UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

AN ELECTROMYOGRAPHIC EXAMINATION OF WRIST MOTION WHILE EXECUTING SELECTED DRUMSTICK TECHNIQUES WITH MATCHED GRIP

A Document

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

Doctor of Musical Arts

BY

Todd Alan Johnson
Norman, Oklahoma
1999

UMI Number: 9934637

AN ELECTROMYOGRAPHIC EXAMINATION OF WRIST MOTION
WHILE EXECUTING SELECTED DRUMSTICK TECHNIQUES
WITH MATCHED GRIP

A Document APPROVED FOR THE
SCHOOL OF MUSIC

BY

Richard Gipson, Chair

Eugene Enrico

Roland Lehr

Michael Rogers

Kenneth Stephenson

ACKNOWLEDGEMENTS

Any research undertaking surely requires the help and support of many people. This project certainly did. Thanks are likely owed to many people I forgot to mention below.

Without the help of many people in the James Madison University Department of Kinesiology, I could not have completed the laboratory work. I need to especially thank Michael Adamo for his help in pilot testing, Ira Smith for daily lab access, and Dr. Judi Flohr for organizing everything.

Among other people at James Madison, Brantley Douglas made software suggestions, helped with scanning, and helped me keep a sense of humor throughout the project. I also need to thank all of the students who enthusiastically participated as subjects, donating time from their summer schedules.

I need of course to thank my committee members for their trenchant suggestions. The final document is considerably better as a result. In particular, I need to thank Dr. Richard Gipson, not just for his contributions to the document, but also for the countless things he taught me about music and teaching.

Finally, I owe the biggest thanks of all to my mother. She proofread, pep-talked, provided financial support, and helped in so many other ways that only a mother can.

TABLE OF CONTENTS

ABSTRACT

Using surface electromyography, this study examined the activity of flexor carpi ulnaris and extensor carpi ulnaris during execution of drumstick single, double, and buzz strokes. Subjects included 9 male and female undergraduate students with 2 months to 12 years of drum playing experience. Maximum voluntary contractions provided the basis for normalizing electromyographic data. Data from extensor activity produced unexpected results, but raised questions about the thoroughness of existing drumstick pedagogical literature. Data from flexor activity suggested that buzz and double strokes require more flexor activity than single strokes, and that for all three strokes, flexor activity in the dominant hand is either consistently more or consistently less than in the non-dominant hand.

AN ELECTROMYOGRAPHIC EXAMINATION OF WRIST MOTION WHILE EXECUTING SELECTED DRUMSTICK TECHNIQUES WITH MATCHED GRIP

Chapter 1

Introduction

Background

In the last century, the family of percussion instruments has grown and developed at a remarkable pace. Various manufacturers and individuals have invented new instruments, such as the drum set, vibraphone, and steel drum, and have significantly refined existing instruments, such as the marimba and many instruments from Africa and Latin America (Blades, pp.450-60, 1984). A predictable side effect of this growth has been the development of new and increasingly sophisticated playing techniques. However, knowledge of the physiology underlying these techniques has not developed as quickly, especially in comparison to the pedagogy of other instruments and voice. Though they are of fundamental importance in orchestral, drum set, and drum corps performance, even modern techniques for playing drums with sticks (drumstick techniques) have not developed with the benefit of a clear physiological understanding.

Rationale

Some might question whether an extensive consideration of physiological issues is of importance to teaching the playing of an instrument. Henderson (1979) provided an unequivocal answer:

Through the years musical performance has been taught in a master-

> apprentice relationship. The successful performer passes to his students the knowledge that he has acquired from his teachers and from his own experience. "Catch" phrases with no definite meaning are generally used to describe some musical or physical phenomena of performance. These worn phrases rarely communicate anything beyond a vague notion of what is intended. Furthermore, different teachers advocate opposite approaches with both claiming the only assured means for success. The student, caught in the web of this vast profusion of knowledge, either devises a method through experience or does not advance on his instrument. (p. 30)

While Henderson may have overstated the case, subjective descriptions, what he calls "catch" phrases, are common to teaching all instruments. In using such imagery, Guetteler (1992) cautioned:

> Some of these images will be based on genuine knowledge of how the body acts; others will merely be a subjective description of how the movement "feels" and what the teacher believes to happen. Both categories may work, as a means of communication, provided the student is able to recognize the images and the comparison makes sense. There is always the danger, however, that the student will try to get more out of the instruction than was intended and that a partly figurative expression could be misleading if interpreted too literally. (p. 303)

Beyond these critiques of the teaching process there are many documented examples of physiological problems among even professional musicians. Often, with more complete knowledge, musicians might have avoided their difficulties, or sought quicker solutions or treatment. Alexander (1990), Brooks (1993), Lederman, (1993), and MacLean (1993) all documented various nerve problems encountered by musicians, including carpal tunnel syndrome. Wilson (1988) described the common problem of occupational cramp in various musicians. Thomas (1993) described how simple wrist over-extension by a clarinetist all but ended the clarinetist's promising professional playing career.

The amount of physiological information available in pedagogical literature varies widely. A reader can categorize pedagogical information in perhaps four tiers based on the extent to which it considers physiological factors. The lowest level of literature essentially ignores the specific physiology underlying a task, though occasionally mentions things like bones, muscles, or tension. Often, studies use the vague "catch phrases" that Henderson (1979) mentioned. Raab (1980) and Ricquier (1980) provide typical examples of first level information, for piano and wind instruments, respectively. Examples of similar first level drumstick instruction include Breithaupt (1991), Cook (1997), and Moeller (1956). Vague suggestions that an instrument should be "an extension of the body" (Ricquier, p. 61), or that relaxation while playing is essential (Ricquier, p. 61; Breithaupt, p. 13), are typical. Similarly, percussionists are instructed that, in holding a drumstick, one should "lightly" or "gently" wrap the last three fingers around the stick (Moeller, p. 4; Cook, p. 40).

Second is literature that mentions specific physiological considerations in playing or singing, but makes no scientific effort to investigate the effect of physiological variations or problems. Raikin (1985) and Rolland (1979) provide typical examples for piano and strings, respectively. Similar studies for drumstick techniques include Hughlett (1984) and "MD Special Report" (1982). All four mentioned specific muscles or muscle activity used in various pedagogical tasks, essentially explaining the basic anatomical units involved in each. However, they demonstrated no connection between this physiological information and specific aspects of playing an instrument.

Third are studies which focus primarily on discovering scientifically demonstrable relationships between selected playing techniques and their physiology. For pianists, Lee (1990) measured the correlation of ergonomic variables, such as hand size, weight and finger spread, with musical variables, such as tempo, volume, and articulation.

Other level three piano studies include Chung, Jaiyoung, Onishi, Rowen, and Headrich (1992); Lee (1990); and Sakai, Liu, Su, Bishop, and An (1996). Hirano (1988b) investigated the laryngeal muscle behavior of William Venard, a noted voice pedagogue. Other level three vocal studies include Wedin (1984); Watson, Hoit, Lansing, and Hixon (1989); and Martin, Siler, and Hoffman (1990). A search of pedagogical literature yielded only three level three studies involving drumstick techniques. Cutietta (1986) and Reynolds and Morasky (1981), who used biofeedback techniques to help reduce excess muscle tension, included some percussionists among their subjects. In the third study, Crocker (1988) measured the effect of hand dominance on beginning drumstick techniques.

The fourth level contains studies that differ from level three studies only in that they are of broader scope. This level includes research that attempts to a) offer thorough scientific support for widely used pedagogical approaches, b) create a complete model of physiological activity for an area of technique, or c) identify the physiological basis for typical problems or injuries. For example, Isley (1973) advanced a complete theory of brass embouchure. White and Basmajian (1974) completed a similar study for trumpet only, validating several widely held theories about trumpet embouchure. Hirano (1988a) detailed a relatively complete model of laryngeal muscle behavior in singing. Chung, Jaiyoung, Onishi, Rowen, and Headrich (1992) compared two standard approaches to striking piano keys. Dennis (1984) compared the effects of various methods of supporting the string bass. Philipson, Sörbye, Larrson, and Kaladjev (1990) identified the cause of a typical muscle pain problem in violin playing. In contrast, a search by this researcher for level four drumstick studies yielded no examples.

Purpose

Research Questions

The above examination of available pedagogical literature clearly shows the need for further level three and level four study of drumstick techniques. In an attempt to fill that need, this research sought answers to two basic questions:

1. Using matched grip, to what degree do forearm flexor and extensor muscles move the wrist to produce a drumstick single stroke, double stroke, or buzz stroke?

2. Does forearm flexor and extensor activity differ between dominant and non-dominant sides of the body for the three strokes?

Need for the Study

Only scientific investigation of playing techniques can clarify the imprecision typical of level one and level two pedagogical information. While drumstick pedagogy contains contradictory and ambiguous level one and level two studies, it contains only one scientific study (Crocker, 1988). Drumstick pedagogy needs precise, physiologically sound descriptions of techniques, descriptions which are available in other instruments' pedadgogies. This study helps to fill that need.

Description of Methods

Using electromyography, this study measured the activity of selected forearm muscles during the execution of drumstick single, double, and buzz strokes on a drum practice pad. Electrodes attached to each forearm measured the electrical activity of flexor carpi ulnaris and extensor carpi ulnaris muscles. An electromyograph gathered the signals generated by each muscle and sent them to a computer for processing and display. Nine undergraduate college students participated in the study. Of the nine, five had less than one year of drumstick instruction and playing experience while four had several years' instruction and experience.

Definition of Terms

Several terms from physiology and drumstick pedagogy require further definition for readers unfamiliar with either area of study.

Anatomical starting or zero position: A physiological reference position in which a person stands fully erect, with arms dropped at the sides, and palms rotated to face forward.

Segment: A portion of a limb. The forearm is a segment of the arm, and the thigh is a segment of the leg.

Flexion: Movement at a joint which causes a reduction of the angle between two segments of a limb. See Figure 1 for wrist flexion.

Extension: The opposite of flexion, movement at a joint which increases the angle between two segments as a limb returns toward anatomical starting or zero position. See Figure 1 for wrist extension.

Hyperextension: A continuation of extension beyond the zero position. See Figure 1 for wrist hyperextension.

Pronation: Rotation of the forearm, from the elbow, inward so that the palm is facing backward.

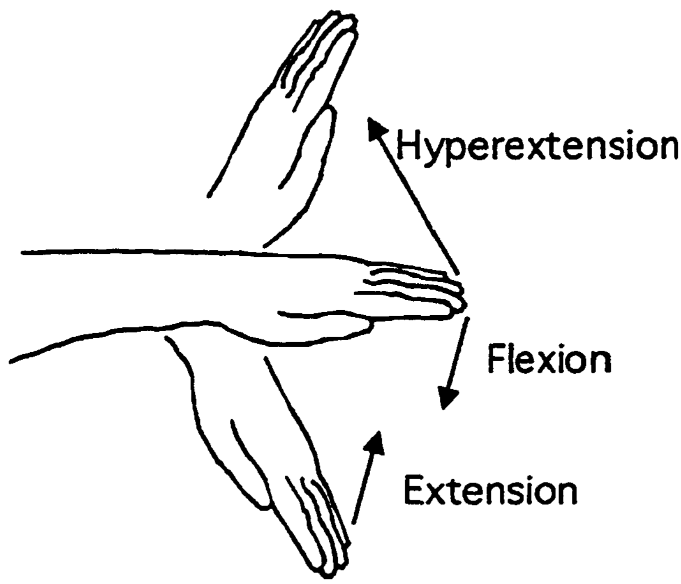


Figure 1. Physiological terms for wrist motions used in matched grip drumstick technique.

Supination: The opposite of pronation, where the forearm is rotated so that the palm faces forward, or returns to the zero position.

Adduction: Movement toward the midline of the body or a segment.

Abduction: Movement away from the midline of the body or a segment.

Ulnar deviation: In the zero position, adduction of the hand at the wrist. Also called ulnar flexion.

Radial deviation: In the zero position, abduction of the hand at the wrist. Also called radial flexion.

Anterior: In the zero position, the front of the body or a body part.

Posterior: In the zero position, the back of the body or a body part.

Palpation: Finding or measuring a muscle movement by touch.

Matched grip: A way of holding a drumstick in which both hands' palms face, and are parallel, to the floor. In physiological terms, the stick is held with the forearm flexed approximately 90° and pronated approximately 180° from the zero position.

Traditional grip: A way of holding a drumstick in which the left hand's palm is facing inward, toward the player, and is perpendicular to the floor. The main physiological difference from matched grip is 90° rather than 180° of forearm pronation. This grip derives from historical military uses of snare drum, and is usually used only in the left hand. The right hand holds a stick using the same position as matched grip.

Downstroke: The motion of a drumstick toward a surface to be struck.

Upstroke: The motion of a drumstick away from a surface to be struck.

Electromyography: Abbreviated EMG, this is a measurement procedure in which electrical signals from activated muscles can be detected and quantified.

Surface electromyography: A form of electromyography which uses electrodes attached to the skin surface.

Needle electromyography: A form of electromyography which uses needles to insert electrodes made of fine wire beneath the skin surface. Sometimes the designation needle electromyography is used more broadly to describe any electromyography which inserts fine wires beneath the skin.

Common mode rejection: In electromyography, a process which compares the recording electrodes' signals, eliminating that portion of the signal common to both electrodes.

Differential amplification: In electromyography, a process which compares the recording electrodes' signals to that of the reference electrode, allowing through only that part of a recording electrode's signal that is different from the that of the reference.

Impedance: The innate hindrance of a tissue or material to the passage of an electrical current.

Chapter 2

Review of Related Literature

Introduction

This chapter describes the many issues raised by an examination of literature related to this study. First, examples from the first level of pedagogical literature demonstrated the kind of information provided at that level, and revealed that level's typical deficiencies. Second, examination of the second through fourth levels of literature for various instruments illustrated the disparity between pedagogy for those instruments and drumstick pedagogy. Third, deciding what to measure necessitated a review of the available drumstick pedagogical literature. Finally, deciding on a process of measurement required a review of human muscle physiology and a related measurement procedure called electromyography (EMG).

Level One Literature and Problems

The room for misinterpretation of pedagogical instructions creates a significant problem for someone reading level one literature. For string players, Raab (1980) described how to gradually replace bad technical habits with good ones, information that could be applied to any instrument's technique. One important principle Raab stated, something likely purveyed by teachers of all instruments, is:

> Efficient muscular or kinesthetic habits can be formed, but only by paying the price of careful, conscious, often tedious and tiring practice. (p. 22)

Raab surely does not intend that a student practice to the point of injury. However, it seems "tedious and tiring practice" could potentially cause the sorts of overuse injuries detailed by Wilson (1988).

Beyond the more extreme possibility of injury, lack of precise meaning could produce misinterpretations. For pianists, Abram (1984) provided information typical of first-level studies. Ostensibly, since no sources are cited, the author derived the pedagogical information presented from personal performing or teaching experience. The height at which a pianist should sit, the angle of the hands, and various kinds of "touch" are mentioned, with occasional mention of generalities such as "muscles," "tension," and "flexibility." To develop wrist flexibility, Abram described several ways for pianists to practice a scale:

> At first, as students play each key, they swing down from the wrist to the horizontal level (not lower). The fingertips are always in contact with the key surface. Immediately after producing the tone, they should eliminate excessive pressure. Then students imagine the wrist filling with helium and very gradually, very slightly, floating up toward the playing of the next key. (pp. 28-29)

While certainly vivid, the final instruction on the key's release seems imprecise. The metaphor implies that the hand should rise, but how far? How far does "very slightly" actually mean? Does the hand not need to move "over" rather than "up" to the next key? If so, does "very gradually" mean that the movement from key to key should be slow? This practice exercise may have helped Abrams' students, but some mention of inches and seconds might clarify the written description.

Level one literature for percussion does not avoid similar problems. Cook (1997) described in detail the various aspects of teaching percussion. He devoted an entire chapter to the development of drumstick techniques. Among other topics, Cook described a way of striking a drum in which sticks are bounced like a ball "with a gentle throw or push of the ball toward the head being initiated primarily from the wrists" (p. 40). He then offered a second way to conceive of the same task:

> Or, with sticks aside, the performer can try placing his or her fingers on the surface of the instrument and *lifting* [Cook's italics] the sound out of the instrument as if testing a hot iron. (p. 40)

This suggests questions similar to those about Abram's description. How gently can one throw the stick down before the bounce back is inadequate? Are not the push to bounce a ball and the pull to remove a finger from heat essentially opposite motions? This makes the two descriptions of the same motion seem contradictory. Once again, a reader has an imprecise description from which to learn a task.

The occasional mention of vague physiological concepts can make level one information more insidiously questionable. Fischer (1995) provided simple, almost generic information about how violinists should shape and move the fingers of the left hand. This included a comparison among the joints of the arm, leg, and finger, that claimed a correspondence between the strongest and weakest in each. The study called the upper arm and leg the "strongest" levers, because they carry out the largest and strongest physical actions. Fischer suggested the finger's base joint had the same importance in the finger, and offered suggestions for playing violin based on that analogy. Apparently, since Fischer cited no references, personal observation or experience suggested the concept. While possibly correct, Fischer's assumptions cry out for some supporting scientific data.

R. T. Nelson (1996) described relief of right wrist pain in oboe playing through use of a clarinet neck strap. From Nelson's description, it appears the problem is not uncommon; the neck strap was offered as a solution to all. One might ask whether there is a better solution, or if the problem, if widespread, might have several causes. The point is not to belittle the efforts of Nelson, or others mentioned above. Literature at level one surely serves a useful purpose for many people playing instruments. What is important is that investigation does not stop there, well short of scientific investigation. Unfortunately, drumstick pedagogical literature contains almost no examples of scientific inquiry.

Level Two, Three, and Four Literature

In searching for pedagogical literature, relatively few level two studies are found. Specific description of bones or muscles used in a task probably has little value without the ability to demonstrate scientifically which bones or muscles execute the task, and to what degree they participate. However, there are some examples.

Raikin (1985) clearly wrote at a more physiologically conscious level two. In detailing a broad range of piano techniques, Raikin made specific mention of the lever action of bones in the hand and arm, discussed "flexor" and "extensor" muscles in the forearm, and cited one source of physiological information. For strings, Rolland (1979) moved marginally up to the second level, briefly differentiating arm flexion and extension from suppination while describing movement in string vibrato.

Drumstick pedagogy does contain some level two information. Hughlett (1984) and "MD Special Report" (1982) are two examples. Hughlett provided information about the muscles used in drumstick pedagogy. A recommended thumb position on the stick allowed more muscles to participate in holding, or gripping, the stick (p. 10). The study described the specific forearm muscles and wrist action used when a stick strikes a drum (pp. 12-13). "MD Special Report" compared the muscles used in matched and traditional grips. However, the research contained a clear error in the description of matched grip. The downstroke, which is described in physiology as hand or wrist flexion, is accomplished by flexor muscles in the arm (Hamill & Knutzen, 1995, pp. 13, 501). "MD Special Report" (p. 23) assigned the downstroke motion to the extensor muscles in the forearm, muscles which are responsible for the opposite motion, extension or upstroke. It appears that a simple confusion of diagrams or terminology could have caused this error. Even so, the error calls into question the validity of the research.

Level three and level four literature significantly improve on the first two levels. They focus on discovering scientifically demonstrable relationships between physiology and playing techniques. Level four differs from level three only in scope. Level four includes research that scientifically supports widely used pedagogical approaches, creates a complete physiological model of a pedagogical task, or identifies the physiological basis for typical problems or injuries.

Piano pedagogy contains several studies at both the third and fourth levels. At the third level, Lee (1990) measured the correlation of ergonomic variables, such as hand size, weight and finger spread, with musical variables such as tempo, volume, and articulation. Thirteen adult, "skilled" pianists, selected for their advanced training and proximity to the research lab, performed two exercises selected from piano pedagogical literature. The electronic keyboard used generated digital data in a MIDI (Musical Instrument Digital Interface) format which a computer recorded. For one exercise, a highly arpeggiated pattern, no significant relationship existed between ergonomic and musical variables. For the second exercise, a much simpler arpeggio pattern played against a held note, pianists with greater wrist mobility produced shorter articulations and faster tempos. Also, those with more wrist mobility and those with heavier hands had less control of the finger holding the sustained note.

Also at the third level, Sakai, Liu, Su, Bishop, and An (1996) studied repetitive motion in pianists, identifying specific joints as most affected by repetition. They used 10 subjects, ranging from 24 to 39 years of age, including "5 professional or semi-professional pianists and 5 amateur pianists" (p. 25). While subjects played two exercises, a video camera recorded data from reflective markers attached at various finger, hand, and forearm locations. From the data, a computer calculated angles at various finger joints and at the wrist. The results provided data about the amount of joint motion in various piano performance tasks. The authors noted that large variations occurred between pianists, even though the exercises were basic chordal and scalar patterns. They concluded that "it would be a great challenge, if possible, to establish a standardized model for motion of the hand on the keyboard" (p. 29). Of particular interest to this study, the researchers used a metronome to insure a steady tempo, and verbally instructed subjects to play each note with consistent force. The researchers noted that getting subjects to attack a note with consistent force was "admittedly somewhat difficult" (p. 26).

Wolf, Keane, Brandt, and Hillberry (1993) identified two conditions that might predispose particular pianists to musculoskeletal injury, results which place the study at the fourth level. Subjects, eight males with 12 to 59 years of playing experience, performed a passage from a piano piece by Felix Mendelssohn. They played on an electronic piano which sent MIDI data to a computer. This data represented a keystroke's force, while a video camera provided visual information regarding joint angles. The data was examined for ten individual notes played in each subject's performance. The researchers concluded that pianists which strike keys excessively hard, or that use extreme finger angles, may predispose themselves to injury. Also, keystroke force decreased with greater years of experience. Like Sakai, Liu, Su, Bishop, and An (1996), this study regulated tempo through a metronome independent of the measuring apparatus.

Chung, Jaiyoung, Onishi, Rowen, and Headrich (1992) completed another fourth-level piano study. They examined "weight playing" and a more traditional approach to striking piano keys, comparing the range of wrist motion used by each method. Nine subjects, two professional teacher/performers and seven graduate music students, played standard trill and octave exercises as well as short excerpts from piano repertoire. Goniometers, devices for measuring joint angles, measured wrist flexion and extension, and wrist adduction and abduction. The study concluded that the weight playing technique required a smaller range of wrist motion. Like research mentioned above, a metronome regulated tempo for this study. No mention was made of an attempt to control the dynamic level at which excerpts were played.

The pedagogy for string instruments shows a range similar to that of piano. At level three, Bejjani, Ferrara, and Pavlidis (1989) analyzed the activity of various muscles during violin vibrato. Seven male and seven female professional violinists, aged 27 to 35 years, played selected notes using vibrato. They used several fingers on different strings of the violin. Surface electromyography (surface EMG), an important scientific procedure described in detail later in this chapter, measured selected back, upper arm, and forearm muscles' activity, while a sound level meter gathered acoustical information. The study made several observations regarding the muscles' activity. These included, a) the synchronization between the vibrato and some muscles' activity, but a lack of synchronicity for other muscles, and b) that muscles began activity in an identical sequence for all subjects. An exceptional attempt was made to control possible variations among subjects. Subjects used the same violin, rather than their own, to avoid biasing acoustical data. The violin was specifically tuned to the modern A440 standard to insure consistent string tension. Finally, measurement occurred in the morning, and subjects could not play that day, in an effort to avoid bias due to muscle fatigue. The authors also set a rigorous standard to which each subject's ability was compared. Each subject had done two of the following: a) recorded on major record labels, b) received reviews from significant critics, c) performed in major concert halls, or d) performed or had recordings played on international radio or television (p. 170).

Guettler (1992) examined vibrato in string bass playing. As did Bejjani, Ferrara, and Pavlidis (1989) for violin, Guettler identified a regular, "pulsating" muscle activity pattern associated with bass vibrato. Muscle activity, measured by surface EMG, was synchronized with finger motion, measured by a potentiometer attached to a subject's finger. In one subject a deviation from that muscle pattern apparently caused deficient vibrato. Guettler did not completely explain the measurement procedure, or the number and nature the study's subjects.

Also at level three, Naill and McNitt-Gray (1993) examined muscle activation patterns while using two different cello string stopping techniques. According to the authors, the techniques are advocated by opposing pedagogical schools of thought. While the researchers did not prove one method to be superior, they identified muscle activity patterns unique to each. One of the researchers served as the only subject, and surface EMG was used to measure muscle activity. Naill and McNitt-Gray justified using only one subject by citing the necessity for consistent implementation of the different stopping techniques. They also noted that the author's cello experience satisfied the standard set by Bejjani, Ferrara, and Pavlidis (1989).

At level four, Dennis (1984) examined back and arm muscle tension for three different methods of string bass support, and the methods' effects on tone quality. Using 33 male and 7 female undergraduate students, Dennis measured muscle activity in selected muscles of the lower and upper back, and left and right arms, while subjects played an orchestral excerpt. An audio tape recorder captured each performance for later evaluation by a panel of judges. Dennis concluded that variations in support methods produced no significant effect on tone quality, as determined by the judges, or muscle activity, as determined from surface EMG readings. Dennis did not attempt to regularize volume or tempo among subjects.

Other level four string studies exist. Philipson, Sörbye, Larrson, and Kaladjev (1990) discovered that violinists' overuse of certain shoulder and upper arm muscles likely caused several subjects' neck and shoulder pain. They used nine professional violinists, measuring muscle activity in each subject with surface EMG. Levy, Lee, Brandfonbrener, Press, and Levy (1992) examined the effect of a violin shoulder rest on muscle activity, identifying neck and shoulder measurements that predicted the relative value of a rest for a particular individual. They used surface EMG to measure muscle activity for 15 "accomplished" violinists. They also provided one of the more specific descriptions of an experimental procedure (p. 104) found in the review of related literature. Each subject played six times through each of two playing exercises, with periods of rest irregularly inserted to prevent any effect from fatigue or "rehearsal" of an exercise. The researchers sampled 10 seconds, or approximately half the length, of each trial. A metronome independent of the measuring apparatus regulated tempo. The study made no mention of controlling volume.

Level three and level four pedagogical information is readily available for voice students. At level three, Wedin (1984) investigated the use of abdominal muscles in phonation. The study hoped to provide some information of use to singers. Four subjects participated, having practiced control of selected abdominal muscles before the experiment. On a signal, each shouted the word "hay." This was done several times while subjects attempted to control muscles in various ways. Wedin reported the activation patterns, and an increase in voice strength due to subjects' practice. This study used a combination of surface EMG and needle EMG, a procedure discussed later in this chapter along with surface EMG.

Watson, Hoit, Lansing, and Hixon (1989) also investigated abdominal muscle activity in singing, in particular verifying and refining their own previous research. They studied four male professional singers, all with a voice range of baritone or below. For each they recorded a) abdominal muscle activity with surface EMG, b) contractions of the abdomen and chest using a device coiled around those regions, and c) the subject's singing through a standard audio microphone. Each subject performed three speaking tasks, one slow song requiring sustained notes, and one fast song. The researchers concluded that only parts of the abdominal musculature are typically active in singing. In addition, this activity changed during some phases of respiration and from singer to singer. Subjects apparently received no specific instructions regarding tempo or volume.

Hirano (1988b) described the laryngeal muscle behavior of William Venard, a noted voice pedagogue. Hirano measured the muscles using needle EMG in three sessions spread over five months. Hirano reported some results of the sessions in earlier research, so confined this report to data previously unpublished. The study's most notable aspect is its use of a single subject.

Martin, Thumfart, Jolk, and Klingholz (1990) measured a specific laryngeal muscle to test the conclusion of Hirano and others that it was inactive during singing. They used only one subject, justifying it in two ways. First, they noted that research by Venard and Hirano had often done so. Further, they noted that, because they and Hirano used needle electrodes inserted beneath the skin, it was difficult to find willing subjects. The research showed that the muscle in question behaved as Hirano and others had described.

At level four, Hirano (1988a) detailed a relatively complete model of laryngeal muscle behavior in singing. Hirano described the underlying anatomy of the human vocal folds and their physiological function in singing, as well as specifying laryngeal muscles' roles in control of vocal register, frequency, intensity. Hirano based the description on 20 years of prior research.

Significant studies at level three and four exist for a variety of wind instruments. Trumpet pedagogy boasts several studies. At level three, Heuser and McNitt-Gray (1991) examined facial muscle activity prior to tone commencement. The subjects were ten "successful" male trumpet players, half professionals and half college students, and two others experiencing difficulties in note attacks. Using surface EMG, the researchers measured activity in selected facial muscles while the subjects played both short and sustained notes in various registers. The researchers controlled tempo with an electronic metronome set at 60 beats per minute. By combining the metronome's signal with that of a microphone recording the tones played, EMG data and a tone's commencement were synchronized. In the successful players, similar muscle activity, especially prior to the attack, was noticed for all exercises. The players experiencing difficulty used inconsistent and random muscle activity clearly at odds with that of the successful players.

Lewis (1985) examined the body positions of 16 professional trumpet players during various playing tasks such as high and low register playing, and playing while in a fatigued state. Measuring his subjects both while playing and from photographs, he cataloged variations in head, neck, and horn angle, as well as positions in selected portions of the spine. He found that his subjects did not conform to several generally held pedagogical principles, including what he called the "military erect posture."

At level four, White and Basmajian (1974) validated several widely held principles of trumpet pedagogy. They measured how selected facial muscles' activity changed with register, volume, and a subject's ability. Eighteen subjects, divided into an advanced and a beginning group, spanned a full gamut of ability from professionals to students with less than one year of playing experience. Subjects played 51 notes or exercises while needle EMG recorded muscle activity. During measurement, each subject controlled volume by watching a decibel meter to constrain themselves to predetermined limits. An electronic marker provided synchronization between EMG data and a subject's playing, including attack and release of a note. The marker's nature was not explained. Apparently a researcher mechanically keyed it to mark various parts of the EMG record. No mention was made of an attempt to control tempo.

Heuser and McNitt-Gray (1993) tested whether asymmetrical or off-center trumpet mouthpiece placement affected muscle activity. They used eight subjects, five professionals with centered mouthpiece placement, and two professionals and a masters degree candidate with off-center placement. As in their previous tone commencement study, discussed above, Heuser and McNitt-Gray electronically synchronized surface EMG data with the tone's signal by using an electronic metronome. Heuser and McNitt-Gray concluded that asymmetrical mouthpiece placement, considered poor technique by many trumpet teachers, produced the same muscle patterns as more conventional placement.

Among other level three studies for other instruments is one for bassoon (Jooste, 1984). Using electromyography, Jooste measured the activity of abdominal and back muscles in changes of register and vibrato. Unlike similar studies, this one contains no sample data, description of subjects, or description of the experimental procedure. Jooste did recommend several playing exercises to increase involvement of back muscles, and strengthen back and abdominal muscles.

Some level three and level four studies include several instruments or an instrument family. Nelson (1989) studied respiratory function for a variety of woodwind and brass instruments. A total of 38 subjects, ranging in ability from high school students to professionals, provided data on respiration while playing a wind instrument. Using surface EMG and a device called a respirgraph to measure the volume of air taken into the abdomen, Nelson concluded that compared to professionals, less experienced players tend to close their throats more, overuse abdominal muscles, breathe less frequently, and take in less air per breath. Like Dennis (1984), Nelson also audiotaped subjects. However, those data were used only to "illuminate" various events such as coughing, laughing, or notes missed during the testing.

Isley (1972) completed one of the earliest and most comprehensive of level four studies. Based on his research, Isley proposed a comprehensive theory for all brass instruments' embouchures. The theory specified in detail optimum facial muscle posture, jaw posture (including the alignment of the teeth), mouthpiece placement, and optimum facial muscle activity patterns. To create it, Isley used needle EMG and eight subjects, including himself, three professional trumpet players, three college sophomore trumpet players, and a clarinet player taking a college brass methods course. More than 40 playing exercises or notes were executed, with subjects playing on both trumpet and trombone. Early in the research, both surface and needle EMG were used, but a lack of correlation between readings from them led to the rejection of surface EMG for the remainder. Other than the sweeping nature of the research, the most interesting difference from needle EMG studies above is the length of recording sessions. Isley stated:

> During the early experiments many technical problems arose. Among these were 60-cycle interference [from power sources of some kind], movement artifact [to be discussed later in this chapter], and electrode slippage. Some experiments ran as long as three hours, leading to considerable fatigue (p. 154).

Given the fact that several studies already described included measures to avoid fatigue, and the fact that Isley made no mention of how fatigue was handled, one might question the validity of his results.

Among other level three and four studies which combine instruments, Gossett (1989) examined concurrent study of voice and oboe, documenting its effect on various muscles facial and abdominal muscles. Of the four subjects, three were undergraduates and one a graduate student, and two were oboists and two vocalists. Each studied voice and oboe playing in a experiment lasting approximately six months. The research suggested that increased abdominal and facial muscle activity in oboe playing could have significant negative impact on successful concurrent study of voice.

Callahan (1987) developed a system to measure finger dexterity in clarinet and trumpet playing, then used it to analyze beginning pedagogical literature. Subjects were drawn from music education majors enrolled in beginning brass and woodwind methods courses at Ohio State University, 12 from the woodwind class and 13 from the brass class. As many times as possible in a set time period, woodwinds players repeated two-, three-, and four-note fingering patterns on a clarinet, and brass players did the same on trumpet. The length of time per pattern and number of times played were measured by electronic switches connecting an instrument to a computer. Patterns used were considered typical of those taught to beginning brass and woodwind students. Callahan concluded that both trumpet players and clarinet players more easily performed two-note than three-note patterns, and three-note than four-note patterns. Also, the results revealed that patterns involving pressing down more than one key at a time, and clarinet patterns involving the left thumb, were harder than patterns that did not.

Schuppert and Wagner (1996) measured biomechanical restrictions in the wrist joints of various piano, string, and woodwind performers, then examined the data to see if it was predictive of performance-related injuries. A device was constructed to measure both active and passive amounts of wrist flexion and extension, as well as unlar and radial deviation. They measured the range of these motions for a control group of 54 healthy, right-handed student or professional musicians, and an experimental group of 14 students and professionals with a variety of performance related wrist problems. Control group ages spanned 16 to 61 years, while the experimental group was younger, ranging from 20 to 29 years old. The control group contained 33 women and 21 men, while the experimental group contained 8 women and 6 men. Control group subjects played a variety of instruments, including piano, guitar, flute. Six control subjects played instruments left unspecified, as did the entire experimental group. Schuppert and Wagner found that, while the control group had no significant differences between left and right wrists, the experimental group showed significant differences in passive range of motion between affected and unaffected wrists, and showed nearly significant differences in active range of motion between wrists.

For a variety of instruments, researchers have used biofeedback as a way of overcoming technique-related limitations or injuries. These studies do not fit clearly into level three or four. They either attempt to solve a specific physiological problem, or create improvement in various tasks, without particular concern for adding to pedagogical knowledge of an instrument. However, they do have at their root a concern with the physiological basis of technique. As a result, such studies at least can be considered level three in significance. Also of interest to this study, many biofeedback studies use surface EMG as the basis for feedback.

Koehler (1993) examined the effect of electromyographic feedback on five different string bowing techniques. Koehler used 45 subjects, split evenly among control and experimental groups, which played violin, viola, string bass, or cello. Subjects ranged in ability from high school students, through university undergraduate and graduate students, to professional performers and teachers. Each subject received four training sessions involving "traditional instruction" probably similar in conceptual content to level one or level two pedagogical literature. In addition, experimental group members received aural and visual feedback for two of the sessions. Surface EMG provided aural feedback by sounding a beeper when a subject passed a certain threshold of muscle activity. Also based on the surface EMG readings, a computer graph presented visual feedback to subjects. After the training, a panel of expert judges evaluated audiotapes of each subject, scoring the experimental group significantly higher for all of the five bowing techniques. Koehler's use of aural feedback is typical of this sort of study.

Both Cutietta (1986) and Reynolds and Morasky (1981) completed biofeedback studies using EMG and aural feedback in manner similar to Koehler. While not thoroughly detailed, Cutietta's experimental procedure appeared to parallel Koehler's. Subjects were music students selected by their private teachers for having difficulty with a specific musical passage. An experimental and a control group, each including three violinists, two singers, a saxophonist, and a percussionist, participated in five training session over approximately two weeks. The training sessions concentrated on only the passages giving the musicians trouble. While the experimental group received aural feedback when tension passed a certain threshold, the control group received randomly produced feedback. Neither subjects nor their teachers were aware of this until after the experiment. For each of the instrumentalists, tension levels in the left forearm flexor muscle group formed the basis for feedback. At the end of the experiment, as measured by their teachers, the experimental group showed greater improvement on the musical passages in question. Muscle tension had decreased significantly for all experimental subjects with the exception of the percussionist.

Reynolds and Morasky (1981) completed another similar study, also including a variety of instruments. Of particular note, two percussionists participated in this study. Both had recently switched from traditional to matched grip. While the muscles measured are not carefully explained, it appears from labels on figures that they included both flexors and extensors of the forearms. As one might expect, as tempo increased for exercises played, the muscle activity in the percussionists' left forearms increased noticeably, while activity in the right arm remained constant. In the review of related literature, the research of Reynolds and Morasky and Cutietta are two of only three studies higher than level two which involve drumstick technique.

Cleveland (1988) described an unusual case study using visual feedback. A fiberoptic scope attached to a video camera allowed a vocalist to observe larynx movement while the subject sang and spoke. Data gained from this, along with subsequent speech therapy, eliminated vocal nodules that had troubled the subject for over two years. The data also revealed that abnormal laryngeal tension while speaking, rather than singing, caused the nodules' formation. One might categorize this study as level four since it addressed and solved a performance-related medical problem.

Crocker (1988) is the one example of a clearly level three drumstick study found in the search of related literature. Crocker examined the effect of left and right hand dominance in drumstick technique among more than 900 fifth graders. Through answers to a questionnaire, Crocker categorized subjects as purely left-handed, purely right-handed, or "mixed-handed." On the questionnaire, subjects indicated which hand, or if either hand, was used to perform tasks such as throwing a ball, holding a toothbrush while brushing teeth, and holding a spoon to eat soup. This information, fed into a formula, provided a score which determined a subject's handedness category. On a specially built device, a subject tapped various rhythms, each hand on a different metal plate. A switch on each plate sent information to a computer. Subjects tapped each rhythm using different permutations of left and right hand. These permutations mirrored typical alternated and stick subtraction, or "natural," sticking patterns used in snare drum playing. Crocker found no significant difference in performance accuracy or in speed for subjects of different handedness. Also, typical alternated and stick subtraction sticking patterns produced no significant differences in speed or accuracy among subjects. While focused on one narrow physiological issue, Crocker's research was very thorough, and the issue is of great significance to drumstick pedagogy.

Steele (1991), Alexander (1990), Judkins (1993), Van Horn (1988), and Ryniker (1981) all described percussion performance-related injuries, so at first glance appear to fit level four. However, none cite specific data or cases, other than personal experience. Judkins and Steele, the most thorough of the two, only speculate on potential problems based on studies done for other instruments. Compared to the number of level three and four studies found for other instruments, the state of percussion pedagogy thus seems deficient.

In addition to revealing the limitations of drumstick pedagogy, the examination of level three and four studies suggested some basic issues for this study. Only a few studies used a large number of subjects. Several used only one, and few used more than 20. Surface or needle electromyography provided data in a large number of the studies. Very few attempted to insure that subjects played exercises or excerpts at similar volumes. In the many cases, researchers did try to insure steady tempos among subjects by using a metronome. These issues will be discussed in further detail later in this chapter or in the next.

Lammers (1983/1984), a level three study not discussed above, provides a particularly informative model for this research. Lammers noted that, while musical pedagogy for several instruments contained significant studies of muscle activity, none existed for trombone. Lammers measured 14 male trombonists' wrist and forearm extension while moving to and from different trombone slide positions. He did so by selecting a representative pair of upper arm muscles, and a representative pair of forearm muscles, the extensor carpi radialis and flexor carpi ulnaris. The subjects were half college-level players, and the rest professionals. In addition to measuring muscle activity using surface EMG, Lammers also measured joint angles. To do so, Lammers had a specialized electronic goniometer built. The goniometer produced inconclusive results. Lammers' study is instructive for many reasons. This study was needed for the same reasons as was Lammers', and measured one of the same basic physiological motions, wrist flexion and extension. As will be described further in Chapter 3, this study also, a) measured only selected muscles of those involved in wrist flexion and extension, and b) avoided the complications of measuring strategies other than EMG (in part because of Lammers' goniometer difficulties).

Henderson (1979), another level three study, is also a good model. Henderson attempted to establish patterns in throat muscle tension of professional trumpet players. Subjects, 18 trumpet players of unspecified age or experience, were selected from participants at the 1979 International Trumpet Guild Convention in Tempe, Arizona. Using surface EMG, Henderson measured muscle activity in one neck muscle while subjects played five different exercises. Each subject received instructions to rest as long as necessary between exercises to avoid fatigue. Henderson demonstrated a consistent pattern of muscle activity: muscle tension increased and decreased in direct relationship to changes in an exercise's register. However, the results varied too much for the establishment of any norms. Like Lammers (1983/1984), Henderson broke new ground. While White and Basmajian (1974) and Isley (1972) had already investigated facial muscles in trumpet and brass playing, neither had considered neck muscles. Possibly due to that fact, Henderson had subjects play relatively simple exercises and limited his data gathering to just EMG readings. This study mimicked that simplicity and Henderson's straightforward goal of establishing baseline information in a new topic area. Finally, this study's analysis and presentation of data mirrored Henderson's.

This study also must also consider the primary topic of Crocker's research, hand dominance. Since this study will measured an area of drumstick technique, hand dominance was an important issue. Few studies above measured tasks as concerned with right and left symmetry as this study. Only Schuppert and Wagner (1996) explicitly considered handedness. Crocker provided a useful model for establishing a subject's dominant hand.

Important Drumstick Techniques

Several of the drumstick pedagogy sources already mentioned are not comprehensive. They focus on only one narrow subject, or are only concerned with the results of basic technique, rather than the physiological details of execution. "MD Special Report" (1982) is an example of the first case, and Crocker (1988) of the second. More comprehensive level one drumstick technique sources include Breithaupt (1991), Cook (1997), Tuthill (1981), Moeller (1956), and Ludwig and Ludwig (1948). Hughlett (1984), a level two study, is also comprehensive. In the effort to identify basic drumstick techniques for examination, commonalties were sought among these sources. Investigation of these common subjects, if any, seemed a logical starting point in developing level three information for drumstick pedagogy.

All of these comprehensive sources addressed several identical issues of basic technique. They all generally agreed in identifying two distinct ways of striking a drum: a basic or single stroke (Breithaupt, pp. 13-15; Cook, pp. 37-8, 39-42; Tuthill, p. 35; Moeller, pp. 6-7; Ludwig and Ludwig, p. 10; and Hughlett, pp. 12-13), and a double stroke used for an open or rudimental roll (Breithaupt, pp. 19-20; Cook, pp. 58-61; Tuthill, p. 35; Moeller, pp. 14-19; Ludwig and Ludwig, p. 11; and Hughlett, pp. 22-3). Breithaupt (pp. 17-18) and Cook (pp. 47-8) also described a third distinct stroke, the buzz or multiple bounce stroke used for a closed or orchestral roll.

Houliff (1983) provided possible reasons why only Cook and Breithaupt mentioned a buzz stroke. Houliff (p. 14) identified the technique as associated with concert or indoor styles of music. Tuthill mentioned that his discussion of technique was for a marching or outdoor styles (p. 34), as did Ludwig and Ludwig (p. 1) and Moeller (p. 1). Houliff (p. 14) also mentioned that until recently, many sources of drumstick pedagogy did not discuss the buzz stroke. It is likely that the Moeller (1956) and Ludwig and Ludwig (1948) sources are not current enough to have avoided that omission. This does not explain why Hughlett omitted a buzz stroke. One can only assume that his information is also intended for marching styles of playing.

The studies do not, however, seem to completely agree on the way in which the fundamental techniques are executed. There are discrepancies in how the single stroke is executed. Moeller said that the single stroke, after striking the drum, should snap away instantly (p. 6). A series of pictures accompanying the description show the stroke ending several inches above the head. Tuthill (p. 35) described a "down stroke," one in which the stroke ends only one inch above the head, as the "primary" stroke. He then mentioned a "secondary stroke" (p. 35) which he calls an "upstroke." This appeared in an accompanying illustration to end several inches off of the head, similar to the stroke Moeller described. Breithaupt appeared to suggest the opposite.

In describing the basic stroke, he instructed that the natural rebound of the stick should not be inhibited (p. 14). However, in describing marching percussion techniques, he described several different strokes, including a full-, half-, and quarter-stroke, as well as a "tap" that appears similar to Tuthill's downstroke (pp. 83-84). Cook's seemingly contradictory single stroke description appeared above in this chapter's discussion on level one literature.

Authors described different methods for producing the double stroke. Hughlett (p. 22) described it as a combination of two single strokes in one hand, except that the second is stopped halfway up to the starting position, then returned to the drum. Hughlett called this second portion a "half stroke." Tuthill described the stroke as two single strokes "played with one motion. One down stroke is played and the second or interior stroke is played at a very low height..." (p. 35). Ludwig and Ludwig specified that at a slow speed, the second stroke is the same as the first, but the player must emphasize or accent it; as the speed increases, however, the second stroke becomes a "controlled rebound." (p. 11).

Those descriptions are somewhat different than Cook's and Breithaupt's description of double strokes. Cook's description sounded more like Ludwig and Ludwig's for fast tempos. Cook described the double stroke as a "stroke-and-a-controlled-bounce" where the middle, ring, and small fingers "help play the bounce of the stroke-and-a-bounce back into the head..." (p. 58). Breithaupt described the double stroke similarly, as a stroke then a bounce, but with the bounce controlled by "lifting the stick off the head" after the second sound (p. 19).

Moeller's description of the double stroke was not easy to follow. Like the other authors, he implied that, at least at slow tempos, it is produced by two single strokes played in a "fanlike motion" (p. 15). Later he described a bounce (p. 19) that is "controlled." While not directly connected to his discussion of double strokes, it resembled the controlled bounce mentioned by other authors. Overall, there seemed less incongruity in the explanation of the double stroke than for the single stroke, but still some discrepancies existed.

Breithaupt described the buzz stroke as a movement of the stick toward the head by the wrist, which is then, as the stick meets the head, allowed to stay on the head "by keeping the wrist in the down position" (p. 17). Cook described the buzz as "a stroke [apparently a single stroke] after which the stick is allowed to rebound or bounce freely several times..." (p. 48). He continued, describing several other considerations, mainly finger position and action, involved in producing the stroke. With information from only these two sources, there seems greater agreement on how the buzz stroke is produced.

One basic physiological consideration seems to unite all authors regarding the three basic strokes. All three seem based on some sort of wrist action. However, authors and strokes appear to differ in the exact amounts of wrist flexion (downward motion) and extension (upward motion) used. These strokes, and particularly the wrist motion involved, thus seem a likely target for level three inquiry. Given the scarcity of available level three and four drumstick information, such an inquiry is long overdue.

Issues Related to Measurement

Scientifically measuring the various physiological tasks required consideration of two basic issues, what to measure and how to measure. Resolving these issues required an examination of basic muscle physiology, and its specific application to drumstick pedagogy. It also required a review of the methods used in the various level three and four studies available for other musical instruments.

Physiological Principles

Most of the level three studies above concern themselves primarily with muscle activity. "Muscles and gravity are the major producers of human movement" (Hamill and Knutzen, 1995, p. 71). Any limb of the body contains several muscles, each a participant in various types of motion. They have various shapes and internal organizations. Deciding whether and how to measure the activity of a particular muscle requires knowledge of its structure.

Hamill and Knutzen (1995, pp. 72-78) and Loeb and Gans (1986, pp. 25-43) described the fundamental construction of muscles (see Figure 2). At the microscopic level, muscles contain myofibrils. Each myofibril consists of a long series of a muscle's most basic unit, the sarcomere. A microscope reveals each sarcomere as an alternating portion of darker and lighter color capped at each end by dark plates, known as Z lines. Each sarcomere contains bundles of two kinds of filaments, which biologists describe as thick and thin. Two thin filament bundles extend from either side of the Z line, each into a different sarcomere. Two thin bundles from each Z line overlap a thick bundle in the middle of a sarcomere. This overlap allows the chemical process which contracts the muscle. In each sarcomere the thick filaments form, break, and reform chemical connections, called cross-bridges, with the thin filaments. "The sarcomere shortens as the myosin [thick] filament 'walks' along the actin [short filament]" (Hamill and Knutzen, p. 74). Shortening of each sarcomere results in an overall shortening of the entire myofibril.

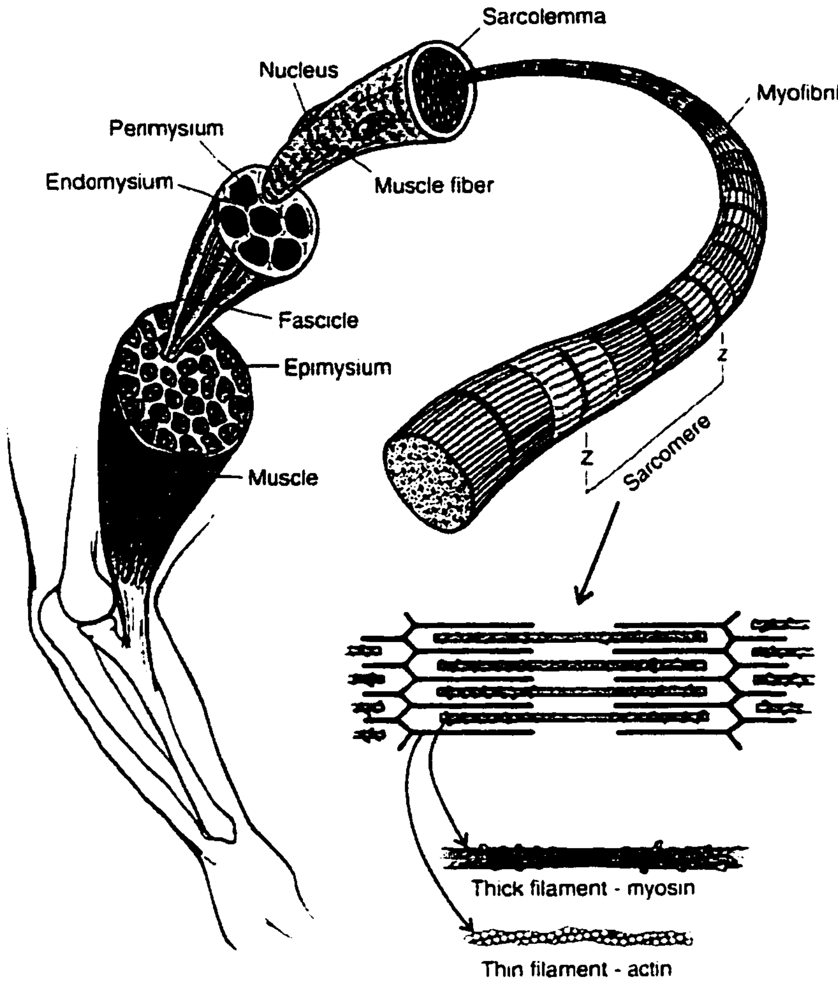


Figure 2. The structure of muscles. Adapted from Biomechanical Basis of Human Movement (p. 73), by J. Hamill and K. M. Knutzen, 1995, Media, PA: Williams and Wilkins. Copyright 1995 by Williams and Wilkins. Used with permission of the publisher and author (see Appendixes D and E).

Hamill and Knutzen (1995, pp. 72-78) and Loeb and Gans (1986, pp. 25-43) continued, describing muscles at the cellular level. An individual muscle fiber contains hundreds or even thousands of myofibrils. Also within the fiber are the organelles associated with cellular control and maintenance, things such as cell nuclei. Each fiber is wrapped in a thin membrane, the sarcolemma, "which also branches into the muscle [fiber]" (Hamill and Knutzen, p. 73). Fibers can be classified into one of three types, based on their contraction time and on how quickly they fatigue. Physiologists describe Type I fibers as slow-twitch and fatigue resistant because they contract slowly and can sustain contraction for prolonged periods. Type II muscle fibers, classed as fast-twitch, are of two kinds. Type IIa, described as intermediate fast-twitch, can either sustain a contraction for long periods, or contract quickly, to provide a burst of force, then fatigue. Type IIb fibers contract rapidly, then quickly fatigue. Each muscle contains a combination of these fiber types.

Hamill and Knutzen (1995, pp. 72-78) and Gray (1985, pp. 431-437) described muscle organization above the cellular level. Up to 200 muscle fibers grouped together form a fascicle. The endomysium, a tissue which surrounds the muscles fibers in a fascicle, "is a very fine sheath carrying the [blood] capillaries and the nerves that nourish and innervate each muscle fiber" (Hamill and Knutzen, p. 73). The endomysium also serves to insulate neurological signals within the muscle. A dense tissue called the perimysium covers each fascicle, and a tissue called the epimysium covers the several fascicles which, grouped together, form a complete muscle. Most muscles have a thicker, centralized portion called the belly. However, some muscles, "like the wrist flexors and extensors, have bellies that are not so apparent to the observer" (Hamill and Knutzen, p. 72). A muscle can have one of two basic arrangements of fibers, penniform or fusiform. In the penniform arrangement, fibers lie at an angle, similar to the veins in a bird's feather. Fusiform muscles have fibers running in parallel from one end of the muscle to the other. Penniform muscles, because of their fiber arrangement, create slower movements, through less range of motion, than do fusiform muscles. However, they also generally can produce more force. Fusiform muscles often perform high velocity motions. Finally, muscles can be collected into groups contained by a fascia, a sheet of fibrous tissue, into what physiologists call a compartment. These compartments group muscles of similar function and help to optimize their mechanical action on the skeleton.

Gray (1985, p. 437) and Hamill and Knutzen (1995, pp. 72-78) described how several different muscles can involve themselves in a task. Physiologists categorize different muscles' activities as that of an agonist, an antagonist, a stabilizer, or a neutralizer. Muscles generally work in opposed pairs. Physiologists call a muscle responsible for a particular joint motion an agonist and a muscle involved in the opposite motion an antagonist. A particular joint motion may have several agonists. These further subdivide into prime movers, those muscles most responsible or active, and assistant movers, those involved if more force is required. Stabilizers support a joint so that motion can occur in another joint. Neutralizers actually prevent movement at another joint. Physiologists sometimes describe stabilizers and neutralizers as synergists since they act simultaneously with, and in support of, agonists.

Physiological Basis for Striking a Drum

The drumstick studies described above agreed that wrist motion underlies the three ways of striking a drum. Clearly, from their descriptions and pictures, wrist motion refers to flexion and extension of the wrist. This wrist flexion and extension occurs with the forearm flexed approximately 90° and pronated approximately 180° from the zero position, or, with the forearm in the typical position for matched grip.

Flexion and extension of the wrist (radiocarpal joint) creates motion primarily between one forearm bone, the radius, and scaphoid and lunate bones, two of the hand's carpals (Hamill and Knutzen, 1995, p. 177) (see Figure 3 for the skeletal structure of the forearm and wrist). Several muscles participate in wrist flexion and several in extension. All originate outside the hand, entering it as tendons, often quite long ones (see Figures 4 and 5 for the relevant muscular structure of the forearm).

Hamill and Knutzen (1995, p. 179) described the primary wrist flexors as the fusiform muscles flexor carpi ulnaris, flexor carpi radialis, and palmaris longus. All originate at end of the humerus (the bone of the upper arm) and become tendons approximately halfway down the forearm. Hamill and Knutzen cautioned that the flexor carpi radialis and flexor carpi ulnaris do most of the work, noting that the palmaris longus is quite variable in size, and is even absent in 13% of the population. The flexor carpi ulnaris is the strongest of the three. Gray (1985, pp. 530-535) described five muscles that can participate in wrist flexion. Gray specified that three muscles described by Hamill and Knutzen, along with the flexor digitorum superficialis, comprise the superficial wrist flexors, those close to the skin surface. The flexor digitorum profundus is the one deep wrist flexor, a muscle covered by superficial muscles. Gray explained that the flexor digitorum superficialis and flexor digitorum profundus, the two wrist flexors not described by Hamill and Knutzen, participate in wrist

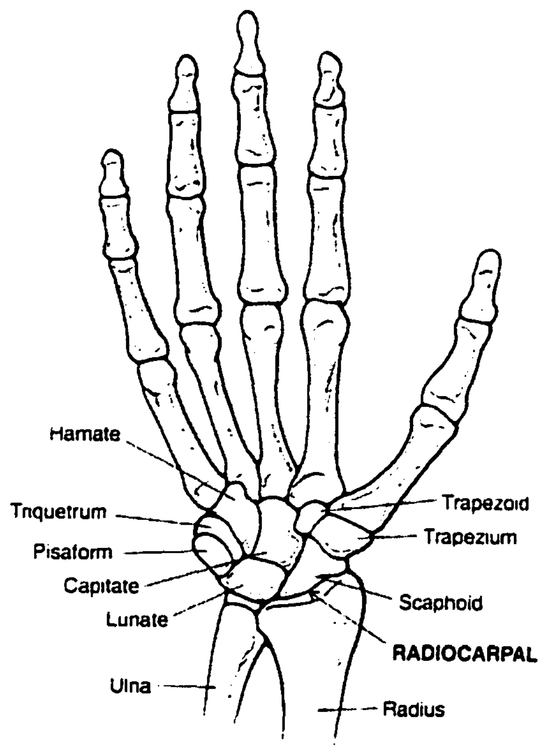


Figure 3. Location of forearm and carpal bones, and the radiocarpal joint. Adapted from Biomechanical Basis of Human Movement (p. 177), by J. Hamill and K. M. Knutzen, 1995, Media, PA: Williams and Wilkins. Copyright 1995 by Williams and Wilkins. Used with permission of the publisher and author (see Appendixes D and E).

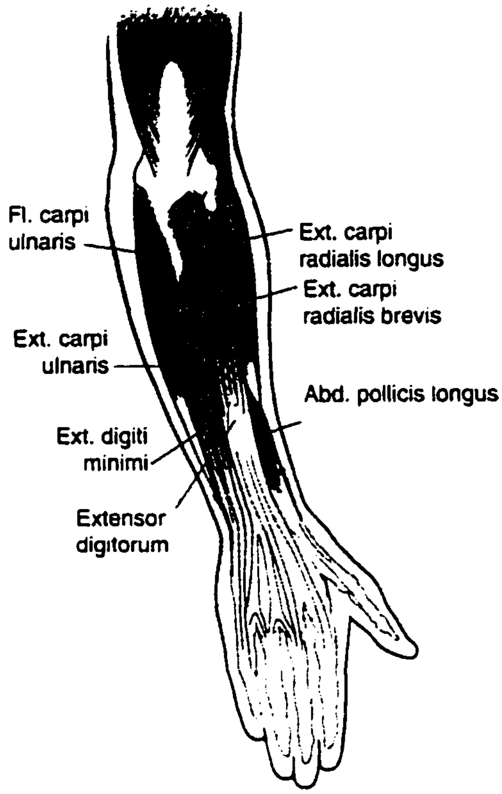


Figure 4. Location of wrist extensors, and the flexor carpi ulnaris, viewed from the posterior of left arm and hand. Adapted from Biomechanical Basis of Human Movement (p. 503), by J. Hamill and K. M. Knutzen, 1995, Media, PA: Williams and Wilkins. Copyright 1995 by Williams and Wilkins. Used with permission of the publisher and author (see Appendixes D and E).

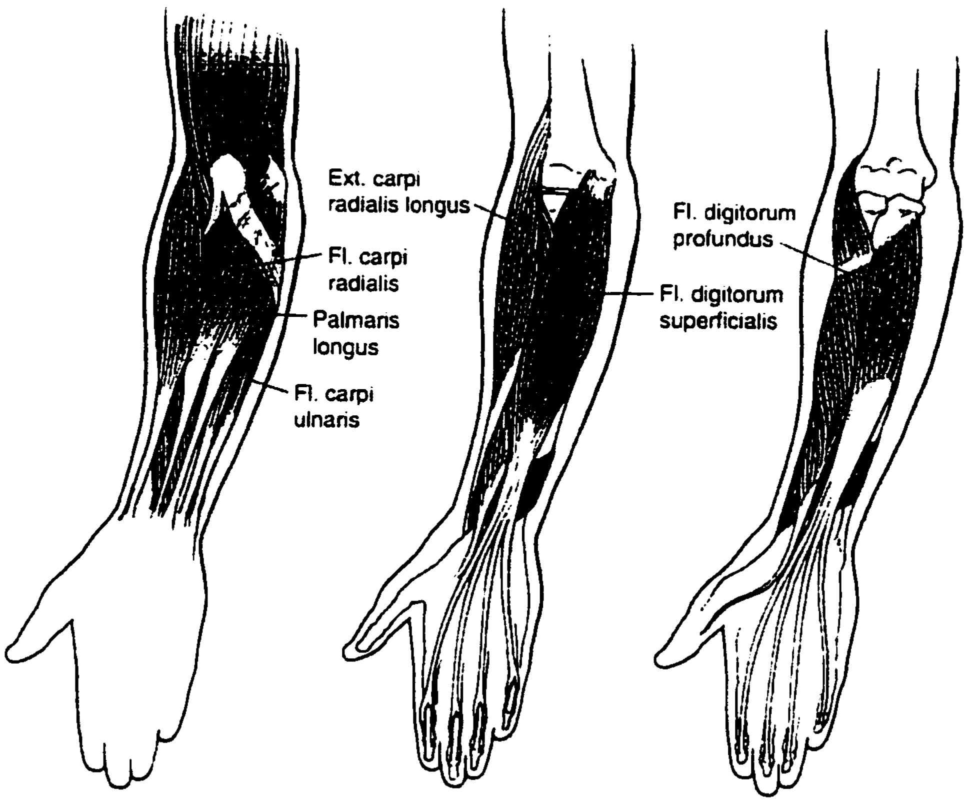


Figure 5. Layers of wrist flexors, and extensor carpi radialis brevis, viewed from the anterior of the right arm and hand. From left to right are superficial to deep muscle layers. Adapted from Biomechanical Basis of Human Movement (p. 502), by J. Hamill and K. M. Knutzen, 1995, Media, PA: Williams and Wilkins. Copyright 1995 by Williams and Wilkins. Used with permission of the publisher and author (see Appendixes D and E).

flexion only in the latter portion of their primary task, flexion of the fingers. Gray also explained that the abductor pollicis longus, though primarily used for abduction and extension of the thumb, is mechanically situated to help in wrist flexion (p. 539).

A similar situation exists for the wrist extensors. The primary wrist extensors are the fusiform muscles extensor carpi ulnaris, extensor carpi radialis longus, and extensor carpi radialis brevis, all of which originate at the end of the humerus and become tendons approximately one third of the way down the forearm (Hamill and Knutzen, 1995, p. 179). Hamill and Knutzen explained that, because the wrist extensors also create movement at the elbow joint, the elbow joint's position has an effect on wrist flexor activity. Specifically, the extensors carpi radialis longus and brevis create flexion of the forearm at the elbow, so that forearm extension increases their mechanical advantage in extending the wrist. Extensor carpi ulnaris does the opposite, creating extension at the elbow. Thus with the forearm flexed, as for instance in matched grip, extensor carpi ulnaris is a more effective wrist extensor. Gray (1985, pp. 535-40) explained that the extensor digitorum, extensor digiti minimi, and extensor indicis, can all participate in wrist extension, but are primarily responsible for some form of finger extension. Gray described all of the wrist extensors as superficial rather than deep muscles, except for extensor digiti minimi.

Measurement of wrist flexion and extension had the potential to clarify some of the issues raised by the above examination of drumstick pedagogical information. As detailed above, Cook (1997) somewhat contradictorily described the basic stroke. His "gentle throw" implied that extension is the primary motion, and thus the forearm extensors are the stroke's agonist muscles. His suggestion of "lifting the sound out of the instrument" implied, however, that flexion is the primary motion, so that the agonist muscles are the flexors. Possibly there are actually two movements in the stroke, first moving the stick down, then moving the stick up. This suggests the upstroke and downstroke described by some authors. The drumstick sources agreed some amount of wrist flexion and extension underlie not just the single stroke, but also the buzz and double strokes. Potentially, scientific measurement of drumstick wrist flexion and extension could clarify not just Cook's internal inconsistencies, but those between sources for all three strokes.

Level one and level two pedagogical literature often suggest a "relaxed" approach as the best way of playing an instrument. For example, Ricquier (1980) and Breithaupt (1991) specifically mentioned this principle, and Cook (1997), Fischer (1995), Houliff (1983), Abram (1984), Raab (1980), Raikin (1985), and Hughlett (1984) made at least passing reference to it. More specifically, the catch phrase "stay relaxed" seems to imply "use a minimum of agonist, antagonist, and synergist tension to produce a particular task." Basmajian (1979) addressed just this issue:

> Training, whether it is the unconscious process of the child learning simple social motor responses or the preparation for a specific skilled act (such as those of a musician or athlete), is a progressive inhibition of many muscles that flood into play when one first attempts to produce the required response (p. 108).

Potentially, comparing wrist flexion and extension between subjects of various abilities, or between different strokes, could help improve the teaching of drumstick techniques.

This study measured the activity of each forearm's flexor carpi ulnaris and extensor carpi ulnaris muscles during execution of the three fundamental drumstick strokes. Since the flexor carpi ulnaris is a primary agonist in wrist flexion and, according to Hamill and Knutzen

(1995), is the strongest wrist flexor, the flexor carpi ulnaris represented overall wrist flexion. According to Hamill and Knutzen (1995) the extensor carpi ulnaris is the most effective of the three primary wrist extensors with the forearm flexed, the position of the forearm in matched grip. For that reason, the extensor carpi ulnaris was chosen to represent overall wrist extension.

Measurement Strategies

Level three and level four studies mentioned above used a variety of strategies and devices to measure different physical actions. Among the more notable were Lewis (1985), Callahan (1987), Crocker (1988) and Cleveland (1988), all level three or four studies. Lewis and Cleveland used visual imagery as the key method in their work. Crocker and Callahan both essentially invented their own devices to measure, respectively, sticking patterns in young drummers and the finger dexterity in young wind players. Most commonly, however, level three and four studies used some form of electromyography in their measurement, since EMG allows quantification of a muscle's activity in a particular task. Often, researchers considered muscle activity concurrent with some other variable, such as quality of sound (Dennis, 1984) or use of a device such as a shoulder rest (Levy, Lee, Brandfonbrener, Press, and Levy, 1992). Researchers sometimes used other measurement tools, such as goniometers, audio taping, or video taping, along with EMG. For example Dennis audiotaped subjects for analysis of string bass tone quality, while Martin, Thumfart, Jolk, and Klingholz (1990) used a sound meter to determine the loudness of their subjects' singing. However, Lammers' use of a goniometer, as mentioned above, produced inconclusive results. He used the device to measure wrist and elbow angles mentioned in trombone pedagogical literature.

The goniometer revealed no discernable patterns at the wrist or elbow. Lammers based his significant conclusions solely on EMG data. Nelson (1989) reported significant problems caused by a respirgraph, a device that measured chest expansion. The respirgraph produced significant interference or "noise" in the EMG readings. While a study concerned primarily with some aspect of human motion would logically use EMG as a measurement tool, the use of additional measurement tools would not necessarily make the study better.

Since this study clearly required a measurement of wrist extensors and flexors, EMG was the logical measurement tool to use. However, there are a variety of different ways to use EMG, each suited to particular situations, and some possible pitfalls that must be avoided. An understanding of its different methodologies and concerns requires a review of the basic science underlying EMG.

Muscles, of course, do not contract without signals from the brain, traveling through nerves. Loeb and Gans (1986, pp. 44-49), Campbell (1999, pp. 29-33), and Hamill and Knutzen (1995, pp. 112-123) described the basic connection of nerve to muscle. A muscle receives signals (or innervation) from a motor neuron, the cell body (or soma) of which is located in the spinal cord or nearby ganglia. An electrical signal travels through an axon, a fiber extending from the nerve's cell body, to the muscle's belly or midpoint. The axon passes the signal through multiple small branches called motor endplates, each of which connects to the muscle at a neuromuscular junction. The nerve and the muscle fibers innervated together form a motor unit. As many as 2000, or as few as 5 or 6, muscle fibers can belong to a motor unit (Hamill and Knutzen, 1995, p. 113). Distribution of the fibers varies, with the fibers spread out through the muscle to different fascicles. A motor unit's muscle fibers are all of one kind, either Type I, IIa, or

IIb.

The electrical signal from a nerve propagates up and down the motor unit's fibers, causing successive contraction of each myofibril's sarcomeres. Loeb and Gans (1986, pp. 44-47), Hamill and Knutzen (1995, pp. 118-119), and Campbell (1999, pp. 43-54) described how this occurs. At the motor endplate, a small space, called the synaptic cleft or synapse, exists between muscle and nerve. When a nerve's electrical signal, often called an action potential, arrives, the chemical acetylcholine is used to transmit the signal across the synaptic cleft. The action potential then travels up and down the muscle at a rate from 2 to 5 meters per second, meaning "a muscle fiber a few centimeters long will experience the action potential within a few milliseconds" (Loeb and Gans, p.47).

A muscle cell's interior has a resting electrical charge, or potential, of approximately -80 mV (millivolts) (Loeb and Gans, p. 44). A higher concentration of positive ions outside the cell than in causes this difference. As the action potential arrives at the motor end plate, it changes a muscle cell's permeability to the positive ions, potassium and sodium. A complicated exchange of ions in and out of the cell then occurs, resulting in a rapid depolarization to a charge of about +30 mV (Hamill and Knutzen, p. 118), then a repolarization to slightly below the resting potential, and finally a return to the resting potential. The action potential then travels along the muscle fiber, causing a similar ion exchange in successive cells, and triggering the formation of cross-bridges between a sarcomere's long and short filaments. In EMG, a reference electrode at a remote site establishes the resting electrical potential of a particular area of the body. Viewed with an oscilloscope, an individual action potential passing along a muscle at a second, recording electrode site appears as a sinusoidal wave. It has a spike above, then below, then returns to the resting potential established by the reference electrode (see Figure 6).

To keep a muscle contracted, action potentials must arrive continuously. Viewed with a time scale of seconds, this series of action potentials produces a dense series of spikes while a muscles is active (see Figure 7). Cram, Kasman, and Holtz (1995, p. 14) explained that Type I slow-twitch muscles typically receive successive action potentials in the range of 10 to 20 Hz (hertz), or cycles per second, thus contracting up to about 25 times per second, while Type II fast-twitch muscles receive action potentials in the 30-50 Hz range, contracting more than 25 times per second.

Probably the most significant variation in EMG is in the type of electrode used. The electrode, the connecting point between human anatomy and EMG apparatus, can come in three basic forms. Loeb and Gans (1986, pp. 110-113) categorized electrodes as those attached to the skin surface, those inserted beneath the skin, and those implanted surgically. For obvious reasons, researchers generally reserve surgical implantation for non-human subjects. For human subjects, researchers commonly use both of the other types, commonly called surface electrodes and fine wire or needle electrodes. Researchers typically, though not exclusively, use a needle for the insertion and removal of fine wire electrodes.

Basmajian (1979, p. 25) cautioned that surface electrodes can only measure superficial muscles, those just beneath the surface of the skin, and "that their pick-up is generally too widespread." The distance and intervening tissue between a surface electrode and muscles being measured can allow the electrode to pick up signals from other nearby muscles. Researchers call this cross talk, and it must be

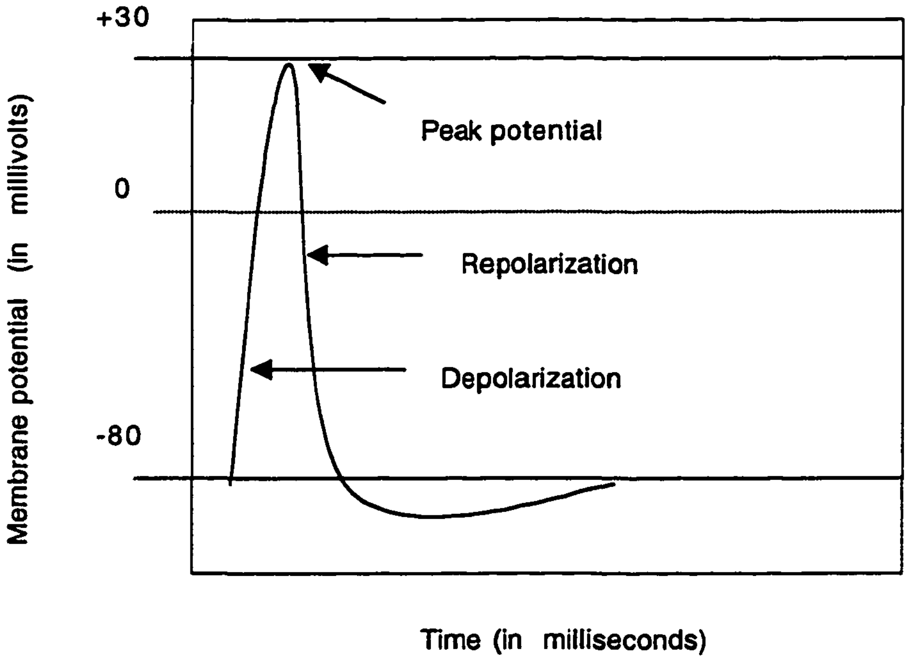


Figure 6. Idealized single action potential measured by EMG.

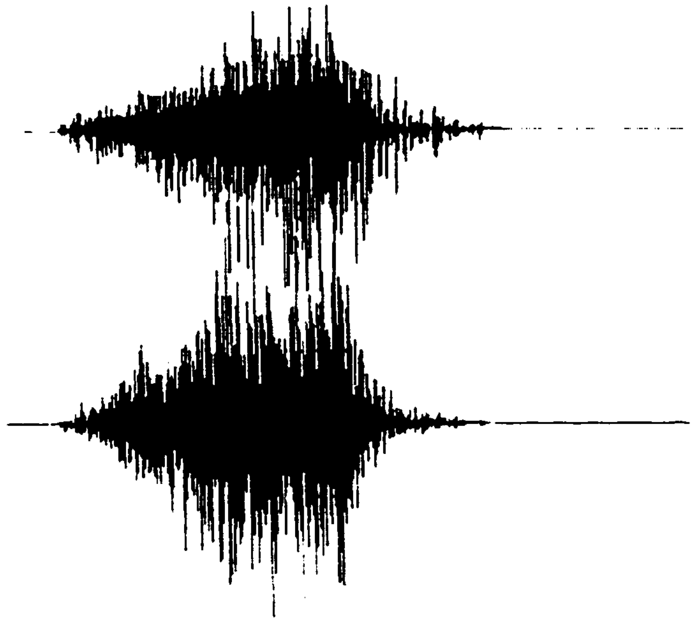


Figure 7. Typical computer-generated EMG data from synergistic activity of two muscles.

considered in designing an experimental procedure. In his collaborations with musicians (White and Basmajian, 1974; Isley, 1973), as well as his other research (as described in Basmajian, 1979), Basmajian clearly preferred needle electrodes, since they imbed directly in a muscle's belly, allowing greater specificity and selectivity in measurement.

However, surface electrodes also offer some advantages over needle electrodes. Basmajian (1979, pp. 25-6) did allow that surface electrodes are useful "where the simultaneous activity or interplay of activity is being studied in a fairly large group of muscles where palpation is impossible." Palpation is examination by touch, which is sometimes possible with superficial muscle. Basmajian noted the impossibility of using palpation to measure, for example, muscles in the lower limb during walking. Several needle electrode insertions would be required, one per muscle, to measure a muscle group for which one surface electrode site would suffice.

Loeb and Gans (1986, pp. 10-11) similarly noted that surface electrodes can be used for the "gross estimate of muscle activity in large, superficial muscle groups" and, in addition, that they have the obvious advantage of being noninvasive. A noninvasive attachment gives surface electrodes some significant advantages over needle electrodes. Campbell (1999, p. 93) described clinical electrodiagnostic medicine, including needle electrode examinations very similar to that in EMG research. This included some of the health risks in using needle electrodes, such as the possibility of transmitting infectious diseases. Also, regarding people's reaction to the insertion of needles, Campbell explained that "most patients tolerate NEE [needle electrode examination] reasonably well, but some do not" (p. 93). As mentioned above, Martin, Thumfart, Jolk, and Klingholz (1990) described the difficulty of finding vocalists for laryngeal research which required the use of needle EMG.

One must also consider the viewpoints of Basmajian and Loeb and Gans. Basmajian's view of surface electrodes was surely colored by his many successes with needle electrodes. Loeb and Gans appeared, based on the scope of their subject matter, more interested in animal than human research. Not only did they obviously prefer inserted to surface electrodes, they implied that needle electrodes are "quick and dirty" compared to electrodes implanted surgically. Cram, Kasman, and Holtz (1998) provided a considerably more recent look at EMG, advocating surface EMG as vigorously as Basmajian and Loeb and Gans advocated other forms. Cram, Kasman, and Holtz provided an anatomical atlas for electrode placement, including placements to measure both muscle groups and specific superficial muscles. Also worth consideration, Heuser and McNitt-Gray (1991, 1993) measured with surface electrodes many of the same specific facial muscles as White and Basmajian (1974) did with needles. It seems fair to conclude that the most recent surface EMG equipment can measure specific superficial muscles. Due to the type of equipment available to this researcher, and a desire to attract a sufficient variety and number of subjects, this research used surface electrodes. Chapter 3 describes the specific superficial forearm muscles to be measured, and the requisite electrode placement specified by Cram, Kasman, and Holtz.

In addition to cross talk, a number of other sources may produce unwanted signals that contaminate the signals from the muscle or muscles to be measured. Loeb and Gans (1986, pp. 21-22, 175-188) described the interfering signals as noise or artifact. They identified biological noise sources, such as heartbeat and respiratory function (Cram, Kasman, and Holtz (1998, p.67) called these noises artifacts).

Loeb and Gans also identified possible external sources, such as power sources for computers, lights, or elements of the measurement apparatus. Artifacts included mechanical interaction between parts of the measurement apparatus or "motion artifact," produced by friction between the electrode and the subject, or between parts of the EMG apparatus.

Researchers have developed several generally accepted procedures to at least minimize the effect of noise and artifact. Loeb and Gans (1986, pp. 151-174, 187-88) and Cram, Kasman, and Holtz (1998, pp. 45-55) reviewed the usual solutions. Initially the action potential passing down a muscle fiber excites nearby tissue's electrons, which in turn excite others', spreading electrical activity outward toward the skin surface. In surface EMG this activity must in turn excite electrons in the electrodes, passing the signal to the EMG apparatus. As mentioned above, the action potential at the fiber is already quite small, measured in millivolts. The more tissue the signal must traverse, the weaker it gets. The weaker the signal, the more likely it can be overcome by noise or artifact. A large amount of fatty tissue, which is greater in some people and some parts of the body, can contribute to the problem. If a subject has significantly thicker layers of fat at a recording site, it can significantly reduce the amplitude, or strength, of the EMG signal in comparison to other subjects. Thus the impedance of the skin, its innate hindrance to the passage of an electrical current, presents a significant problem. A comparison of signal amplitudes between needle and surface electrodes illustrates this. Needle electrodes produce signals in the millivolt (thousandths of a volt) range while surface electrodes produce signals in the microvolt (millionths of a volt) range (Cram, Kasman, and Holtz, 1998, p. 32). For surface electrodes, removal of dead skin and hair at the electrode sites, and the use of an electrolytic medium or gel between electrode and skin, significantly reduce skin impedance. Also, the input impedance at the next, amplification stage should be significantly higher than the skin impedance, preferably 10 to 100 times higher (Cram, Kasman, and Holtz, p.47). A greater amplification impedance helps compensate for greater skin impedance.

Loeb and Gans (1986) and Cram, Kasman, and Holtz (1998) described the usual amplification step. In addition to simply increasing the signal strength, or gain, two other refinements are typically made during amplification in an effort to remove noise. First, the signal at each recording electrode is compared to the reference electrode. This process, called differential amplification, allows through only that part of the recording electrodes' signals that are different from the reference electrode's signal. Also a process called common mode rejection further refines the signal. That process compares the recording electrodes' signals, eliminating that portion of the signal common to both electrodes. For example, noise at a 60 Hz frequency, generated by the power supply of such things as lights or computers, typically bombards both electrode sites and the rest of the EMG apparatus. Because the action potential passes beneath each electrode at different times, that portion of the signal differs between the electrodes, and is thus the portion to be passed through the pre-amplification process. The signal continues for further amplification, to further increase the gain (strength), and usually for filtering. In a computerized system, filtering is sometimes applied digitally, after the signal is recorded.

Loeb and Gans (1986) and Cram, Kasman, and Holtz (1998) described the typical filters that process the signal to remove noise and artifact missed by amplification. Typically a notch filter, one set to remove certain frequencies, attempts to block remaining 60 Hz noise. A large enough amount of 60 Hz noise, however, can saturate the filter, corrupting the signal. In addition, band pass filters are used, cutting off frequencies above and below certain points. Different sources recommended slightly different cutoff points for surface EMG. Cram, Kasman, and Holtz (1998, p. 55), in the interest of including all possible parts of the EMG signal, suggested allowing frequencies from 20 to 300 Hz to pass the filtering stage. "Standards for Reporting" (1996) established 10 to 350 Hz as the publication standard for the Journal of Electromyography and Kinesiology, an important journal published by the primary international forum for electromyographic research, the International Society of Electrophysiological Kinesiology (Cram, Kasman, and Holtz, 1998, p. 5).

Cross talk presents a more difficult problem. Electrode size and spacing provide the only controls over it. Cram, Kasman, and Holtz (1998) provided specific surface electrode placement and size recommendations for various muscles and muscle groups, including the forearm flexor and extensor muscles. Specific recommendations relevant to this study appear in Chapter 3.

A final consideration is a caution regarding exactly what information EMG can provide. Cram, Kasman, and Holtz (1998, p. 36) stated clearly that the amplitude of an EMG signal does not indicate the specific tension or force generated by a muscle. Hamill and Knutzen (1995, pp. 81-88) described the reasons for the non-linear relationship between tension and EMG amplitude. A muscle's tissue can be divided into two parts, contractile and elastic. Myofibrils, each a series of sarcomeres, constitute the contractile tissue. Elastic tissue includes a tendon by which a muscle attaches to a bone as well as the endomysium, perimysium, and epimysium. The elastic portions of a muscle can contribute to and even continue tension after the contractile portions' tension, and thus EMG activity, ebbs. Cram, Kasman, and Holtz (1998, p. 34-35) and Hamill and Knutzen (1995, pp. 81-85) described the main reasons for the non-linear relationship between force and EMG amplitude. The most significant is the effect of gravity. Physiologists categorize body movements in three broad categories. Isometric movements show no visible change in joint position while developing muscle tension. Holding the arm horizontal to the ground at the elbow is an isometric movement. Concentric movements involve muscle activity in which the muscle length visibly shortens. In this category, the agonist muscles control the action, moving a body segment in the same direction as the joint movement or movements involved. Lifting the arm at the elbow to a position horizontal to the ground is a concentric movement. Eccentric movements occur when an external force is greater than the internal force generated by a muscle, resulting in a lengthening of the muscle. In this category antagonist muscles control the action, working in the direction opposite to the joint movement involved. Dropping the arm from a raised position is an eccentric action. Usually a concentric motion, and sometimes an isometric motion, fights gravity, while an eccentric motion usually follows the pull of gravity. The effect of gravity means that under many conditions, an eccentric movement can produce the same force as the other two types with fewer muscle fibers activated. Thus the number of active fibers, as indicated by EMG amplitude, does not necessarily correlate with a muscle's force output.

Conclusion

Drumstick pedagogical sources generally agree on three ways of striking a drum, but do not clearly agree on the way in which the wrist is used to execute the three strokes. These discrepancies can be resolved, as they have been for other instruments' pedagogy, through scientific examination of the problem. The physiological components underlying wrist motion are clear, and an established method, electromyography, exists which can measure those components in action. The next chapter describes an experimental procedure which used electromyography to measure wrist muscle activity for the three ways of striking a drum.

Chapter 3

Methods

Introduction

This chapter describes subjects, equipment, and an experimental procedure designed to provide answers to the research questions posed in Chapter 1. Subjects played simple musical exercises containing the three different strokes mentioned in percussion pedagogical literature. Using surface EMG, the researcher took a sample of selected muscles' activity during each exercise. Chapter 4 reports the results and Chapter 5 analyzes them.

Subjects

The researcher sought subjects at two different ability levels. First, a general request for volunteers was made in the James Madison University (JMU) percussion techniques course. Undergraduate students from the course studied drumstick techniques for two months while pursuing an undergraduate music education degree. The researcher taught the course. Second, a similar request was made to all of the undergraduate percussion majors currently attending JMU. These students all had at least three years of private percussion lessons as part of their JMU course work. In addition, all had several years of experience, and some additional years of instruction, prior to entering college.

Students who indicated an interest in participating were asked to complete and return an initial questionnaire (see Appendix A). The questionnaire described the experimental procedure and solicited information about each subject's background, most importantly a) years of training and years of experience, b) whether the subject used primarily matched or traditional grip, c) which hand, if either, was dominant in the subject's drumstick playing, and d) whether or not the subject had previously significantly injured either forearm. The questionnaire also offered each subject $50.00 to compensate for time in and travel to the lab.

The information reported by the questionnaire was of significant importance. Many of the studies described in Chapter 2 used the amount of study and experience as a measure of a subject's ability. This study's subjects formed two groups sharply differentiated by amounts of experience and training (see Table 1 below). Crocker (1988) used a questionnaire to determine handedness. While Crocker asked about several tasks, rather than just one, this research involved subjects of much greater maturity than Crocker's fifth-graders. Thus, for this study, a subject's own determination of right, left, or equal handedness was sufficiently accurate for the playing techniques to be measured. That determination was necessary to answer this study's second research question. Reynolds and Morasky (1981) reported that two drummers switching their primary grip from traditional to matched grip displayed significantly heightened left forearm muscle activity. Therefore, any subject reporting traditional grip as the primary grip was rejected for use in this study. Any subject reporting a significant injury was rejected. Cram, Kasman, and Holtz (1998) and Loeb and Gans (1985) warned that scar tissue or damage to muscle tissue can significantly affect EMG readings.

Of 17 people returning questionnaires 2 reported significant injuries, one scarring and the other previously broken bones. A third reported chronic tendonitis in both wrists. While tendonitis would not likely have directly affected EMG readings, it did have the potential to do so indirectly by changing drumstick stroke execution. The researcher rejected these potential subjects, and another who used primarily traditional grip. Of the remaining 13 possible subjects, only 10 could be scheduled in the limited lab times available. The 3 students with schedule conflicts were rejected. Of the 10 scheduled for lab sessions, 2 had previously taken private lessons with the researcher. To have as many subjects as possible, those 2 subjects were not rejected. To each of the 17 people who returned questionnaires, the researcher sent an email either explaining the person's rejection or assigning the person a lab time. To facilitate electrode placement, those assigned a lab time were instructed to wear a short sleeve shirt or top. For measurement, each subject met the researcher at the Music Building on the campus of James Madison University. Both then traveled to the laboratory in Godwin Hall. The subject and the researcher signed a consent form (see Appendix B) in the presence of a witness. The consent form described the experimental procedure in layman's terms, indicating any possible risks and the measures in place to minimize them. It conformed to specific requirements of Institutional Review Boards at both the University of Oklahoma and James Madison University. These boards must approve all research involving human subjects (see Appendixes F and G for notifications of approval). At the laboratory, the researcher recorded some of the questionnaire information, and the subject's age and gender, in the subject's computer data file. The researcher did not record mailing addresses, email addresses, or telephone numbers. After the experiment's completion, a number was assigned to each subject, and the questionnaires were destroyed.

Although 10 subjects were actually measured, data from only 9 were useable. From watching data plotted on a computer monitor, the researcher determined during one subject's measurement that electrode placement on the right arm was incorrect. The researcher completed the measurement, then reattached the right arm's electrodes. He then attempted to repeat the measurements to gather accurate data for the right arm. However, even though the monitor was positioned out of direct view, the subject could not help turning to look at it. Probably this was the result of the researcher's explanation for reattaching the electrodes. From verbal comments that the subject made, the researcher concluded that onscreen information influenced the subject's performance of some tasks in the second measurement. As a result, the researcher decided not to use data from that subject. Table 1 describes the nine subjects used for this study.

The nine subjects measured provided a small sample from an already restricted population. Most had received training exclusively from the researcher. For those reasons, tests of statistical significance, together with their consequent inference to larger populations, were clearly not appropriate for any data gathered. This limitation was unavoidable due to the study's occurrence during the summer, and the limited lab time available.

Equipment

Electromyograph

The JMU Department of Kinesiology's Myosystem 1200 electromyograph, manufactured by Noraxon USA, was used for this

Table 1

Description of Subjects

				Background	
Subject	Age	Gender	Handedness	Instruction	Experience
1	20	female	left	2 months	2 months
2	21	female	right	10 years	10 years
3	21	male	right	2 months	2 months
4	20	male	right	2 months	2 months
5	20	male	right	2 months	2 months
6	21	male	right	4 years	10 years
7	20	female	right	2 months	2 months
8	21	male	right	4 years	11 years
9	21	female	right	12 years	12 years

research. It had four electrode leads, one pair of electrodes per lead, plus a separate reference electrode. All were shielded against extraneous noise. This electrode arrangement allowed measurement of at most four muscles simultaneously. Both differential amplification and common mode rejection were performed as part of the Myosystem 1200's amplification process. In addition, the Myosystem multiplied the detected signal by 1000. The machine had a minimum input impedance of 20 MΩ (megaohms), a sensitivity of 1 μV (microvolt), and a Common Mode Rejection Ratio (CMRR) of 100 decibels at 60 Hz. These met the respective minimums of 1 MΩ, 1 μV, and 70 decibels suggested by Cram, Kasman, and Holtz (1998, pp. 72-73).

Electrodes

The research used electrodes manufactured by Noraxon USA, model M-00-S. The electrodes were 7.5 cm in diameter, and of silver-silver-chloride construction with an attached wet-gel. At the skin-electrode contact point, the gel lowered input impedance, reduced the likelihood of motion artifact, and held an electrode in place. A removable plastic cover protected the gel prior to attachment. Airtight metal foil containers packaged the electrodes in units of 50.

Computer

A Dell laptop computer, model Latitude XPi CD, gathered data from the electromyograph. It had 32 megabytes of RAM, a 635-megabyte hard drive, and a processor speed of 133 megahertz. It used Microsoft's Windows 95 operating system. It included a type 2 PCMCIA card for data acquisition from the electromyograph. The card was the PCM-16/330 model manufactured by RUN Technologies. The card had an analog-to-digital conversion speed of 333 kHz (kilohertz) and 12 bits resolution for video display. These satisfied the minimums of 100 kHz and 12 bits recommended by Campbell (1999, p. 25).

Software

The software used was Datapac III for Windows, version 1.59, manufactured by RUN Technologies. It had digital filters under operator control, and features for statistical processing. Chapter 4 further describes statistical preparation of the experiment's data.

Data Acquisition and Filtering

For each subject the electromyograph sent the raw EMG signal, with amplitudes multiplied 1000 times, to the computer. The computer sampled the data at 2 kHz. The researcher experimented with higher sampling rates, but any higher setting caused an "acquisition overflow error." This software message indicated the computer's inability to maintain the sampling rate while still accurately displaying and recording data. After acquisition of the raw signal, a digital bandpass filter eliminated frequencies lower than 10 Hz and higher than 350 Hz. This filtering was the range required by "Standards for Reporting" (1996) for publication of surface EMG research. The sampling rate also met the minimum of "twice the highest frequency" in the recorded signal, as specified in "Standards for Reporting." A digital notch filter eliminated signals at 60 Hz to decrease any noise from nearby power sources.

Experimental Procedure

Pilot Testing

Prior to experimentation, the researcher conducted a series of pilot tests. With the aid of a JMU Department of Kinesiology graduate assistant, the researcher used the pilot tests to learn proper preparation of the electrode sites and attachment of the electrodes. The electrode placement sites were those recommended by Cram, Kasman, and Holtz (1998, pp. 313, 322) for measurement of the specific muscles in question. The pilot tests also familiarized the researcher with the Datapac III software used to collect data.

Electrode Placement

After arrival at the laboratory, the researcher prepared sites for electrodes on the subject's forearm as follows:

1) Using palpation, the researcher found and marked the bellies' of the four muscles to be measured. To do so, the researcher supported the weight of each of the subject's arms while the subject performed an ulnar deviation. The resulting muscle contractions allowed the researcher to feel the belly of the flexor carpi ulnaris and extensor carpi ulnaris on each forearm. The belly's were apparent, respectively, on the forearm's anterior and posterior, both bellies a few centimeters up from the elbow. The researcher marked each site with a laundry marking pen.

2) The researcher washed his hands and put on sterile gloves. This protected both the researcher and later subjects against infection if blood was raised in subsequent site preparation.

3) The researcher used alcohol swabs to clean around the pen

markings, and the back of the non-dominant arm's elbow. The swabs were disposed of in a biohazard waste container maintained in the lab. The researcher then directed each subject to remove a patch of hair approximately 5 cm wide and 8 cm long around each laundry pen mark. Then, the subject removed hair over a similarly sized region on the back of the non-dominant arm's elbow. Each subject used a hand-held Gillette razor that the researcher discarded in a second biohazard container, one intended for needle and sharp object disposal.

4) The researcher again cleaned the sites with alcohol swabs, Then, using a piece of "scratch tape," he scraped several times at each pen mark to remove dead skin. The scratch tape, similar in roughness to very fine sandpaper, was manufactured by Noraxon, the same company that made the electromyograph used in this research. The skin removal required one piece of scratch tape per arm, and each piece was disposed of in the same biohazard container as all alcohol swabs.

5) After again cleaning the sites with alcohol swabs, the researcher attached a pair of electrodes at each mark. Electrodes were situated along a line parallel to the muscle's fibers, with an inter-electrode distance of 2 cm. That inter-electrode distance required a partial overlap of electrodes' insulation. For the muscles measured, Cram, Kasman, and Holtz (1998) specified a 2 cm distance to minimize cross talk from nearby muscles. The electrodes were disposable, and after use with a subject, were disposed of in the biohazard container.

6) The researcher placed a final electrode at the non-dominant elbow site, on the tip of the ulna. This served as the reference electrode. As an additional precaution, a piece of cloth athletic tape secured this electrode to the elbow. The researcher experienced

occasional slipping of this electrode during pilot testing.

7) The researcher then removed the sterile gloves, disposing of them in the biohazard container. He then attached each electrode to the appropriate lead from the electromyograph. Finally, with the subject positioned facing away from the electromyograph and computer, leads were taped to the subject's shoulders to avoid motion artifact caused by cables hitting each other.

The electrode attachment process went smoothly except for one instance. While clearing hair on the right elbow, one subject nicked his skin, raising a small bit of blood. The subject immediately cleaned the area with an alcohol swab. The bleeding was very minimal, and electrode attachment continued as soon as it stopped. The nick was below the area where electrodes were placed, and so did not prevent completion of the session.

Measurement

After electrode attachment, data acquisition began. A Seiko model DM-10 digital metronome, set to sound at 70 beats per minute, timed each task performed. For each task, the researcher verbally counted four preparatory beats, and then the subject performed the task over five more beats. While the subject performed, the researcher manually keyed the computer to begin recording EMG data on the second beat and stop recording on the fifth beat. Beginning on the second beat was intended to insure that the subject had settled into usual and consistent muscle activity for a particular task.

First, a subject performed a series of maximum voluntary contractions (MVCs) for each muscle. This established baseline values necessary for comparing other data gathered in the experiment. To determine the MVC values, a subject held a drumstick in matched grip, with the forearm flexed 90° and pronated 180° from the zero position. From that position, the wrist of each hand was flexed or hyperextended as far as possible under the subject's voluntary control. The researcher explained to each subject the purpose of the procedure, to "establish a maximum level of flexion or extension," and allowed a subject to practice it once for the first motion (left flexion). The metronome timing described above controlled each contraction's length. Each subject performed an MVC three times for each muscle, with 15 seconds of enforced rest in between each contraction, in the order of three left flexions, three right flexions, three left hyperextensions, and three right hyperextensions. The enforced rest, and alternation of MVC motions between hands, were intended to prevent muscle fatigue from affecting EMG readings.

After establishing an MVC for each muscle, subjects performed tasks with drumsticks. To measure wrist flexion and extension during stroke execution, the researcher measured the activity of both the left and right flexor carpi ulnaris and the left and right extensor carpi ulnaris while a subject played three simple musical exercises. Each exercise was a succession of the three basic strokes identified in Chapter 2 (see Appendix C). The metronome marked tempo in exactly the same fashion as during the measurement of MVCs. The researcher again manually keyed the computer to record EMG activity for the second beat through fifth beats of each pattern. To create familiarity with an exercise, a subject was allowed to play each exercise one time prior to measurement. Then a subject played the exercise three times, with data gathered each time. To avoid fatigue, 15 seconds of enforced rest, with arms dropped at the sides, occurred between each familiarization and each trial on all exercises. No instructions were given regarding sticking or volume unless a subject asked. No subjects asked about stickings. In the three cases where subjects inquired about volume, the researcher instructed subjects to play at a comfortable, medium volume. Subjects used a pair of Vic Firth model SD1 drumsticks, and played on a Remo 8-inch diameter drum practice pad, all provided by the researcher. Subjects stood to play all exercises. Each session took approximately 75 minutes to complete, including the time to transport the subject to the lab. At the end of each lab session, the subject removed the electrodes, disposing of them in a biohazard container, while the researcher put away lab materials. The researcher then paid each subject $50.00 in the form of a personal check.

Experimental Considerations

Many of the studies mentioned in Chapter 2 actually restricted themselves to either a specific agonist/antagonist pair of muscles, or one muscle representing several involved in a task. Lammers (1983/1984) was an example of the first case, and Henderson (1979) an example of the second. The Noraxon electromyograph available could measure a total of only four muscles simultaneously, necessitating movement of the electrodes to other sites if more than two muscle pairs were to be measured. Moving electrodes could have extended a measurement session long enough for fatigue to become a factor. As described in Chapter 2, Isley (1973), because of the extensive number of tasks measured and the need to move electrodes, had sessions running upwards of two hours per subject. For these reasons, this study measured only one flexor/extensor pair in each arm. Since the flexor carpi ulnaris is a primary agonist in wrist flexion and, according to Hamill and Knutzen (1995), is the strongest wrist flexor, flexor carpi ulnaris was chosen to represent wrist flexion. The logical choice for extensor was the extensor carpi ulnaris. According to Hamill and Knutzen (1995) extensor carpi ulnaris is the most effective of the three main extensors with the forearm flexed.

The metronome signal provided both a tempo control for the subject and a signal to the researcher to trigger EMG measurement. While Heuser and McNitt-Gray (1991 and 1993) electronically recorded a metronome signal for more exact synchronization of data, researchers like Levy, Lee, Brandfonbrener, Press, and Levy (1992) and Sakai, Liu, Su, Bishop, and An (1996) apparently did not, since no mention was made of doing so. The prior musical experience of this study's subjects allowed them to accurately maintain the established tempo.

Finally, while some researchers, such as White and Basmajian (1974), attempted to control volume, some such as Sakai, Liu, Su, Bishop, and An (1996) reported significant difficulties in doing so. Many researchers, including Henderson (1979) and Lammers (1983/1984), made no mention of any effort to do so. As already described, this study made no attempt to control volume. Constraining a subject to play at a specific volume might have significantly altered the muscle patterns he or she normally used for the techniques in question, especially for those subjects with limited experience and training. Training a subject to adequately control volume would also have significantly increased a measurement session's length. Similarly, constraining a subject to use specific stickings might have significantly altered the muscle patterns he or she normally used for a particular stroke, especially those subjects with limited experience and training.

Chapter 4

Results

Introduction

This chapter presents both visual and statistical data derived from the experiment described in Chapter 3. This chapter also describes the process of normalization, a statistical preparation necessary to compare different muscles' EMG activity. At the end of the chapter, Table 3 presents normalized data, the primary information analyzed in Chapter 5. Two different computers prepared data for the study. The Dell laptop used to initially record the data also allowed specialized processing of the EMG signal. However, due to limited lab access, and the lab's low quality printer, the researcher used a Power Mac 6500/275 for further preparation of data. Further description is provided below about the processing done on each computer.

To more easily refer to portions of the data, the following conventions are used in Chapter 4. The right extensor carpi ulnaris is referred to as the "right extensor," and the right flexor carpi ulnaris muscle as the "right flexor." Similarly shortened are references to the corresponding left forearm muscles. Each subject performed three trials of each maximum voluntary contraction and of each stroke exercise, producing a total of 21 trials per subject. To refer to individual trials, Chapter 4 describes a subject's first single stroke trial, second buzz stroke trial, and third double stroke trial, as "Single 1," "Buzz 2," and "Double 3." All strokes' trials are referred to in this fashion. The second maximum voluntary contraction trial of the right flexor carpi ulnaris muscle is described as "right flexor MVC 2." Other MVC trials are identified in a similarly abbreviated fashion. All Chapter 4 tables and figures make use of these conventions.

Raw Data

Figures 8 and 9 visually display raw EMG data from selected subjects and tasks. Throughout the data, raw signal amplitudes fell in the microvolt range, varying from only a few microvolts to isolated spikes of nearly 1000 μV. As described in Chapter 2, surface EMG typically produces signals in this range, in contrast to needle EMG, which produces signals in the millivolt range. The only processing done on the signals in Figure 8 and 9 was application of the 10-350 Hz bandpass and 60 Hz notch filters described in Chapter 3. The Datapac III software, running on the Dell laptop, applied the filters and plotted the data visually. The software then converted the visual image to a Windows 95 metafile format. For printing, metafiles were transferred by floppy disk to the Power Mac computer, and converted to a bitmap image in Microsoft Word 98.

In addition to signal amplitudes, the duration of each trial should be considered. Careful examination of Figures 8 and 9 will reveal that, although a metronome controlled acquisition of each maximum voluntary contraction and stroke performance trial, the lengths of the trials differ. Chapter 3 described the timing and manual computer keystrokes that marked the beginning and end of each trial. Theoretically the lengths of all trials should have been equal. In practice, manually starting and stopping data acquisition produced small variations in the beginning and end of each trial, thus creating different lengths. For an example, Table 2 presents the length of each of the 21 trials for subjects 2 and 5. From all trials for all subjects the longest trials were 1887 ms (Subject 5's Double 3, and Subject 7's Double 1 and Double 2) while the shortest were 1599 ms (Subject 9's Double 1 and Subject 6's Double 1).

Hardware and software limitations made discrepancies in trials'

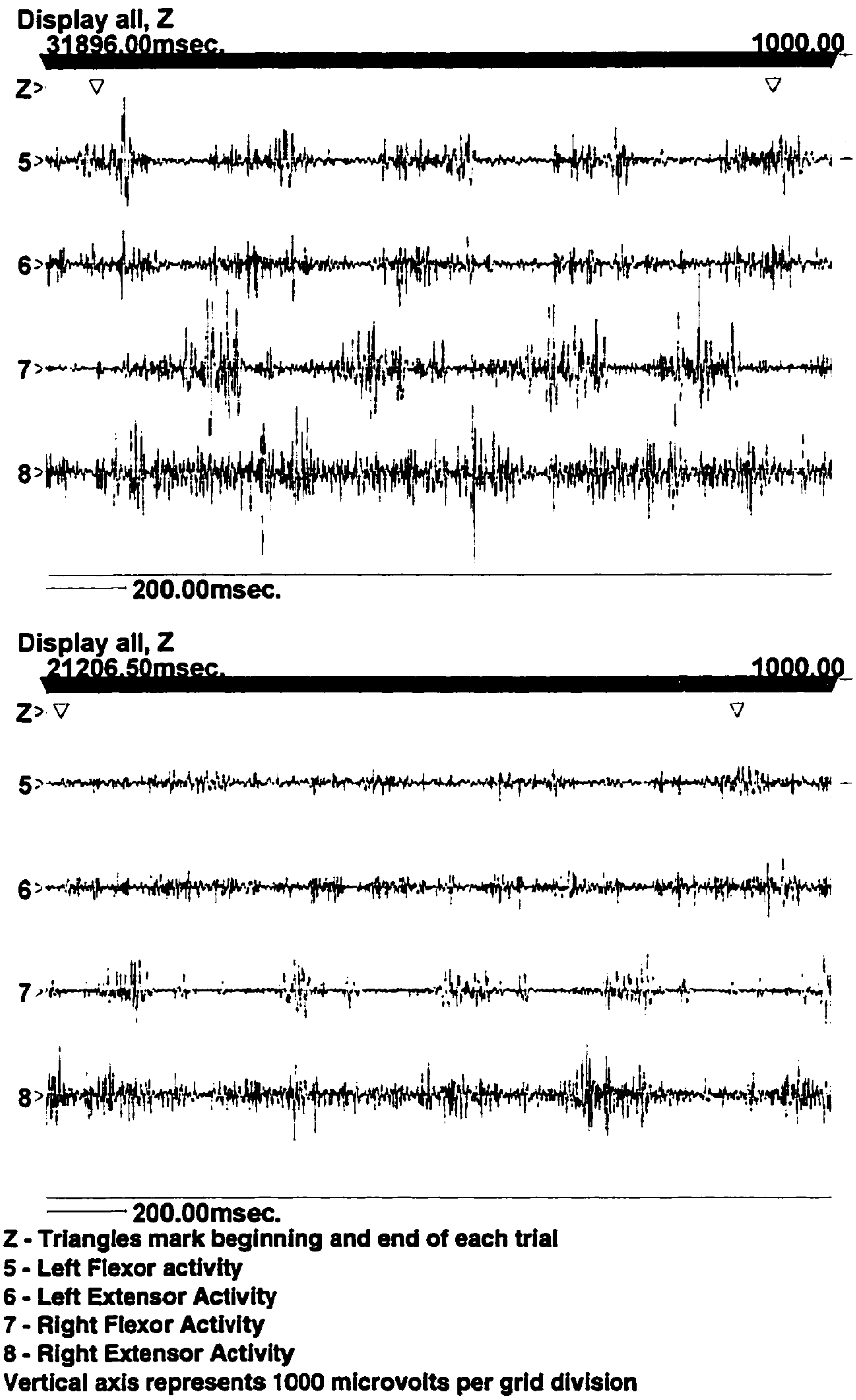
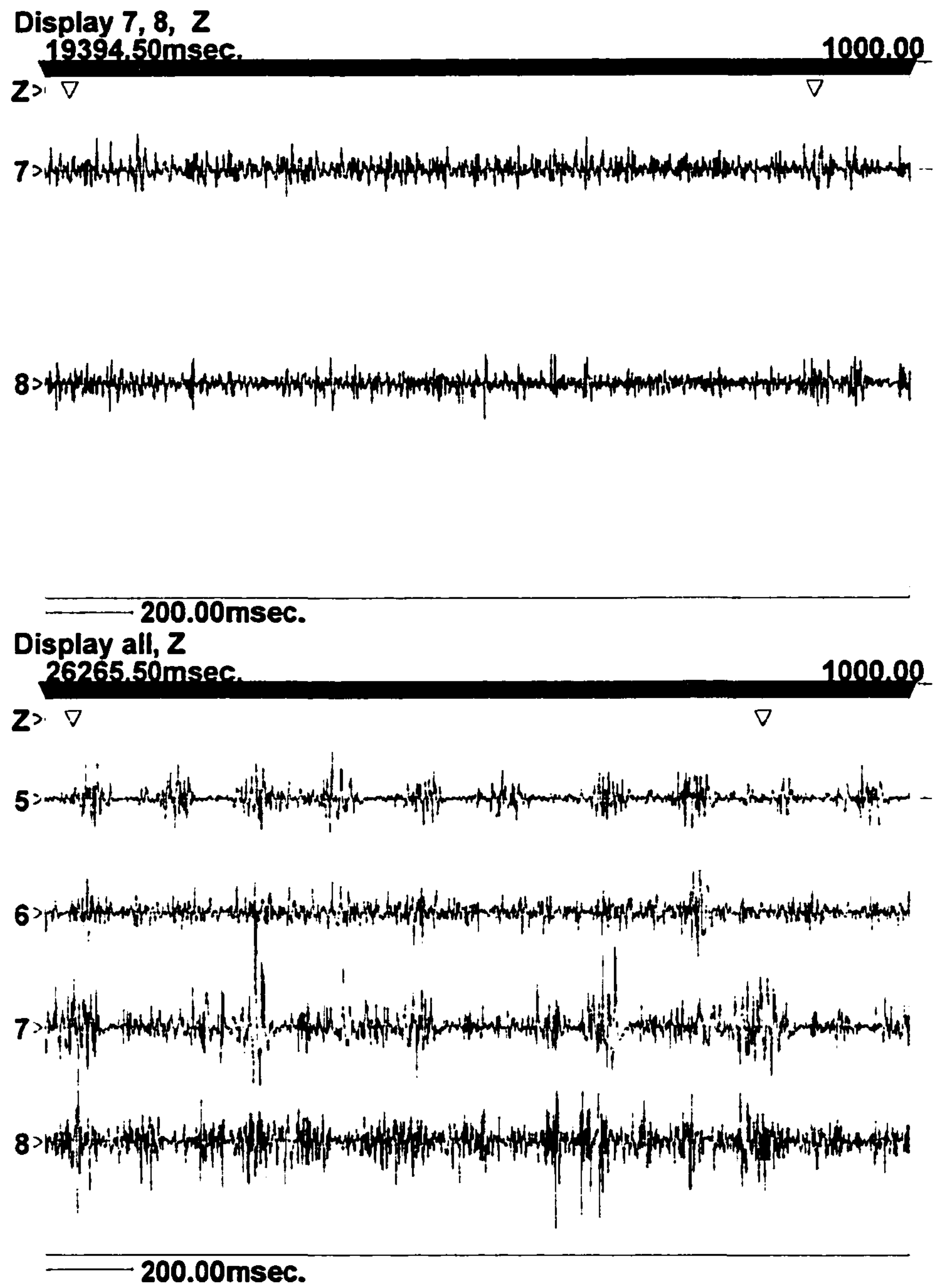


Figure 8. Sample Subject 1 raw EMG data. Top picture is Buzz 1 trial and bottom picture is Single 1 trial.



Z - Triangles mark beginning and end of each trial
5 - Left Flexor activity
6 - Left Extensor Activity
7 - Right Flexor Activity
8 - Right Extensor Activity
Vertical axis represents 1000 microvolts per grid division

Figure 9. Sample Subject 9 raw EMG data. Top picture is right flexor's MVC 3 trial and bottom picture is Double 1 trial.

Table 2

Length of trials for Subjects 2 and 5

Trial	Length in milliseconds	
	Subject 2	Subject 5
Left flexor MVC 1	1662	1695
Left flexor MVC 2	1662	1791
Left flexor MVC 3	1790	1791
Right flexor MVC 1	1790	1823
Right flexor MVC 2	1726	1727
Right flexor MVC 3	1790	1727
Left extensor MVC 1	1790	1759
Left extensor MVC 2	1854	1695
Left extensor MVC 3	1790	1759
Right extensor MVC 1	1790	1823
Right extensor MVC 2	1854	1759
Right extensor MVC 3	1726	1823
Single 1	1790	1631
Single 2	1790	1695
Single 3	1790	1855
Double 1	1790	1823
Double 2	1726	1823
Double 3	1854	1887
Buzz 1	1726	1823
Buzz 2	1726	1759
Buzz 3	1726	1759

lengths unavoidable. Theoretically the researcher could have electronically synchronized the metronome's signal with EMG data. However, the Datapac III EMG software used came in several modules. The version of Datapac III available to the researcher did not contain the module necessary for acquiring and synchronizing additional electronic signals with EMG readings. Also, no standard connector existed to connect an audio jack from the metronome to the coaxial input available on the electromyograph. Constructing a specialized connector of unproven reliability seemed of questionable worth, especially given the problems of Lammers (1984) and others in adapting specialized devices to their research (see Chapter 2). Manually marking events is not new to EMG research. To mark various events, Lammers (1984) penned marks on the polygraph paper which recorded his data. This was apparently not an uncommon way to mark events of interest before the advent of computerized EMG processing (Basmajian, 1979). A small discrepancy in trial lengths is inevitable with any manual approach. As in other studies, the discrepancy did not significantly affect this study's results.

Normalization of the Data

To quantify an muscle's EMG activity over a time period, this study used the most commonly chosen method, the root mean squared or RMS calculation (Cram, Kasman, and Holtz, 1998, p. 59). The RMS value for each trial's EMG activity was calculated by, a) squaring each digital sample's amplitude, b) summing all of the squares, c) dividing that sum by the number of samples in the trial, and d) taking the square root of that quotient.

Comparison of EMG data from different muscles and different subjects required normalization of data. As did this study, most research normalizes EMG data by treating a maximum voluntary contraction as a 100% level of activity (Cram, Kasman, and Holtz, 1998, p. 62). After application of the 10-350 Hz bandpass and 60 Hz notch filters described in Chapter 3, the Datapac III software calculated the RMS value for each of a subject's 21 trials. The software then exported an ASCII-formatted table of this data to a floppy disk. The Power Mac computer converted the table into a Microsoft Excel 98 spreadsheet. Exporting the data from Datapac III to an ASCII format converted an RMS value from floating point storage to storage using a fixed number of decimal places. In converting the data, the researcher maintained data to the fourth decimal place of the original floating point format, allowing more than sufficient accuracy for subsequent calculations. Using the Power Mac's Microsoft Excel 98 software, the researcher then calculated a normalized average value for each subject's single, double, and buzz stroke EMG activity. This was done as follows:

1) The researcher calculated the arithmetic mean of the RMS values of a muscle's three MVC trials. This value represented the maximum or 100% activity level of that muscle.

2) The researcher calculated the arithmetic mean of the RMS values for a muscle during three trials of one stroke type. This created an average EMG activity level for that muscle during execution of that stroke.

3) The researcher divided the average activity level in the second calculation, by the average MVC in the first calculation. This created a normalized average activity level of a particular muscle for a particular stroke type. That average activity level is expressed as a percentage of the average MVC. Table 3 presents all subjects' normalized activity levels in each muscle for each stroke type. It provides the data for discussion in Chapter 5.

Table 3

Normalized RMS Muscle Activity by Subject and Stroke Type

	Left Flexor	Left Extensor	Right Flexor	Right Extensor
Subject 1				
Single	42.64%	44.81%	33.86%	55.51%
Double	55.04%	63.18%	43.71%	70.19%
Buzz	64.22%	55.80%	52.98%	66.88%
Subject 2				
Single	108.89%	132.69%	19.54%	95.04%
Double	146.78%	349.28%	50.59%	209.12%
Buzz	88.10%	300.67%	24.21%	208.11%
Subject 3				
Single	41.69%	140.41%	21.58%	86.07%
Double	39.02%	186.60%	25.09%	104.04%
Buzz	60.32%	221.29%	25.08%	108.88%
Subject 4				
Single	22.34%	90.54%	38.20%	236.01%
Double	11.08%	92.93%	19.96%	264.83%
Buzz	10.95%	100.43%	19.65%	270.22%
Subject 5				
Single	29.00%	79.53%	26.33%	79.48%
Double	46.06%	103.84%	35.46%	110.41%
Buzz	41.76%	94.05%	39.90%	113.03%
Subject 6				
Single	53.75%	368.40%	110.69%	318.17%
Double	77.30%	511.09%	110.25%	354.85%
Buzz	71.10%	550.79%	61.79%	445.43%
Subject 7				
Single	25.93%	114.32%	20.64%	109.13%
Double	27.21%	137.56%	48.20%	150.80%
Buzz	29.13%	101.76%	45.39%	127.34%

Table 3 (continued from previous page)

	Left Flexor	Left Extensor	Right Flexor	Right Extensor
Subject 8				
Single	25.41%	106.68%	32.37%	154.45%
Double	46.41%	250.16%	69.78%	192.09%
Buzz	61.16%	330.29%	85.65%	316.10%
Subject 9				
Single	33.49%	33.53%	31.49%	98.44%
Double	71.51%	49.36%	43.49%	143.23%
Buzz	34.07%	53.05%	26.96%	132.23%

Chapter 5

Discussion

Introduction

Chapter 5 analyzes the normalized muscle activity presented in Chapter 4. The analysis provides some answers for the research questions posed in Chapter 1. In addition, unexpected results for extensor muscle activity raise questions about the thoroughness of drumstick pedagogical literature.

Extensor Activity

An examination of Table 3 reveals a surprising amount of extensor carpi ulnaris activity above the 100% level. Subjects' maximum voluntary contractions of the right and left extensors should have established an activity level above that used for execution of any drumstick stroke. Instead, only Subject 1 used less than 100% activity for both extensors on all three stroke types. Subjects 2, 4, 6, and 8 all had activity levels higher than 200% for at least one extensor over the three strokes. This is an unexpected result that can only be explained by one of two things. Either the subjects did not truly execute a maximum effort during the maximum voluntary contractions, or the extensors did more than just extend the wrist during stroke execution.

Cram, Kasman, and Holtz (1998, p. 63) cautioned that, no matter how objective the concept of a maximum voluntary contraction is, there is no way in practice to insure that a subject actually makes a maximum effort to contract a muscle. A lack of maximum effort might account for some subjects exceeding their maximum voluntary contraction. However, all subjects but one exceeded their MVC for either the left or right extensor carpi ulnaris, and most did so for both extensors. This implies the effect of some factor other than a lack of maximum effort.

The second alternative, the extensors' involvement in another task besides wrist extension, seems a more likely reason for the unexpectedly excessive activity. Chapter 2 described the grouping of a muscle's fibers into motor units. A selected number of motor units in a muscle produce a particular motion. In other words, a particular motion does not necessarily utilize all of a muscle's motor units. An EMG signal is a combination of signals from all motor units active for a particular motion. For a particular motion, an MVC activates all motor units that would potentially participate in the motion. Thus, because most subjects' extensor activity well exceeded the 100% level established by the extensor MVC, execution of the strokes likely activated additional motor units, units not activated by the MVC. Activation of motor units not used in the MVC implies that stroke execution required the extensor carpi ulnaris to do more than just extend the wrist.

The extensor carpi ulnaris can engage in three tasks other than wrist extension. Gray (1985) and Hamill and Knutzen (1995) both described the extensor carpi ulnaris as an agonist in ulnar deviation. That was the motion used to palpate each extensors' muscle belly during electrode placement. Gray also noted that the extensor carpi ulnaris can act as a neutralizer, keeping the wrist extended during finger flexion. Doing so lends additional strength in grasping an object with the fingers. Finally, Hamill and Knutzen (1995) described extensor carpi radialis as an agonist in forearm extension (movement at the elbow). The presence of ulnar deviation, wrist neutralization, or elbow extension in any of the drumstick strokes is significant to drumstick pedagogy.

None of the drumstick pedagogical sources reviewed in Chapter 2 described any ulnar deviation in striking the drum. Instead, from pictures, figures, and written descriptions, the sources clearly intended that a single stroke should use only wrist flexion and extension. Cook (1997), Breithaupt (1991), and Hughlett (1984) compared the required wrist motion to "waving goodbye." Drumstick sources consistently implied that the double and buzz strokes' wrist motion parallels that of the single stroke. Cook did this through the use of time lapse photography, and Breithaupt, Hughlett, and Tuthill (1981) did so by describing double and buzz strokes as modified single strokes. Table 3 showed that Subjects 2, 6, and 8, three of the four players with the most training, exhibited the largest extensor muscle activity. If ulnar deviation was involved in the strokes, drumstick pedagogy clearly has apparently ignored an important physiological aspect of striking the drum. Similarly, the drumstick sources reviewed made no mention of forearm extension in striking a drum. If forearm extension is involved in any of the strokes, drumstick pedagogy has apparently ignored an important physiological aspect of striking the drum.

Neutralization of the wrist during finger flexion may be the most likely cause of the heightened extensor activity. Cook specified the action of each finger in the buzz roll, and explained exercises for developing finger motion used in double strokes. Cook's description implied that some fingers actually "pump" in some fashion, while others tighten and loosen their grip on the stick. Tightening and loosening the fingers' grasp of the stick is the very action in which the extensor carpi ulnaris muscle would act as a wrist neutralizer.

Other than Cook, however, no sources described finger motion in the double or buzz strokes. Including Cook, no sources described finger motion in the single stroke. Table 3 showed that many subjects exceeded the 100% extensor activity level for all three strokes. If finger motion or increased grasping tension caused the excessive flexor activity, then drumstick pedagogy clearly has apparently all but ignored an important physiological aspect of striking the drum.

The maximum voluntary contractions of the extensors did not represent 100% of those muscles' activities in the three drumstick strokes. Without a clear maximum output against which to normalize a muscle's activity, using the gathered extensor data for comparisons among subjects and between left and rights extensors is not valid. However, examining extensor activity muscle-by-muscle does reveal one pattern. In only one instance did a subject's single stroke muscle activity exceed activity during double or buzz stroke execution. Subject 7's left extensor demonstrated greater activity for single strokes than for buzz strokes. Double and buzz strokes require the execution of two more note attacks in the time that the single stroke produces one attack. From this, it seems logical to conclude that double and buzz strokes would thus require greater extensor muscle activity. However, the question of whether or not increased wrist extension alone causes the increased activity still remains. Possibly the increased extensor activity is due to the double and buzz stroke finger activity which Cook (1997) described.

Flexor Activity

In contrast to extensor activity, flexor activity for the various strokes generally stopped considerably short of the 100% level. Only Subject 2's left flexor and Subject 6's right flexor exceeded 100%. As described for extensor activity exceeding 100%, two things might have caused the two subjects' excessive flexor activity: Subjects 2 and 6 did not make a maximum contraction in establishing the 100% level for the flexor in question, or their flexors participated in some motion other than wrist flexion.

Most likely a less than maximum effort for the maximum voluntary contractions caused Subject 2 and 6 to produce excessive flexor activity. Excessive flexor activity occurred for no other subjects, and only for only one of Subject 2's or Subject 6's flexors. In addition, the two subjects exceeded their 100% flexor levels to a considerably lesser degree than most subjects exceeded their 100% extensor levels. The fewer subjects and smaller magnitudes involved imply that flexor muscle participation in a motion other than wrist flexion did not cause the excessive activity levels.

The likelihood that the subjects used flexor muscles only for wrist flexion has significance for the previous discussion of excessive extensor activity. Gray (1985) and Hamill and Knutzen (1995) both described the flexor carpi ulnaris as an agonist in ulnar deviation. The extensor carpi ulnaris is also an agonist in ulnar deviation. If ulnar deviation is not the cause of excessive flexor activity, then it also most likely did not cause the excessive extensor activity exhibited by most subjects. If ulnar deviation did not cause the excessive extensor activity, then excessive extensor activity likely resulted from either the finger activity which Cook (1997) described or from forearm extension.

By assuming that the flexor muscle activity in Table 3 reflects only wrist flexion, and ignoring the potentially inaccurate flexor activity values for Subjects 2 and 6, comparison of flexion across subjects and strokes types was possible. Tables 4, 5, 6, and 7 present the changes of flexor activity between different strokes and between dominant and non-dominant hands for all subjects other than Subjects 2

Table 4

Change in Flexor Activity from non-Dominant to Dominant hand

	Stroke		
Subject	Single	Double	Buzz
1	8.78%	11.33%	11.24%
3	-20.10%	-13.93%	-35.25%
4	15.86%	8.89%	8.70%
5	-2.67%	-10.60%	-1.85%
7	-5.29%	20.99%	16.27%
8	6.96%	23.37%	24.49%
9	-2.00%	-28.02%	-7.11%
M	0.22%	1.72%	2.36%
SD	10.82	17.99	19.68

Note. Negative scores indicate a decrease, and positive scores an increase, in activity. Values are derived from Table 3 (see Chapter 4).

Table 5

Change in Flexor Activity from Single to Double strokes

Subject	Left Flexor	Right Flexor
1	12.40%	9.85%
3	-2.67%	3.50%
4	-11.26%	-18.24%
5	17.06%	9.13%
7	1.28%	27.56%
8	20.10%	37.41%
9	38.01%	12.00%
M	10.70%	11.60%
SD	16.47	17.73

Note. Negative scores indicate a decrease, and positive scores an increase, in activity. Values are derived from Table 3 (see Chapter 4).

Table 6

Change in Flexor Activity from Single to Buzz strokes

Subject	Left Flexor	Right Flexor
1	21.57%	19.11%
3	18.64%	3.50%
4	-11.38%	-18.55%
5	12.76%	13.57%
7	3.20%	24.76%
8	35.76%	53.29%
9	0.58%	-4.54%
M	11.59%	13.02%
SD	15.57	23.07

Note. Negative scores indicate a decrease, and positive scores an increase, in activity. Values are derived from Table 3 (see Chapter 4).

Table 7

Change in flexor activity from Double to Buzz strokes

Subject	Left Flexor	Right Flexor
1	9.18%	9.26%
3	21.31%	-0.01%
4	-0.12%	-0.31%
5	-4.30%	4.44%
7	1.92%	-2.80%
8	14.76%	15.88%
9	-37.44%	-16.54%
M	0.76%	1.42%
SD	19.04	10.21

Note. Negative scores indicate a decrease, and positive scores an increase, in activity. Values are derived from Table 3 (see Chapter 4).

and 6. An examination of these tables provides some direct answers to the research questions posed in Chapter 1.

Table 4 presents the differences between dominant and non-dominant arms' flexor activity during execution of each stroke. A positive value indicates increased flexor activity in the dominant hand, while a negative value indicates decreased activity. With the exception of subject 7, all subjects showed either consistently increased or decreased activity over all three stroke types. That pattern does indicate a consistent variation in activity between hands for an individual subject. However, one hand does not appear consistently more or less active than the other across subjects. Subjects 1, 4, and 8 all showed consistently increased activity, while subjects 3, 5, and 9 showed consistently decreased activity. Subjects 8 and 9 were considerably more experienced than the other four subjects, but demonstrated opposite changes in activity. Handedness did not appear to be an issue. Subject 1 was the only left-handed subject studied, but that subject's flexor activity did not noticeably differ from that of Subjects 4 or 8. In answer to the second research question, analysis of Table 4 implies that a teacher of drumstick techniques can expect either consistently less or consistently more flexor activity in a student's dominant forearm for all stroke types.

Table 5 shows the changes in flexor activity between single and double strokes. With the exception of both of Subject 4's flexors, and Subject 3's left flexor, flexor activity increased for double strokes. The average increase for all flexors measured was 11.22. The most experienced subjects, Subject 8 and Subject 9, increased both flexors' activity more than the average. In answer to the first research question, analysis of Table 5 implies that a teacher of drumstick techniques can expect a student's flexor activity for double strokes to exceed that for single strokes.

Table 6 shows the changes in flexor activity between single and buzz strokes. With the exception of both of Subject 4's flexors, and Subject 9's right flexor, flexor activity increased for buzz strokes. This pattern of increase is less convincing than that for double strokes in that one of the more experienced subjects, Subject 9, is an exception to the pattern. However, the Table 6 trend is still strong. In answer to the first research question, examination of Table 6 implies that a teacher of drumstick techniques can expect a student's flexor activity for buzz strokes to exceed that for single strokes.

Table 7 shows the change in flexor activity between double and buzz strokes. Subjects demonstrated no clear difference in flexor activity between double and buzz strokes. Of the 14 flexors' activity listed, 7 showed a decrease in activity from double to buzz stroke, while 7 showed an increase. Of seven subjects, three demonstrated an increase in one flexor simultaneous with a decrease in the other. The average change for all flexors measured was 1.09. Table 7 does not reveal any information helpful in answering the research questions.

For several reasons, the results of the flexor activity were not subjected to any tests of statistical significance. The study examined a relatively small number of subjects, and the researcher had taught the three drumstick strokes to the majority of the subjects. Also, the initial population from which subjects were drawn was quite limited. For those reasons, tests of statistical significance, together with their consequent inference to larger populations, were inappropriate. A replication of this study with a larger, more diverse population, and randomly selected subjects, should better confirm the conclusions suggested by this study's data.

Summary

This study sought to answer two questions. The first was how active forearm extensors and flexors were in producing three fundamental drumstick strokes. Second, the study attempted to determine differences in that same muscle activity between dominant and non-dominant hands. A procedure designed to answer these questions used electromyography to measure flexor carpi ulnaris and extensor carpi ulnaris activity during stroke execution. The research provided some answers to both questions regarding flexor activity. The data gathered suggested that:

1) Flexor activity for double strokes, in both dominant and non-dominant forearms, exceeds that for single strokes.

2) Flexor activity for buzz strokes, in both dominant and non-dominant forearms, exceeds that for single strokes.

3) During execution of all three strokes, flexor activity in the dominant forearm is either consistently less or consistently more than activity in the non-dominant forearm.

For extensor activity, the study produced unexpected data. While executing strokes, all but one subject exceeded the 100% extensor activity level established by maximum voluntary contractions. This suggested that, during stroke execution, extensor muscles engaged in some motion in addition to wrist extension. Of the three possibilities, only one, neutralization of the wrist during finger flexion, is a possibility implied by stroke descriptions in drumstick pedagogical literature. Pedagogical literature contains no stroke descriptions that implied the other possibilities, ulnar wrist flexion or forearm extension. While the extensor data did not suggest answers to the research questions, it did reveal possibly significant failings in pedagogical literature's descriptions of stroke execution.

The lack of accurate MVC extensor values prevents comparison of extensor activity across subjects and muscles. It also prevents comparison of extensor and flexor activity. This means this research cannot resolve the drumstick pedagogical discrepancies that Chapter 2 revealed. In particular, resolving Cook's inconsistent single stroke description requires comparison of flexor data with extensor data. Without that comparison, deciding whether any of the three strokes use primarily extension or primarily flexion is impossible. Resolving the discrepancies will require further research.

Suggestions for Further Study

The results of this research immediately suggest three ideas for further study. First, to generate more information about wrist extensors' activity, this study could be repeated with different maximum voluntary extensor contractions. Several versions of a maximum contraction could combine wrist extension with any or all of the three possible additional extensor roles suggested by this research. Such a study could potentially yield extensor data equivalent to this study's flexor data. The obvious second approach would be to conduct a study similar to this one, but including separate EMG measurement of finger and elbow motion. While more complicated, and impossible with this study's hardware and software limitations, such research could potentially reveal important information about the finger and elbow motion in stroke execution. Third, a similar study utilizing a larger, more diverse group of subjects could better confirm this study's suggestions regarding flexor activity. In particular, the inclusion of professionals, with more experience and training than this study's subjects, would be a significant improvement.

The research reviewed in Chapter 2 suggests other possible extensions of this study. With a flexible enough computer program, biofeedback research could use threshold values based on this study's conclusions regarding flexor activity. Also, an attempt might be made to further refine this researcher's results by finding correlation between the patterns revealed and the quality of a subject's playing. Some of the flexor activity patterns revealed in this research may not produce aesthetically acceptable results.

Hopefully this research provides only a beginning. Drumstick pedagogy needs further, scientifically grounded research if ever increasing uses of its techniques can be matched by physiologically sound teaching strategies. The desire to fulfill that need was the initial spark that set this study in motion.

References

Abram, B. (1984). Musical tension and muscular ease. Clavier, 23(6), 28-9.

Alexander, S. (1990, September). Health and science: Dealing with carpal tunnel syndrome. Modern Drummer, 14, 72-3.

Basmajian, J. V. (1979). Muscles alive: Their functions revealed by electromyography (4th ed.). Baltimore: Williams and Wilkins.

Bejjani, F. J., Ferrara, L., Pavlidis, L. (1989). A comparative electromyographic and acoustic analysis of violin vibrato in healthy professional violinists. Medical Problems of Performing Artists, 4(4), 168-175.

Blades, J. (1984). Percussion instruments and their history (2nd ed.). London: Faber and Faber Limited.

Breithaupt, R. B. (1991). The Complete Percussionist. Oskaloosa, IA: C.L. Barnhouse Company.

Callahan, G. L. (1987). The measurement of finger dexterity in woodwind and brass instrumentalists: Developmental study. Journal of Band Research, 23(1), 50-60.

Campbell, W. W. (1999). Essentials of electrodiagnostic medicine. Baltimore: Williams and Wilkins.

Chung, I., Jaiyoung, R., Onishi, N., Rowen, B., & Headrich, J. (1992). Wrist motion analysis in pianists. Medical Problems of Performing Artists, 7(1), 1-5.

Cleveland, T. F. (1988). Vocal pedagogy in the twenty-first century. Viewing the voice: A picture is worth a thousand words. The NATS Journal, 45(2), 31-2.

Cook, G. D. (1997). Teaching percussion (2nd ed.). New York: Schirmer Books.

Cram, J. R., Kasman, G. S., & Holtz, J. (1998). Introduction to surface electromyography. Gaithersburg, MD: Aspen Publishers.

Crocker, R. J (1988). Effects of hand dominance on the speed and accuracy of tapping patterns in beginning percussion performance (Doctoral dissertation, University of Northern Colorado, 1987). Dissertation Abstracts International, 48, 2270A.

Cutietta, R. (1986). Biofeedback training in music: from experimental to clinical applications. Council for Research in Music Education Bulletin, 87, 35-42.

Dennis, A. W. (1981). The effect of three different methods of supporting the double bass on muscle tension (Doctoral dissertation, Indiana University, 1981). Dissertation Abstracts International, 43, 716A.

Fischer, S. (1995). Technique basics: Moving the fingers from the base joint. The Strad, 106(1266), 1006-1007.

Gosset, C. W. Jr. (1989). Electromyographical investigation of the relationship of the effects of selected parameters on concurrent study of voice and oboe. Journal of Voice, 3(1), 52-64.

Gray, H. (1985). Anatomy of the human body (30th ed., Clemente, C. D., Ed.). Philadelphia: Lea & Febiger.

Guettler, K. (1992). Electromyography and muscle activities in double bass playing. Music Perception, 9(3), 303-9.

Hamill, J., & Knutzen, K. M. (1995). Biomechanical basis of human movement. Media, PA: Williams and Wilkins.

Henderson, W. A. (1979). EMG potentials of the sternocleidomastoid muscle during trumpet performance. Journal of the International Trumpeter's Guild, 4, 30-35,52.

Heuser, F. and McNitt-Gray, J. L. (1991). EMG potentials prior to tone commencement in trumpet players. Medical Problems of Performing Artists, 6(2), 51-6.

Heuser, F. and McNitt-Gray, J. L. (1993). EMG patterns in embouchure muscles of trumpet players with asymmetrical mouthpiece placement. Medical Problems of Performing Artists, 8(3), 96-102.

Hirano, M. (1988a). Vocal mechanisms in singing: laryngological and phoniatric aspects. Journal of Voice, 2(1), 51-69.

Hirano, M. (1988b). Behavior of laryngeal muscles of the late William Vennard. Journal of Voice, 2(4), 291-300.

Houliff, M. (1983). Developing the snare drum roll. Woodwind, Brass, and Percussion, 22(5), 14-16.

Hughlett, D. (1984). Understanding drum techniques. Dallas: UDT Publishing Company.

Isley, C. L., Jr. (1973). A theory of brasswind embouchure based on facial anatomy, electromyographic kinesiology, and brasswind embouchure pedagogy (Doctoral dissertation, University of North Texas, 1972). Dissertation Abstracts International, 33, 3956A.

Jooste, F. (1984). The use of muscles during bassoon playing. Woodwind, Brass, and Percussion, 2/3(8), 16-18.

Judkins, J. (1993). The percussionist's shoulder: rehabilitation in practice. Percussive Notes, 31(3), 72-74.

Koehler. W. K. (1993). The effect of electromyographic feedback on achievement in bowing technique (Doctoral dissertation, Indiana University, 1993). Dissertation Abstracts International, 55, 2758A.

Lammers, M. E. (1984). An electromyographic examination of selected muscles in the right arm during trombone performance (Doctoral dissertation, University of Minnesota, 1983). Dissertation Abstracts International, 44, 3315A.

Lee, S. H. (1990). Pianists' hand ergonomics and touch control. Medical Problems of Performing Artists, 5(2), 72-8.

Levy, C. E., Lee, W. A., Brandfonbrener, A. G., Press, J., & Levy, A. E. (1992). Electromyographic analysis of muscular activity in the upper extremity generated by supporting a violin with and without a shoulder rest. Medical Problems of Performing Artists, 7(4), 103-109.

Lewis, E. L. (1985). A photographic study of the body positions of sixteen trumpet virtuosi while playing selected exercises (Doctoral dissertation, New York University, 1985). Dissertation Abstracts International, 46, 3644A.

Loeb, G. E., & Gans, C. (1986). Electromyography for experimentalists. Chicago: The University of Chicago Press.

Ludwig, W. F., & Ludwig, W. F., Jr. (1948). The WFL drum corps manual. Chicago: Ludwig Drum Company.

Martin, F., Thumfart, W. F., Jolk, A., & Klingholz, F. (1990). The electromyographic activity of the posterior cricoarytenoid muscle during singing. Journal of Voice, 4(1), 25-29.

MD special report: A realistic look at the matched grip. (1982, April). Modern Drummer, 6, 22-5.

Moeller, S. A. (1956). The Moeller book: The art of snare drumming. Cleveland: Ludwig Music Publishing Company.

Naill, R. and McNitt-Gray, J. L. (1993). Surface EMG as a method for observing muscle activation patterns associated with strategies of string depression used by cellists. Medical Problems of Performing Artists, 8(1), 7-13.

Nelson, R. T. (1996). Wrist pain from oboe playing. The Double Reed, 19(1), 80.

Nelson, S. A. (1989). Respiratory physiology of the wind instrumentalist (Doctoral dissertation, University of Cincinnati, 1989). Dissertation Abstracts International, 51, 339A.

Philipson, L., Sörbye, R, Larrson, P., & Kaladjev, S. (1990). Muscular load levels in performing musicians as monitored by quantitative electromyography. Medical Problems of Performing Artists, 5(2), 79-82.

Raab, E. (1980). Kinesthetic considerations in String Playing. American String Teacher, 30(2), 22.

Raikin, B. (1985). Towards a better understanding of piano technique. British Journal of Education, 2(2), 133-44.

Reynolds, C. and Morasky, R. (1981, May). Intensity without tension: biofeedback. Music Educators Journal, 67, 53-5.

Ricquier, M. (1980). La relaxtion et la pratique instrumentale. Brass Bulletin, 29, 61-6.

Rolland, P. (1979). Movement in string players as it relates to the violin. American String Teacher, 29, 8-11.

Ryniker, D. H. (1981, July). Dealing with the aches and pains of drumming, Modern Drummer, 5, 29-30+.

Sakai, N., Liu, M. C., Su, F-C. Bishop, A. T., & An, K-N. (1996). Motion analysis of the fingers and wrist of the pianist. Medical Problems of Performing Artists, 11(1), 24-9.

Schuppert, M. and Wagner, C. (1996). Wrist symptoms in instrumental musicians: due to biomechanical restrictions? Medical Problems of Performing Artists, 11(2), 37-42.

Sisto, D. J., Jobe, F. W., Moynes, D. R., & Antonelli, D. J. (1987). An electromyographic analysis of the elbow in pitching. The American Journal of Sports Medicine, 15, 260-3.

Standards for reporting EMG data. (1996). Journal of Electromyography and Kinesiology, 6(4), pp. iii-iv.

Steele, G. (1991). Pumping mallets: a preliminary investigation into musicians' performance-related injuries, injury prevention, and performance enhancement. Percussive Notes, 29(5), 26-34.

Thomas, E. (1993). Anatomical essentials in clarinet hand position Clarinet, 20(3), 18-21.

Tuthill, G. H. (1981). Percussion on the March: A look at technique. Percussive Notes, 19(2), 34-6.

Van Horn, R. (1988, April). Club scene: ergonomics. Modern Drummer, 12, 110, 112.

Watson, P. J., Hoit, J. D., Lansing, R. W., & Hixon, T. J. (1989). Abdominal muscle activity during classical singing. Journal of Voice, 3, 24-31.

Wedin, S. (1984). EMG investigation of abdominal musculature during phonation. Journal of Research in Singing, 7(2), 34-44.

White, E. R., & Basmajian, J. V. (1974). Electromyographic analysis of embouchure music function in trumpet playing. Journal of Research in Music Education, 22, 292-304.

Wilson, F. R. (1988). Teaching hands, treating hands (occupational cramp). Piano Quarterly, 36(141), 34-41.

Wolf, F. G., Keane, M.S., Brandt, K.D, & Hillberry, B. M. (1993). An investigation of finger joint and tendon forces in experienced pianists. Medical Problems of Performing Artists, 8(3), 84-95.

APPENDIX A

School of Music, MSC 7301
James Madison University
Harrisonburg, VA 22807
Email: johns2ta@jmu.edu
Ph. (540) 568-6763

May 15, 1999

Dear ____________________ ,

Thank you for your interest in my research project. It will measure the activity of selected muscles used in snare drum playing. To do so, I will attach four electrodes to each of your forearms and one electrode to an elbow. Attaching the electrodes involves removing a small patch of body hair and lightly scraping the same area with a special "scratch" tape. This tape has the roughness of very fine sandpaper. It removes a thin layer of dead skin, allowing the electrodes to more easily monitor muscle activity. The electrodes have a gel that will stick them to your skin. After the electrodes are attached, you will perform various snare drum exercises on a practice pad. As you do this, I will gather data from the muscles. The whole session should take a maximum of 90 minutes. I plan to complete the measurement later this month.

As part of the research, I need you to fill out the questionnaire below. All data I gather, including the questionnaire, will be held in strict confidence. Return the questionnaire to me through normal mail. Once I have it, I will contact you to schedule a specific measurement time. To defray your travel expenses I will pay you $50.00 in the form of a personal check. Thanks again for your help.

Sincerely,

Todd Johnson

<u>Preliminary Questionnaire</u>

____

First Name Last Name Summer Mailing Address

____

Summer Telephone Summer Email address

1) How many years have you played snare drum or drumset? ________________ (If less than one, estimate the number of months).
2) How many years do you have of formal training in drumstick technique? ____________________ (If less than one, estimate the number of months. Count years in a school band program, private lessons, a percussion techniques class, or other similar experiences).
3) Do you use primarily traditional or matched grip? ____________________.
4) Which hand do you consider dominant in using drumsticks? ________________ (In other words are you a right- or left-handed drummer? If neither hand is dominant, answer "neither").
5) If you have ever had any significant injury to either forearm, such as a wound that left a scar, please briefly describe it:

APPENDIX B

Consent to Participate in Doctoral Research

Purpose

Your signature on this form indicates your willingness to participate in research conducted by Todd A. Johnson. He is conducting the research toward the completion of a doctoral degree at the University of Oklahoma-Norman Campus. Dr. Richard C. Gipson chairs the committee overseeing Mr. Johnson's degree. Your measurement session will be completed in James Madison University's Human Performance Laboratory at Godwin Hall. The research is being conducted under the auspices of both universities. The title of the research is An Examination of Selected Muscles Used in the Movement of the Wrist While Executing Selected Drumstick Techniques with Matched Grip.

Description of the Study

The study will measure the activity of selected muscles used in snare drum playing. To measure the muscles, the researcher will attach four surface electrodes to each of your forearms and one electrode to an elbow. These electrodes measure the electrical signals generated by muscles, functioning very much like the electrodes that measure someone's heart rate for medical purposes. After the electrodes are attached, you will perform various snare drum techniques on a practice pad. As you do this, the researcher will gather data from the muscles. The whole session should take a maximum of 90 minutes.

Attaching the electrodes involves removing five patches of body hair, two on each forearm and the fifth at one elbow. Each patch will cover an area approximately two inches wide and three inches long. For hair removal, a hand-held, disposable Gillete razor will be used. After hair removal, each electrode site will be lightly scraped with a special "scratch" tape. This tape has the roughness of very fine sandpaper. It will remove a thin layer of dead skin, allowing the electrodes to more easily monitor muscle activity. The electrodes have a gel which makes them stick to your skin. The researcher will wear sterile latex gloves for all electrode site preparation and for removal of the electrodes. After both preparation and removal, he will dispose of all materials used in a standard biohazard safety container. Before each preparation step (hair removal, scraping, and electrode attachment) the sites will be cleaned with an alcohol-soaked pad.

Risks and benefits

There is minimal risk associated with this research. The procedure described above will prevent any harm if, as happens in rare cases, a little blood is raised by scraping the skin. All data gathered about you will be kept strictly confidential. In publication of the research you will be referred to only by a number assigned at your measuring session. Also for your protection, you must be 18 years of age or older to participate in the study.

Your participation in the study is very much appreciated. The results of the research should provide important baseline information for the development of improved snare drum teaching techniques.

Questions or Problems

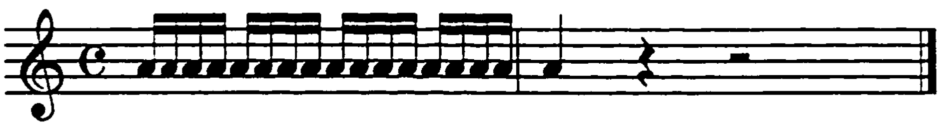
Your participation in this research is strictly voluntary. You have the right to withdraw from the research at any time, for any reason. If you choose to do so, you may still keep the $50.00 travel stipend. Please direct any questions you have concerning the research to Todd

Johnson at (540) 568-6763. If you have questions regarding your rights as a research participant please call the University of Oklahoma Office of Research Administration at (405) 325-4757, or Janet Gloeckner, Chair of the JMU Institutional Review Board, at (540) 568-7084.

Signature of Researcher	Date	Signature of Subject	Date
Signature of Witness	Date		

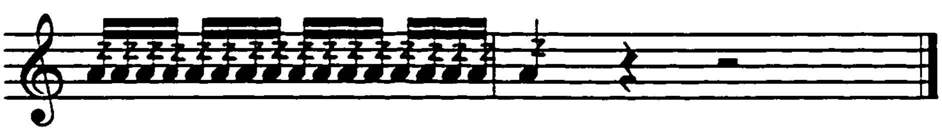
♩ = 70 For all examples

Single strokes



Double strokes

Individual Buzz strokes (not a roll)



APPENDIX D

LIPPINCOTT WILLIAMS & WILKINS

A Wolters Kluwer Company

05/12/99

JAMES MADISON UNIVERSITY
TODD JOHNSON
SCHOOL OF MUSIC JMU MSC 7301
HARRISONBURG, VA 22807-0001

Invoice # P32582803 Customer # 000105555546 FEE: 0.00
Re: HAMILL, ANAT BIOMECH HUMAN MOV
Spec Mat: Pages 73, 177, 502, and 503

CONDITIONS OF AGREEMENT

Permission is granted upon the return of this signed agreement to Lippincott Williams & Wilkins (LWW). Please sign and date this form and return with payment (if applicable) in the enclosed envelope. Please retain a copy for your files. This permission is subject to the following conditions:

1) A credit line will be prominently placed and include: for books - the author(s), title of book, editor, copyright holder, year of publication; for journals - the author(s), title of article, title of journal, volume number, issue number and inclusive pages.

2) The requestor warrants that the material shall not be used in any manner which may be considered derogatory to the title, content, or authors of the material or to LWW.

3) Permission is granted for one time use only as specified in your correspondence. Rights herein do not apply to future reproductions, editions, revisions, or other derivative works.

4) Permission granted is non-exclusive, and is valid throughout the world in the English language only.

5) LWW cannot supply the requestor with the original artwork or a "clean copy."

6) The requestor agrees to secure written permission from the author (for book material only).

7) Permission is valid if the borrowed material is original to a LWW imprint (Lippincott-Raven Publishers, Williams & Wilkins, Lea & Febiger, Harwal, Igaku-Shoin, Rapid Science, Little Brown and Company, Harper & Row Medical American Journal of Nursing Co, and Urban & Schwarzenberg - English Language).

8) Payment can be made via credit card (Amex, VISA, Discover and MC) or by check.

Card # ______________________ Exp Date: __________

Requestor accepts: Todd G. Johnson Date: May 18, 1999

227 East Washington Square, Philadelphia, PA 19106 • Tel: 215-238-4200 • Fax: 215-238-4227 • www.lww.com

APPENDIX E

```
          Return-Path: <jhamill@excsci.umass.edu>
             Received: from pobox1.oit.umass.edu (mailhub.oit.umass.edu
                       [128.119.166.151]) by roc.jmu.edu (8.8.8/8.8.8) with
ESMTP id
                       IAA06787 for <johns2ta@jmu.edu>; Fri, 21 May 1999
08:50:48
                       -0400 (EDT)
             Received:from totm111.umass.edu (totm-112.dhcp.umass.edu
                       [128.119.66.112]) by pobox1.oit.umass.edu (PMDF V5.2-32
                       #37024) with SMTP id
                       <0FC300B0C2C41M@pobox1.oit.umass.edu> for
                       johns2ta@jmu.edu; Fri, 21 May 1999 08:50:29 -0400 (EDT)
                 Date: Fri, 21 May 1999 08:42:38 -0400
                 From: Joe Hamill <jhamill@excsci.umass.edu>
              Subject: Re: Copyright Permission
             X-Sender: jhamill@mailsrv-unix.oit.umass.edu
                   To: johns2ta@jmu.edu
           Message-ID: <1.5.4.32.19990521124238.006ad54c@mailsrv-
unix.oit.umass.edu>
         MIME-version: 1.0
             X-Mailer: Windows Eudora Light Version 1.5.4 (32)
         Content-type: text/plain; charset=us-ascii
 Content-transfer-encoding: 7BIT
     X-Mozilla-Status: 8091


Todd,
Please be my guest. I hope that the sections of the book are
useful to you.

At 04:39 PM 5/20/99 +0000, you wrote:
>I am contacting you regarding your book, Biomechanical Basis of Human
>Movement. It has been an excellent source of physioloigcal information for my
>doctoral research. The publisher, Lippincott Williams and Wilkins, granted me
>permission to use several illustrations from the book for my dissertation.
>However, the permission is conditional; I also need to obtain your consent.  I
>would like to use portions of illustrations on pp.73, 177, 502 and 503. I
>digitally scanned the relevant parts,  then removed extraneous labeling.
>Could I send you the examples as they would appear in the dissertation, and
>ask for your permission to use them?  Please let me know your mailing address.
> Thanks very much.
>--
>Todd A. Johnson
>Adjunct Instructor of Music
>Ph. (540) 568-6763
>FAX (540) 568-7819

J. Hamill, Ph.D.
Professor and Chair
Department of Exercise Science
Totman 110
University of Massachusetts
Amherst, MA 01003

Tel.: (413) 545-2245
Fax : (413) 545-2906

E-Mail : JHamill@EXCSCI.Umass.Edu
```

APPENDIX F

The University of Oklahoma

OFFICE OF RESEARCH ADMINISTRATION

May 25, 1999

Mr. Todd A. Johnson
953 Chicago Avenue #18
Harrisonburg, VA 22802

Dear Mr. Johnson:

The Institutional Review Board-Norman Campus has reviewed your proposal, "An Examination of Selected Muscles Used in the Movement of the Wrist While Executing Selected Drumstick Techniques with Matched Grip," under the University's expedited review procedures. The Board found that this research would not constitute a risk to participants beyond those of normal, everyday life, except in the area of privacy, which is adequately protected by the confidentiality procedures. Therefore, the Board has approved the use of human subjects in this research.

This approval is for a period of twelve months from this date, provided that the research procedures are not changed significantly from those described in your "Application for Approval of the Use of Humans Subjects" and attachments. Should you wish to deviate significantly from the described subject procedures, you must notify me and obtain prior approval from the Board for the changes.

At the end of the research, you must submit a short report describing your use of human subjects in the research and the results obtained. Should the research extend beyond 12 months, a progress report must be submitted with the request for re-approval, and a final report must be submitted at the end of the research.

Sincerely yours,

Susan Wyatt Sedwick

Susan Wyatt Sedwick, Ph.D.
Administrative Officer
Institutional Review Board-Norman Campus

SWS:pw
FY99-233

Cc: Dr. E. Laurette Taylor, Chair, Institutional Review Board
Dr. Richard C. Gipson, Music

1000 Asp Avenue, Suite 314, Norman, Oklahoma 73019-0430 PHONE: (405) 325-4757 FAX: (405) 325-6029

APPENDIX G

Serial #9899081

Proposal Approval Form
The Institutional Review Board (IRB)
on the Use of Human Subjects in Research
James Madison University

PRINCIPAL INVESTIGATOR: Todd Johnson

PROJECT TITLE: **An Examination of Selected Muscles Used in the Movement of the Wrist While Executing Selected Drumstick Techniques with Matched Grip**

In accordance with JMU Policy Number 1104 and the Guidelines of the Department of Mental Health and Mental Retardation, it is hereby certified that the above stated project:

__XX__ being exempt from full review was reviewed by subcommittee and in its present form was

_____ being exempt from full review was reviewed by subcommittee and in its revised form was

_____ was reviewed by the IRB and, in its revised form, was

Approved on 5/6/1999

Disapproved on ________

Comments: A follow-up Report for Research Proposal form is attached and should be returned on or before May 1, 1999.

Human subjects are adequately informed of any risks.

Signature: Janet W Gloeckner
Chair

Date: 5/6/99

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989