Average Range Of Motion for Subject DSP

Figure 33. Average Range Of Motion for Subject DSP: Task 2.

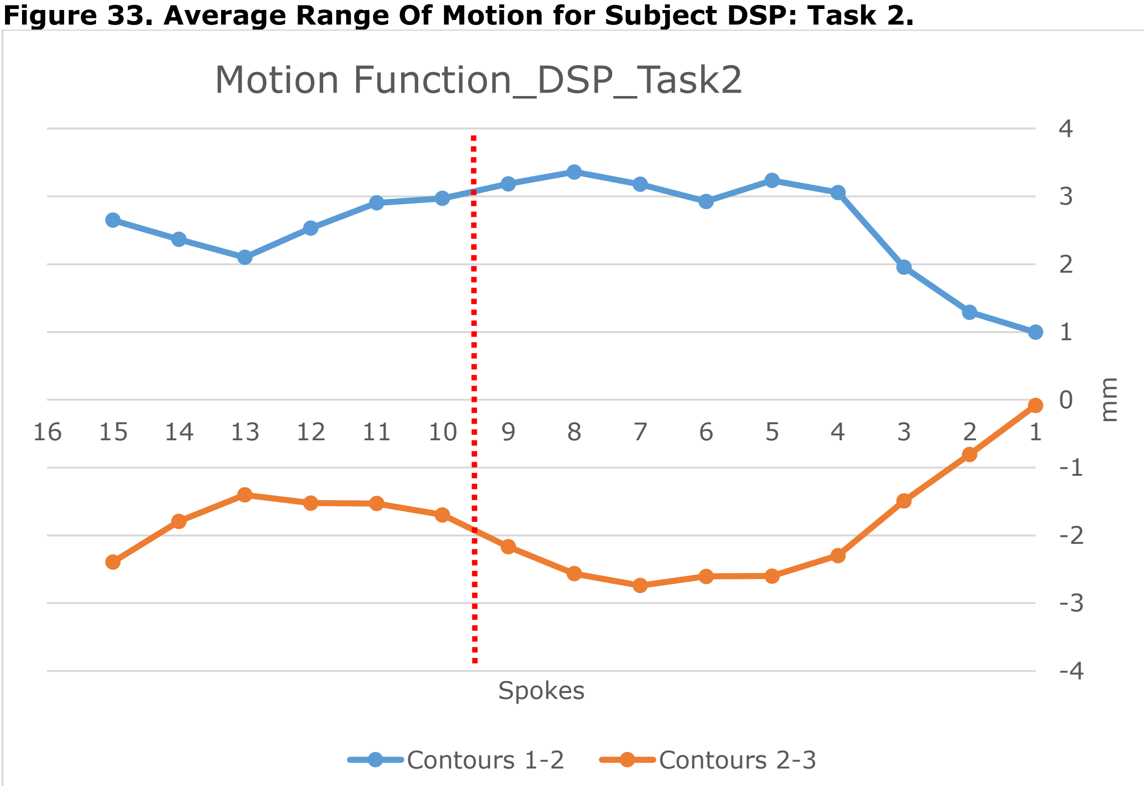


Figure 34. Average Range Of Motion for Subject DSP: Task 3b.

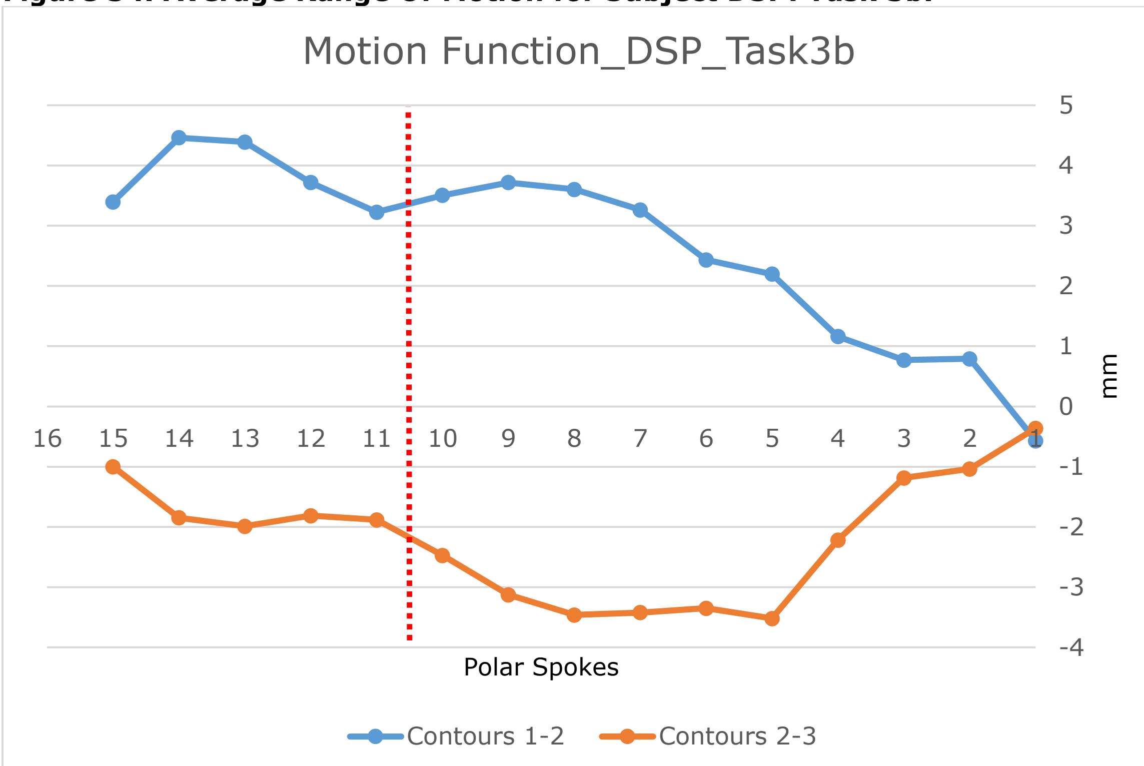


Figure 35. Average Range Of Motion for Subject DSP: Task 4.

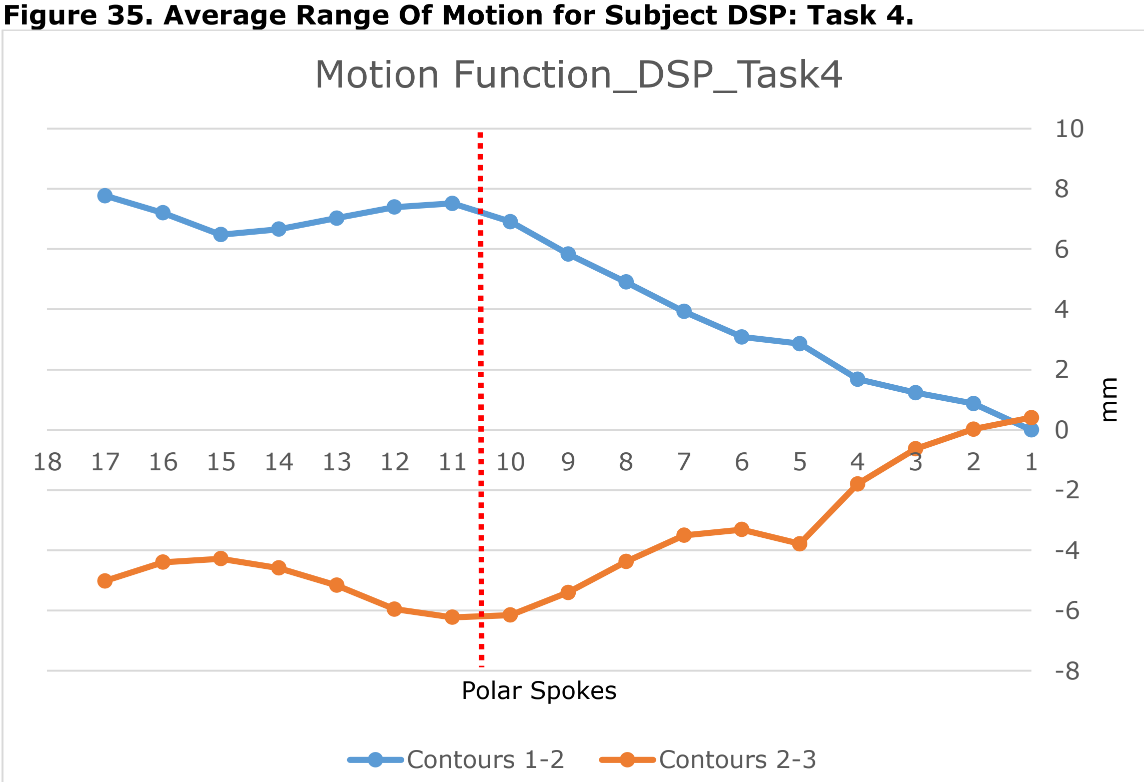


Figure 36. Average Range Of Motion for Subject DSP: Task 5b.

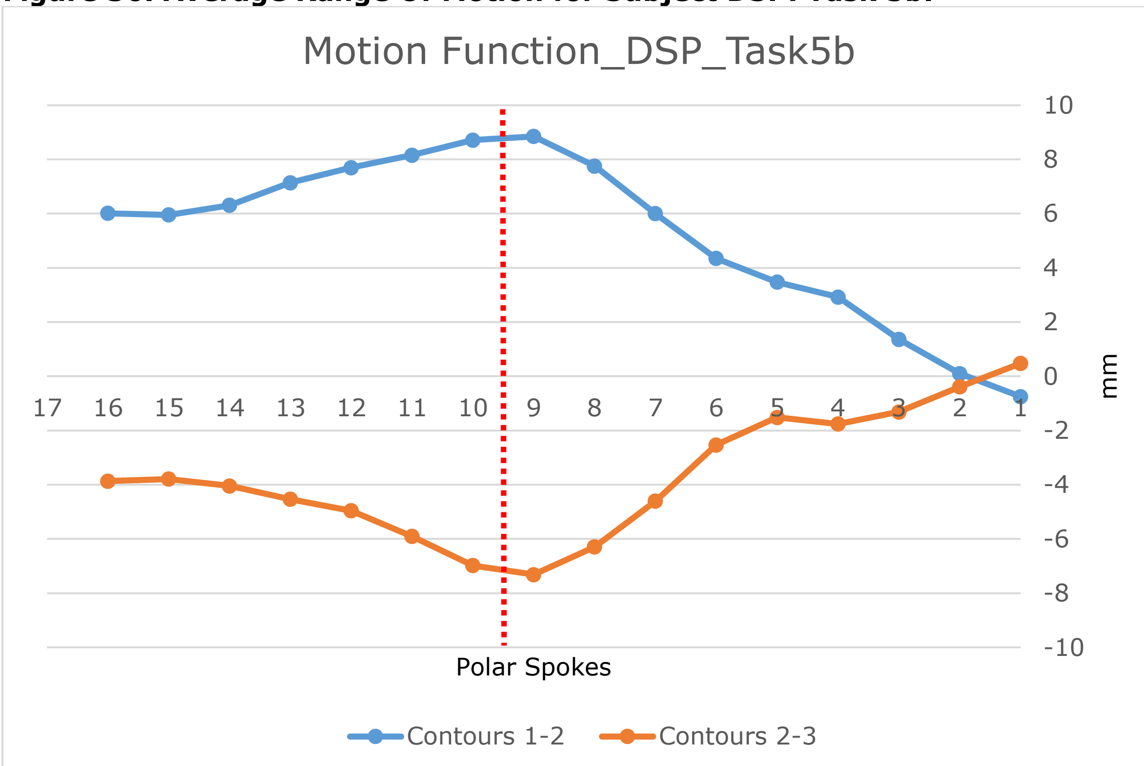


Figure 37. Average Range Of Motion for Subject DSP: Task 6.

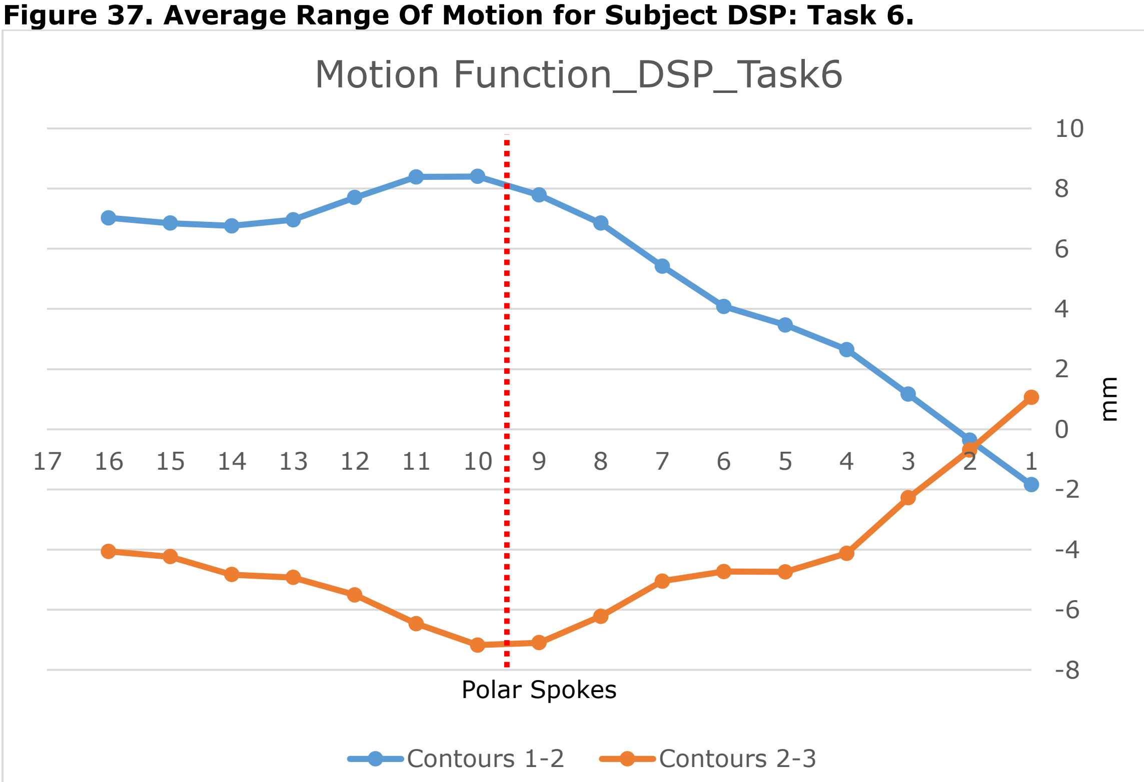
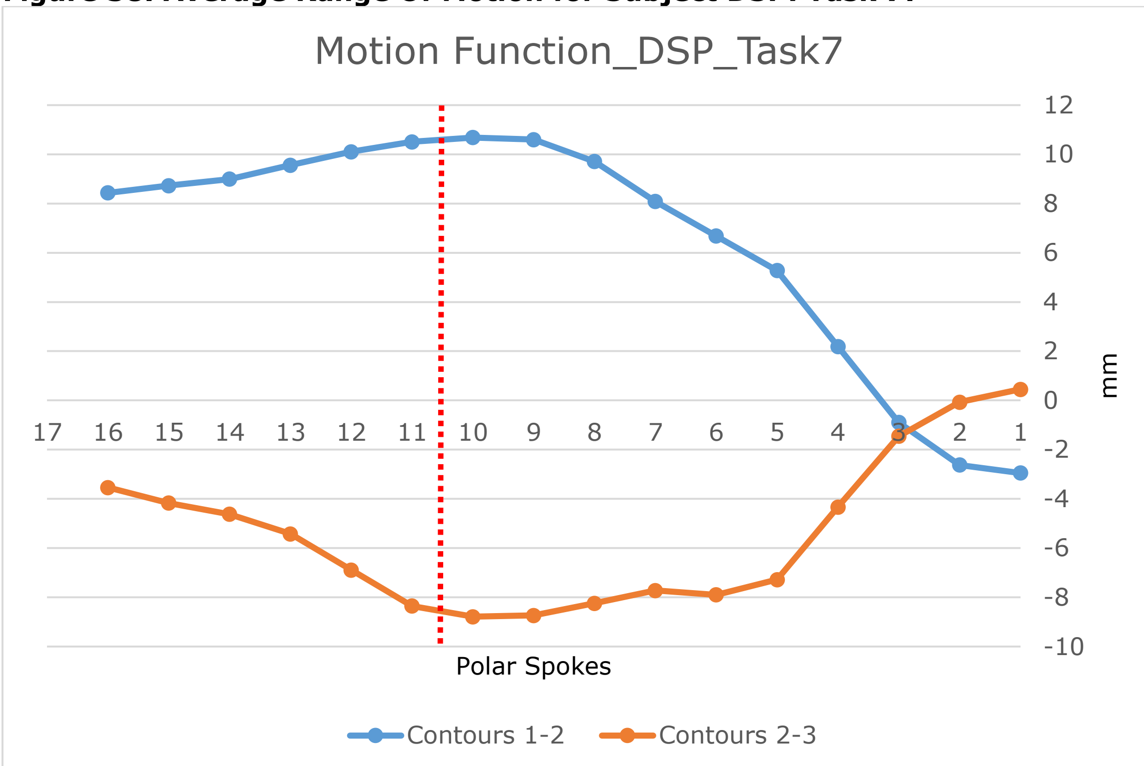


Figure 38. Average Range Of Motion for Subject DSP: Task 7.



APPENDIX E

SUBJECT: EMB02132015

Personal Alto Saxophone Equipment:

Saxophone: Yamaha Custom Z (Silver Plated)

Neck: Yamaha V1 (Silver Plated)

Mouthpiece: Selmer Soloist C** (refaced)

Ligature: Ishimori (copper)

Reed: Vandoren Traditional 3.0

Wisdom Teeth: Still Has Wisdom Teeth

Average Range Of Motion for Subject EMB

Figure 39. Average Range Of Motion for Subject EMB: Task 2.

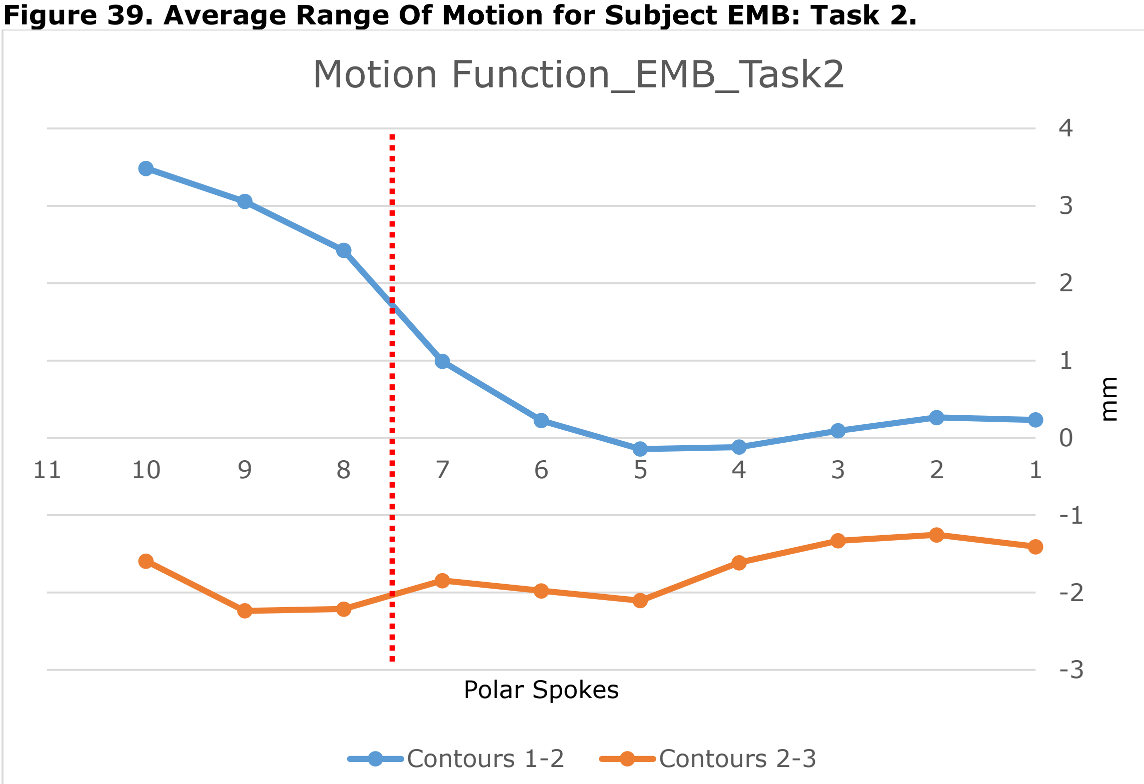


Figure 40. Average Range Of Motion for Subject EMB: Task 3.

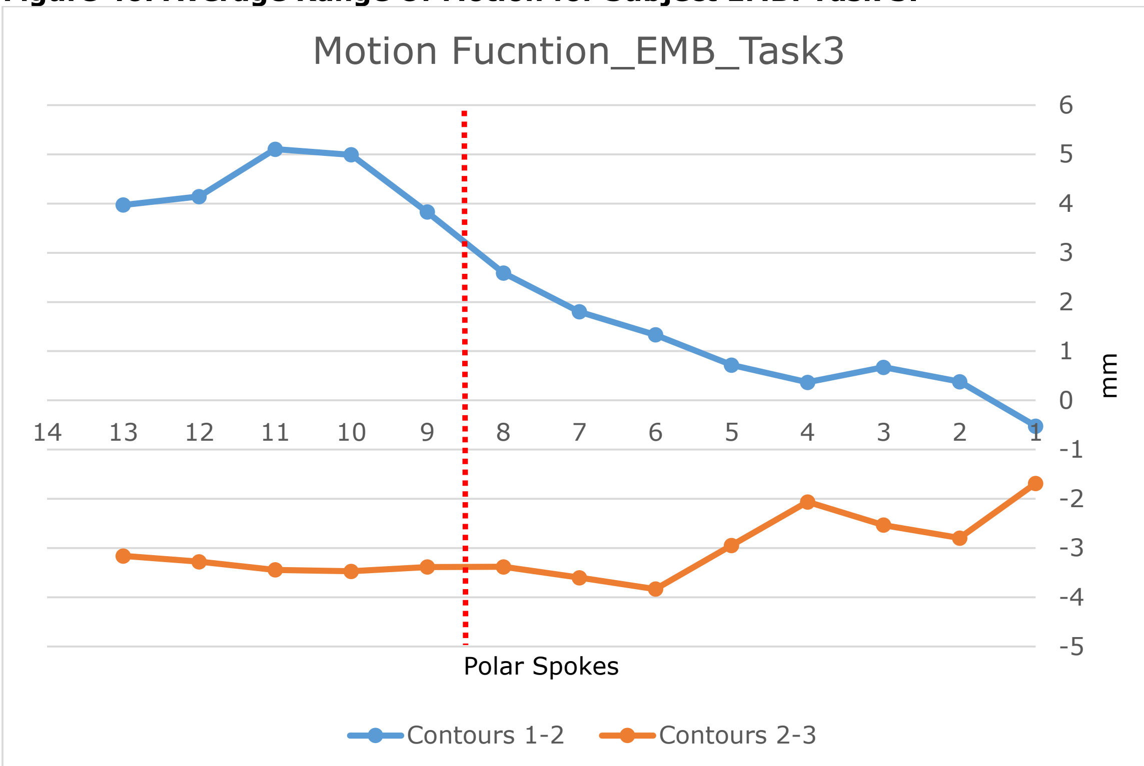


Figure 41. Average Range Of Motion for Subject EMB: Task 4b.

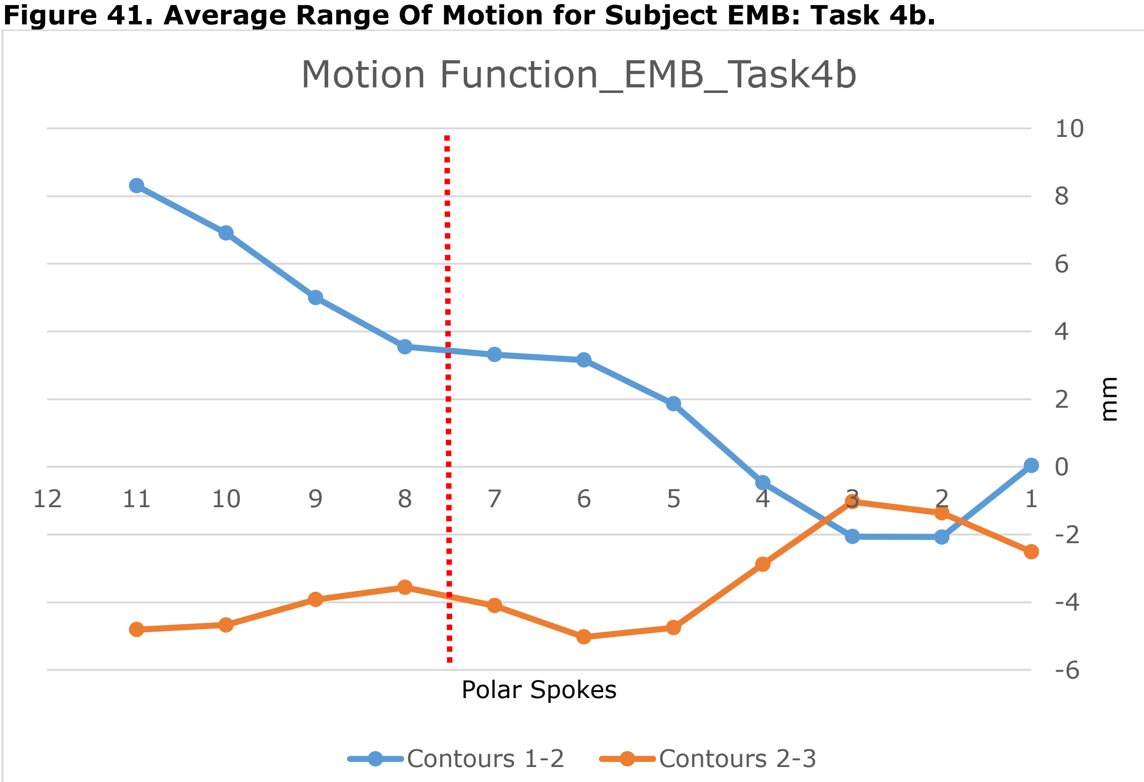


Figure 42. Average Range Of Motion for Subject EMB: Task 5.

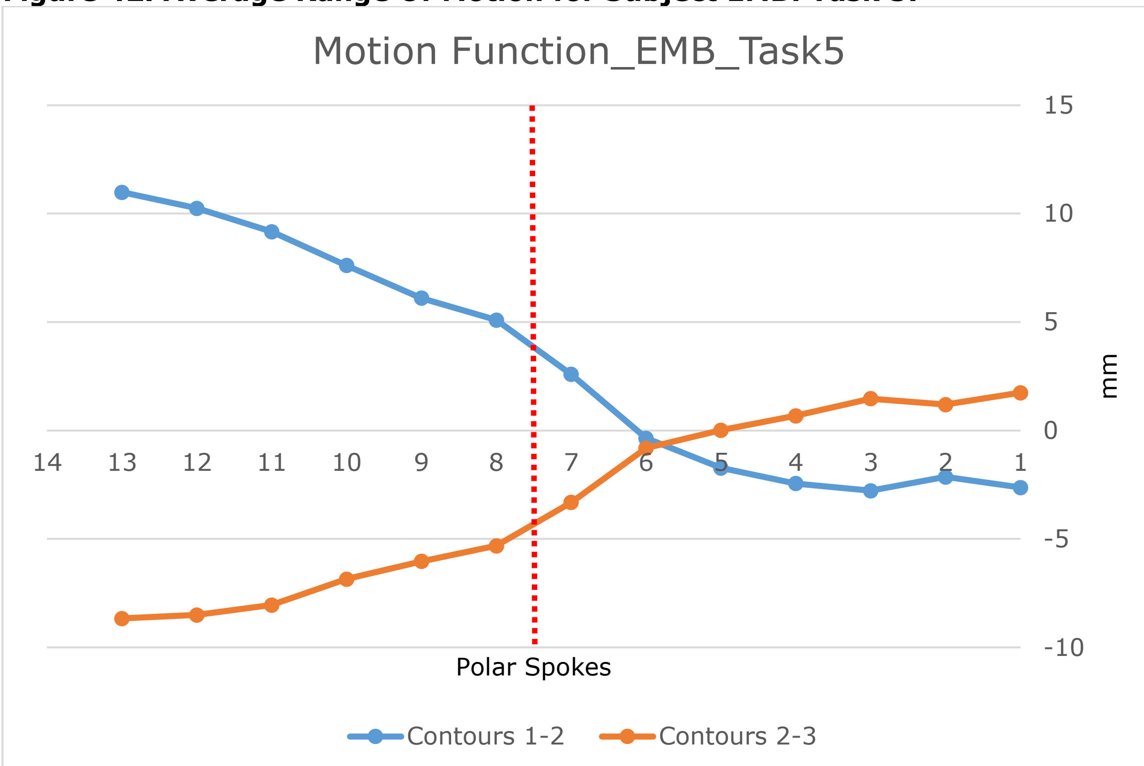


Figure 43. Average Range Of Motion for Subject EMB: Task 6.

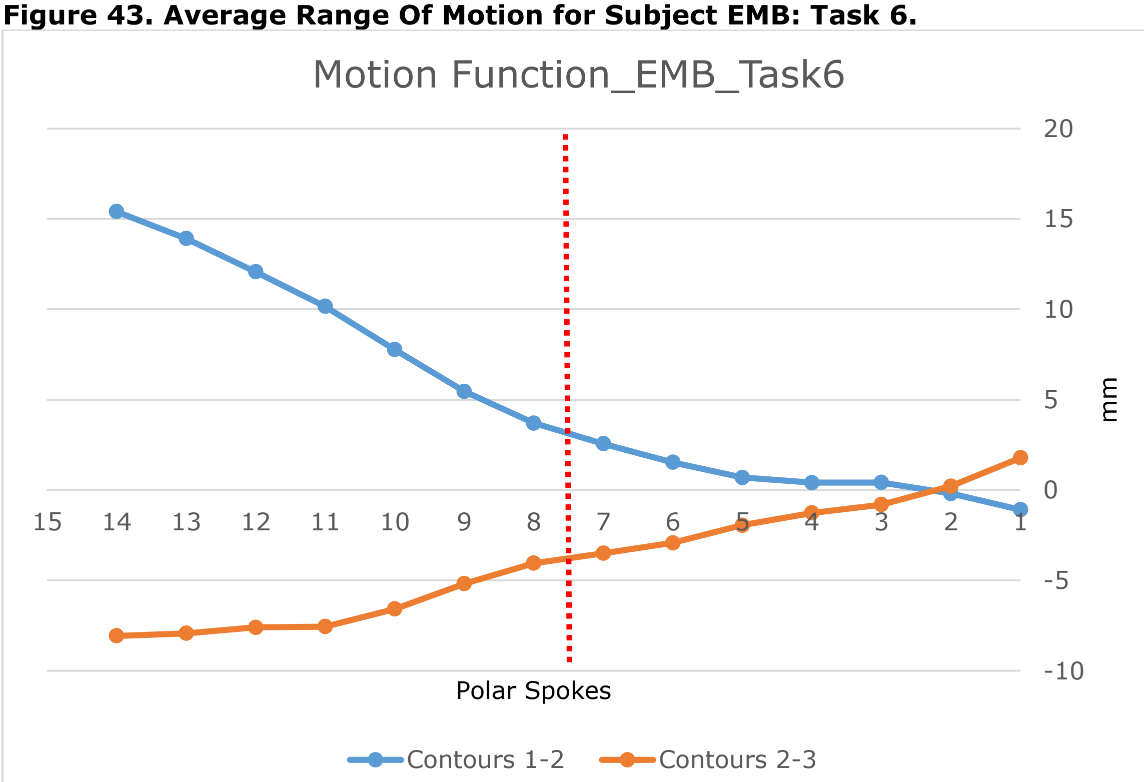
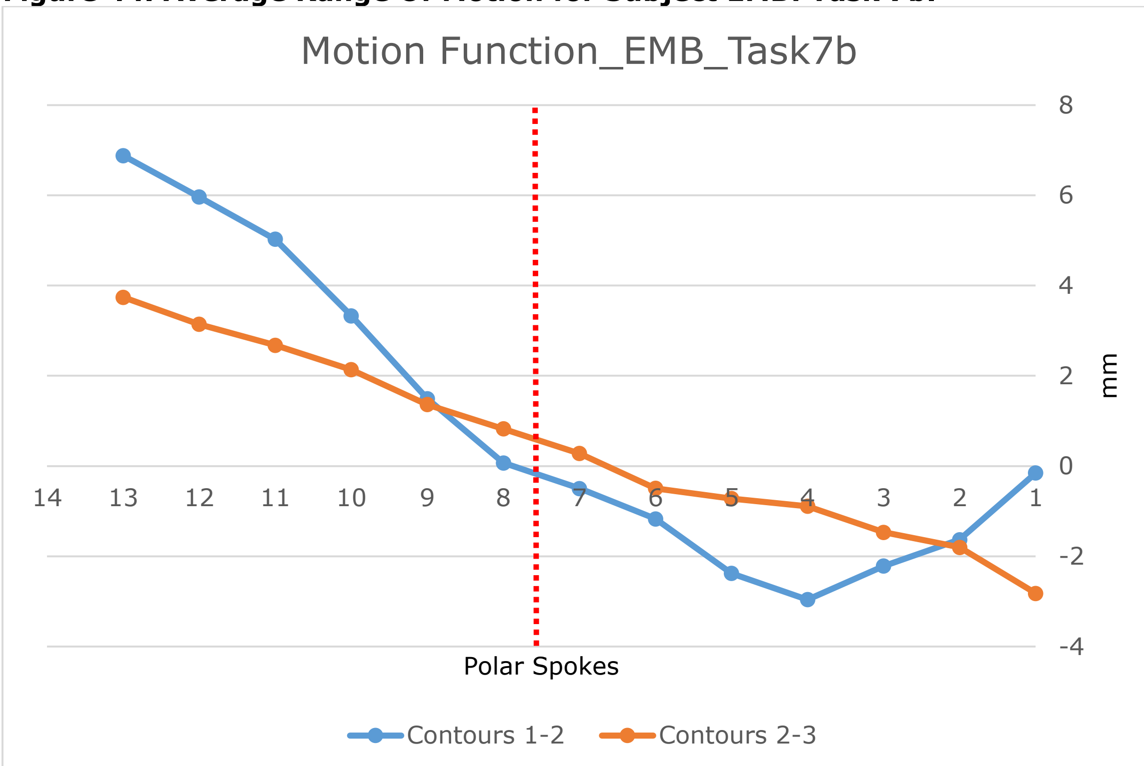


Figure 44. Average Range Of Motion for Subject EMB: Task 7b.



APPENDIX F

SUBJECT: JDR02192015

Personal Alto Saxophone Equipment:

Saxophone: Yamaha Custom EX (Gold-Plated)

Neck: Yamaha V1 (Solid-Silver

Mouthpiece: Selmer S90/190

Ligature: Ishimori (Brushed)

Reed: Vandoren Traditional 3.5

Wisdom Teeth: Wisdom Teeth Removed

Average Range Of Motion for Subject JDR

Figure 45. Average Range Of Motion for Subject JDR: Task 2.

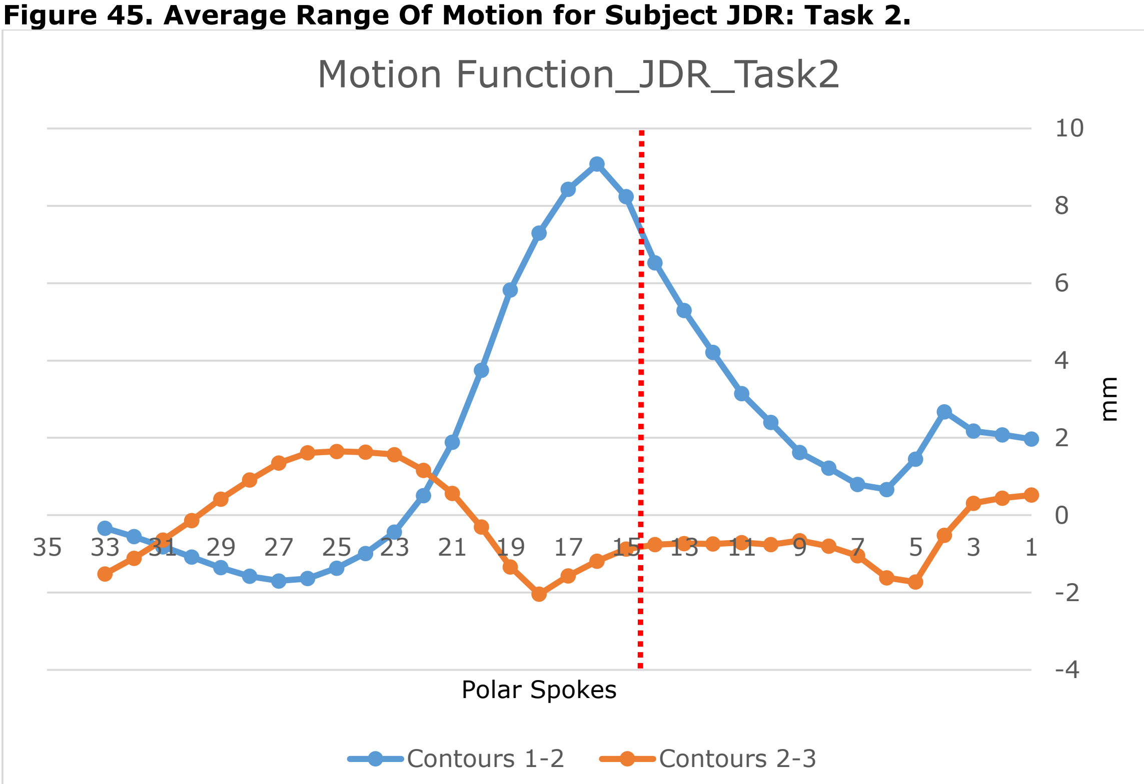


Figure 46. Average Range Of Motion for Subject JDR: Task 3.

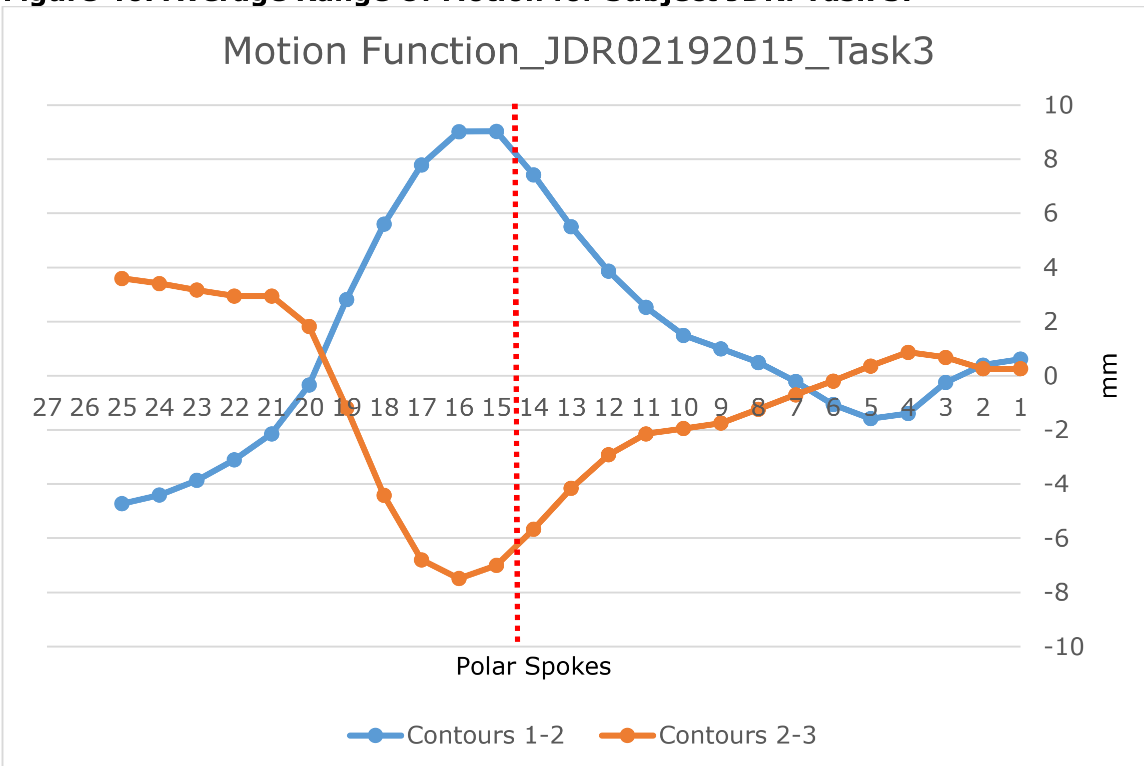


Figure 47. Average Range Of Motion for Subject JDR: Task 4.

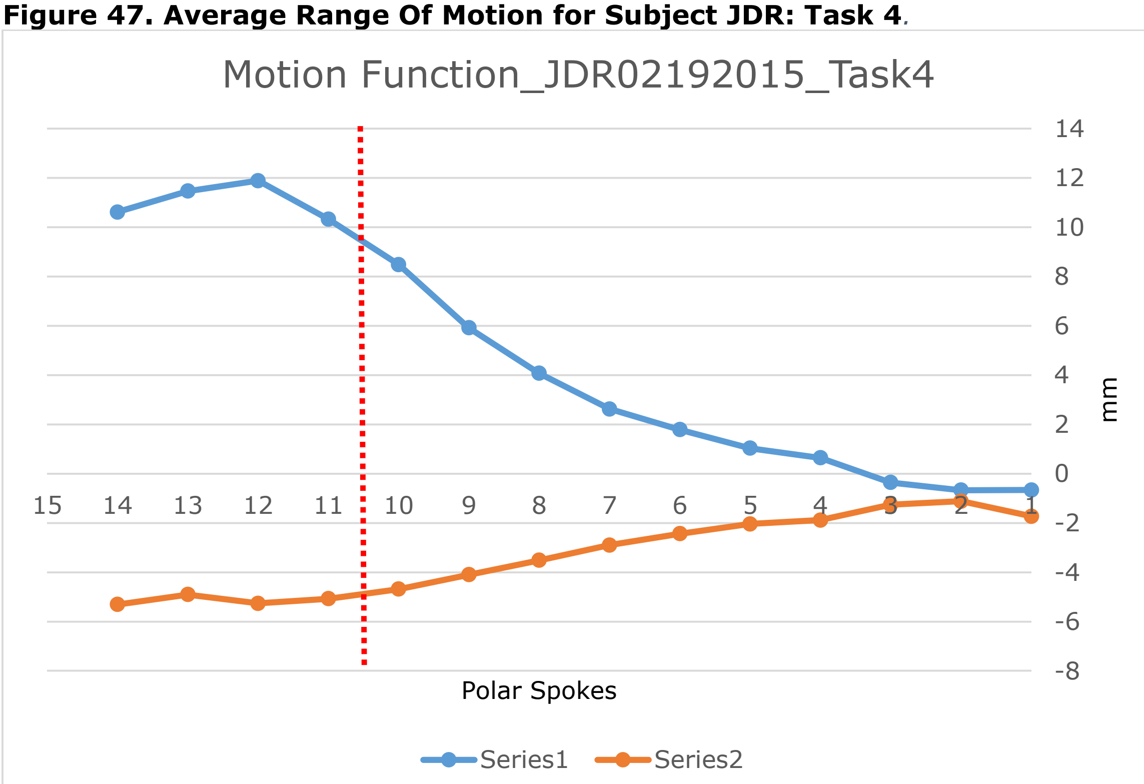


Figure 48. Average Range Of Motion for Subject JDR: Task 5.

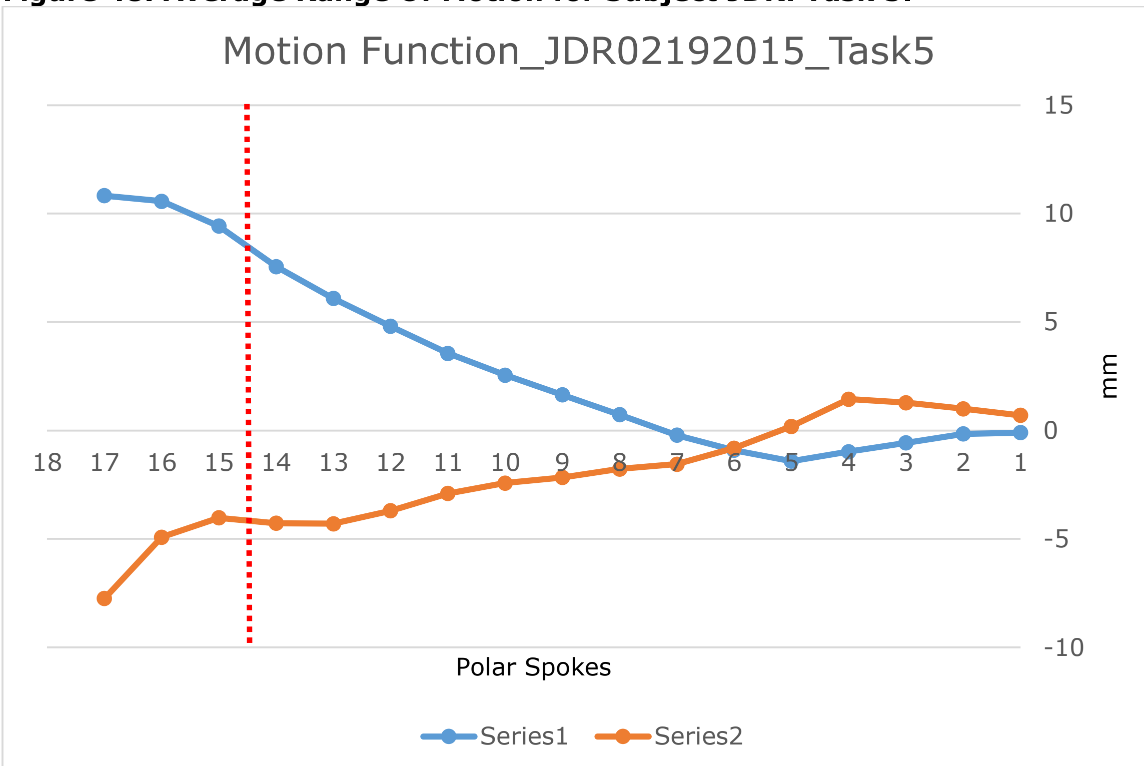


Figure 49. Average Range Of Motion for Subject JDR: Task 6b.

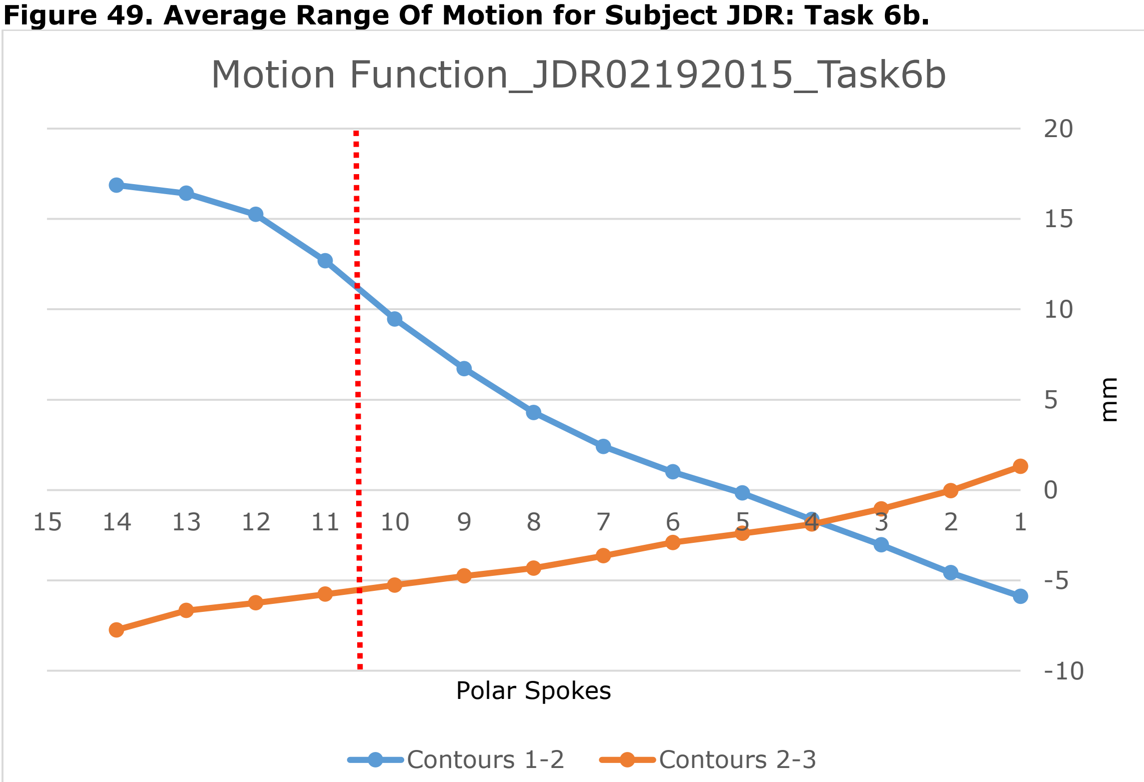
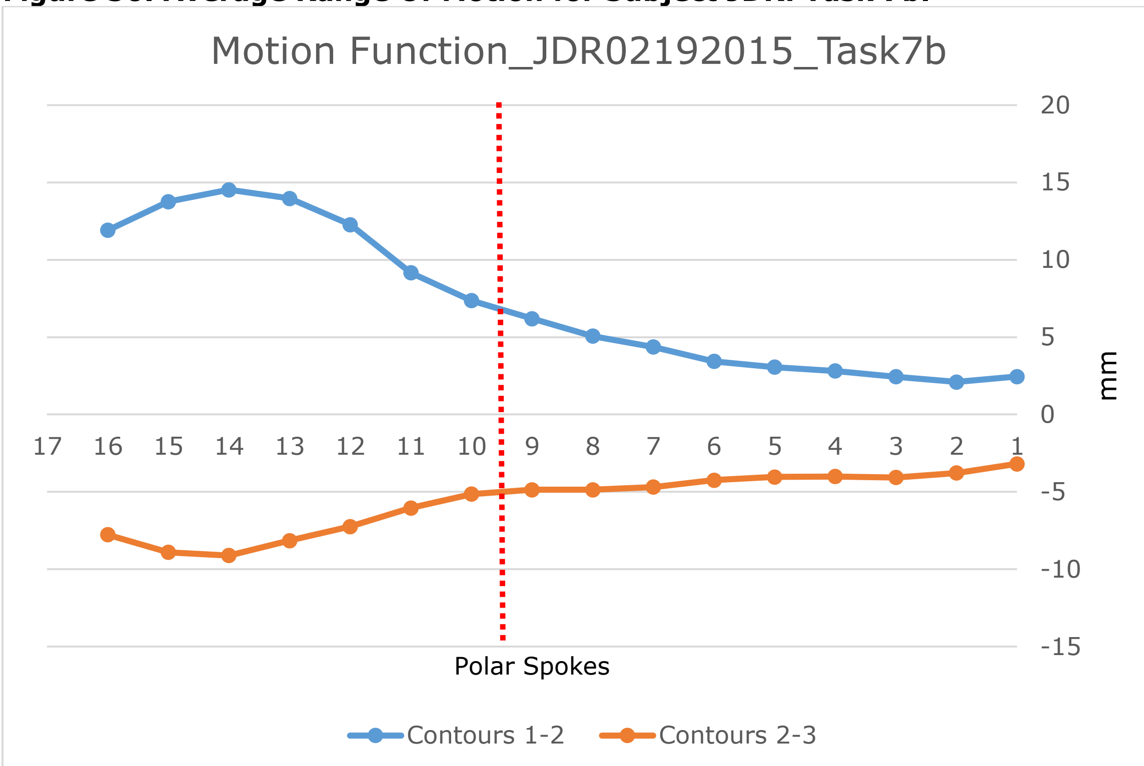


Figure 50. Average Range Of Motion for Subject JDR: Task 7b.



APPENDIX G

SUBJECT: PJM02242015

Personal Alto Saxophone Equipment:

Saxophone: Yamaha Custom EX

Neck: (stock neck)

Mouthpiece: Vandoren Optimum AL3

Ligature: Ishimori (Gold)

Reed: D'addario Reserve 3.5

Wisdom Teeth: Wisdom Teeth Removed

Average Range Of Motion for Subject PJM

Figure 51. Average Range Of Motion for Subject PJM: Task 2.

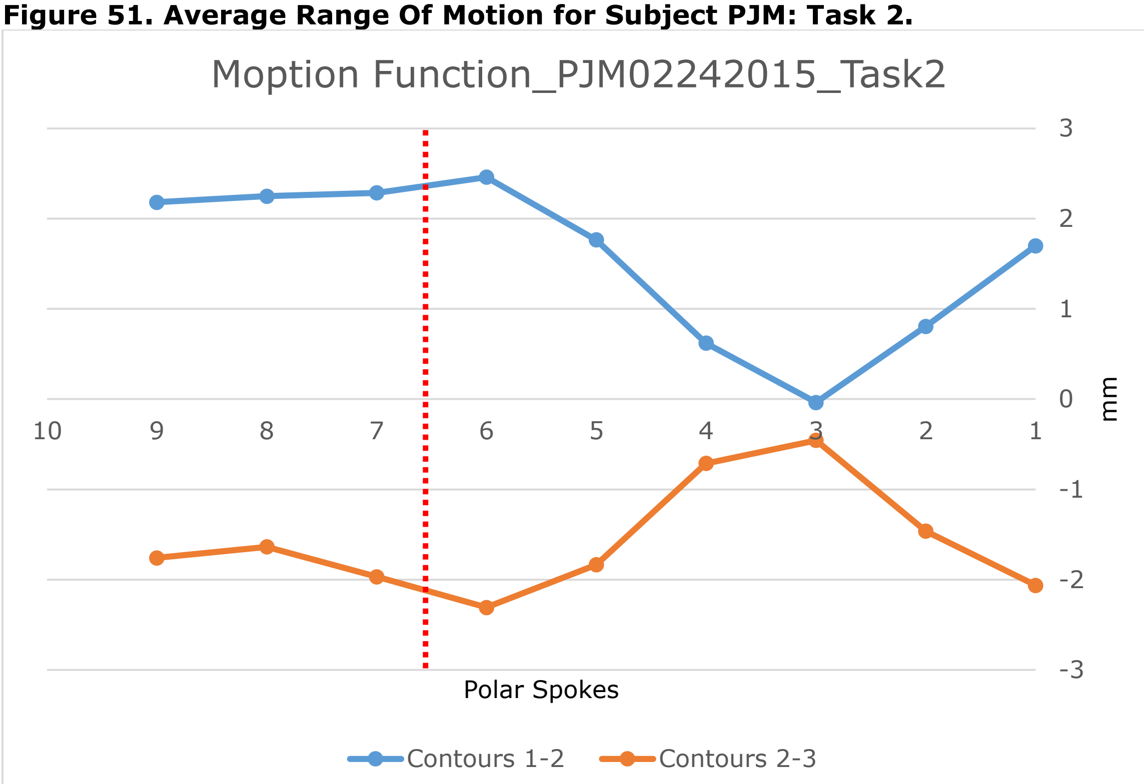


Figure 52. Average Range Of Motion for Subject PJM: Task 3.

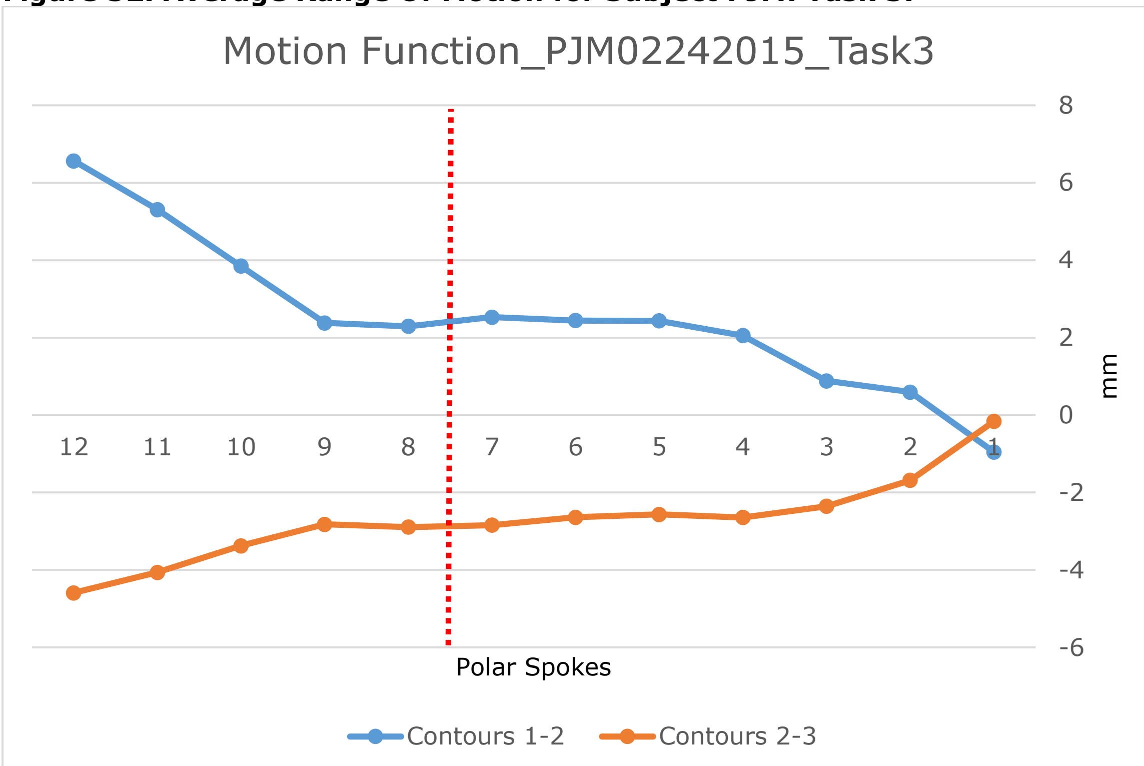


Figure 53. Average Range Of Motion for Subject PJM: Task 4.

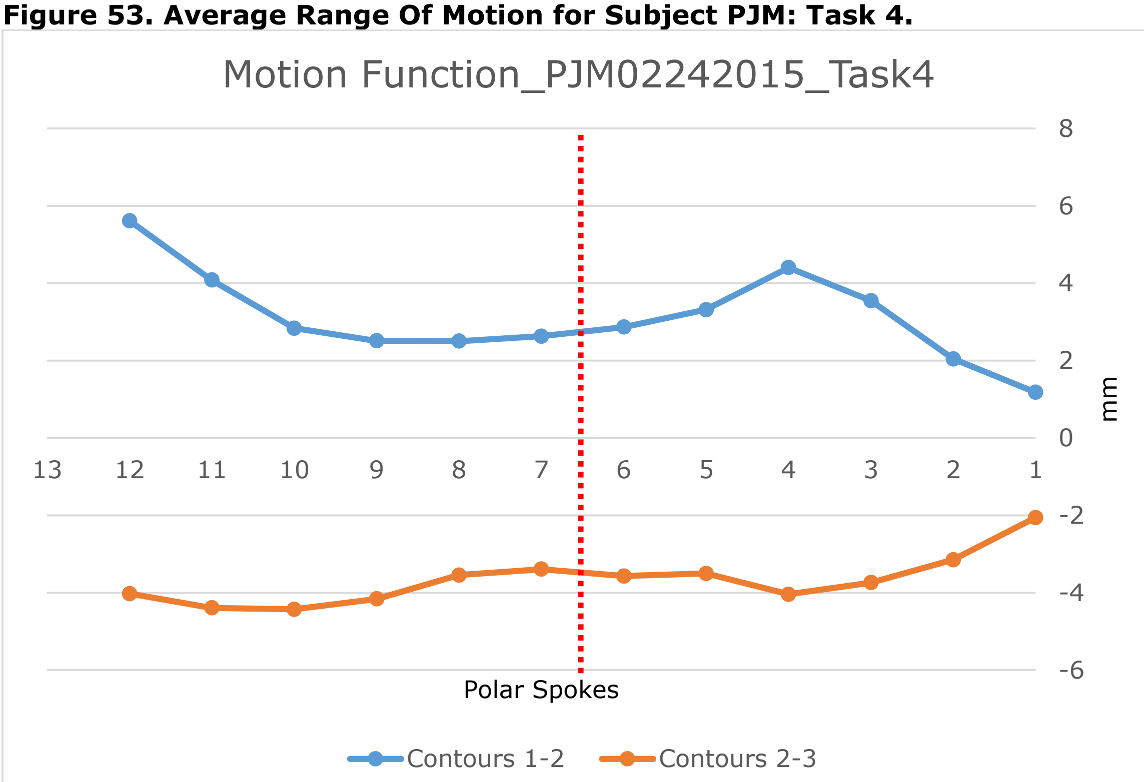


Figure 54. Average Range Of Motion for Subject PJM: Task 5.

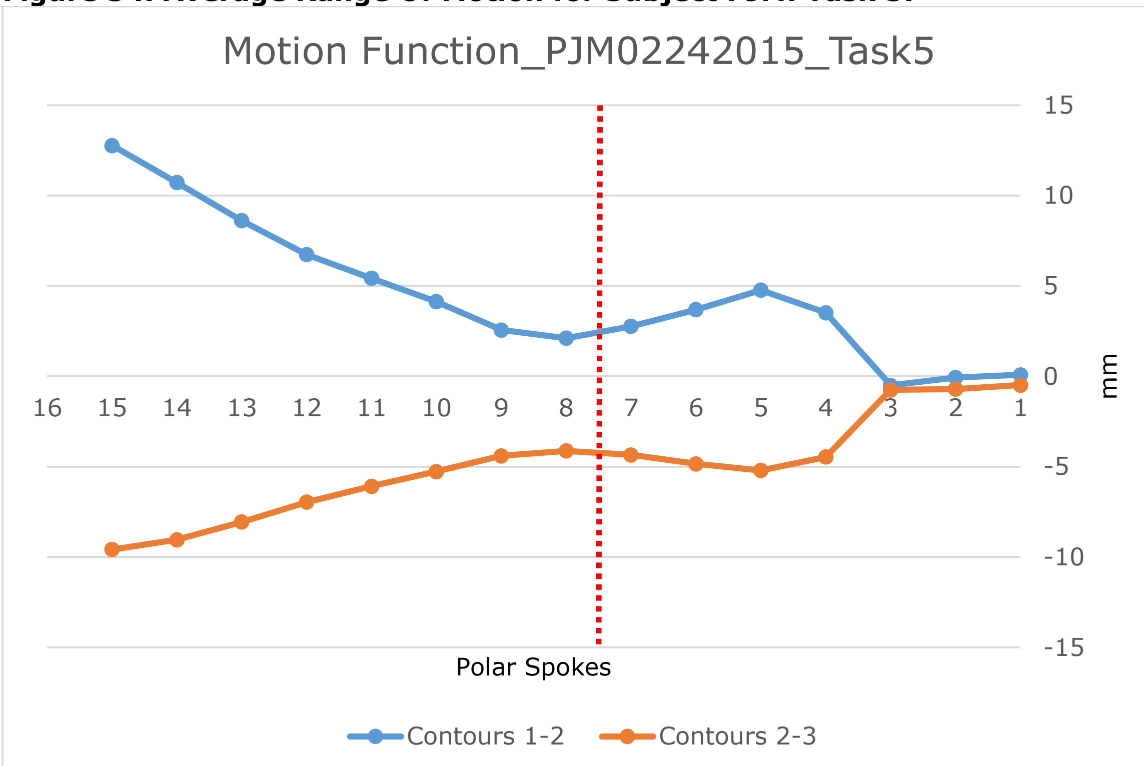


Figure 55. Average Range Of Motion for Subject PJM: Task 6.

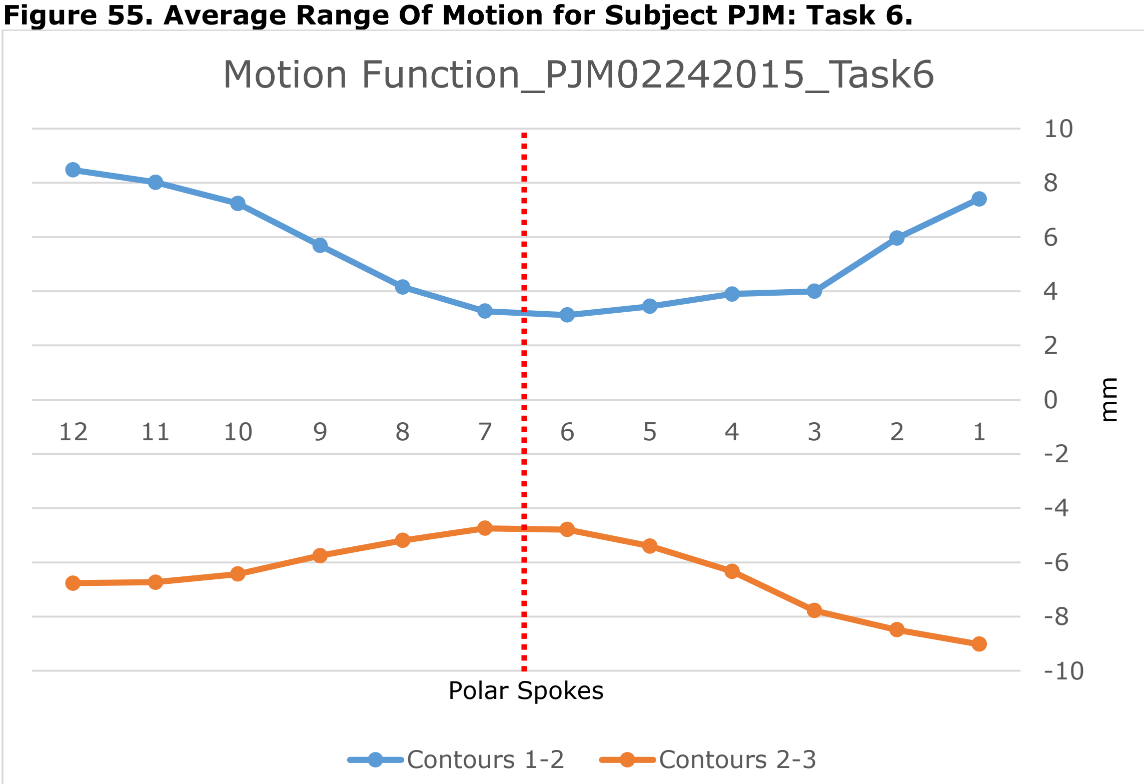
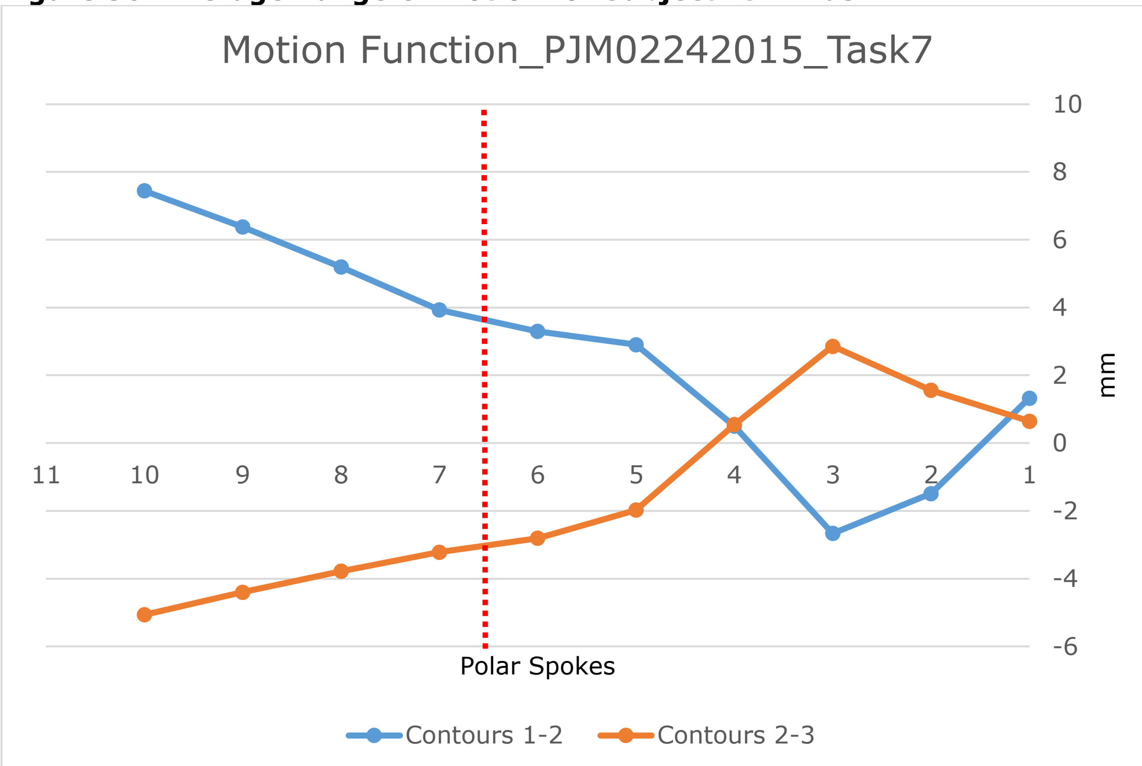


Figure 56. Average Range Of Motion for Subject PJM: Task 7.



APPENDIX H

SUBJECT: RCL02242015

Personal Alto Saxophone Equipment:

Saxophone: Selmer Super Action 80 SERIE II

Neck: (stock neck)

Mouthpiece: Selmer S90/180

Ligature: BG Traditional

Reed: Vandoren Traditional 3.5

Wisdom Teeth: Wisdom Teeth Removed

Average Range Of Motion for Subject RCL

Figure 57. Average Range Of Motion for Subject RCL: Task 2.

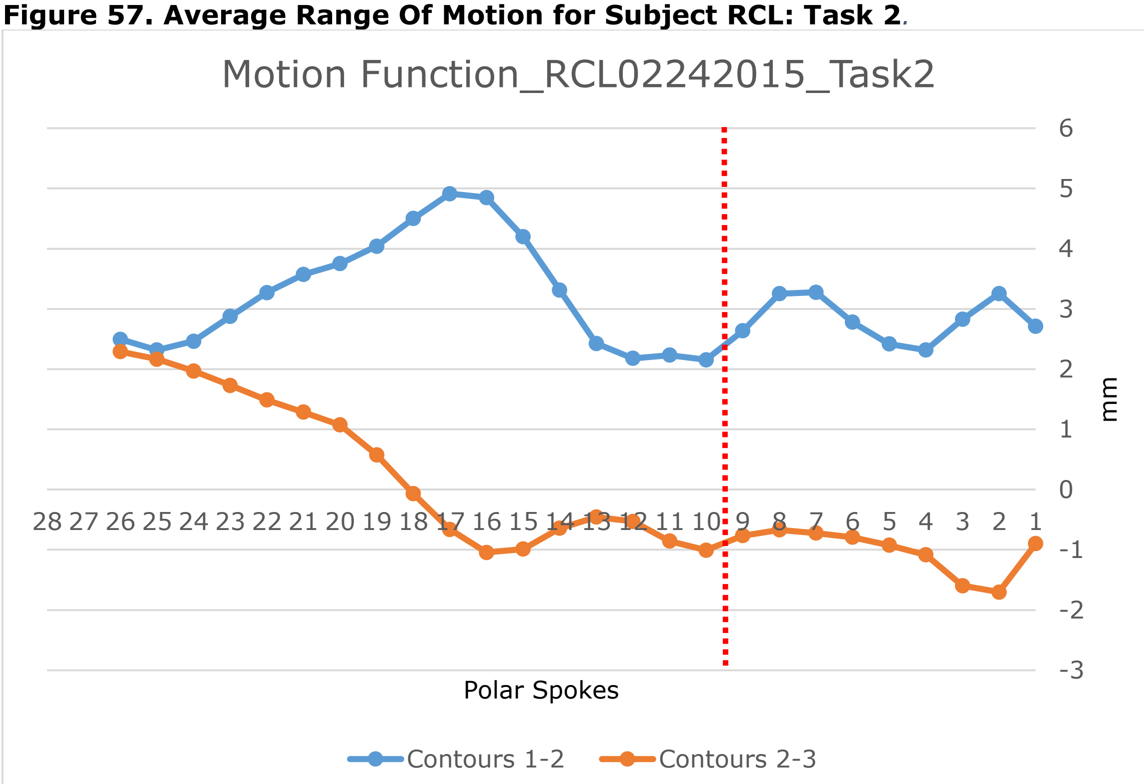


Figure 58. Average Range Of Motion for Subject RCL: Task 3.

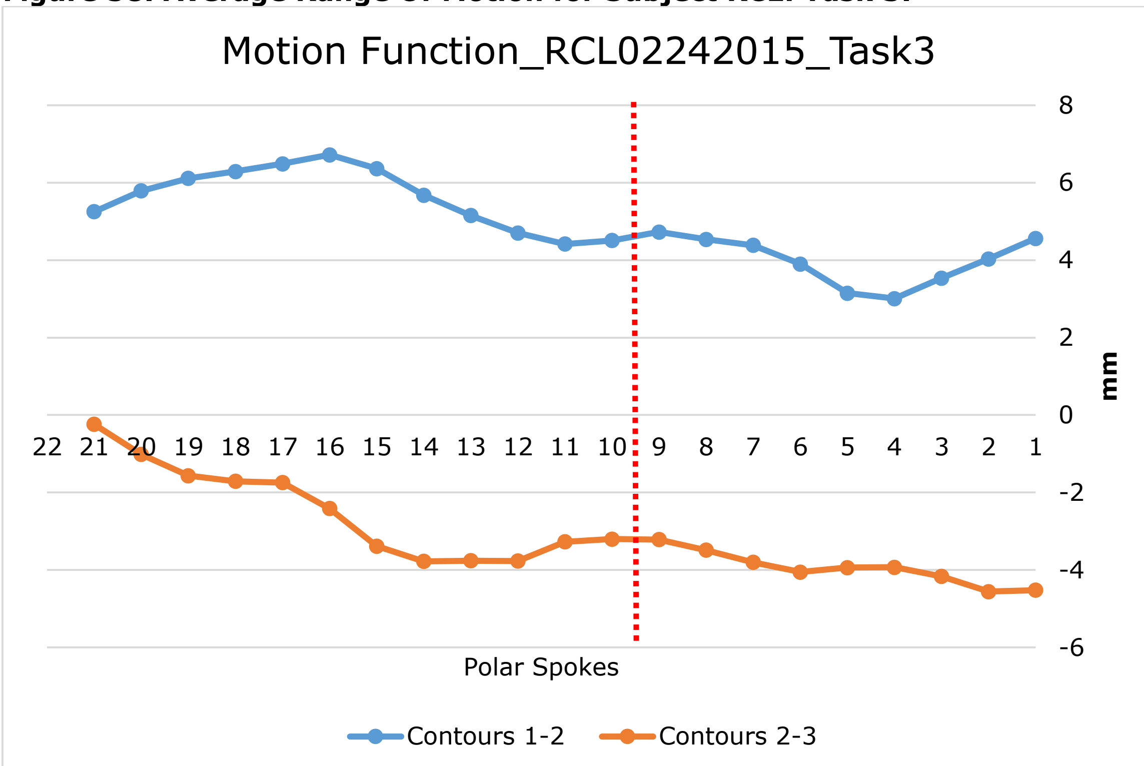


Figure 59. Average Range Of Motion for Subject RCL: Task 4.

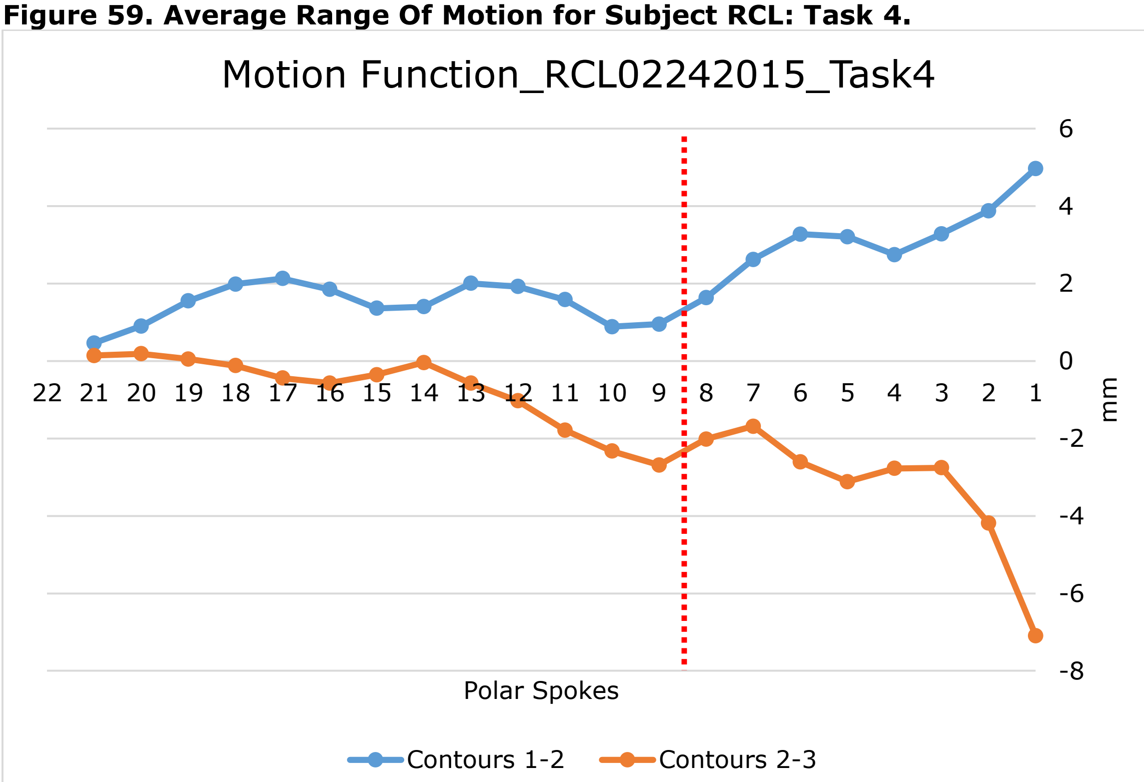


Figure 60. Average Range Of Motion for Subject RCL: Task 5.

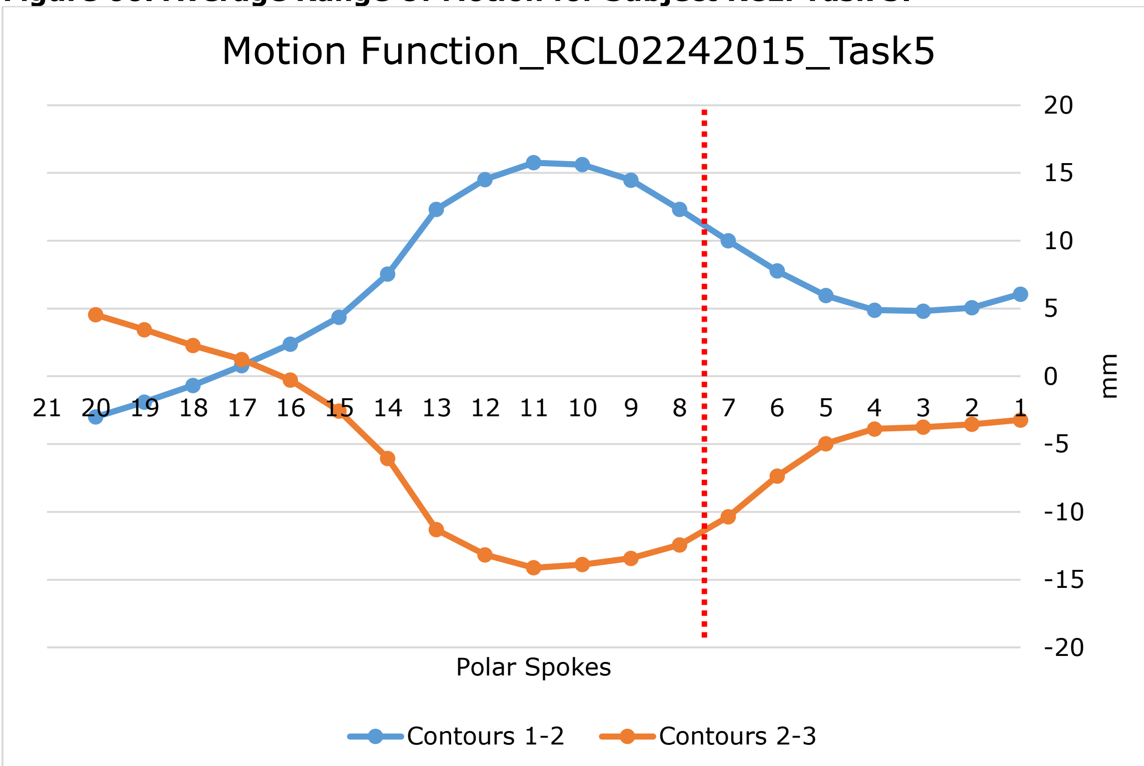


Figure 61. Average Range Of Motion for Subject RCL: Task 6.

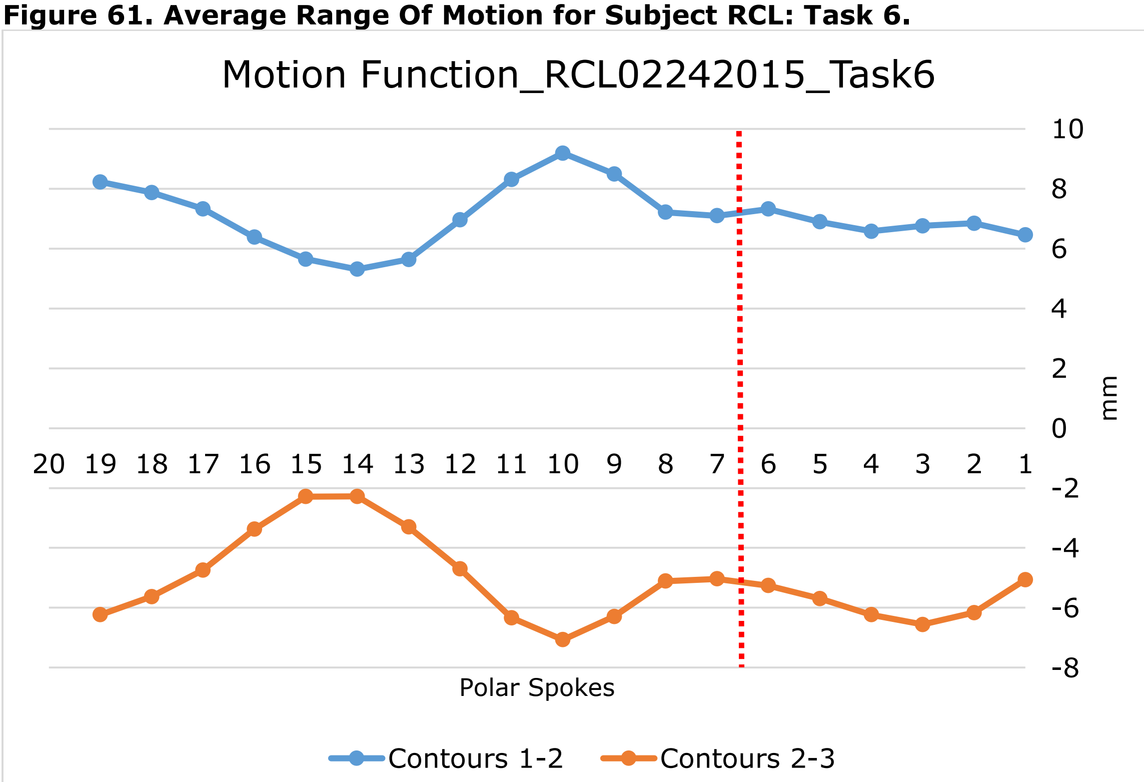
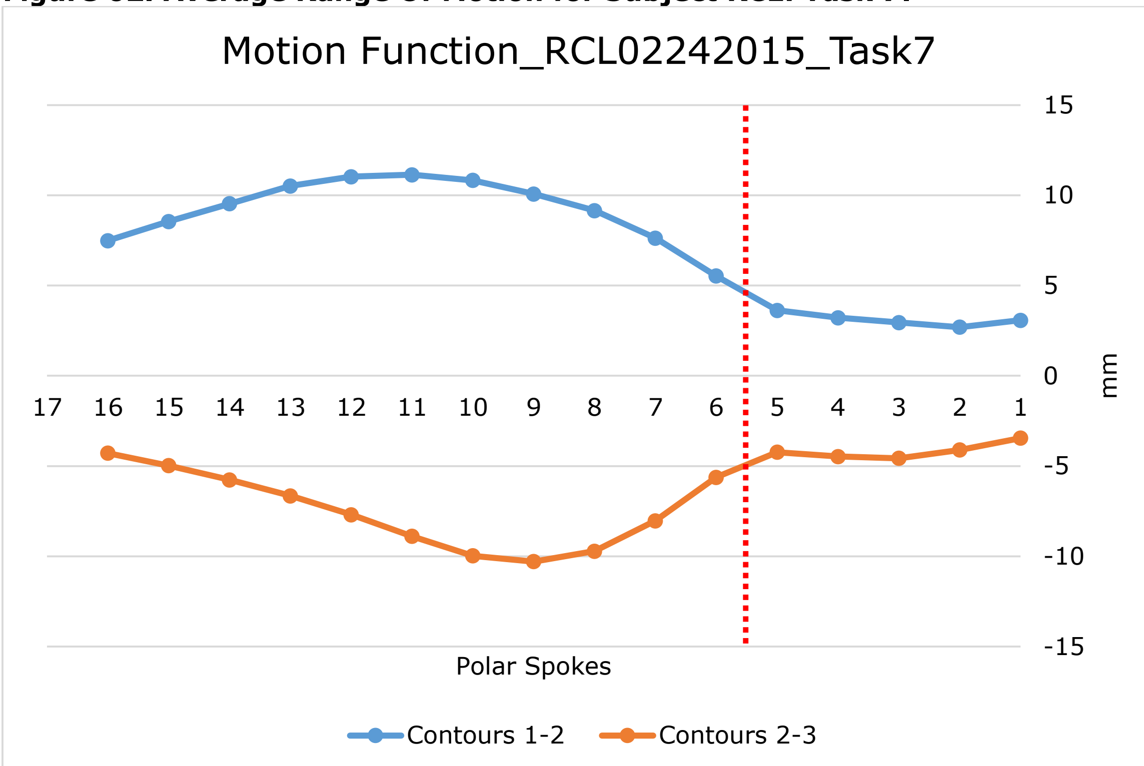


Figure 62. Average Range Of Motion for Subject RCL: Task 7.



APPENDIX I

SUBJECT: SAD02132015

Personal Alto Saxophone Equipment:

Saxophone: Yamaha Z2 (Unlaquered)

Neck: Yamaha V1 (Sterling Silver)

Mouthpiece: Selmer S90/190

Ligature: Bay Baroque (Gold-Plated

Reed: Rico Reserve 3.5

Wisdom Teeth: Wisdom Teeth Removed

Average Range Of Motion for Subject SAD

Figure 63. Average Range Of Motion for Subject SAD: Task 2.

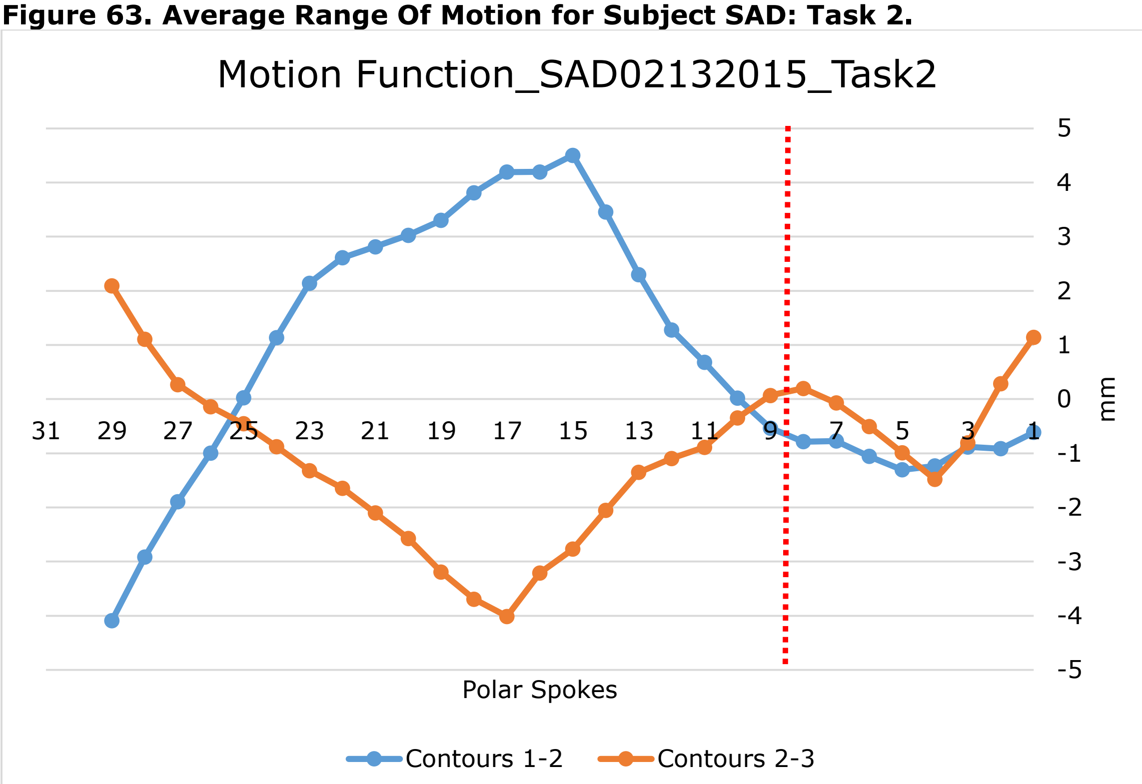


Figure 64. Average Range Of Motion for Subject SAD: Task 3.

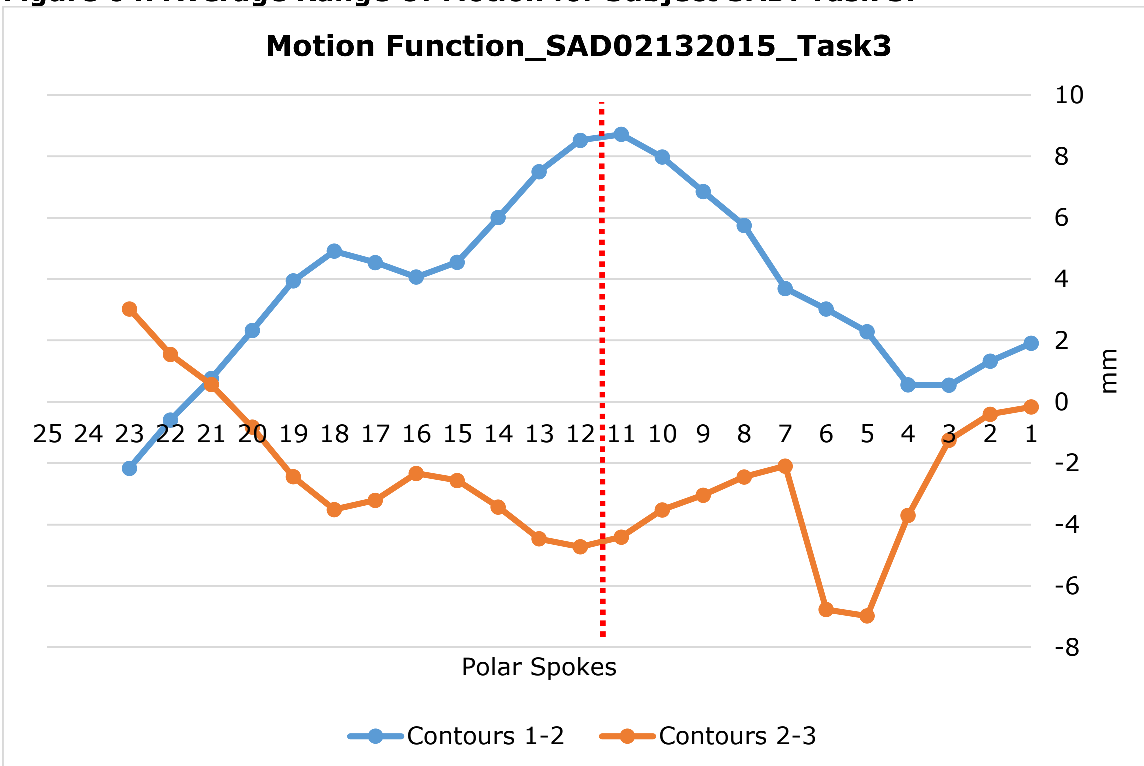


Figure 65. Average Range Of Motion for Subject SAD: Task 4.

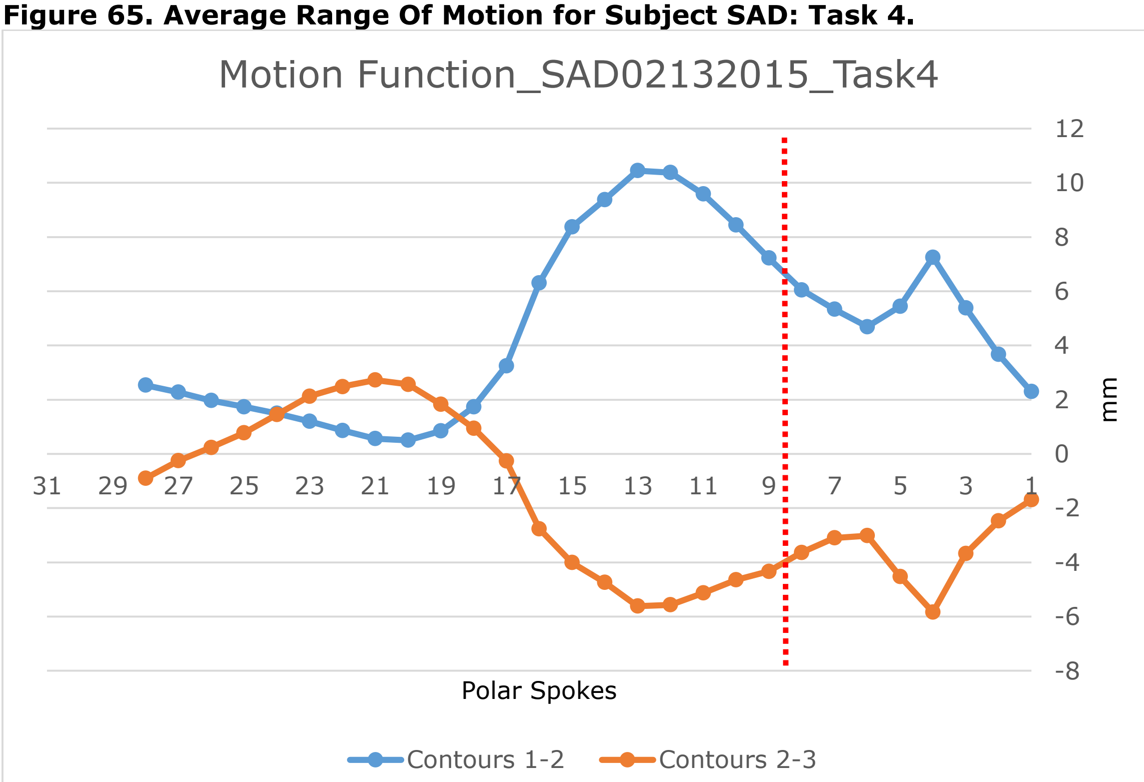


Figure 66. Average Range Of Motion for Subject SAD: Task 5.

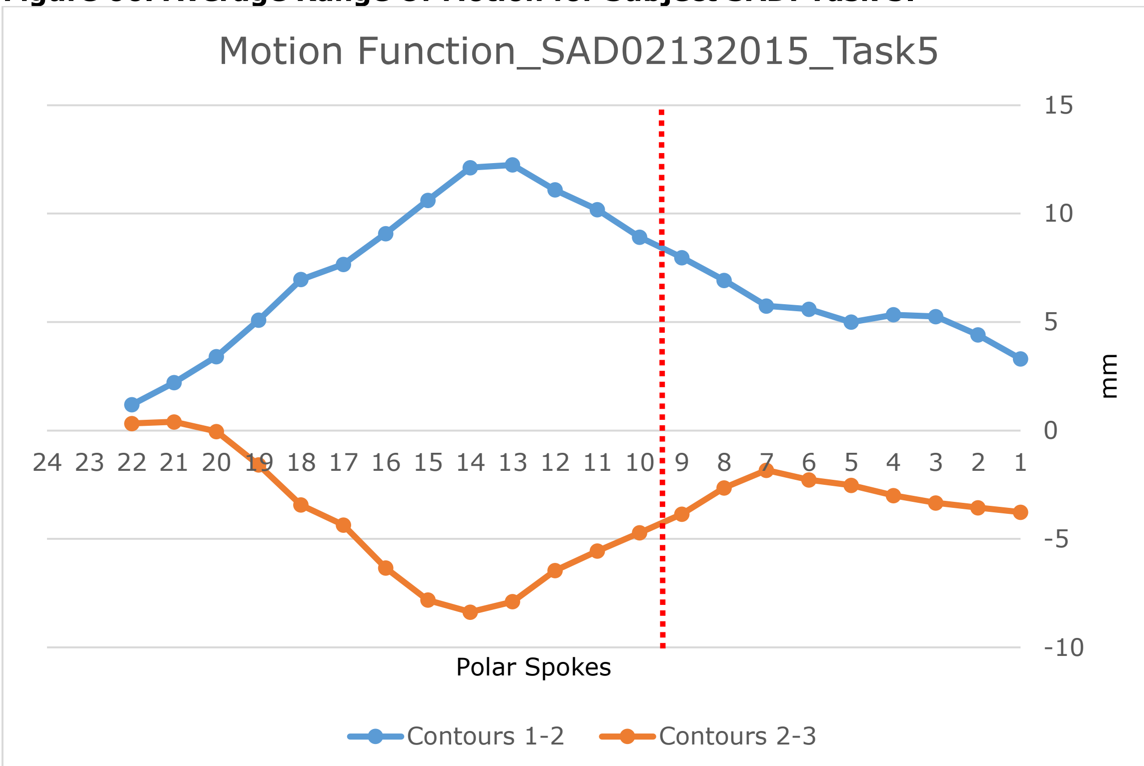


Figure 67. Average Range Of Motion for Subject SAD: Task 6.

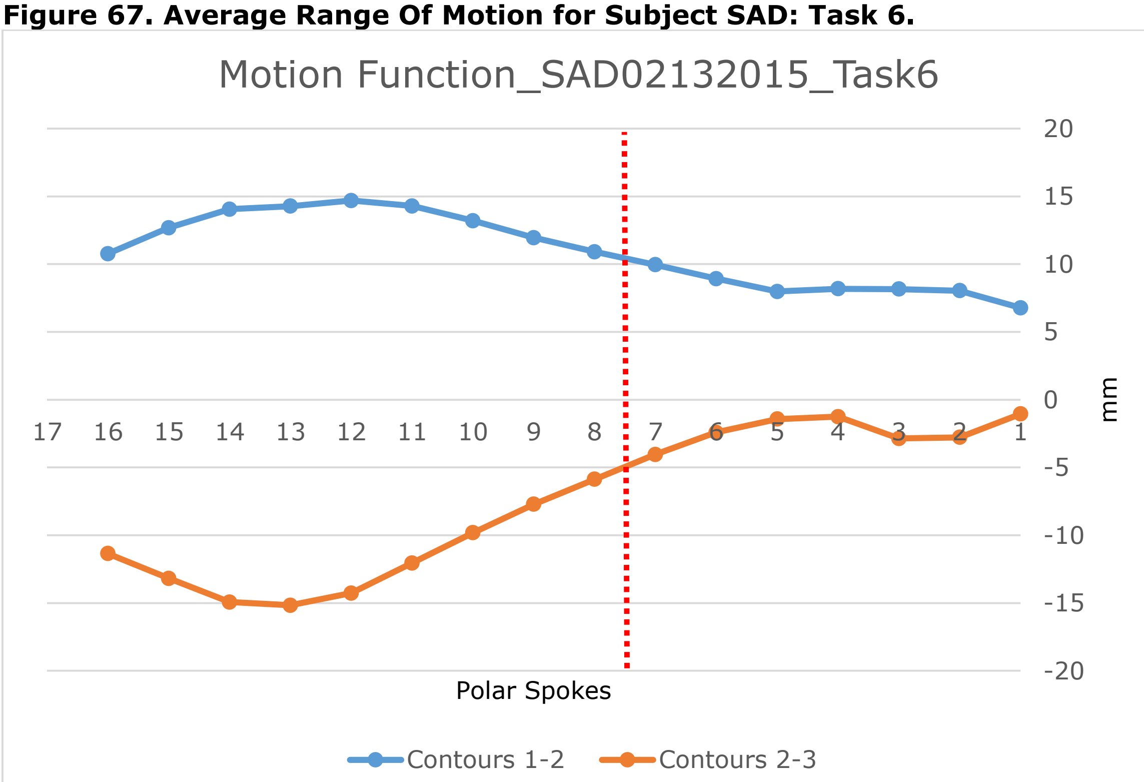
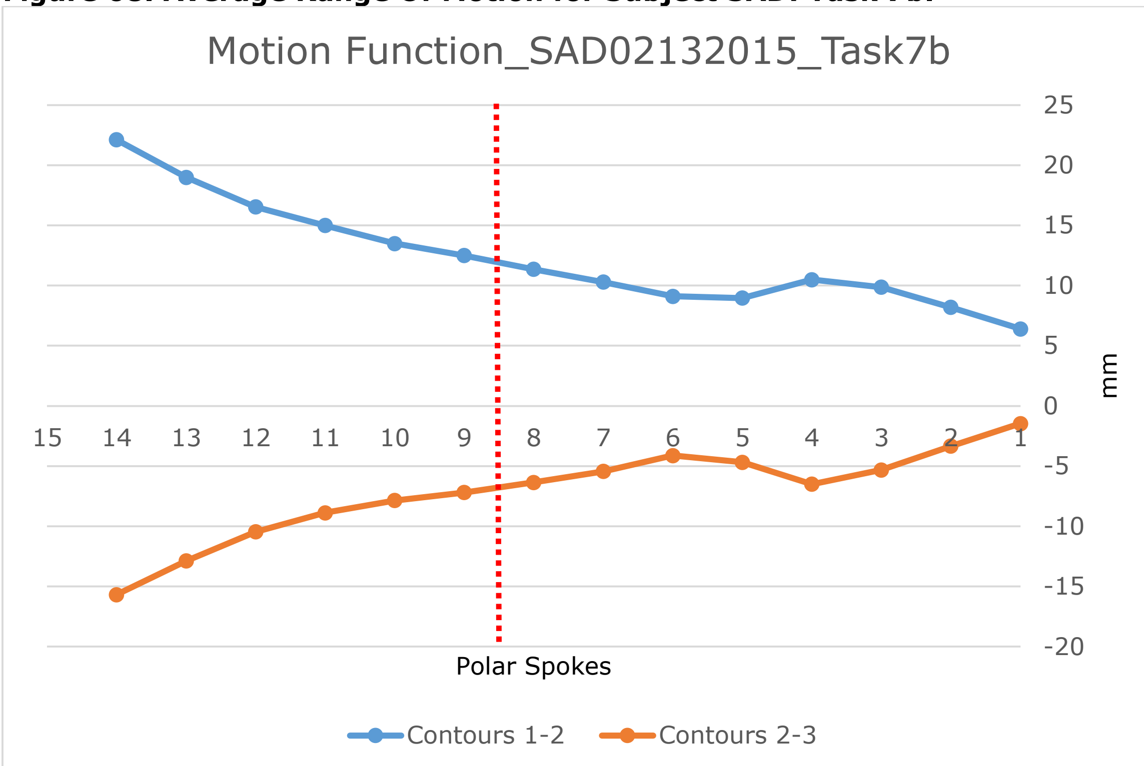


Figure 68. Average Range Of Motion for Subject SAD: Task 7b.



APPENDIX J

SUBJECT: TJF02172015

Personal Alto Saxophone Equipment:

Saxophone: Selmer Super Action 80 SERIES II

Neck: (stock neck)

Mouthpiece: Selmer S90/180

Ligature: Ishimori (Solid-Silver)

Reed: Rico Reserve Classic 3.5

Wisdom Teeth: Wisdom Teeth Removed

Average Range Of Motion for Subject TJF

Figure 69. Average Range Of Motion for Subject TJF: Task 2.

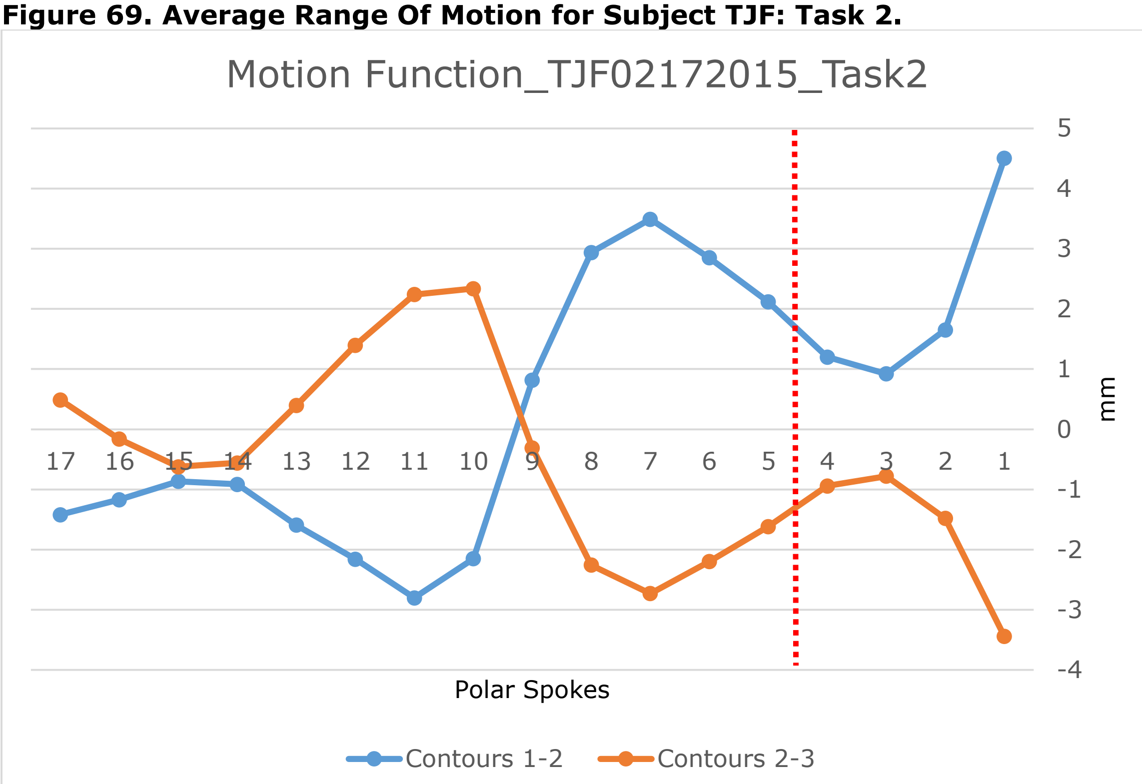


Figure 70. Average Range Of Motion for Subject TJF: Task 3.

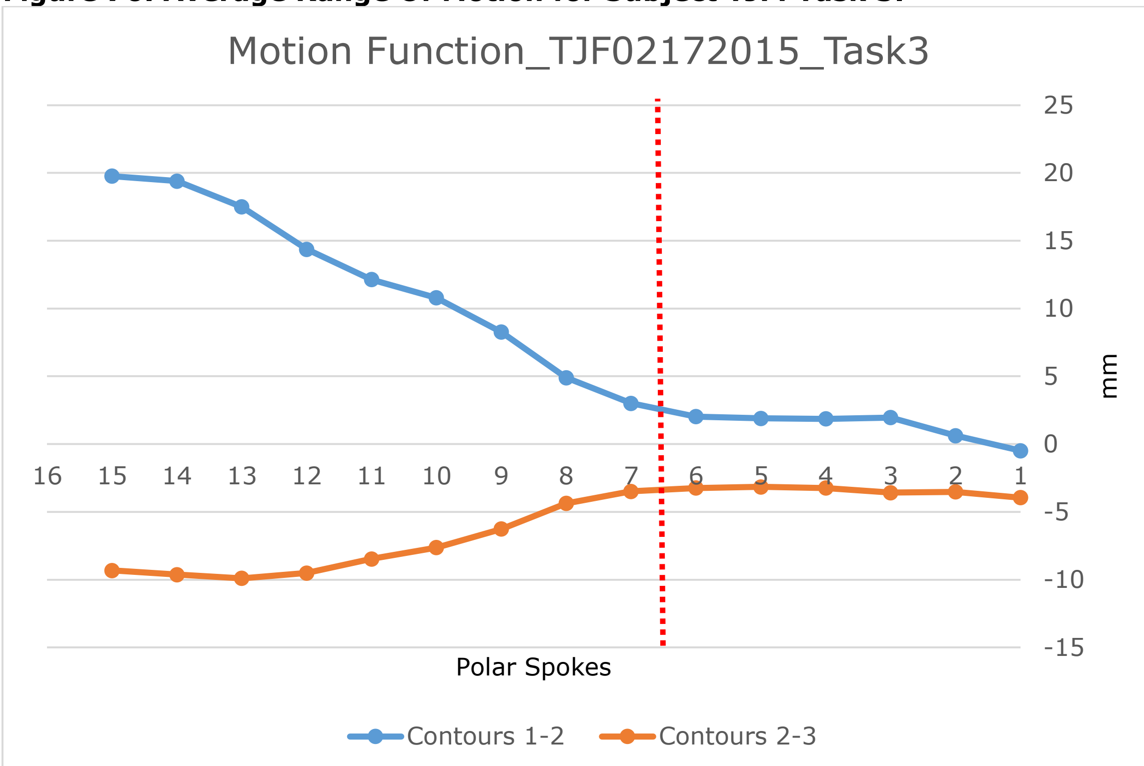


Figure 71. Average Range Of Motion for Subject TJF: Task 4.

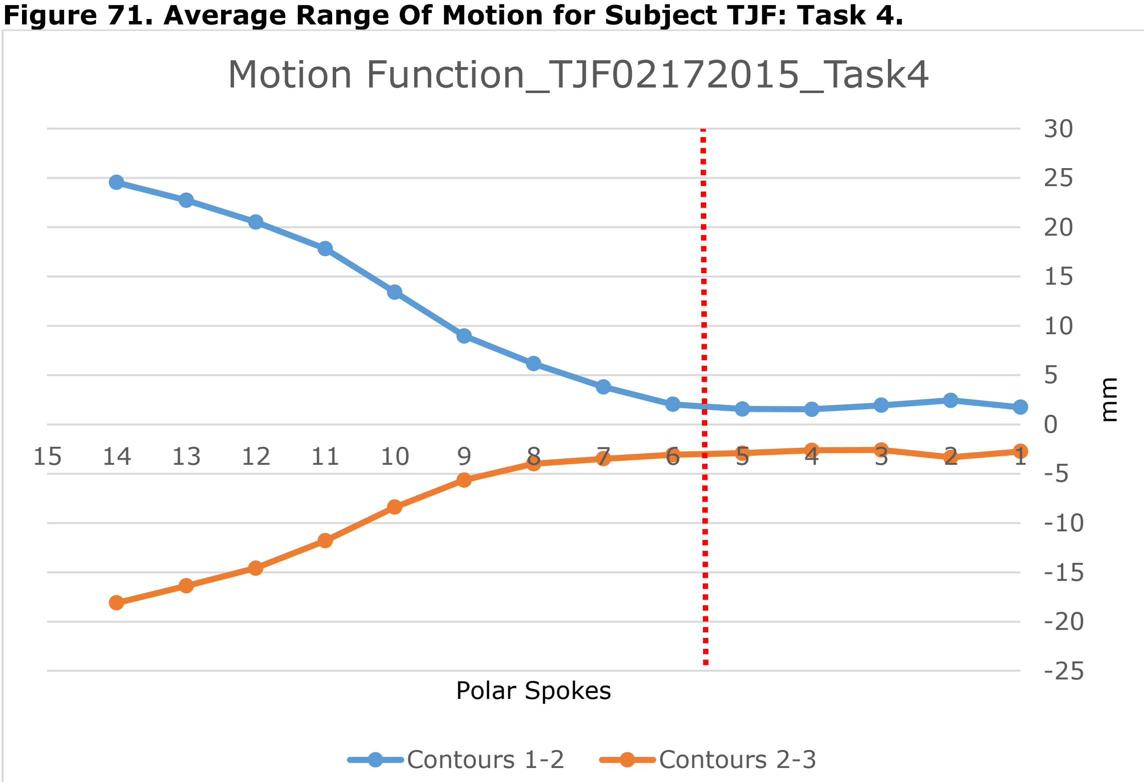


Figure 72. Average Range Of Motion for Subject TJF: Task 5b.

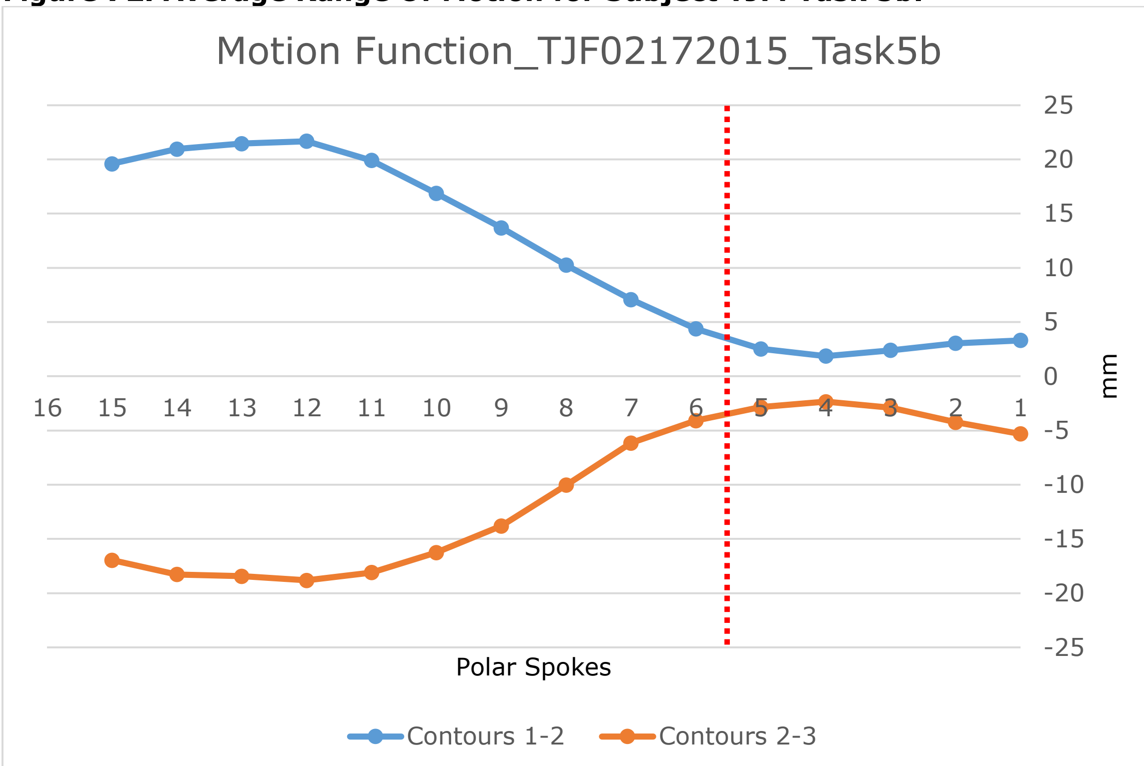


Figure 73. Average Range Of Motion for Subject TJF: Task 6.

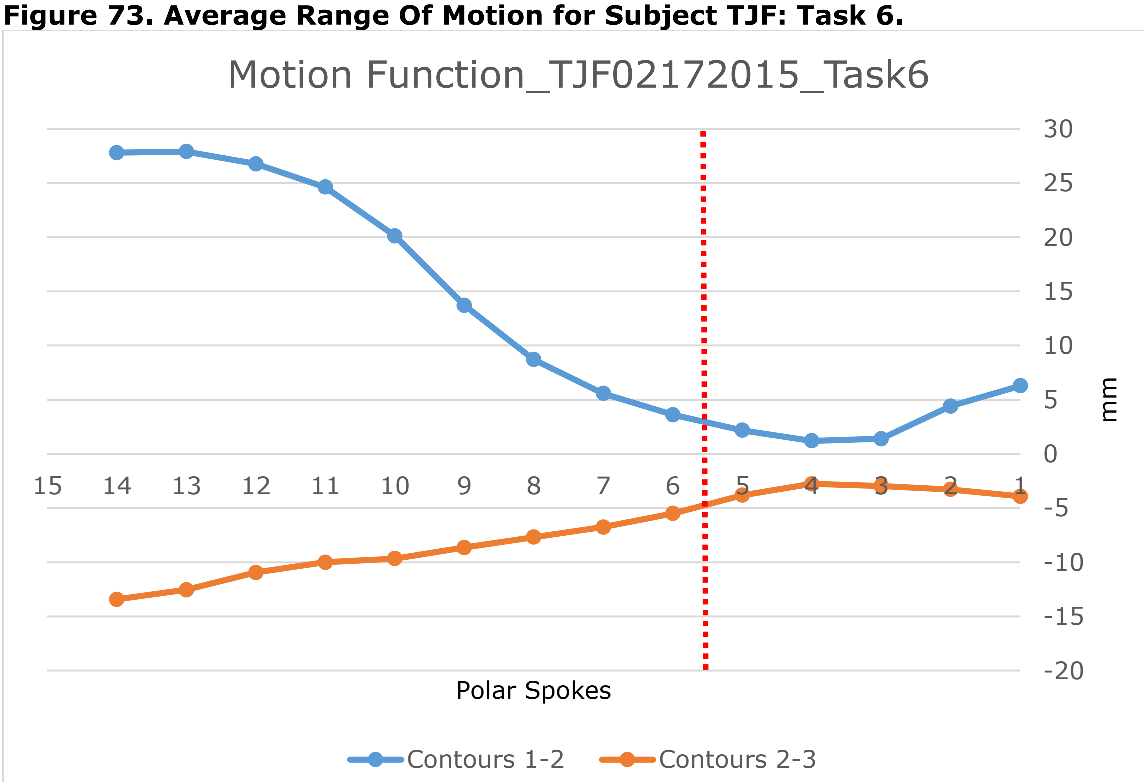
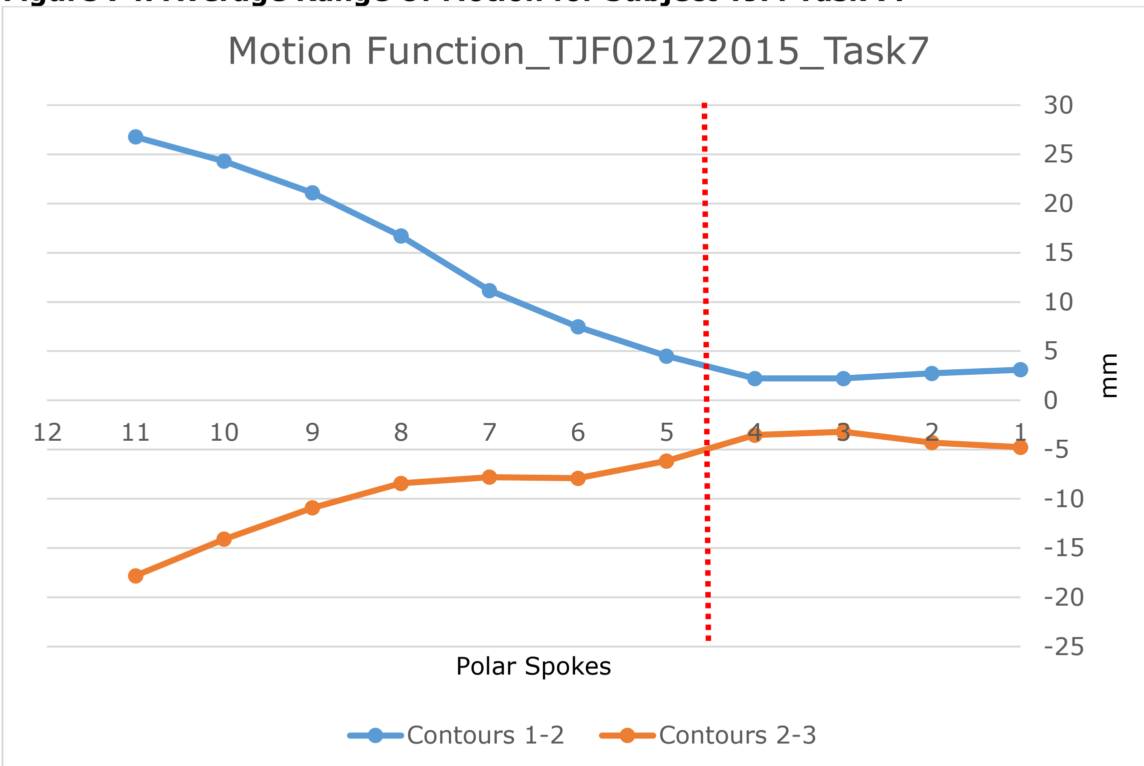


Figure 74. Average Range Of Motion for Subject TJF: Task 7.



APPENDIX K

AVERAGED RANGE OF MOTION FOR ALL SUBJECTS PER TASK

Figure 75. Averaged Range Of Motion for Task 2: All Subjects.

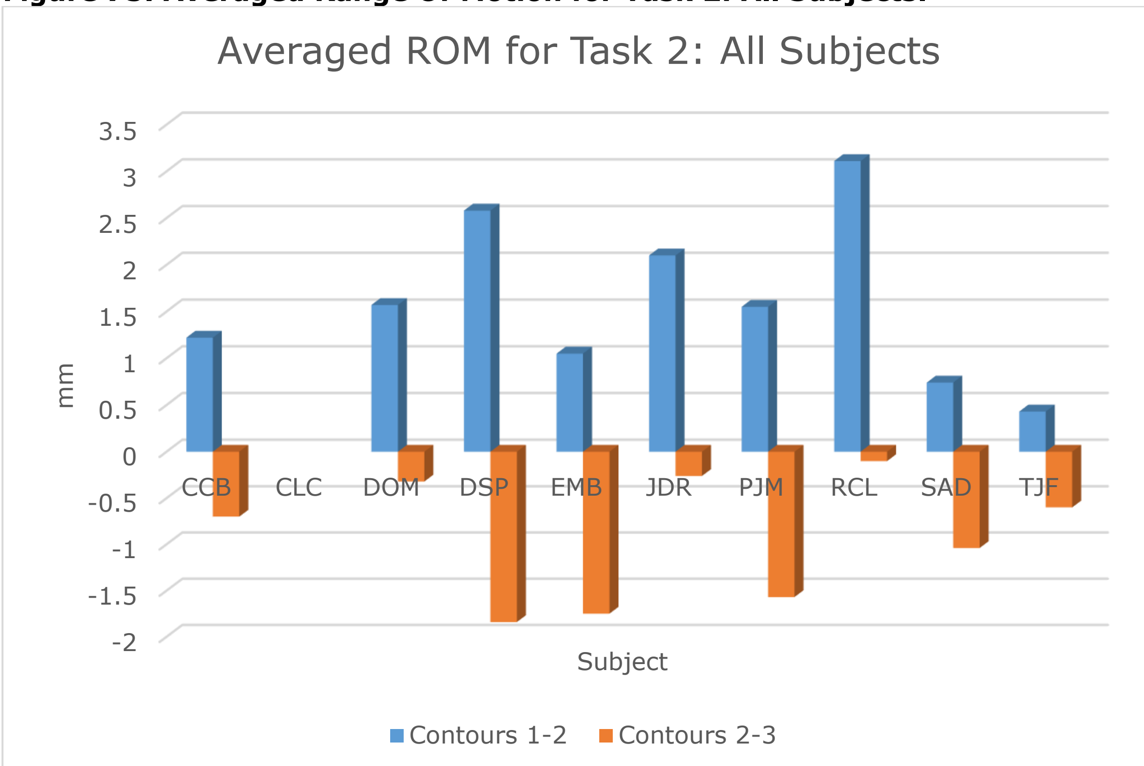


Figure 76. Averaged Range Of Motion for Task 3: All Subjects.

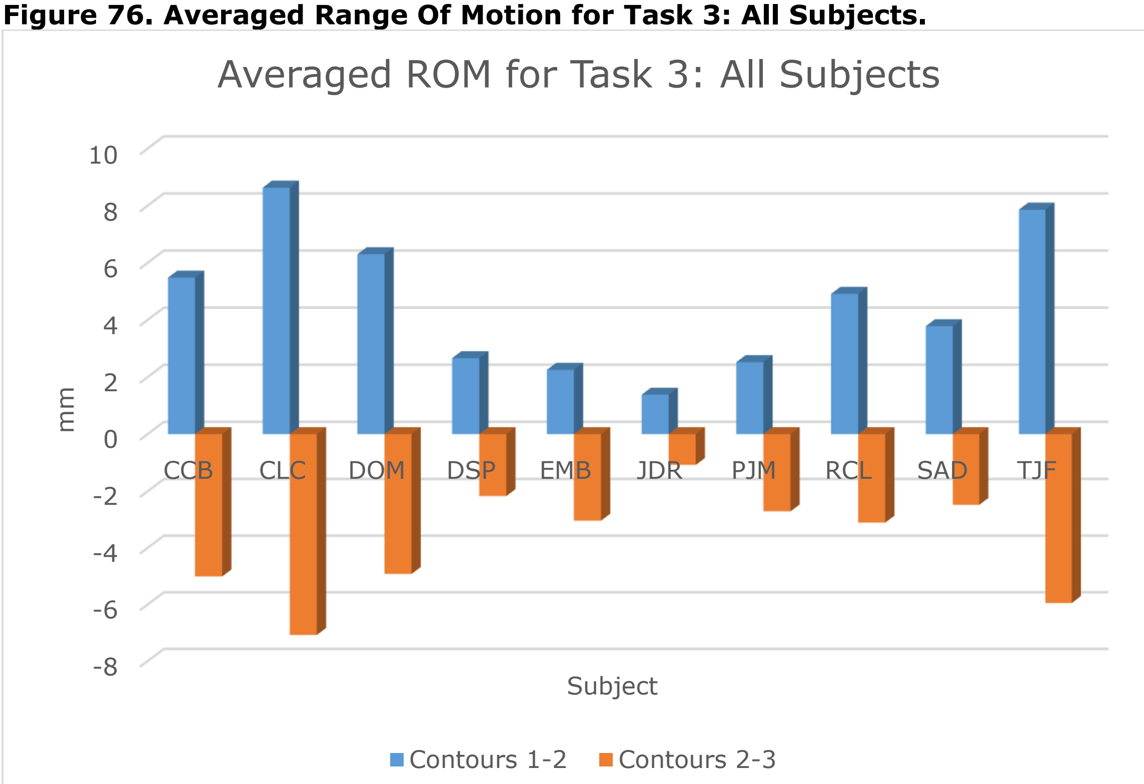


Figure 77. Averaged Range Of Motion for Task 4: All Subjects.

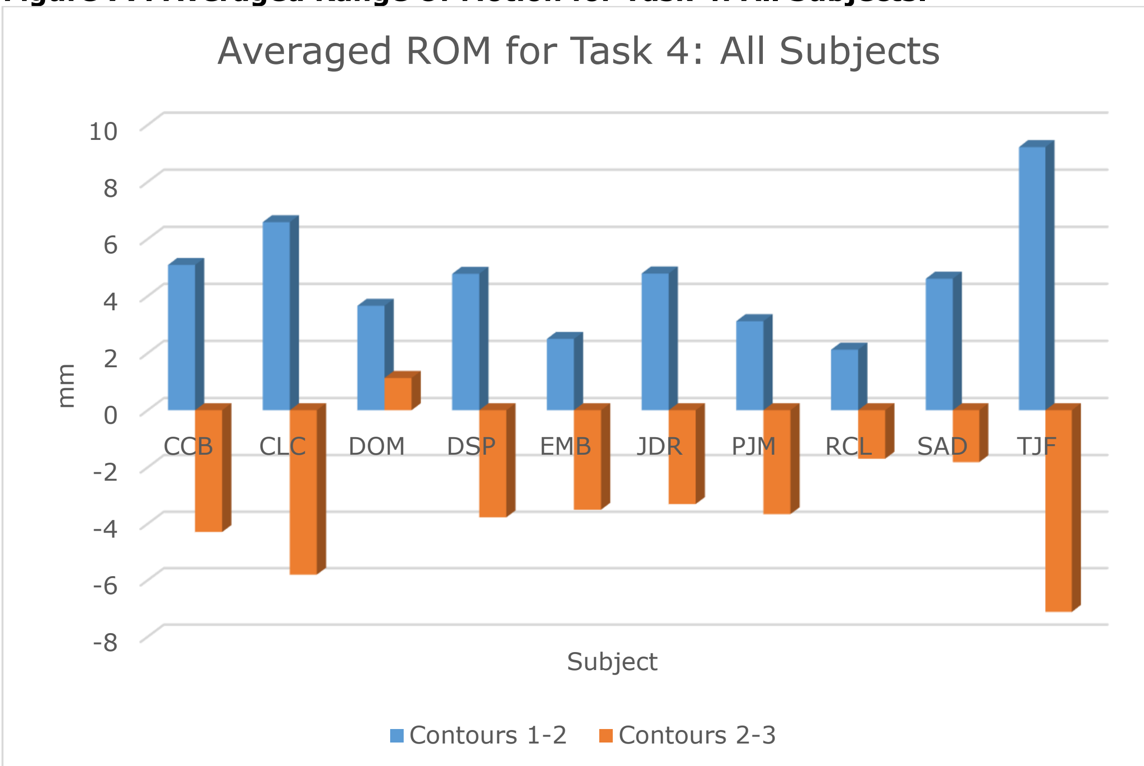


Figure 78. Averaged Range Of Motion for Task 5: All Subjects.

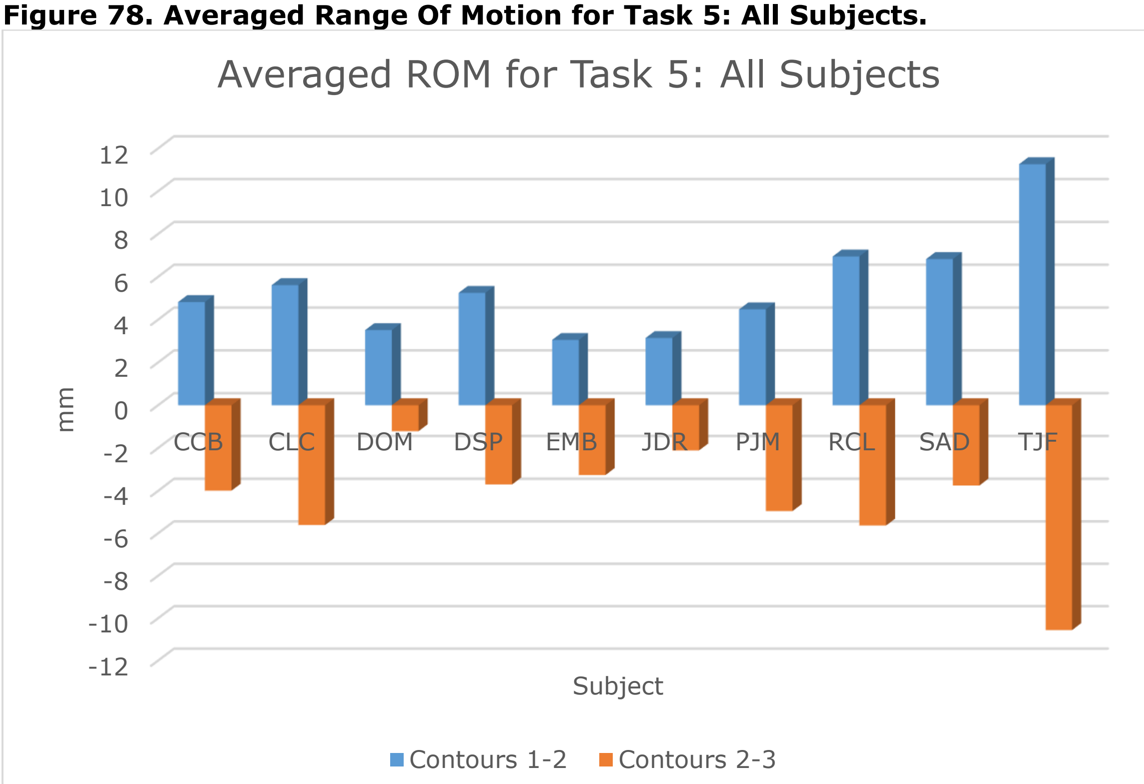


Figure 79. Averaged Range Of Motion for Task 6: All Subjects.

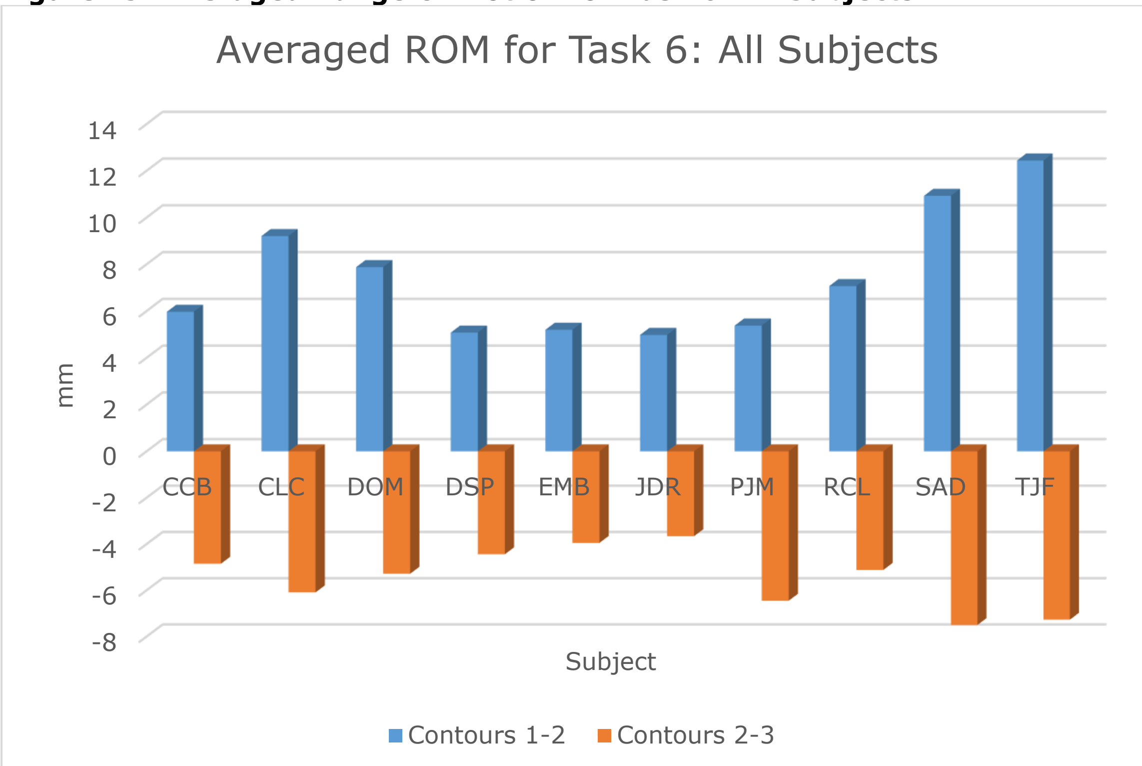
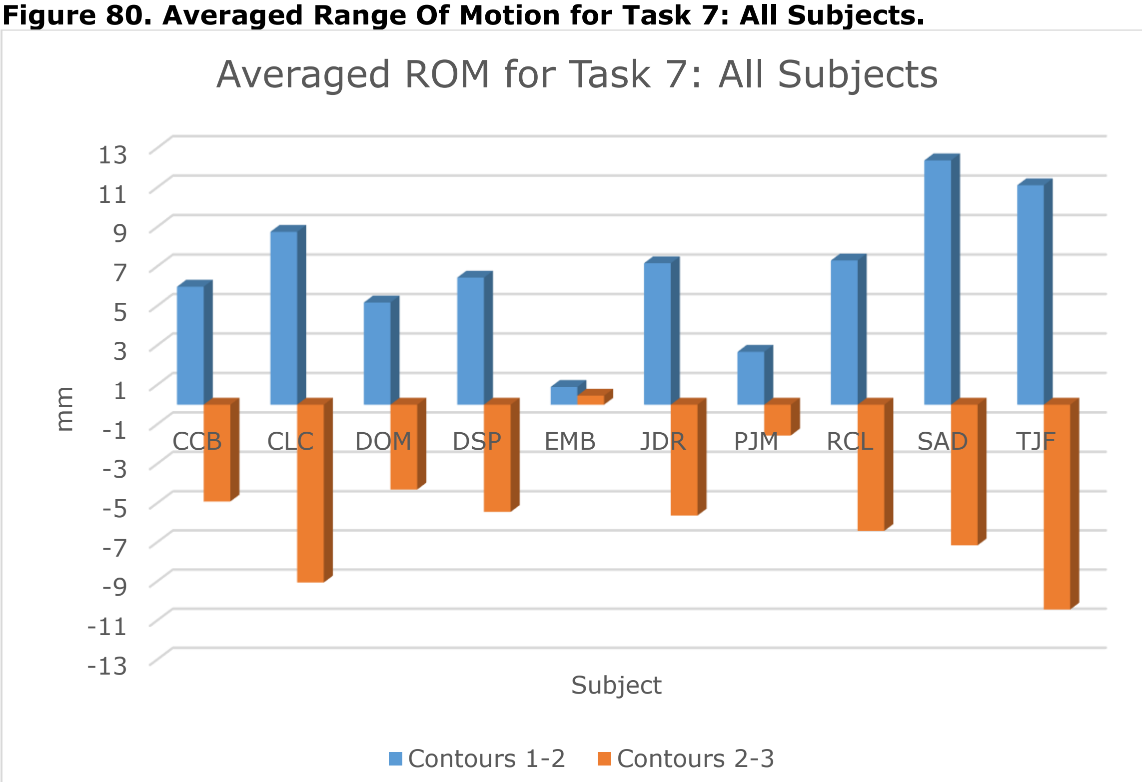


Figure 80. Averaged Range Of Motion for Task 7: All Subjects.



APPENDIX L

ANTERIOR AND POSTERIOR RANGE OF MOTION PER SUBJECT

Figure 81. Anterior and Posterior Range Of Motion: CCB.

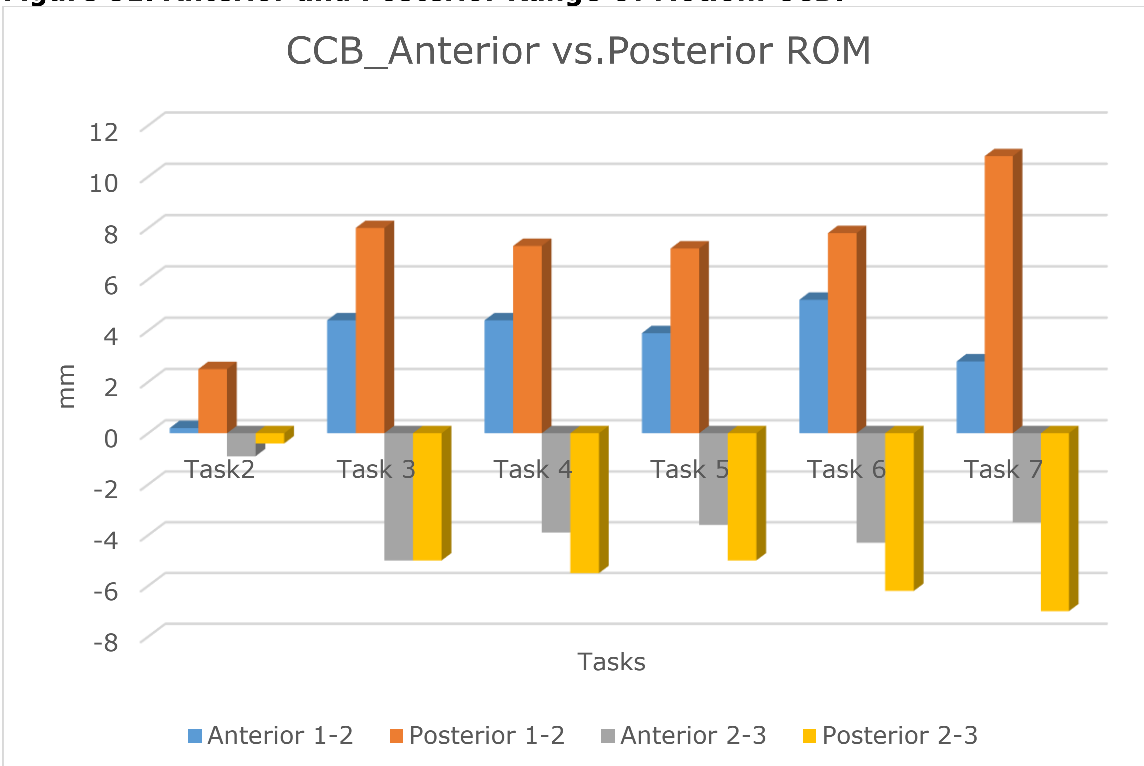


Figure 82. Anterior and Posterior Range of Motion: CLC.

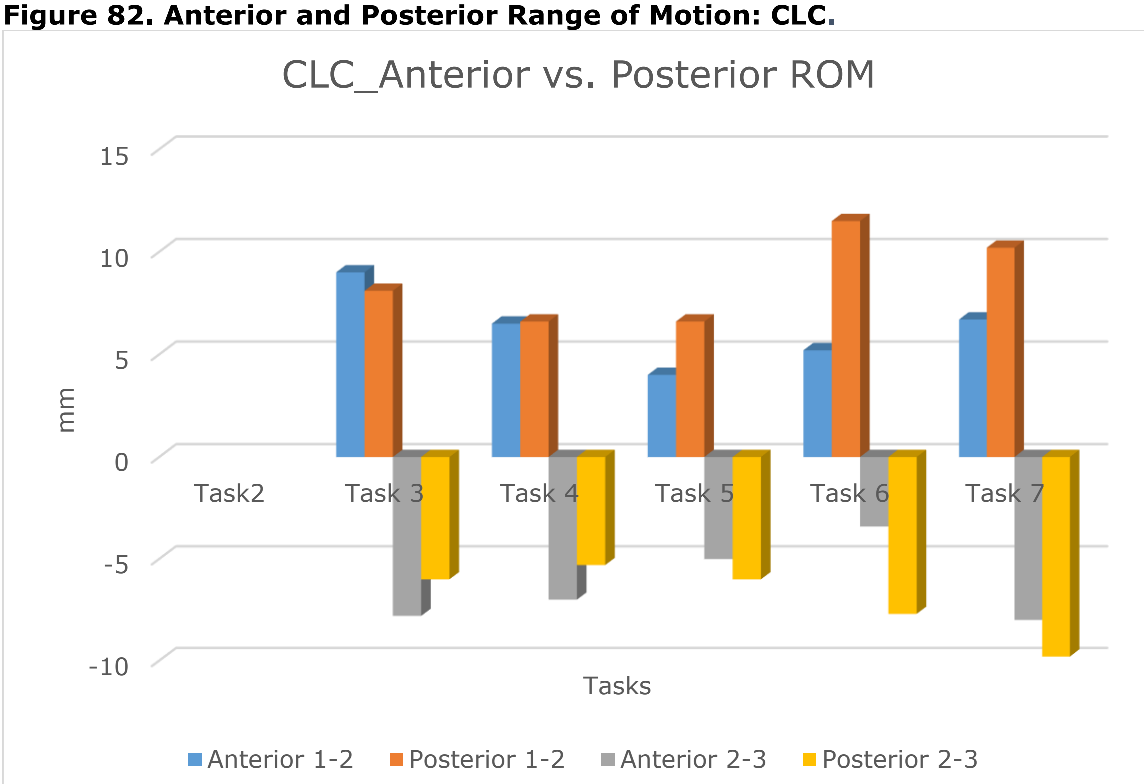


Figure 83. Anterior and Posterior Range Of Motion: DOM.

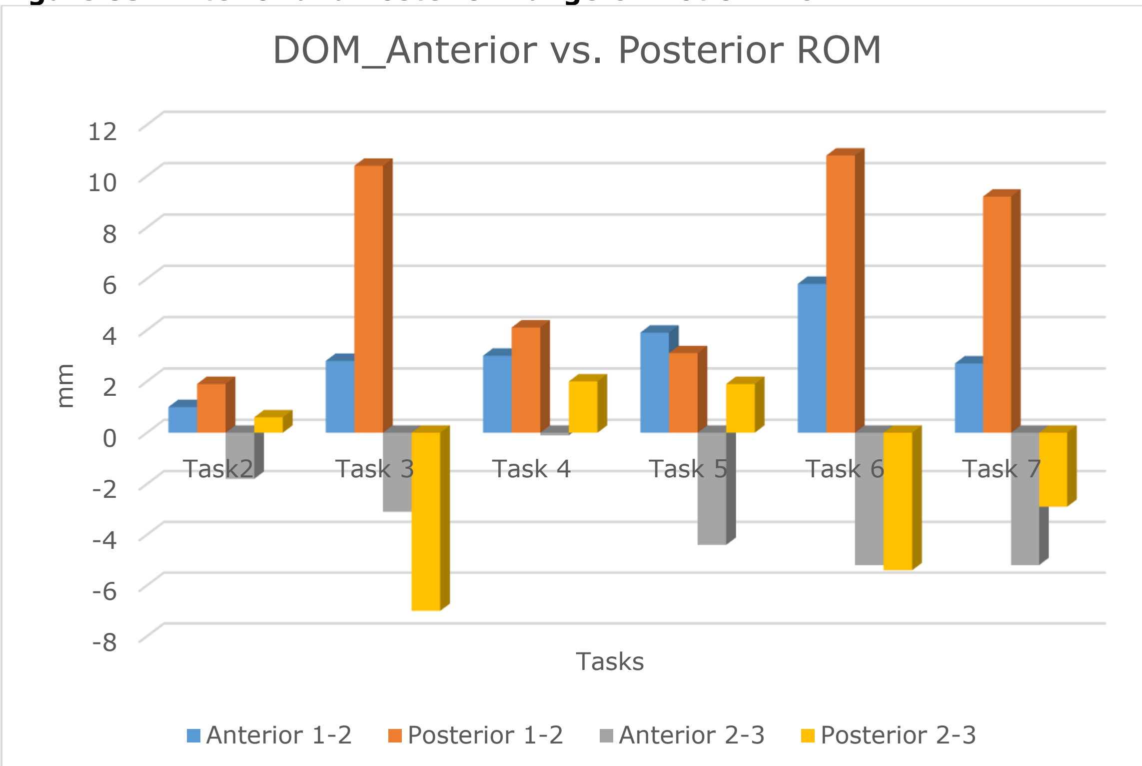


Figure 84. Anterior and Posterior Range Of Motion: DSP.

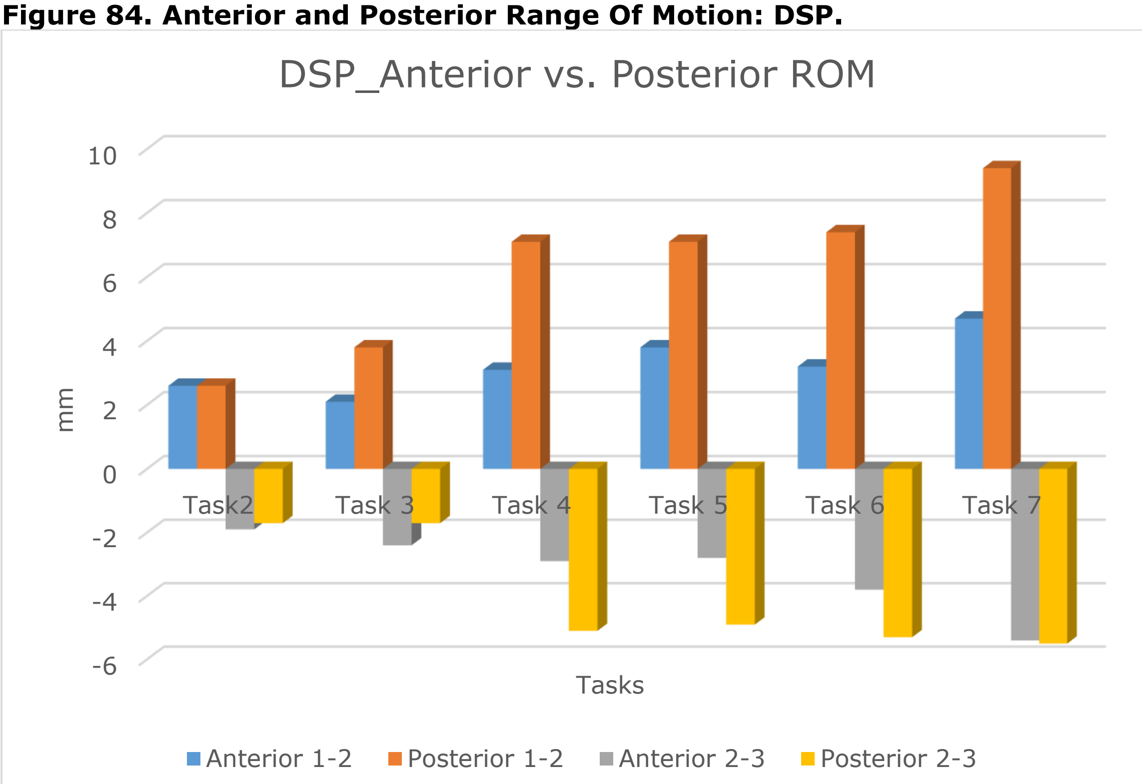


Figure 85. Anterior and Posterior Range Of Motion: EMB.

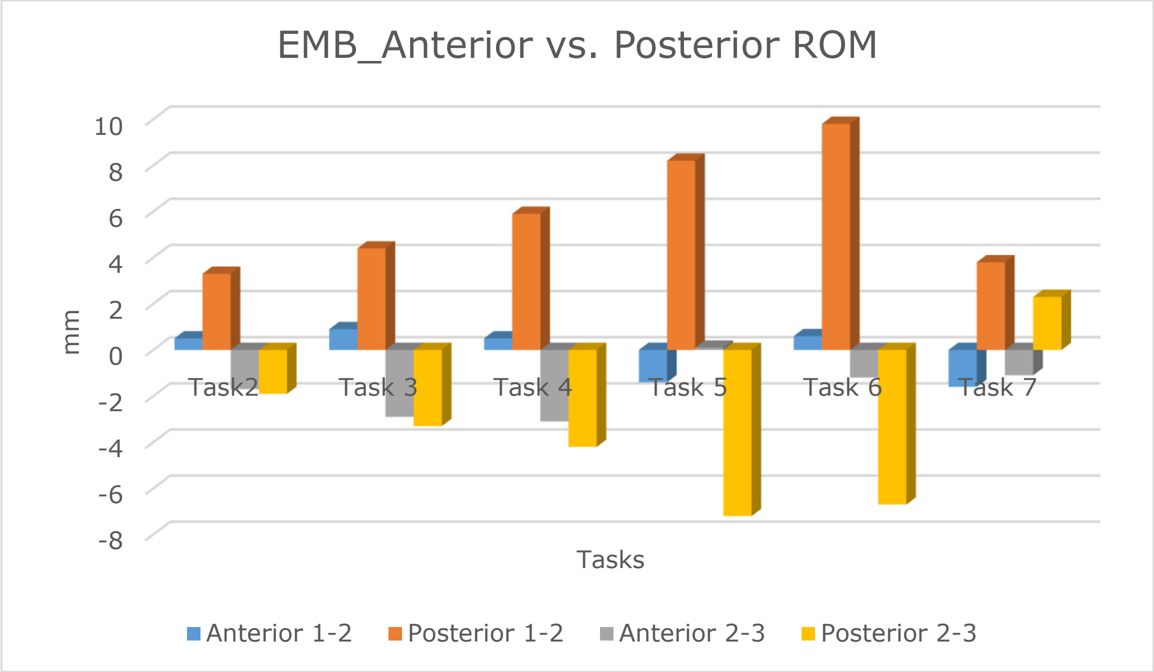


Figure 86. Anterior and Posterior Range Of Motion: JDR.

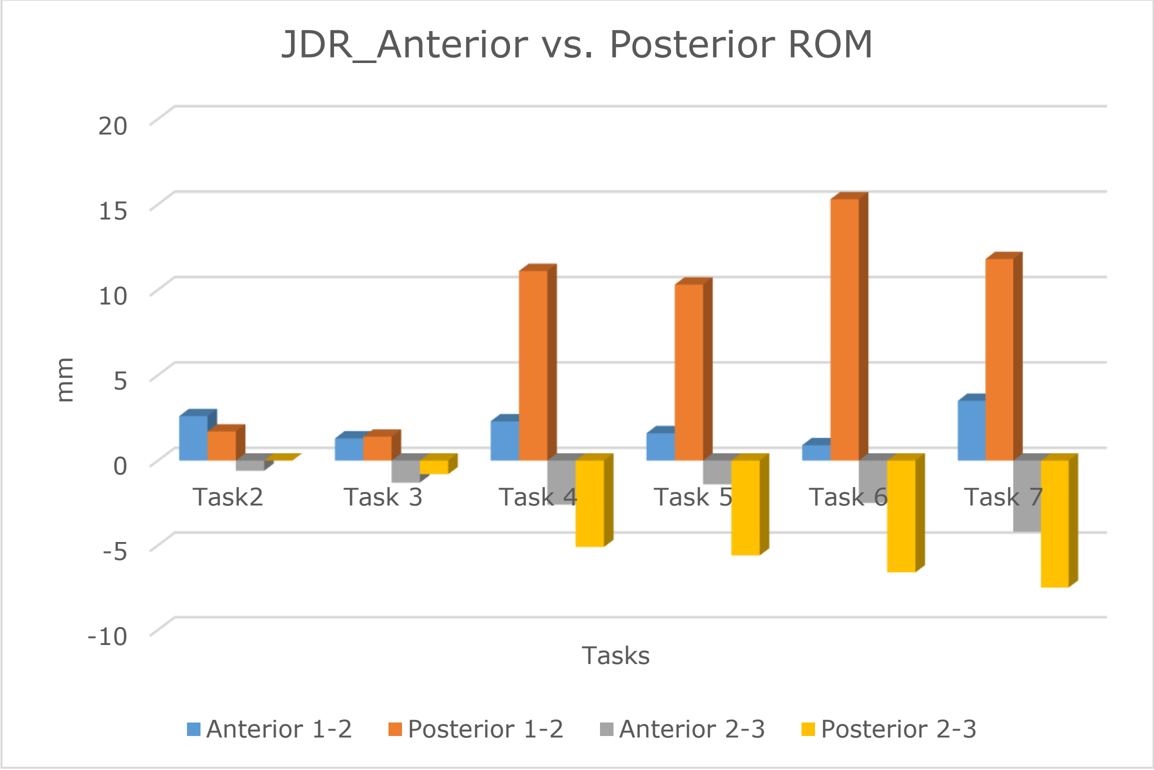


Figure 87. Anterior and Posterior Range Of Motion: PJM.

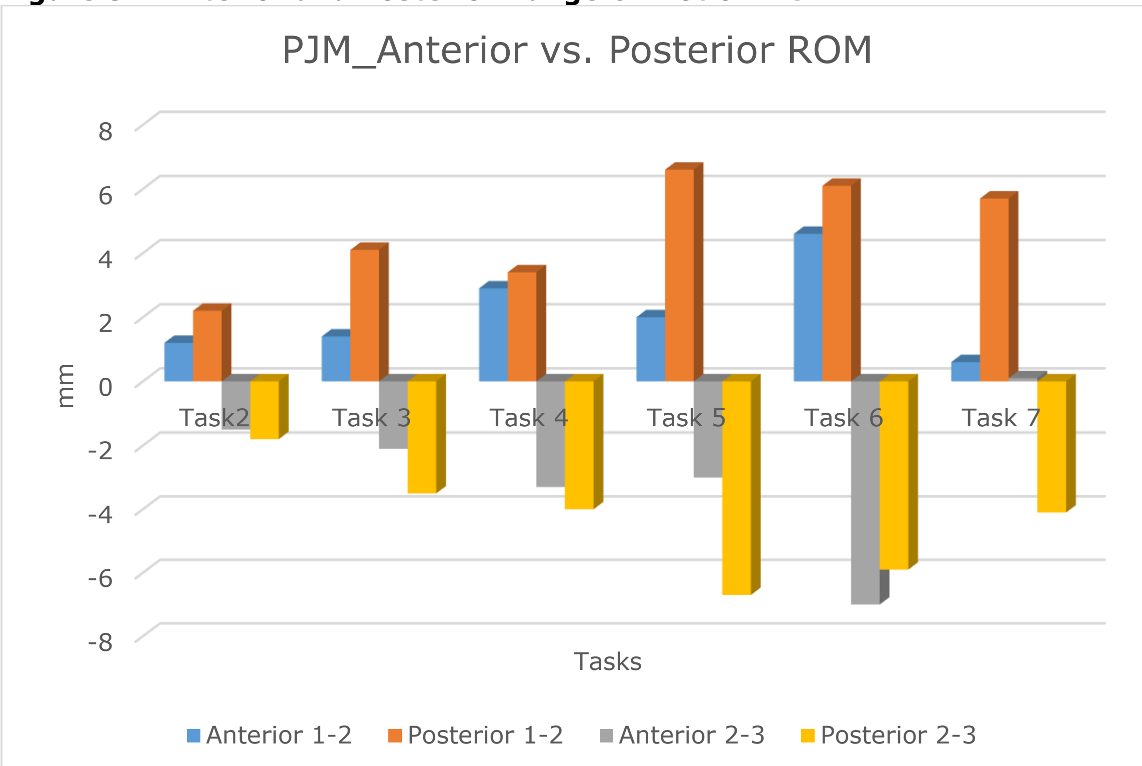


Figure 88. Anterior and Posterior Range Of Motion: RCL.

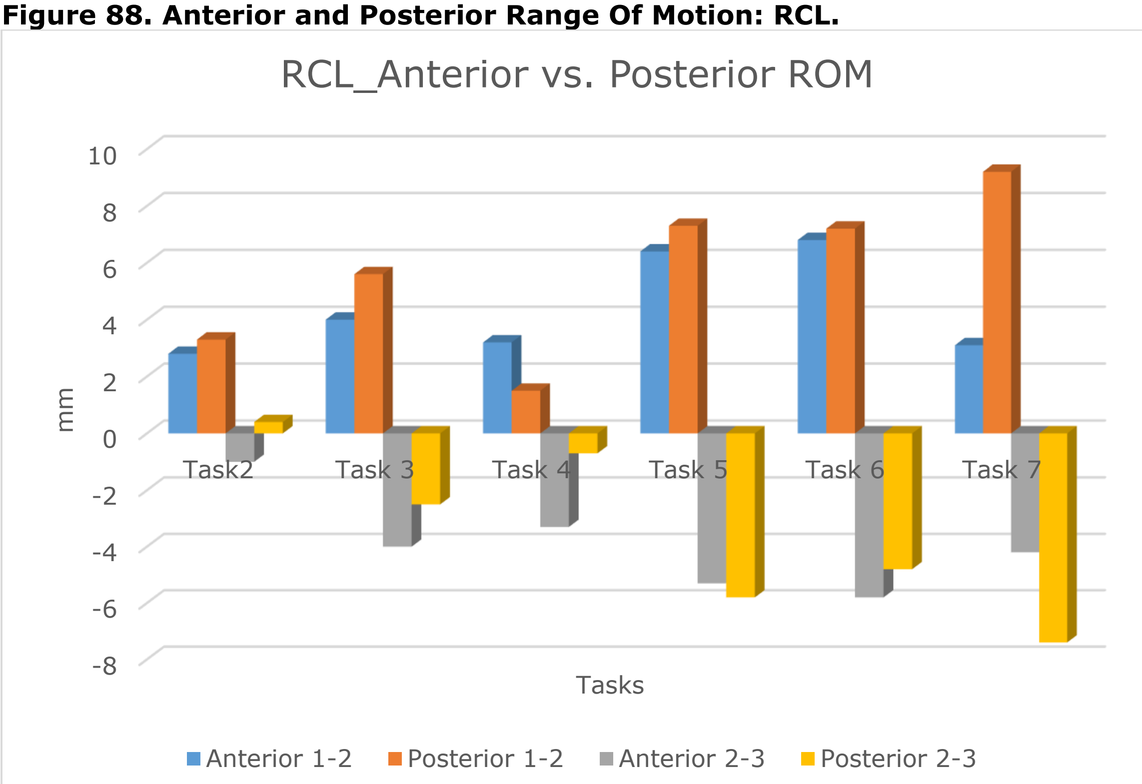


Figure 89. Anterior and Posterior Range Of Motion: SAD.

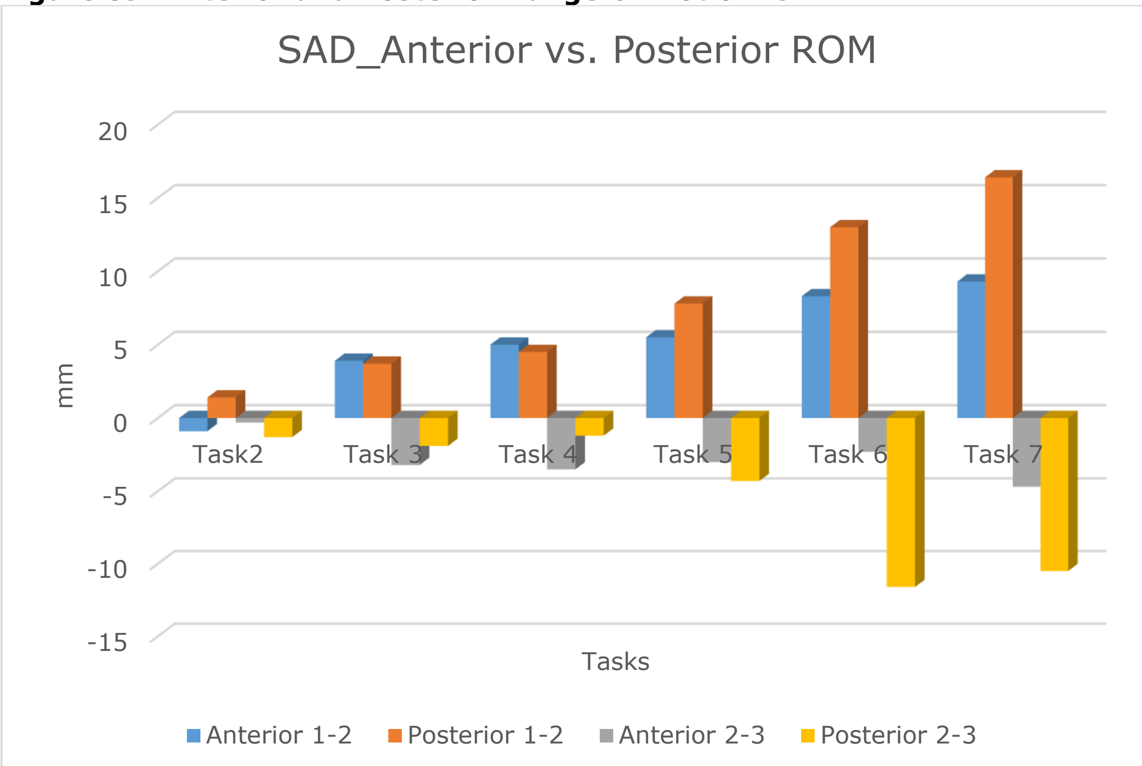
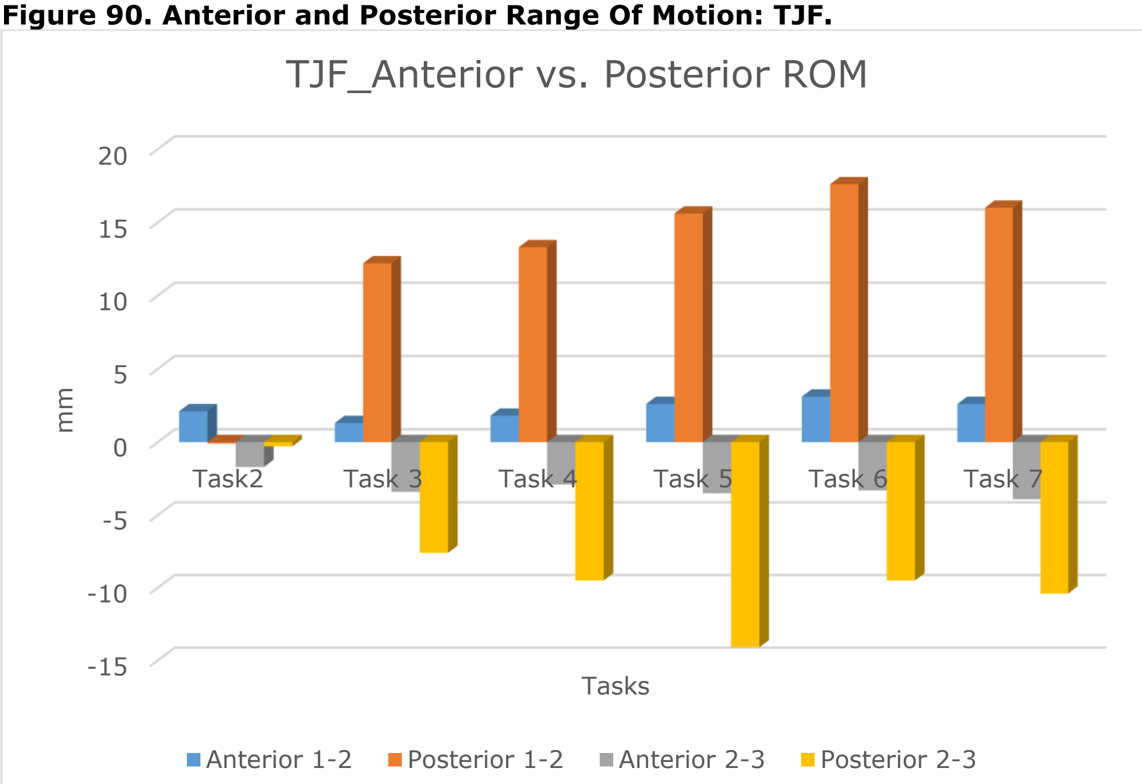


Figure 90. Anterior and Posterior Range Of Motion: TJF.



APPENDIX M

ANTERIOR AND POSTERIOR CONTOUR RESULT TABLES

Table 3. Average Anterior Range Of Motion for Contours 1-2.

Average Anterior Range of Motion: Contours 1-2						
	Task 2	Task 3	Task 4	Task 5	Task6	Task 7
CCB02242015	0.2	4.4	4.4	3.9	5.2	2.8
CLC02242015	-	9.0	6.5	4.0	5.2	6.7
DOM02172015	1.0	2.8	3.0	3.9	5.8	2.7
DSP05142015	2.6	*2.1	3.1	*3.8	3.2	4.7
EMB02132015	0.5	0.9	*0.5	-1.4	0.6	**-1.6
JDR02192015	2.6	1.3	2.3	1.6	*0.9	*3.5
PJM02242015	1.2	1.4	2.9	2.0	4.6	0.6
RCL02242015	2.8	4.0	3.2	6.4	6.8	3.1
SAD02132015	-0.9	3.9	5.0	5.5	8.3	*9.3
TJF02172015	2.1	1.3	1.8	*2.6	3.1	2.6

Note: Task 1 is omitted because there is no ROM for a single contour.
**Notates the second attempt of task (Task #b).*
***Notates only task where subject pitch bend exceeded one octave.*

Table 4. Average Posterior Range Of Motion for Contours 1-2.

Average Posterior Range of Motion: Contours 1-2						
	Task 2	Task 3	Task 4	Task 5	Task6	Task 7
CCB02242015	2.5	8.0	7.3	7.2	7.8	10.8
CLC02242015	-	8.1	6.6	6.6	11.5	10.2
DOM02172015	1.9	10.4	4.1	3.1	10.8	9.2
DSP05142015	2.6	*3.8	7.1	*7.1	7.4	9.4
EMB02132015	3.3	4.4	*5.9	8.2	9.8	**3.8
JDR02192015	1.7	1.4	11.1	10.3	*15.3	*11.8
PJM02242015	2.2	4.1	3.4	6.6	6.1	5.7
RCL02242015	3.3	5.6	1.5	7.3	7.2	9.2
SAD02132015	1.4	3.7	4.5	7.8	13.0	*16.4
TJF02172015	-0.1	12.2	13.3	*15.6	17.6	16.0

Note: Task 1 is omitted because there is no ROM for a single contour.
**Notates the second attempt of task (Task #b).*
***Notates only task where subject pitch bend exceeded one octave.*

Table 5. Average Anterior Range Of Motion for Contours 2-3.

Average Anterior Range of Motion: Contours 2-3						
	Task 2	Task 3	Task 4	Task 5	Task6	Task 7
CCB02242015	-0.9	-5.0	-3.9	-3.6	-4.3	-3.5
CLC02242015	-	-7.8	-7.0	-5.0	-3.4	-8.0
DOM02172015	-1.8	-3.1	-0.1	-4.4	-5.2	-5.2
DSP05142015	-1.9	*-2.4	-2.9	*-2.8	-3.8	-5.4
EMB02132015	-1.7	-2.9	*-3.1	0.1	-1.2	**-1.1
JDR02192015	-0.6	-1.3	-2.6	-1.4	*-2.5	*-4.2
PJM02242015	-1.5	-2.1	-3.3	-3.0	-7.0	0.1
RCL02242015	-1.0	-4.0	-3.3	-5.3	-5.8	-4.2
SAD02132015	-0.3	-3.2	-3.5	-3.0	-2.3	*-4.7
TJF02172015	-1.7	-3.4	-2.9	*-3.5	-3.3	-3.9

Note: Task 1 is omitted because there is no ROM for a single contour.
**Notates the second attempt of task (Task #b).*
***Notates only task where subject pitch bend exceeded one octave.*

Table 6. Average Posterior Range Of Motion for Contours 2-3.

Average Posterior Range of Motion: Contours 2-3						
	Task 2	Task 3	Task 4	Task 5	Task6	Task 7
CCB02242015	-0.4	-5.0	-5.5	-5.0	-6.2	-7.0
CLC02242015	-	-6.0	-5.3	-6.0	-7.7	-9.8
DOM02172015	0.6	-7.0	2.0	1.9	-5.4	-2.9
DSP05142015	-1.7	*-1.7	-5.1	*-4.9	-5.3	-5.5
EMB02132015	-1.9	-3.3	*-4.2	-7.2	-6.7	**2.3
JDR02192015	0.0	-0.8	-5.1	-5.6	*-6.6	*-7.5
PJM02242015	-1.8	-3.5	-4.0	-6.7	-5.9	-4.1
RCL02242015	0.4	-2.5	-0.7	-5.8	-4.8	-7.4
SAD02132015	-1.3	-1.9	-1.2	-4.3	-11.6	*-10.5
TJF02172015	-0.3	-7.6	-9.5	*-14.1	-9.5	-10.4

Note: Task 1 is omitted because there is no ROM for a single contour.
**Notates the second attempt of task (Task #b).*
***Notates only task where subject pitch bend exceeded one octave.*

APPENDIX N

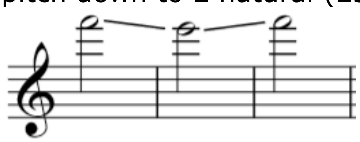
PERFORMANCE TASKS

Project Performance Tasks:

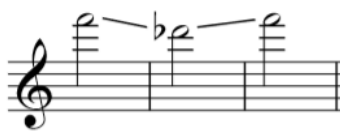
♩=40 for all

1. Using Front F fingering, play F6.

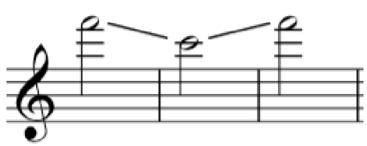
2. Without interruption of continuous tone, bend (without using jaw motion) the pitch down to E natural (E5), and return to the F natural.



3. In the same manner, begin on F6 and bend down to Db5, and return to F6 without break.

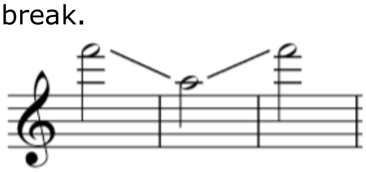


4. In the same manner, begin on F6 and bend down to C5, and return to F6 without break.



5. In the same manner, begin on F6 and bend down to B5, and return to F6 without break.

6. In the same manner, begin on F6 and bend down to A5, and return to F6 without break.



7. In the same manner, begin on F6, and bend down as far as you can without losing the tone, and then return to F6.

-Repeat all five (5) tasks on the control saxophone setup.

APPENDIX O

IRB APPROVAL AND RENEWAL

APPROVAL:CONTINUATION

Joshua Gardner
Music, School of
-
Joshua.T.Gardner@asu.edu

Dear Joshua Gardner:

On 5/21/2014 the ASU IRB reviewed the following protocol:

Type of Review:	Continuing Review
Title:	Ultrasound Examination of Tongue Behavior during Wind Instrument and Vocal Performance
Investigator:	Joshua Gardner
IRB ID:	1205007871
Category of review:	(4) Noninvasive procedures, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• 1205007871.pdf, Category: IRB Protocol;

The IRB approved the protocol from 5/21/2014 to 6/5/2015 inclusive. Three weeks before 6/5/2015 you are to submit a completed "FORM: Continuing Review (HRP-212)" and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 6/5/2015 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

APPROVAL:CONTINUATION

Joshua Gardner
Music, School of
-
Joshua.T.Gardner@asu.edu

Dear Joshua Gardner:

On 6/8/2015 the ASU IRB reviewed the following protocol:

Type of Review:	Continuing Review
Title:	Ultrasound Examination of Tongue Behavior during Wind Instrument and Vocal Performance
Investigator:	Joshua Gardner
IRB ID:	1205007871
Category of review:	(4) Noninvasive procedures, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• PPRL_Informed Consent_update5-10-13.pdf, Category: Consent Form; • PPRL_Parental Consent_update5-10-13.pdf, Category: Consent Form; • PPRL_Child Assent_update5-10-13.pdf, Category: Consent Form;

The IRB approved the protocol from 6/8/2015 to 6/4/2016 inclusive. Three weeks before 6/4/2016 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 6/4/2016 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.