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An Investigation of Drummers’ Trunk and Upper Limb Muscle Activation Profiles During High-Velocity Cymbal Crashes

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ABSTRACT

Drumming is a physically demanding activity, and skilled drummers share many physical and cognitive attributes with elite athletes. The “double pulse” muscle activation (DPMA) pattern is a motor control strategy that has been observed in athletes of sports involving ballistic movements, such as baseball, golf, and elite Mixed Martial Arts fighters. The two pulses are believed to function to increase striking velocity and effective mass, thus increasing force transfer onto the target. The purpose of this study was to examine the muscle activation patterns of highly skilled drummers for evidence of a DPMA during high-velocity cymbal crashes. Three highly skilled drummers were instrumented with EMG electrodes on the right latissimus dorsi, triceps brachii, erector spinae, rectus abdominis, deltoideus posterior (DP), teres major (TM), flexor carpi ulnaris, and extensor carpi radialis muscles. Six trials of data were collected, including a resting baseline, three maximum voluntary exertions (MVE) consisting of maximal effort cymbal crashes, a drumming pattern that included multiple crashes, and a free play trial. The DPMA waveform was observed in all trials, but the MVE trials were the only trials where DPMAs were confirmed to coincide with the crashing movement via video analysis. The DP and TM muscles exhibited the DPMA the most frequently, with both muscles functioning to extend the shoulder joint to crash the stick onto the cymbal. The extent to which drummers use the DPMA motor control strategy to produce high velocity cymbal crashes safely and efficiently in authentic playing conditions is inconclusive and needs further examination. Future study of the DPMA phenomenon in drummers would benefit from the addition of 3-dimensional motion capture systems (e.g., the Xsens Awinda™) to further understand the purpose of the muscle contractions of the DPMA.

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LIST OF ABBREVIATIONS

Abbreviation	Description
3-D	3-dimensional
BPM	Beats Per Minute
DP	Deltoideus Posterior
DPMA	Double Pulse in Muscle Activation
ECR	Extensor Carpi Radialis
EMG	Electromyography
ES	Erector Spinae
FCU	Flexor Carpi Ulnaris
Hz	Hertz (Frequency)
LD	Latissimus Dorsi
MVC	Maximal Voluntary Contraction
MVE	Maximal Voluntary Exertion
MMA	Mixed Martial Arts
RA	Rectus Abdominis
RMS	Root Mean Square
TB	Triceps Brachii
TM	Teres Major

CHAPTER 1: INTRODUCTION

Drums are instruments that are used in the production of music. In the earlier ages of drums, they were used in cultural contexts and for ritual purposes such as spiritual ceremonies, hunting, battle, and in coming-of-age ceremonies (Dean, 2011). In today's music, the drums are the key factor in keeping rhythm and to connect with the audience (Strong, 2006). The beats produced by the drums can alter the responses of the audience by changing the intensity of the music. What was once an improvisation of banging objects together to make noise has become a very technical and precise practice in music (Reimer, 2013). The modern drum kit has evolved into a combination of different drums and cymbals that are played by a single drummer using all four limbs (Strong, 2006). Drummers must be able to coordinate their entire body in perfect harmony to create the basic rhythm and provide complex drumming patterns and dramatic accents (Reimer, 2013). Doing so requires a great deal of skill, coordination, and stamina.

Like athletes, drummers must be able to maintain a vigorous intensity for extended periods without making mistakes for the best performance possible (De La Rue et al., 2013). The levels of physical exertion professional drummers achieve are comparable to those observed during high level athletic performance, such as playing in a professional soccer match (Azar, 2021). Furthermore, just like athletes, highly skilled drummers require certain physical abilities that allow them to excel. Drummers must be coordinated, but their performance must also to be consistent, even while playing at fast tempi (Fujii et al., 2011). As the key rhythmic factor in music, it is important that the drummer be able to deliver every stroke in time and with low variability of force and spacing between strokes (Fujii & Oda, 2006). Furthermore, drummers and athletes showed similar brain adaptations in motor readiness and proactive inhibitory control, allowing them to react and detect errors more quickly than non-drummer musicians and non-athletes (Bianco et al., 2017). Another similarity between drummers and athletes is that they can both perform complex movement patterns with apparent ease (Fujii et al., 2009b). This demonstrates the drummers' tremendous skill as well as allows them to reduce the metabolic demand of performance and reduce the risk of injury.

Whether through person-to-person contact or through collisions with other objects, creating large amounts of force quickly is necessary in many sports. The outcome of a collision is governed by Newton's Second Law (Acceleration), which states that the force an object can deliver upon impact is directly proportional to that object's mass and its acceleration (i.e., its rate of change of velocity over the duration of the collision; Bartlett, 2007). Objects with a greater mass travelling at higher velocities can produce more force upon impact. Combat sports are one of the best examples for the necessity of creating large forces in short spaces of time (Pinto Neto et al., 2007). In sports like boxing and mixed martial arts (MMA), delivering powerful blows to the opponent is crucial for victory. Research has shown that forceful strikes can be produced by increasing the effective mass behind the striking limb (Lenetsky et al., 2015). Effective mass is defined as measure of how much momentum the body is able generate and transfer to another object (Pinto Neto et al., 2007). There are two ways that one can increase the effective mass of a strike. The first is to increase the amount of mass behind the strike. This can be accomplished by acquiring more muscle mass through workout regimens, or by recruiting more muscles while delivering a strike (Pinto Neto et al., 2007). Studies have shown that when the core is strongly activated during a strike, a strong kinetic chain is formed from the center of the body to the hand during contact. Instead of just the muscles of the arm, these athletes use the mass of their entire body to deliver more powerful strikes onto the opponent (e.g., McGill et al., 2010; Lenetsky et al., 2015; Lee & McGill, 2016). The second way to increase effective mass is to increase the velocity at which the strike is delivered (Pinto Neto et al., 2007). A faster punch will deliver a larger impact force than a slower one because of the larger change in the impacting object's velocity over the duration of the impact and the transfer of momentum to the impacted object.

However, there is paradoxical relationship between velocity and force that athletes face when punching or kicking: when muscles contract, they become stiff and the velocity of the movement decreases (McGill, 2011). McGill et al. (2010) found a way that these athletes can overcome the speed force paradox. When they examined the EMG profiles of top MMA athletes, McGill et al. (2010) observed a double pulse in muscle activation (DPMA) in the athletes' trunk muscles when delivering a strike. The first pulse in muscle activation was associated with the initiation of the movement, and the second pulse immediately preceded the moment of impact to support the body and transfer force onto the punching bag. The period of muscle relaxation in the middle of the motion allowed the limb to accelerate, increasing strike velocity and, ultimately, the effective mass of the strike (McGill et al., 2010).

Martial arts are not the only sport where the DPMA phenomenon occurs. Other studies have reported a DPMA of trunk, rotator cuff, and/or upper limb muscles when driving a golf ball (Jobe et al., 1983; McGill, 2009, Silva et al., 2013), as well as in baseball pitching (Gowan et al., 1987) and batting (Ball et al., 2019). The DPMA allowed golfers to increase the momentum of the head of the golf club and transfer more force to the golf ball. A larger force applied to the ball would allow it to travel faster and further. Similarly, the distinct pulses of muscle activation during the phases swinging a baseball bat increased the velocity of the bat upon contact with the ball, leading to a greater force transfer and ultimately increasing the velocity and distance of the ball flight (Ball et al., 2019). Thus, in sporting scenarios that require quick ballistic movements, the DPMA phenomenon appears to be a motor control strategy that is used to increase force production.

Drumming is an activity that also requires high force production to create loud dynamics (i.e., volume), such as during high-velocity cymbal crashes. However, research on the motor control and biomechanics of drumming is scarce. Fujii & Oda (2006) investigated tapping speed asymmetry between drummers and non-drummers. They demonstrated that with training, drummers were able to tap at similar frequencies (i.e., taps/second) with both the dominant and non-dominant hands, whereas non-drummers could not. From there, Fujii et al. (2009a; 2009b) used electromyography (EMG) to examine muscle activation patterns to try to explain why drummers could tap at higher frequencies than non-drummers. The world's fastest drummer also participated, and his EMG profile was examined further. The authors observed that with increased years of drum training, drummers achieve faster rates of muscle activation onset and offset, allowing for faster drumming with low variability. While the studies from this research group showed that skilled drummers have more efficient muscle activation strategies, they only focused on fast repetitive drumming and no other aspects of the mechanics of drumming (e.g., cymbal crashes). They also only examined the EMG profiles of the wrist flexor and extensor muscle groups. Another research group investigated movement patterns and timing in drumming (Dahl, 2005; Dahl et al., 2011; González-Sánchez et al., 2019). These studies indicated that highly skilled drummers were able to strike the drums with greater velocity and more force (leading to a higher dynamic range) by increasing the preparatory height of a strike. Even at increasing tempi, professional drummers could strike faster than novice drummers while maintaining a steady rhythm and despite the limited inter-tap interval. However, these researchers did not use EMG to investigate the muscle activation patterns during these high velocity and high force impacts.

Most of the research on the biomechanics and motor control of drumming began only in the 21st century, therefore there are many areas in the research that have yet to be examined. The results thus far show the similarities between drummers and athletes, and the differences between drummers and non-drummers and between highly skilled drummers and novice drummers. Skilled drummers have modified muscle activation patterns, with increased contraction and relaxation rates that allow them to play faster and while also being able to deliver harder strikes with increased dynamic range (Dahl et al., 2011; Fujii & Moritani, 2012). More research is needed to examine the relationships between muscle activation patterns and high force impacts in drumming. The DPMA phenomenon may be a strategy used by skilled drummers to increase striking velocity and effective mass, allowing them to create more forceful strikes on the drums. However, this has yet to be demonstrated in the research literature.

1.0 Statement of Purpose

Therefore, the purpose of this study is to examine the muscle activation patterns of highly skilled drummers for evidence of a DPMA during high velocity cymbal crashes. The DPMA is a motor control strategy used in impact sports to increase effective mass and overall force of strikes. The research literature has shown that professional drummers are able to strike faster and harder to achieve higher dynamic levels compared to non-drummers and novice drummers (Dahl et al., 2011). This study will attempt to demonstrate that drummers are able to do so by effectively using the DPMA strategy. Drummers of all skill levels will benefit from this study by providing them with a visualization of how louder and more forceful cymbal crashes are created, allowing skilled drummers to refine their skills, and giving amateur drummers a specific goal to achieve through their training.

CHAPTER 2: LITERATURE REVIEW

2.0 What is Drumming?

Drums are a very important instrument in all genres of popular music. From pop, to rock, to jazz, to hip-hop, and metal, drums are played in different ways but for the same reason: to keep time and rhythm in music (Strong, 2006). Drummers must keep a regular beat at different tempi to synchronize the timing of the entire musical ensemble.

In the simplest terms, drums are percussion instruments that produce sounds when struck. The drums have been used throughout history, beginning thousands of years ago with the stamped pit: a plank of wood covering a hollow pit in the earth that would be jumped on to create percussive sounds (Dean, 2011). Eventually, the drum evolved into a membranophone, a cylindrical barrel with the top and bottom openings covered by stretched membranes (i.e., the drumhead; Dean, 2011). When the drumhead is struck the membrane deforms, which compresses the air inside the drum and subsequently deforms the bottom membrane. The vibrations of the membranes cause the surrounding air molecules to vibrate, creating sound waves that can be heard by the human ear (Wagner, 2006). The "tone" of the sound can be changed by loosening or tightening the membranes and by striking different locations on the drumhead (Wagner, 2006).

The modern drum kit is a product of western civilization and involves a combination of different percussive instruments to be played by one person (Strong, 2006). A modern drum kit typically consists of a bass drum, a snare drum, tom-tom drums, and a variety of cymbals (Figure 1). Strong (2006) describes the purpose and uses of the various components of the modern drum kit. The bass drum is the largest; it is placed vertically on the floor and is played using a foot pedal. The primary purpose of the bass drum is to create

Figure 1. Example of a modern drum kit. Image: Dixon Drums, 2007: Flickr, CC BY-NC-SA 2.0.

the basic tempo of the music. The snare drum has a series of metal wires inside the drum; when played, the drumhead vibrates against the wires, creating a hissing sound for the backbeat. The tom-tom drums are the simplest membranophone and the most numerous, with most kits having at least two but often more. Tom-toms are used to create rhythmic sounds and as a break in the main drumbeat. Modern drum kits also include a variety of cymbals such as the ride, crash, splash, Chinese, and gongs. Cymbals are used for many purposes including accentuating parts of the music, creating louder and fuller sounds, and are used as part of the basic beat. There is also a hi-hat cymbal, which consists of two opposing cymbals that are mounted on a stand and can be pushed together using a foot pedal and/or hit with the drumstick to create a variety of sounds. Most drumsticks are made of wood (e.g., maple, hickory, or oak) and are typically 38 to 42 cm in length with a mass 40 to 70 grams (Wagner, 2006). The composition and size of the drumsticks will affect the weight, speed, and durability of the drumsticks (Azzarto, 2010). The tip of the drumsticks also varies in shape and composition. Because the tip comes in contact with the drumhead and cymbal, the different shape and material will alter the sound that is produced (Azzarto, 2010). Each drummer will have their own preference depending on the style of music and the drumming patterns to be played. Altogether, the drum kit offers a wide range of sound production possibilities that are used in the making of popular music today.

Beginning as a very simple task, drumming has become very methodical, requiring high precision movements and timing abilities. Drumming has been defined as "The use of coordinated independence with both hands and feet on a collection of drums and cymbals … set up for convenient playing by one person" (Reimer, 2013). There are two main components to this definition. First, whereas drums and cymbals were once played by separate percussionists in the musical ensemble, modern drumming requires a single person to play multiple drums and cymbals while altogether maintaining a fluid and nice-sounding composition of music. As a result, modern drumming requires the use of coordinated independence of both hands and feet. Drummers must be able to coordinate the movements of all four of their limbs to hit all the drums and cymbals very quickly and in rhythm. Therefore, drumming can be viewed as a collection of impulsive ballistic movements that are joined to form a continuous movement with the goal of creating music (Dahl, 2011).

2.1 Drumming as an Athletic Endeavour

2.1.1 Metabolic Demands

Although it is not typically viewed as a practice for physical activity and healthy living, drumming is a very physically demanding activity. Original data from Germany revealed that seated drumming required an energy expenditure of 240 kilocalories per hour (kcal/h; Loewy & Schroetter, 1926, as cited in De La Rue et al., 2013). However, De La Rue et al. (2013) stated that due to the age of the Loewy and Schroetter study and the orchestral style of drumming, the results were not applicable to modern rock/pop drummers. Therefore, they performed their own study to examine heart rate and energy expenditure in professional and semi-professional drummers during laboratory tests and live concert performances (De La Rue et al., 2013). The relationship between heart rate and energy expenditure during laboratory cycle ergometer tests to exhaustion was calculated using linear regression, and this relationship was then used to estimate energy expenditure (kcal/hr) based on the heart rate profile recorded during a live performance. The results of this study indicated that drumming during a live performance is more physically demanding than previously thought. During a live performance, the participants' mean heart rate was 166 beats per minute (bpm) and their mean energy expenditure was 623 kcal/hr. When expressed in metabolic equivalents (METs), these results are equivalent to 8.2 METs, which placed drumming in the hard/vigorous physical activity category as defined by the American College of Sports Medicine (ACSM; De La Rue et al., 2013).

Likewise, Romero et al. (2016) confirmed that drumming is a vigorous physical activity based on physiological demands. They monitored heart rate, oxygen consumption, and energy expenditure in five semi-professional heavy metal drummers during an eight-song performance in a laboratory setting. They calculated that the drummers reached an average of 91 % of their maximal oxygen consumption during the drum performance, as well as a mean heart rate of 145 bpm and an energy expenditure of 518 kcal/h. These results place drumming in the vigorous physical activity category, with an energy expenditure of 6.3 METs. It was speculated that heart rate and energy expenditure were not quite as high as in the study by De La Rue et al. (2013) due to the lack of a live concert environment where other stimuli (e.g., heat, crowd interaction, increased intensity) would further increase physiological demand.

Most recently, Azar (2021) monitored heart rate and energy expenditure in 40 professional drummers during live performances. The average rate of energy expenditure was 10 kcal/min, which compares favourably to the results reported by Romero et al. (2016) and De La Rue et al. (2013), despite differences in the methods used to estimate energy expenditure. Furthermore, the average heart rate was 144 bpm, representing 79 % of the drummers' age-predicted maximum heart rate (maxHR). On average, participants spent 26 % of their performance at 'moderate intensity' (64-75 %maxHR), 54 % of their performance at 'vigorous intensity' (77-95 %maxHR), and 3 % of their performance at 'near or at maximal intensity' (96-100 %maxHR). Azar (2021) reported that these results were comparable to running at 8 km/h, cycling at 22 km/h, and playing professional sports such as soccer (where the average peak heart rate was 86 % maxHR). All the studies described above demonstrate that drumming is a physically demanding activity and that professional drummers experience physiological and metabolic demands comparable to those exhibited by professional athletes.

2.1.2 Physical Attributes

It is not only the physiological demands that are similar for drummers and athletes; there are many physical attributes required from athletes that are needed from professional drummers, as well. To excel in both domains, all the systems in the body need to be fine-tuned and perfected throughout many years of practice. It is a popular theory, proposed by Malcom Gladwell (2008), that to become an expert in any given field, one must deliberately practice for at least 10,000 hours. Ericsson et al. (1993) found that like professional athletes, the best musicians have spent over 10,000 hours practicing their instrument by the age of 21 years. During this time, athletes and drummers adjust their motor and sensory systems to constantly better their performance (Ericsson et al., 1993). Abernethy (1997) has also stated that regardless of field of expertise, there are similarities between all skilled performers. Expert performers can be fast yet accurate, consistent yet adaptable, and maximally effective yet with minimal attention and effort (Abernethy, 1997). Although the field is in its infancy, there is research evidence that skilled drummers exhibit movement abilities and characteristics like those of elite athletes.

Expert drummers must be very careful and precise while also being able to reproduce actions with very little error. In a series of stick tapping studies, Fujii and colleagues have demonstrated that skilled drummers were able to be fast yet precise and consistent (Fujii and Oda, 2006; Fujii et al., 2009a, 2011). In these studies, drummers were asked to tap a drum pad with drumsticks at different speeds and as fast as possible. The number of taps per second, the force of the taps, and the timing of the taps were monitored and compared to the results of non-drummers. With the dominant hand, both non-drummers and drummers were able to tap at an average frequency of 7.2 taps per second.

However, with non-dominant hand, drummers maintained a similar mean tapping rate of 7 taps per second, whereas the mean tapping rate in non-drummers dropped to 6 taps per second (Fujii & Oda, 2006). As the years of drumming experience increased, the maximum achievable tapping rate also increased linearly up to 10 taps per second (Fujii et al., 2009a), suggesting that the drummers learned through practice to increase the speed of tapping.

Notably, the drummers did not sacrifice the accuracy of the timing of their strokes as they gained speed. Fujii et al. (2011) examined synchronization errors in professional drummers who were asked to tap along to a metronome at different tempi (i.e., 60 bpm, 120 bpm, and 200 bpm). The synchronization error was defined as the difference between the timing of the metronome and the taps performed by the drummers' various limbs. They reported that the taps of the left hand, right hand, and right foot did not differ substantially from the metronome at any tempo. Mean synchronization error was approximately 10 milliseconds for all three tempi. Fujii et al. (2011) noted that this was a considerably smaller outcome than the results of previous tapping studies, where the mean synchronization error of professional percussionists was 25 milliseconds and for non-drummers ranged from 20 to 80 milliseconds (Aschersleben, 2002). The low synchronization error illustrated how professional drummers can perform very fast movements while maintaining timing accuracy.

Coordination of multiple limbs is important in athletics to enhance performance and to reduce the risk of injury. Drummers must be capable of limb independence, where each limb is moving separately (i.e., striking different components of the drum kit, possibly in different time signatures) yet all four limbs are coordinated in producing a coherent beat. The results of the Fujii et al. (2011) study also demonstrate the high level of multi-limb coordination of drummers. It was not only the dominant hand that had a low synchronization error to the metronome, but rather all the limbs. The drummers were able to simultaneously control the left hand, right hand, and right foot respectively, so that each limb had a low synchronization error at the various tempi. Furthermore, Fujii and Oda (2009) examined the variability of relative phase in a rapid anti-phase tapping study on drummers. The goal was to perform alternate hand taps and consistently achieve an equal amount of time between opposite hand taps. The authors reported that with increased years of drumming experience, the variability of relative phase between taps decreased. Thus, more experienced drummers were able to coordinate their limbs in such a way that reduced the timing variability in their performance and increased the consistency of their playing. Reducing variability of playing performance is an important aspect of drumming. In all studies comparing drummers and non-drummers, the variability of each drummer and standard deviation of the drummer group were very low (Fujii & Oda, 2006; Fujii & Oda, 2009; Fujii et al., 2009a; Fujii et al., 2009b). Drummers have shown that consistency in their performance is critical, just as it is for other elite athletes in their respective activities.

One of the most notable aspects of professional performance is the apparent ease with which athletes can execute complex and difficult tasks. In many of the studies described above, the authors reported that drummers seem to perform the exercises with minimal effort compared to non-drummers. Drummers were able to complete the tasks while maintaining a relaxed demeanor, whereas the non-drummers appeared to be trying very hard. In a study examining muscle activation patterns while drumming, Fujii et al. (2009b) found a higher level of co-contraction of the wrist flexor and extensors muscles of non-drummers, whereas drummers used a more reciprocal muscle activation strategy, which reduced the overall amount of effort needed to perform the task. Moreover, Fujisawa and Miura (2010) calculated the amplitude of mean EMG of the wrist flexor and extensor muscles for the first and last minutes of drumming at various tempi. They observed that in all conditions, the mean EMG in the last minute of playing was significantly higher than the first minute of playing in the non-drummer group. In contrast, the mean EMG remained the same throughout the entire performance of all the drummers. The authors suggested that the increase in muscle activity in non-drummers indicated higher strain and fatigue, whereas the stable EMG levels revealed that drummers remain relaxed throughout their performance. Less strain and fatigue would allow drummers to perform for longer periods of time, even with the high metabolic demand.

Being an athlete and training for many years produces physical adaptations while also causing brain adaptations to sensory-motor abilities. Bianco et al. (2017) conducted a study on athletes, drummers, non-drummer musicians, and non-athletes to further illustrate the similarities of athletes and drummers. The groups participated in a Go/No-Go cognitive task where they had to press a button when the correct visual stimulus appeared while also repressing the action when the incorrect stimulus appeared. Brain activity was monitored using an electroencephalogram (EEG) cap for pre- and post-stimulus potentials. The results indicated that the athletes and drummers were similar in all aspects, whereas the non-drummer musicians were comparable to the non-athletes. The drummers and athletes exhibited considerably faster reaction times while also committing fewer errors. There was also an increase in pre-stimulus brain activity for the drummers and athletes, which the authors stated was a demonstration of motor readiness and proactive inhibitory control. The non-drummer musician group did not exhibit the faster reaction time or the increase in brain activity seen in the athletes and drummers. The authors hypothesized that the physical activity that athletes and drummers experienced led them to develop increased sensory-motor abilities, allowing them to be fast and accurate in cognitive tasks.

Another important characteristic of athletes and drummers is enhanced sensory abilities to detect errors. In studies examining the audiovisual synchrony abilities of professional and novice drummers, the ability to detect errors was greater in the more advanced drummers. Petrini at al. (2009) showed professional and novice drummers a video of a drumming pattern along with the corresponding audio track. The video and the audio would not always be compatible in tempo, dynamic level, or pitch. The participants were required to analyze the movements and decide if there was an asynchrony in the audio and video. The authors reported that the professional drummers were more sensitive to the audiovisual information and were able to detect errors more often than the novices. Petrini et al. (2011) conducted a follow-up study using the same procedures with the addition functional magnetic resonance imaging (fMRI) to assess the level of brain activity required to detect asynchronies in the audiovisual information. They discovered that for the expert drummers, activity was reduced in the motor and action representation areas of the brain when the stimuli were matched. The similar low brain activity was seen in the novice drummers when the stimuli were mismatched, whereas brain activity increased in the novice drummers when the stimuli were matched. The drummers' enhanced sensory abilities allow them to recognize possible errors in their performance with ease with the goal of advancing their skills.

In expert athletic performance, the ability to increase speed and force of movements is paramount in gaining the advantage over the opponent. In drumming, speed and force are also important in creating intricate and complex drumming combinations and in increasing the dynamic range of the musical piece. Louder dynamics require the drummer to apply higher forces to the drums and cymbals. Dahl (2005) observed that expert drummers create larger impact forces than novice drummers when performing accent strokes, regardless of the tempo. The variables of interest in this study were the timing of strokes, preparatory height, and striking velocity. To produce larger impact forces, the preparatory height before delivering the stroke must be higher and strike velocity must be faster (Dahl, 2005). The author reported that expert drummers raised their sticks to a greater height in preparation of an accent stroke, allowing them to strike the target harder and faster all the while maintaining perfect timing. Being able to produce fast and forceful movements is another skill that expert drummers and athletes share that have propelled them to the next level of their performance.

2.2 Mechanics of Force Production

The skeletal muscles are the primary factor responsible force production (Winter, 2009). At the cellular level, muscles are made up of very small cylindrical muscle fiber cells that contain myofibrils. The myofibrils are arranged in a repeating pattern (called sarcomeres) along the length of the cell, which form the contractile element of the muscle (Figure 2). The myofibrils are arranged in a repeating pattern (called sarcomeres) along the length of the cell, which form the contractile element of the muscle (Figure 2).

Winter (2009) describes the series of electrochemical events that must take place for a muscle to contract and generate force. When stimulated by the nervous system, electrical impulses called action potentials will travel down the motor neurons to the neuromuscular junction (i.e., the synaptic connection of a motor neuron and a muscle).

Hormones will then travel from the neuron to the muscle cell membrane (i.e., the sarcolemma), setting off a cascade of events called potential will be created and will travel down the sarcolemma into the sarcoplasmic reticulum.

The action potential will cause an efflux of calcium ions from the sarcoplasmic reticulum, which are necessary for cross-bridge cycling and muscle contractions. The myofibrils contain overlapping thick (myosin) and thin (actin) protein filaments that are bound to transverse structures at the M line and Z disc, respectively. The calcium ions bind to the thin filaments and change their shape. The myosin heads (i.e., the cross-bridges) can then bind to the actin filament and flex, creating a sliding movement and changing the length of the muscle fiber before releasing and preparing for the next binding. The binding of actin and myosin, flexing of the myosin head, and the detachment of myosin from actin is referred to as one cross-bridge cycle. Multiple action potentials and multiple cross bridge cycles are required very quickly to complete a full change in muscle length. Whether the

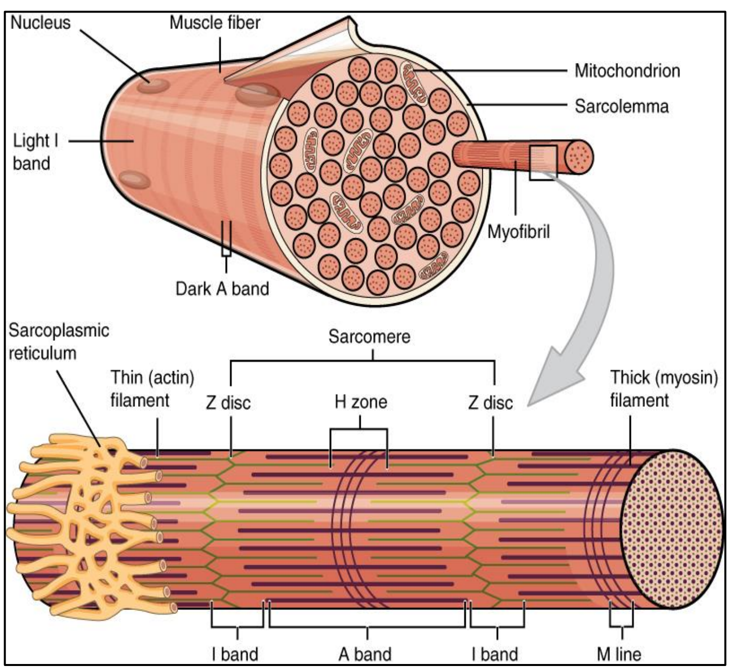

Figure 2. Muscle fiber structure. Image: OpenStax, 2016: Wikimedia Commons, CC BY 4.0.

muscle gets longer, shorter, or stays the same length will depend on the external loads acting on the muscle (Winter, 2009). When all muscle fibers get shorter or longer, the whole muscle itself will also get shorter or longer. Skeletal muscles have attachments sites on different bones, and when the muscle changes in length, the muscle contractions cause the bones to move in relation to one another, resulting in movement. Humans can effortlessly coordinate muscle contractions throughout the entire body to create more complex movements and to build up forces that they can use accomplish a task (Winter, 2009).

The amount of force a muscle is capable of producing is influenced by numerous factors such as the size of muscles, size of muscles fibers, length of muscles, speed of contractions, the neural drive, and the pennation angle of the muscle fibers (McGill, 2009). There are also many different external forces that influence movement such as gravity, ground reaction, friction, drag, and lift forces. One of the most notable external forces in sport is impact force, which occurs when two or more objects collide. Collisions can involve several objects such as body parts, the ground, balls, bats, and rackets. When two objects collide, the outcome is governed by Newton's laws of linear motion, specifically, Newton's Law of Acceleration. According to the Law of Acceleration, the magnitude of the force an object will deliver upon impact is equal to the product of the object's mass and its acceleration (i.e., the rate of change of velocity with respect to time; Bartlett, 2007). The greater the change in the impacting object's velocity over the duration of the impact, the larger the impact force will be. Producing large forces is very important in many sports where hitting, kicking, and throwing is involved. For example, in baseball, a ball that is struck with a greater force will be able to travel faster and further than a ball that is struck with less force. In many cases, athletes need to optimize muscle contractions and body movements to produce the largest amount of force possible. In the case of collisions, the contact time between the colliding objects is very short – for example, the contact time of a bat hitting a baseball is approximately 0.7 milliseconds (Nathan, 2000). Thus, there are two main ways to increase the force of an impact: by either increasing the impacting object's mass or by increasing its velocity (Bartlett, 2007). In sporting scenarios, the physical mass of an object cannot be changed; therefore, the concept of effective mass becomes very important with respect to increasing impact force.

2.2.1 Effective Mass

Effective mass can be described most simply as mass in motion (Lenetsky et al., 2015). Pinto Neto et al. (2007) defines effective mass as a measure of how much momentum the body is able generate and transfer to another object during a collision. The human body can be viewed as a compilation of individual moving segments such as the forearm, upper, and torso. Each segment contains rigid bones and soft muscles, tendons, and ligaments. The soft components will deform upon impact due to their elastic nature and will not be able to transfer forces as well as rigid masses would (Lenetsky et al., 2015). An example demonstrating this would be hitting a baseball with a bat (i.e., a hard, rigid structure) or with a pool noodle (i.e., a soft, pliable structure). The rigid bat can transfer more force onto the ball than the pool noodle, allowing the ball to fly faster and further. When muscles contract, tension increases and they become stiff, losing their elastic nature and thus being able to transfer higher forces. Thus, by contracting the muscles upon impact (e.g., during a punch or a kick), the effective mass of the striking object increases (Lenetsky et al., 2015).

The concept of effective mass can be used in all sports, although it has been most studied in combat sports such as boxing and MMA. In these sports, athletes attempt to strike the opponent as hard as they possibly can. By increasing the effective mass of a strike, one would be able to transfer more force onto the other object (Pinto Neto et al., 2007). To increase the effective mass delivered during a strike, increasing the number of muscles that contract is crucial. Of course, in a hand strike the muscles of the arm need to contract, otherwise the arm would bend and not transfer force to the other object. However, studies have found that it is also very important that the core musculature is activated during a strike (McGill, 2009). When the core activates, it forms a stiff structure from the fist, through the glenohumeral joint to the body's center of mass, ultimately enhancing the effective mass. Instead of striking with the mass of the arm alone, one can strike with the mass of the entire body, therefore creating more impact force (McGill, 2011). To further show the importance that core strength has on impact forces, Lee & McGill (2016) conducted a study where combat athletes underwent different core training programs for six weeks. Pre- and post-test for impact forces during different strikes were conducted for a dynamic training group, an isometric training group, and a control group. After the training program, both the core training groups were able to increase their striking forces by up to 18 % for a total of approximately 3000 Newtons of force in a simple jab. The evidence from this study supports the idea that core strength is important in increasing effective mass and impact force during ballistic strikes (Lee & McGill, 2016).

Another way to increase the effective mass is to increase the velocity of the mass at impact. Pinto Neto et al. (2007) observed differences in effective mass between martial arts athletes and a control group when examining hand speed during a palm strike against a basketball. The participants were asked to strike a basketball at rest as hard as they could while their lower bodies also remained stationary. The speed of the hand was calculated immediately prior to contact and ball speed was calculated immediately following impact. The authors reported that the martial arts group had average hand and ball speeds of 6.7 m/s and 9.0 m/s, and the control group had average hand and ball speeds of 5.0 m/s and 5.7 m/s, respectively. Hand speed was 32 % greater and ball speed was 57 % greater in the martial arts groups. As for overall effective mass during the strike, the mean effective mass was 97 % greater in the martial arts group than in the control group (2.62 kg and 1.33 kg, respectively). The professional martial arts athletes were able to increase the effective mass in ballistic maneuvers, ultimately creating larger impact forces (Pinto Neto et al., 2007). The implications on effective mass go beyond the realm of combat sports into other activities where striking other objects is involved, such as drumming.

2.3 Muscle Activation Strategy: The Double Pulse

In certain sporting scenarios, the goal is to create the most forceful and fastest movements to gain an advantage over the competition. In ballistic movements in sports, athletes strive to throw, kick, or strike as hard and as fast as they can. In martial arts, Pinto Neto at al. (2007) observed that professional athletes were able to increase striking velocity and effective mass to strike harder and faster compared to a control group. With the knowledge that professional martial artists create larger impact forces, McGill et al. (2010) conducted a study examining the muscle contraction profiles of MMA fighters using EMG. They were interested in examining exactly how these athletes contract their muscles to maximize effective mass and impact force. The study began with a practice session with a highly trained MMA coach who was extremely strong, quick, and proficient at kicking.

The investigators placed EMG electrodes on the rectus abdominis, internal obliques, external obliques, erector spinae, latissimus dorsi, gluteus maximus, gluteus medius, rectus femoris, and biceps femoris muscles to monitor the coach's muscle contraction patterns when delivering strikes and kicks. During these initial tests, McGill et al. (2010) observed a DPMA, which generated the hypothesis to be tested in their study: that a DPMA would be observed in other expert MMA fighters for the purpose of creating more forceful strikes. Five MMA fighters, all veterans of the Ultimate Fighting Championship, were recruited for the study. The participants were asked to deliver a variety of hand strikes and kicks to a bag; strikes that they believed would result in high velocity and high contact force (e.g., jabs, hooks, roundhouse kick, and spinning back kicks). The same muscle groups as those in the pilot study were monitored during all kicks and strikes. No statistical analysis was possible due to the design of the study. The purpose was simply to record muscle activity during a variety of striking movements and to explore interesting muscle activation patterns that emerged.

As hypothesized, the elite level MMA fighters exhibited the same DPMA when delivering a strike (Figure 3.). The kicks created a more distinct DPMA EMG profile than the strikes did. The erector spinae were the primary muscle showing a DPMA during a side kick. Muscles in the abdomen showed a similar DPMA along with other muscles in the surrounding area. Some muscles such as the latissimus dorsi contracted only during the movement initiation pulse, while others only contracted for the contact pulse (e.g., rectus

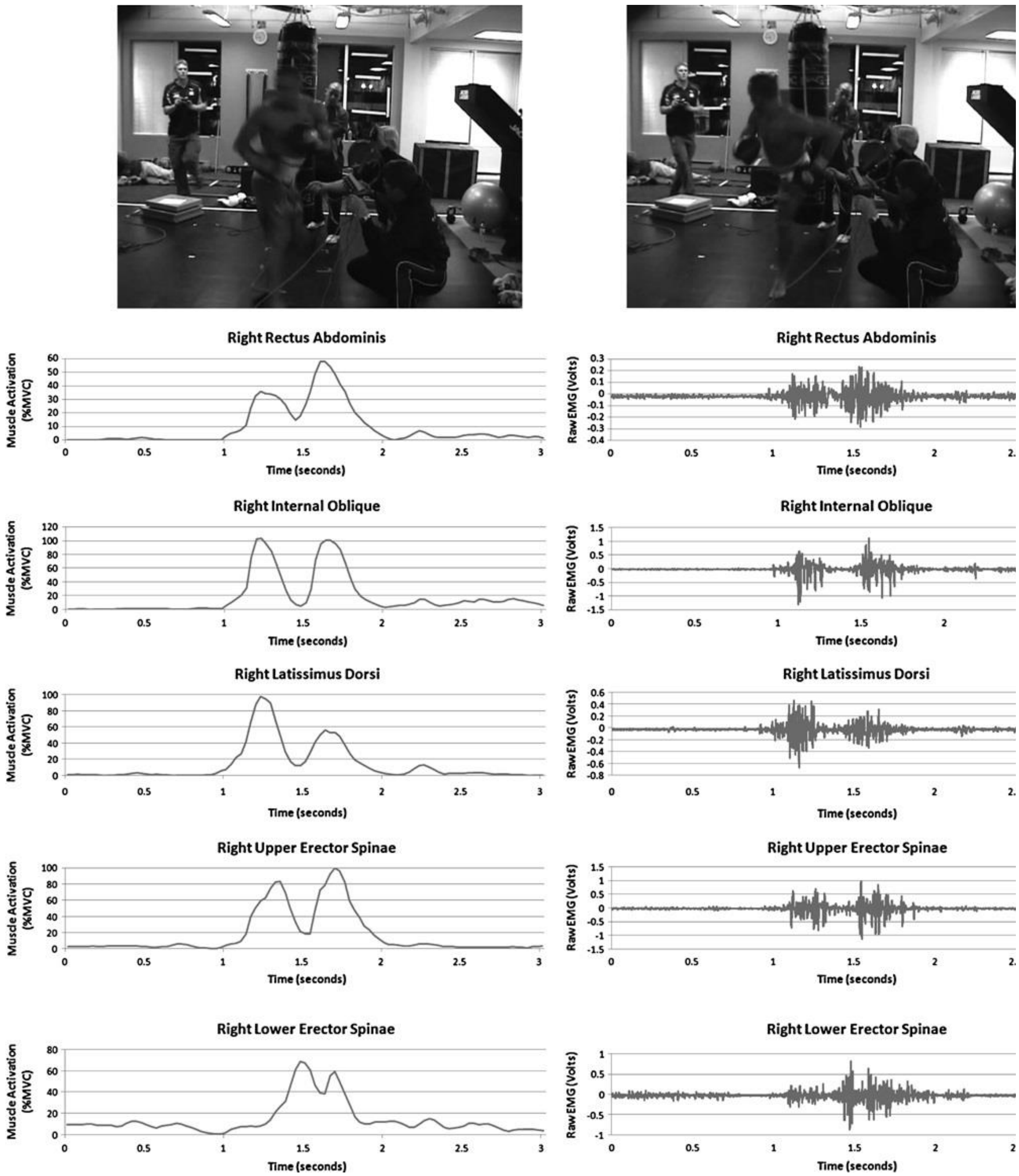

Figure 3. Double pulse during spinning back kick. Image: McGill et al., 2010. Used with permission.

abdominis). The DPMA was less pronounced in the hand strikes, particularly in the single punches, but was still observed in combination punches. The primary muscles showing the DPMA during hand strikes were the rectus abdominis and obliques.

McGill et al. (2010) explained that the first pulse was to initiate the striking movement and the second pulse was to stiffen the body during motion and enhance the effective mass upon contact. The relaxation in muscle activity between the two pulses was for the purpose of accelerating the limb. When the muscles contract, they become stiff and more tension is created, which will increase the resistance to the muscles changing speed and length. It is important that the muscles are not contracted so that the limb can accelerate faster towards the target (McGill, 2009). When the limb is moving at a faster velocity, this also increases effective mass and therefore, the strike force. This evidence shows that it is not only the rate of muscle contraction that is important to performance, but also the rate of muscle relaxation. The athlete whose muscles relax the fastest will be able to gain more velocity and increase the effective mass of the strike. What is more impressive is that these striking movements all occurred in a short time frame of only 300 milliseconds. McGill (2011) stated that faster muscle relaxation rates is one of the many features that separates elite athletes from novices. Matveev and Zdornyh (1981) reported muscle relaxation rates up to 8 times faster in elite athletes compared to non-athletes. It may be that the contraction-relaxation-contraction cycle of muscle activity determines elite performance by enhancing striking speed and force (McGill, 2011).

Elite MMA fighters are not the only group of athletes who make use of the DPMA phenomenon. McGill (2009) reported that this phenomenon also occurs in golfers when attempting to hit the ball with considerable force. After initiation of the downward swing of a drive, the torso muscles are relaxed until they contract rapidly at the instant of contact with the ball. Due to the relaxation, the club head travels at a faster velocity, thus allowing for increased contact force and a longer drive. Jobe et al. (1986) observed similar DPMA patterns in the rotator cuff muscles of professional golfers during a swing. Specifically, the pectoralis major (PM), the latissimus dorsi (LD), and subscapularis (SS) muscles were most responsible for execution of the golf swing. During the back swing, all the muscles were activated at very low levels. At the start of the forward swing to midway through, the PM, the LD, and the SS were the only muscles that elevated to moderate muscle activity. However, these three muscles further increased their activation levels before the moment of impact, thus increasing contact force and ball drive distance. Additionally, Silva et al., (2013) recorded temporal activity of trunk muscle activation in a golf swing using EMG. The muscles examined included the rectus abdominis (RA), the external oblique (EO), and the erector spinae (ES) muscles, and their findings were in line with those of McGill (2009). At the initiation of the downswing, muscle activation occurred and was followed by a relaxation period. Right before the moment of contact, the muscles contracted again. The DPMA was seen in the RA and the ES muscles. Peak muscle activity of the RA occurred between 170 ms and 130 ms before contact, whereas peak muscle activity of the ES occurred between 125 ms to 85 ms before contact. Silva et al. (2013) stated that the results of this study followed a pattern of maximal activity near the moment of impact as seen in other professional athletes. Overall, professional golfers appear to use the DPMA strategy in both the shoulder muscles and trunk muscles to enhance the performance of their golf swing.

Another sport where the DPMA phenomenon occurs is in baseball. This is understandable given that the very nature of the game is to throw as fast as you can and to hit the ball as hard as you can (most times). Gowan et al. (1987) detected differences in muscle activation patterns of professional and amateur baseball players when pitching.

EMG electrodes were placed on 12 different muscle groups in the shoulder area that were thought to assist in the performance of a baseball pitch. Ball velocity was also measured, with the professionals averaging pitching speeds of 68 miles per hour and the amateurs averaging 56 miles per hour. Overall, a distinction was seen in muscle activation strategies between both groups of participants. In the preparatory phase of the pitch, there were no significant differences between professional and amateur pitchers; all the same muscles activated at low intensities. The differences arose in the late phase of cocking, with the start of forward shoulder movement into the acceleration phase. During acceleration, amateur pitchers had strong muscle activation in most of the muscles around the shoulder including the supraspinatus (SS), infraspinatus (IS), biceps brachii (BB), subscapularis (SSc), and LD. However, in the professional pitchers, there was selective muscle activation during the acceleration phase. There was minimal activity in the SS, IS, and BB, and there was even greater muscle activity in the SSc and LD. Gowan et al. (1987) concluded that the professional pitchers were able to use the contraction-relaxation-contraction cycle in certain muscles to gain speed in the acceleration phase, while also very strongly firing the muscles that would aid in throwing faster. The amateur athletes did not have the ability to selectively turn on and off certain muscles; rather, they strongly fired nearly all muscles used in the task, leading to slower pitches.

The DPMA phenomenon has also been observed during baseball batting. Ball et al. (2019) examined the trunk muscle activation patterns of collegiate-level baseball players at different phases of a baseball swing. Based on the findings from McGill et al. (2011) and Silva et al. (2013), Ball et al. (2019) expected to observe a DPMA during batting. They did, in fact, observe the phenomenon in the RA and ES muscles, with the RA producing a more prominent DPMA. They found a first pulse at the initial movement swing toward the ball, a decrease in muscle activation during early to mid-swing, and then a second higher pulse at the instant of bat-to-ball contact. As with the other sports, the authors concluded that this muscle activation pattern served to increase the effective mass transferred into the object, resulting in stronger and more forceful actions.

It is clear from the studies described above that professional athletes have modified their muscle activations strategies to allow them to increase striking velocity by relaxing muscles during the acceleration phases of their movements. At the instant of contact, by contracting their muscles once again, the athletes also increase the effective mass of the striking implement, and therefore increase the power of the strike. This allows them to deliver harder blows, or throw faster, or hit a ball harder and further. If skilled drummers share many of the same physical attributes as elite athletes, is it possible that they also use the DPMA phenomenon during forceful cymbal crashes or louder dynamics?

2.4 The Biomechanics and Motor Control of Drumming

Although there is a large quantity of research on pianists and string instrumentalists (e.g., Wagner, 1988; Globerson & Nelken, 2013; Kelleher et al., 2013), there is very little research on the biomechanics and motor control of drumming. Most of the research on drumming involves playing the drums as a therapeutic treatment (e.g., Chong et al., 2016; Hill et al., 2019) or the role of drumming and its use within different cultures (e.g., Winkelman, 2003; Stone, 2005). The few studies that have been conducted on drummers have demonstrated the difficulty of the task and the exceptional changes to the control of the body that skilled drummers have undergone. It is important to review the knowledge gained from this research to shape the research to come.

One the first and most well-known researchers in this area is Shinya Fujii (Ph.D.), professor in the department of Environment and Information Studies at Keio University in Japan. Dr. Fujii's area of expertise is in the neuroscience and motor control of music performance. The first investigations he conducted on drummers (described in Section 2.1.2) assessed stick tapping performance for speed asymmetries and bimanual coordination (Fujii & Oda, 2006, 2009). The purpose of those studies was to indicate differences in these measures between drummers and non-drummers. The authors reported that the drummers had better control during repetitive tapping with drumsticks because of their training on the drums. As the research progressed, Fujii and colleagues attempted to explain the differences in performance measures using EMG to monitor muscle activation patterns. Fujii et al. (2009b) asked drummers and non-drummers to tap a drum pad as quickly as possible for ten seconds. The primary purpose of this study was to investigate the levels of muscle co-contraction between the flexor carpi ulnaris (FCU) and the extensor carpi radialis (ECR) muscles during repetitive tapping. Co-contraction was assessed using the relative difference signal (RDS) between FCU and ECR muscles (Fujii et al., 2009b). The difference between normalized EMG waves from the two muscles was calculated at each individual point in time, creating a third signal (i.e., the RDS). RDS values are scaled from negative one to positive one; closer to zero represented less difference between FCU and ECR muscle activity, indicating a higher level of co-contraction. Values closer to negative and positive one reflects larger differences in the muscles' EMG signals, indicating more reciprocal contraction.

A comparison of the RDS between the groups revealed three main findings. First, RDS values for the drummers clustered toward negative and positive one, indicating that the two muscles did not activate at the same time. RDS values for the non-drummers clustered towards zero, indicating that the muscles were often activated at the same time. Thus, non-drummers exhibited more co-contraction during repetitive tapping, whereas drummers used a more reciprocal muscle activation strategy. Second, within-participant variability in muscle activity was much smaller in drummers, indicating a more consistent performance. Lastly, and most importantly for the purpose of this thesis; drummers showed an earlier offset and a faster decline of muscle activity after onset. Mean muscle activation time in the FCU muscle for a single tap in drummers was approximately 60 milliseconds, whereas it was approximately 80 milliseconds for the non-drummers. Overall, the results suggested that with training, drummers have modified their muscle activation patterns to be more efficient, more consistent, and to perform more complex drumming patterns (Fujii et al., 2009b)

To further examine muscle activation modifications, Fujii and colleagues recruited the world's fastest drummer (WFD) to participate in their studies. Fujii et al. (2009a) conducted a study using the same methodology as Fujii et al. (2009b), but with the inclusion of the WFD. They found that the WFD could tap at a maximum frequency of 10 Hz, whereas the ordinary drummers (OD) and non-drummers (ND) reached a maximum tapping frequency of 7 Hz. Furthermore, the WFD had almost perfect symmetry between both hands, less variability in inter-tap intervals (ITIs), and even greater reciprocal muscle activation patterns than the ODs. Fujii & Moritani (2012) examined the features of the EMG waves of the WFD to possibly explain his fast and consistent tapping abilities. Specifically, the rise rate, the timing, and variability of EMG activity were the main variables of interest. When compared to the NDs and ODs, the WFD achieved a 150 %

faster tapping frequency and a 150 % faster rise rate in EMG activity. The timing and phase of the offset in EMG activity was also much sooner in the WFD. When comparing all three groups, the results suggested that the WFD was an extremely unique individual (Fujii & Moritani, 2012). However, after conducting a Spearman correlation analysis on years of drumming experience and EMG parameters while omitting the data from the NDs, the authors found that individuals with more years of playing experience revealed an earlier and faster EMG rise rate in the FCU and ECR muscles as well as an earlier decline in EMG activity. Longer playing experience was also associated with lower variability in time at maximum EMG rise rate in the FCU and ECR. In this study, there was a large range of drumming experience (3 to 41 years), with the WFD having the most. Fujii & Moritani (2012) explained that with continual practice, the speed of voluntary muscle contractions and relaxations can increase by altering motor unit recruitment and discharge rates. The body learned to discharge action potentials down motor neurons faster, in order to activate the motor units for muscle contraction more quickly. Thus, with more years of playing experience, drummers can achieve faster and more stable stick tapping performance due to their faster increases in muscle activity.

As described in Section 2.1.2, Dahl (2005) reported that drummers increased both preparatory height and striking velocity when delivering an accent stroke while maintaining perfect timing. To further the results, Dahl et al. 2011 built upon the earlier study with the addition of measuring impact force and duration, and sound level. The purpose was to further investigate how drummers control the dynamic level of their drumming. Four right-handed professional percussionists participated in this study. They were asked to play repeated single strokes at different tempi (50, 120, and 300 bpm) and dynamic levels (*piano*, *mezzo-forte*, and *forte*, i.e., ‘soft’, ‘moderately loud’, and ‘loud’: Farrant, 2020). Striking velocity was recorded using a motion capture system with markers placed on the tip of the drumstick, index finger, outer and inner wrist, elbow, and shoulder. Contact forces were measured using two strain gauges glued to the stick. To measure contact time, a thin layer of copper foil was placed on the tip of the drumstick and thin layer of graphite was sprayed onto the drumhead forming an electrical circuit between the two objects. When the foil contacted the conductive layer of the drumhead, the electrical system would close, and this would register in the data collection system as a contact. Finally, dynamic level was recorded with a high-quality omnidirectional condenser microphone. For each trial, the investigator indicated which dynamic level to play and used a metronome to set the tapping frequency. The authors found that the louder the dynamic level, the higher the participants’ preparatory heights became. Preparatory height ranged from 10 cm to 60 cm as the dynamic level increased. Furthermore, with an increase in preparatory height, striking velocity also increased. At the lowest dynamic level, striking velocity was in the range of 1-2 m/s, and at the highest dynamic level, striking velocity was in the range of 8-12 m/s. There was a nearly perfect linear relationship between dynamic level, preparatory height, and striking velocity (Dahl et al., 2011). There was also an inverse relationship between contact force and contact duration. At higher striking velocities, there was an increase in contact force and a decrease in the duration of contact on the drumhead. Thus, professional drummers use preparatory height to control striking velocity and dynamic levels all while maintaining a consistent tempo (Dahl et al., 2011).

Recently, González-Sánchez et al. (2019) also investigated striking velocity in drumming. The goal of the study was to investigate movement fluency while performing in professional and amateur drummers. Fluency was assessed by quantifying smoothness and coordination of movements and was measured using motion capture and EMG. The participants, one professional and two amateur drummers, were asked to perform a single stroke roll (i.e., alternating hand single strokes) with a gradual increase in tempo until reaching maximum speed. After the task was complete, the authors were able to calculate the impact velocity using the motion capture recording. The ITI at the slowest tempo was approximately 1 second and decreased gradually to almost 0.1 seconds at the fastest tempo possible. As the tempo got faster, the striking velocity got slower due to the closing of the range of motion: to continue tapping at faster speeds, the participants lowered the preparatory height for the next hit. Although Dahl et al. (2011) conducted trials at various tempi, they made no comments on the relationship of strike velocity or preparatory height and tempo. Interestingly, at all tempi, the striking velocity for the professional drummer was always faster than the two amateur players, despite the equal amount of time between strokes (González-Sánchez et al., 2019). At the slowest tempo, velocity was approximately 6 m/s for the professional and 3-4 m/s in the amateurs. At the fastest tempo, velocity decreased to 4.5 m/s for the professional and 2.5 m/s for the amateurs. The authors also used EMG to record muscle activity during the task, and the EMG profiles were subjected to a principal component analysis to assess co-articulation from burst patterns across strokes. However, no comment on the shape of the signal was made to explain the differences in striking velocity of the participants. Overall, EMG was used to indicate that the professional drummer did in fact have smoother and less variable movements than the two amateur drummers while creating higher striking velocity.

To date, research on the motor control and biomechanics of drumming is very limited. The studies described above and in Section 2.1.2 have begun to describe the coordination and movement strategies of drummers when performing repetitive tapping. However, although EMG was used to observe muscle activation patterns during fast repetitive drumming (Fujii et al., 2009a; Fujii et al., 2009b), no studies have used EMG to observe muscle activation patterns during single high velocity impacts (e.g., cymbal crashes). Furthermore, no studies have monitored the activity of the proximal upper arm muscles or the torso muscles, which are most likely to be responsible for producing forceful strikes. The limited existing research suggests that skilled drummers have modified EMG profiles showing increased rates of contraction and relaxation (Fujii & Moritani, 2012; Fujii et al., 2009a). Drummers need to be able to strike the drums or cymbals with more force for more dramatic/higher volume impacts. Thus, drummers could benefit from using a DPMA playing strategy to create larger impact forces. However, to date no one has examined drummers' EMG profiles for the presence of the DPMA.

2.5 Summary

The drums have changed from a simple stamping pit to the modern drum kit used today. The drums play the very important role of keeping time and rhythm in all genres of today's music. Drummers must be able to coordinate all four of their limbs to play the various drums and cymbals in a controlled and precise manner with varying dynamic levels. Drummers are very similar to athletes with respect to the metabolic demands and physical attributes required to play the drums at the elite levels. The metabolic demands of playing the drums during a professional, live performance are comparable to those exhibited by professional soccer players during competitive match play. Skilled drummers are also like athletes due to their increased speed, coordination, precision, consistency, and ability to detect errors in their performance. In many areas of sport, the goal is to create as much force as possible to strike, throw, or kick faster and harder. One way to accomplish this is to increase the effective mass of the striking limb to create larger impact forces. In combat sports, the top athletes can increase the effective mass of their limbs by engaging the core musculature, forming a link of stiff muscle from the core to the distal limb. To achieve this, MMA fighters produced a DPMA when delivering a strike. The first contraction is used to stabilize the body and to initiate the movement. The relaxation period following the first contraction allows the limb to accelerate, which increases the velocity of the strike. The second contraction increases the effective mass of the limb during the impact by forming a kinetic chain with the core, which, combined with the increased limb velocity, leads to more forceful strikes being delivered to the target. The DPMA has also been observed in golfers and baseball players. From the existing research on the biomechanics and motor control of playing the drums, it is evident that skilled drummers have modified muscle activation patterns and motor control systems, which enhances their performance compared to novices and non-drummers. Drummers can play faster with less variability and are able to deliver harder and louder strikes than non-drummers. Drummers may benefit from the use of the DPMA strategy to create faster and more forceful strikes more efficiently on the drums, but to date this has not been demonstrated in the research literature.

CHAPTER 3: METHODS

3.0 Target Population

The participants for this study were highly skilled drummers who play a drum kit like the one described in Section 2.0. A multiple case study design (N = 3) was used to allow an in-depth investigation of each participant's EMG patterns and to qualitatively compare muscle activation patterns between subjects. The participants for this study were highly skilled drummers who are professionally established (e.g., touring/recording artists, or those who regularly perform in public). Rock drummers were preferred due to the high physiologically demanding style of drumming (Azar, 2021; De la Rue et al., 2013) but drummers of all genres were eligible to participate. The participants must have been a minimum of 18 years of age or older, and they must have been free from injuries that prevented them from playing the drums at their accustomed level of proficiency for at least 30 days. If they had sustained such injuries within the last 12 months, they were still eligible to participate if they had returned to their pre-injury/ailment drumming skill and intensity levels for at least 30 days. They must have predominantly used a closed hi-hat/snare drumming pattern (i.e., in a right-handed drum kit, the hi-hat is played with the right hand and the snare drum is played with the left hand). All participants also needed to be fully immunized against COVID-19 as per the University of Windsor's mandated vaccination policy for students, employees, and visitors. Exclusion from this study occurred if the participant was less than 18 years old, was not a touring/recording artist or did not regularly perform in public, was currently injured or had been injured within the last 12 months and had not returned to their pre-injury playing intensity and skill levels for at least 30 days, was not willing or able to travel to the study location at the University of Windsor, and/or was not fully vaccinated against COVID-19. Drummers were also excluded from the study if they were not able to successfully perform the drum pattern described in Section 3.3. All participants read and signed an informed consent form prior to participating in the study. All study procedures were reviewed and cleared by the University of Windsor's Research Ethics Board (REB #: 21-065) before commencement of the study.

3.1 Participant Recruitment

Participants were recruited through social media, an email list developed by the research supervisor from past studies involving drummers, and by word of mouth. Interested individuals contacted the investigator through email. An email containing a copy of the letter of information was sent to the participant, the investigator screened participants for inclusion and exclusion criteria, and a mutually agreeable day and time for data collection was arranged via email communication. The participants were also asked to shave the areas where the electrodes were placed, if necessary (see Section 3.3).

3.2 Instrumentation

EMG was used to monitor the electrical activity of the selected muscles (listed in Section 3.3). Self-adhesive silver/silver chloride surface EMG electrodes (Ambu Blue Sensor, N-00-S; King Medical, King City, Ontario, Canada) were placed in a bipolar configuration over the selected muscles. The signal was recorded with a differential alternating current amplifier with a common mode rejection ratio of 115-db (at 60 Hz), a gain capability of up to 15,000, and a 10 to 1,000 Hz analog band-pass filter (model AMT-8; Bortec Biomedical Ltd, Calgary, Alberta, Canada). The raw EMG signals were stored on a computer after being digitized at a sampling rate of 2,048 Hz through a 16-bit analog-to digital conversion card (NI USB-6216; National Instruments, Austin, TX). A reference (ground) electrode was placed over the spinous process of vertebra C7. All electrode preamplifiers were secured to the skin using medical-grade tape (Hypafix; BSN Medical, Hamburg, Germany) to prevent movement artifacts from appearing in the EMG signal.

All trials were video recorded at 30 Hz using two GoPro cameras to obtain a sagittal and a high angle frontal view (Figure 4). The videos were synchronized with the EMG signals so that observations made in the EMG signal could be associated with specific actions taken by the participants during the drumming pattern. Videos were synchronized with the EMG signals using a light signal in view of the camera that sent a pulse to the EMG system when the light was on. The EMG and light signals were acquired using

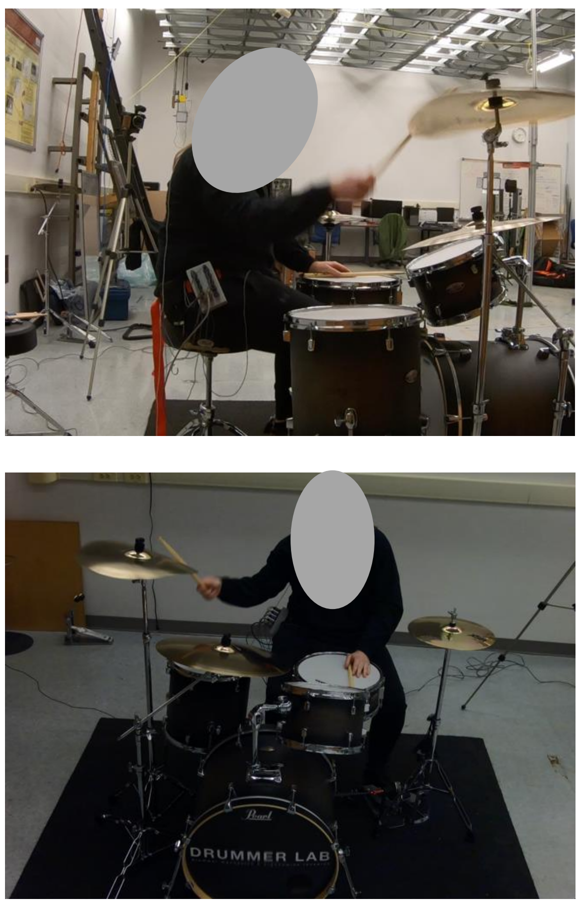

Figure 4. Sagittal (top) and high angle frontal (bottom) view of GoPro cameras.

customized LabView software (2012, National Instruments, Austin, TX). All trials were also audio recorded at 50 Hz on a Samsung Galaxy S20 FE (Android 12, One UI 4.1) using the Decibel X application (9.0.0, SkyPaw Co., Ltd) to obtain sound level readings of the participants playing.

All participants used the drum kit in the Drummer Mechanics & Ergonomics Research (DRUMMER) Lab (Figure 5). The kit includes Pearl Drums Decade Maple Series shells, consisting of a 14” snare drum (A), 22” bass drum (B), 12” and 14” rack toms (C), and a 16” floor tom (D). Evans UV2 series drumheads cover all the drums. The drum kit also contains Sabian XSR cymbals including 14” hi-hats (E), 16” and 18” crashes (F), and a 20” ride cymbal (G). The hardware includes the Pearl Drums HWP-830 package with P930/931 Longboard bass drum pedal and double-pedal conversion kit. Participants were asked to bring their own drumsticks to play with on their scheduled day of investigation.

3.3 Procedures

The investigator met the participants at the East Entrance of the Human Kinetics building and led the participants to the data collection room (HK 242). Once in the room, the study procedures were reviewed, and the participants were able to ask any question before signing the informed consent form (Appendix A). The participant then completed a short intake survey that included questions about participant demographic information (e.g., age, preferred gender pronouns, etc.), playing history, injury history, and performance style (Appendix B).

The locations of EMG electrodes placement were shaved (if necessary and if the participant did not do so ahead of time), cleaned with rubbing alcohol, and lightly abraded using a paper towel. The purpose of these procedures was to enhance the adhesion of the

Figure 5. DRUMMER Lab drum kit.

electrodes to the skin and to improve the electrical conductivity of the skin (Bartlett, 2007). EMG electrodes were placed 20 millimeters apart (Bartlett, 2007) on the selected muscles, as follows:

- Triceps brachii (long head) (TB): two finger widths medial and half-way down the line between the posterior crista of the acromion and the olecranon (Davis, 1959),
- Deltoideus posterior (DP): centered in the area two finger breadths behind the angle of the acromion (Perotto at al., 2011),
- Flexor carpi ulnaris (FCU): one third the distance from the medial humeral epicondyle in line with the styloid process of the radius (Davis, 1959),
- Extensor carpi radialis (ECR): one third the distance from the lateral humeral epicondyle in line with the styloid process of the radius (Davis, 1959),
- Rectus abdominis (RA): two centimeters lateral to the navel (McGill et al., 2010),
- Latissimus dorsi (LD): over the muscle belly below the inferior angle of the scapula (McGill et al., 2010)
- Erector spinae (ES): approximately 5 centimeters lateral to the spinous process of T9 (McGill et al., 2010),
- Teres major (TM): three finger breadths above the inferior angle of the scapula along the lateral border (Perotto et al., 2011).

The long head of the TB was selected for its function to extend the lower arm at the elbow and the DP, TM, and LD muscles were selected because their functions are to extend the shoulder (Davis, 1959; Perotto et al., 2011), which is needed during the downward crash movement. The FCU, ECR, RA, and ES muscles were selected so that qualitative comparisons could be made with other studies (e.g., Fujii et al., 2009b; McGill et al., 2010).

Muscle activity was only recorded from the dominant side. Approximate locations of electrode placements can be seen in Figure 6.

After EMG instrumentation set-up was complete and proper function was verified, as resting baseline trial conducted to quantify the noise in the signals. For this trial, the participant laid supine on a massage table and were asked to relax as much as possible and lie still for two minutes. After the baseline was collected, the participants adjusted the drum-kit to their preference and were asked to play for 5 minutes as a warmup. After the participants were sufficiently warmed up, the videos cameras began recording and all the trials occurred in the following order: begin recording EMG signals, activate the light signal in view of the cameras three times, begin recording sound levels, then the participant began playing. The video camera recorded continuously through all trials, but the EMG data and light on/off signal for each trial were saved as individual files. Three maximum voluntary exertion (MVE) trials of the participant crashing on a cymbal were recorded for signal normalization purposes. For these trials, the participants were asked to strike the crash cymbal on the right side of the drum kit with their right hand as hard as they could.

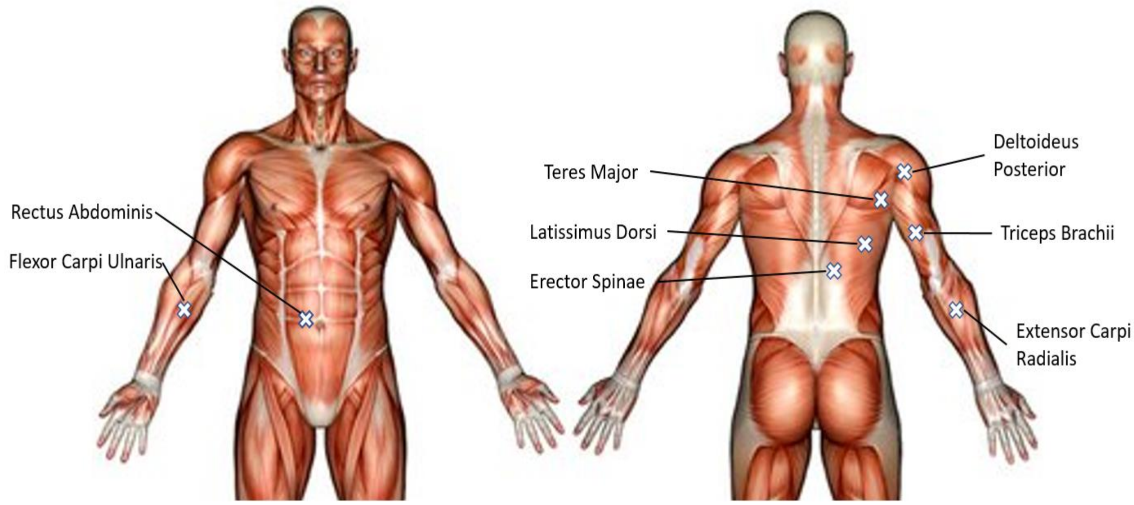

Figure 6. Electrode placement locations. Image adapted from Vector Cliparts, 2015: Pixy.Org, CC BY-NC-ND 4.0.

Next, the participants played the specified drum pattern (Figure 7). The eight-bar pattern consisted of steady eighth notes on the hi-hat over a count of four (played with the right hand), resulting in eight hi-hat impacts per bar (counted as “one and two and three and four”). The snare drum was struck with the left hand on beats two and four. The bass drum was played on beat one with a single foot kick and then with three consecutive foot kicks on the 'and three and' of the beat. The crash cymbal was played on the first beat (i.e., the “one”) of each eight-bar pattern; this is where the DPMA was expected to appear.

This beat was designed to mimic typical rock drumming while being simple enough for drummers to play without producing undesirable tension, but also still requires energy and

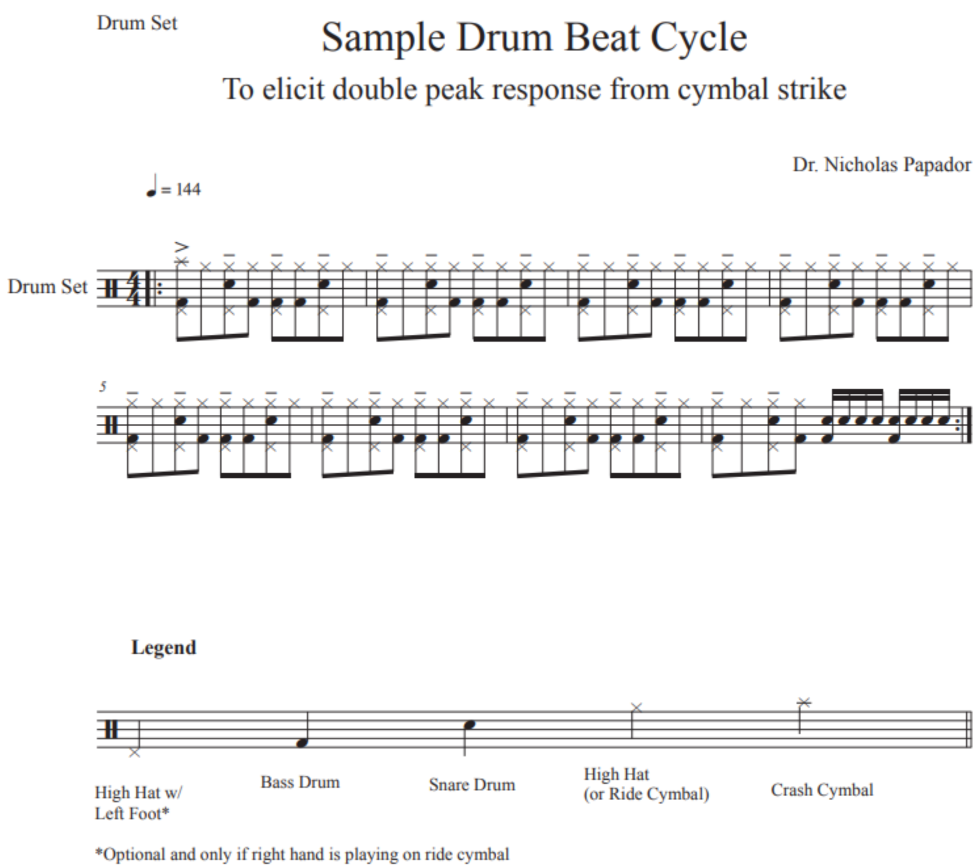

Figure 7. Sample drum beat cycle. Image by Dr. N. Papador (October 11, 2020). Used with permission.

stamina. The participants played this pattern at a tempo of 144 bpm, and they repeated this pattern a total of 10 times, producing 10 individual cymbal crashes. For all participants, the crash cymbal was positioned such that the participants were required to flex and abduct their shoulders to reach it (see Figure 4). The last trial, termed the "free-play", consisted of the participant playing whatever they want (i.e., improvised patterns and fills, or part of a song) for two minutes so that muscle activation patterns could be observed in more authentic playing conditions. After data collection was complete, the electrodes and tape were removed, and the participant's skin was cleansed with water. The investigator then led the participant out of the building.

3.4 Data Processing

The mean of each raw EMG signal was calculated and subtracted from the signal to ensure it fluctuated around a mean of zero. The "zeroed" EMG signals were high-pass filtered at 250 Hz, full-wave rectified, and then low-pass filtered with a dual-pass, first order, low-pass Butterworth filter with a cutoff frequency of 2 Hz to create a linear envelope (Potvin & Brown, 2004; Staudenmann et al., 2007). The root-mean-square (RMS) amplitude of the filtered resting baseline trial (i.e., signal noise estimate) was then subtracted from every data point of the filtered MVE, pattern, and free-play trials. All trial signals (except the resting baseline) were normalized to the peak amplitude found in the MVE trials, pattern trials, or free-play trials (whichever was largest). Finally, the normalized EMG signals and the light signal were down sampled to 30 Hz using a spline interpolation algorithm to match the frame rate of the video cameras. All EMG data were processed using customized LabView software (2021, National Instruments, Austin, TX).

The extreme high-pass filter functioned to remove lower frequency signals such as 60 Hz electrical noise, electrocardiographic contamination, and movement artifacts (Staudenmann et al., 2010). High-pass filtering has also been shown to improve the precision of EMG amplitude estimates and representativeness of deep and superficial motor units, such that the contribution of deep motor units is more present in the signal when high-pass filtering (Staudenmann et al., 2010). Although this study did not estimate muscle force, drumming requires very forceful movements, therefore, having more precise EMG signals is important when examining filtered signals for DPMAs. Staudenmann et al. (2010) recommended that the optimal low pass-pass filter for rectified EMG signals for muscle force is 2-3 Hz and Potvin & Brown (2004) recommend a low-pass filter surrounding 2 Hz, therefore, a 2 Hz cutoff frequency was chosen. The dual-pass filter removed the phase shift created by the first pass of the filter, which is crucial when synchronizing video and EMG to make observations (Winter, 2009).

The EMG signals were synchronized to the video by using the electrical signal from the light source. The light transmitted a signal to the EMG system and was simultaneously visible in both camera views. For each trial, the first frame where the light was visibly on was located within each video, and the corresponding instant in the down sampled light signal was also located. The videos and the EMG signals were trimmed to include only the frames following the onset of the light signal. By doing so, the EMG and video were synchronized, and specific patterns observed in the EMG signal were able to be associated to specific moments in the video recording.

3.5 Data Analysis

The purpose of this study was to obtain a "proof of principle" of the muscle activation patterns of drummers during high-impact crashes, and not to quantitatively compare differences between subjects. Therefore, no statistical analysis was performed on the data. The root-mean-square (RMS) amplitude of the filtered, rectified baseline trials was calculated and compared to acceptable standards from the literature to ensure that the noise in the signals was minimal. Konrad (2005) states that the averaged baseline noise should not be greater than 3-5 μV and that 1-2 μV should be the target.

3.51 Determination of the Presence of a DPMA

The investigator examined each filtered and normalized trial (including MVEs) for the presence of a DPMA, and its presence (or absence) was noted for each muscle and for each participant. First, a visual inspection of the signals at the instant of the crash was used to see if DPMAs were evident. Next, standards for the minimum absolute change in %MVE for the peaks and valley of the DPMA were set to examine the use of objective criteria for defining what constitutes a DPMA. When examining visual traces from previous DPMAs (McGill et al., 2010), an absolute difference of approximately 20 %MVE between DPMA peaks and valley appeared to be the most common minimum occurrence for traces that were deemed to contain a DPMA. Criteria of absolute differences of >10 % and >5 % were also selected to explore which criteria might best match the visual inspection for categorizing DPMAs. Therefore, criteria of absolute differences >5 %, >10 %, > 20% were used to determine what standards matched more accurately to the visual inspections. In applying these criteria, the determination of whether a potential DPMA met each criterion was based on the %MVE change between the lower of the two peaks and the valley, so that both peaks would meet the criterion (Figure 8).

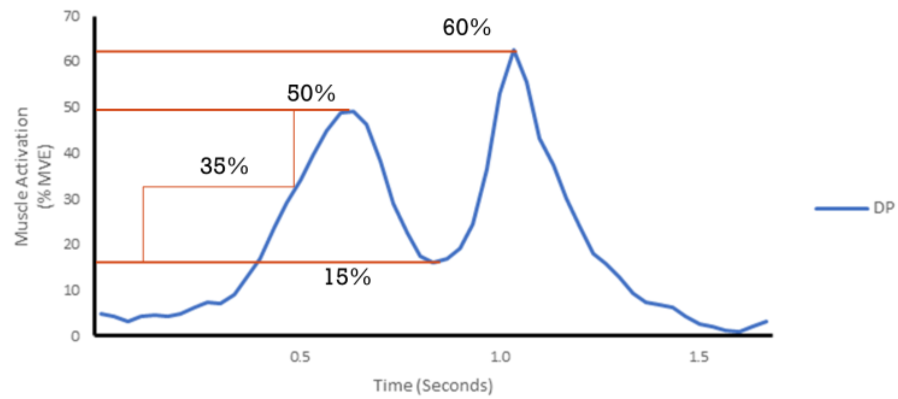

Figure 8. Example of DPMA criterion categorization calculation. In this example, the absolute difference between the lowest of the two pulses and the valley is approximately 35 %MVE, meaning this DPMA would meet all three criteria.

Finally, some of the EMG traces from the MVE, pattern, and free play trials containing DPMA waveforms were selected for further review. These traces were examined in conjunction with the video so that observations could be made regarding the profile of the EMG signals at the instant of the high impact crash, and to confirm whether the timing of the DPMA matched the timing of the participants' crash motions. Three crashes from the pattern trial exhibiting the most obvious DPMAs were chosen to analyze with the video. Due to the repetitive nature of the pattern, not all crashes were deemed necessary to analyze. The crashes that exhibited DPMAs that met the >10% and >20% criteria in the most muscles were chosen for video analysis. For the purposes of this study, the two pulses of the DPMA waveform must have associated with the same crashing motion to be considered a "true" DPMA.

3.5.2 Inter-rater Reliability Analysis

An inter-rater reliability analysis was conducted to determine the degree to which visual inspection of EMG signals for DPMAs would yield similar results among different raters. Filtered EMG traces from the MVE trials of all participants was first inspected by the primary investigator and given a yes (YES), no (X), or inconclusive (--) rating. An inconclusive rating could have been given for many reasons, such as uncertainty to the change in percent MVE or the association of the trace to the movement. The same traces were then given to a second rater who was blinded to all aspects of the signals. They had no information regarding the subject, the muscles from which the EMG trace originated, the time course, or the magnitude of the signal. They would simply say yes or no to the presence of a DPMA solely based on the shape of the waveform. A percentage agreement (P_a) was determined by calculating the quotient of matching responses (M_r) to the presence/absence of a DPMA and the number of waveforms (W) inspected, using the following equation:

$$P_a = M_r/W \times 100 \qquad \text{Eq. (1)}$$

CHAPTER 4: RESULTS

4.1 Participants

Three adult male drummers (ages: 24 to 37 years) participated in this study. The means and standard deviations of the intake survey data (i.e., age, start age of playing drums, weekly playing hours, and average paying session duration) across the three participants are presented in Table 1. The participants' data have been de-identified and therefore, participants will be referred to as Drummer A-C, and he/him pronouns will be used. The results for the three participants are reported separately (i.e., case study format) and group results are reported in the last section of this chapter.

Table 1. Summary of demographic data across all participants. Values in brackets are the standard deviations.

Current Age (years)	Average Age of Playing Onset (years)	Average Weekly Playing Time (hours)	Average duration of playing session (hours)
31.3 (5.4)	13.0 (1.4)	9.0 (2.9)	1.6 (0.4)

4.2 Drummer A

4.2.1 Intake Summary

Drummer A is a 33-year-old male drummer in the rock genre who started playing the drums at 12 years of age. He has been teaching drum lessons for 17 years, performing up to four times a week for 14 years, and has been a touring drummer for the last three years. He is right-hand dominant, uses a matched grip style, plays with a closed hi-hat/snare pattern, and uses a single bass drum kick pedal. He plays an average of 12 hours/week in two-hour playing sessions. He has taken formal drum lessons for five years and he has been playing for more than five hours/week for 20 years. He had not sustained any injuries within the last 12 months which prevented him from playing to the intensity and skill levels to which he is accustomed. Drummer A used Vater Los Angeles 5A drumsticks for this study.

4.2.2 Muscle Activation Patterns

The mean RMS amplitude of the filtered baseline signals for all eight muscles was 1.8 ± 0.5 μV (range: 1.2 – 2.4 μV). These baseline RMS values fall within the ideal range provided by Konrad (2005). The peak values for most of the muscles occurred during the free play trial. The exceptions were the DP and LD muscles, where the third MVE trial (i.e., 'MVE 3') produced the peak value. The signals were first visually inspected for the presence of a DPMA and then the percent change between the lowest pulse and valley was calculated for each muscle where a DPMA was believed to be present. All DPMAs that met at least the >10 % criterion underwent video analysis to identify which motions the pulses were associated with. Table 2 presents the results of the DPMA inspection for

Table 2. Drummer A DPMA observations for MVE trials. The DP and TM muscles met the >20 % criterion while the LD and TB muscles met the >10% criterion, with all DPMAs being confirmed with video analysis ('YES': DPMA present, 'X': DPMA not present, '--': inconclusive).

Trial	Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
MVE 1	Visual	YES	YES	X	X	YES	YES	X	--
	5%	YES	YES	X	X	YES	YES	X	YES
	10%	YES	YES	X	X	YES	YES	X	X
	20%	X	X	X	X	YES	YES	X	X
	Video Analysis	YES	YES	X	X	YES	YES	X	X
MVE 2	Visual	YES	X	X	--	YES	YES	X	--
	5%	YES	X	X	YES	YES	YES	X	X
	10%	X	X	X	X	YES	YES	X	X
	20%	X	X	X	X	X	YES	X	X
	Video Analysis	X	X	X	X	YES	YES	X	X
MVE 3	Visual	--	--	X	X	YES	YES	X	X
	5%	YES	YES	X	X	YES	YES	X	X
	10%	X	X	X	X	YES	YES	X	X
	20%	X	X	X	X	YES	X	X	X
	Video Analysis	X	X	X	X	YES	YES	X	X

Drummer A during the MVE trials. DPMAs occurred most frequently in the DP (Figure 9) and TM; both of which exhibited DPMAs that met the >10 % criterion in all three MVE trials and the >20 % criterion in two trials. The LD exhibited DPMAs that met the >5 % criterion in all three trials, one of which also met the >10 % criterion. The TB exhibited two DPMAs that met the >5 % criterion, one of which also met the >10 % criterion. The RA and ECR each displayed one DPMA that met the >5 % criterion but were inconclusive upon visual inspection. The ES and FCU did not display a DPMA in any MVE trial. Under video analysis, the DPMAs for the LD, TM and DP all occurred at similar instances and were all associated with the same shoulder extension whereas the DPMA for the TB would occur slightly later, at the beginning of elbow extension. The first pulses occurred near the height of arm elevation, and the second pulses occurred right before the moment of impact with the cymbal (Figure 10). A peak decibel reading of 101.0 dB was recorded during the MVE trials, which exceeded the forte dynamic level (80 dB) that was aimed for in this study (Rath, 2010).

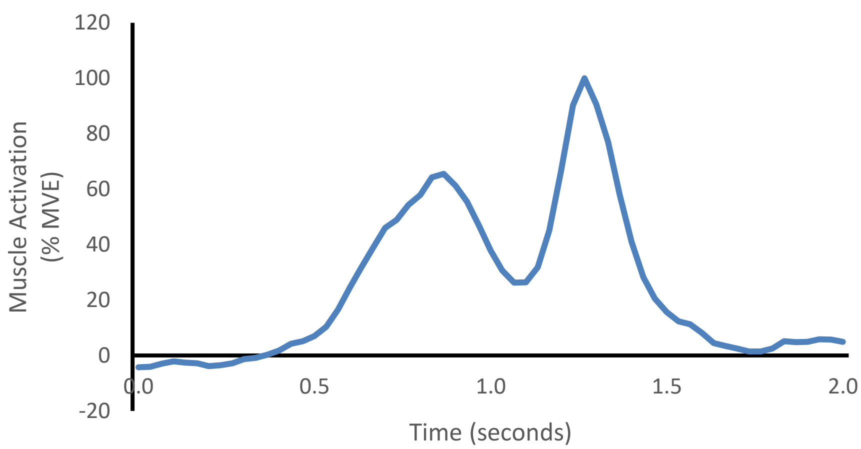

Figure 9. DPMA waveform in the deltoideus posterior of Drummer A during the MVE 3 trial. Each pulse lasted approximately 0.5 seconds with >20 % change in MVE between the lowest peak and the valley.

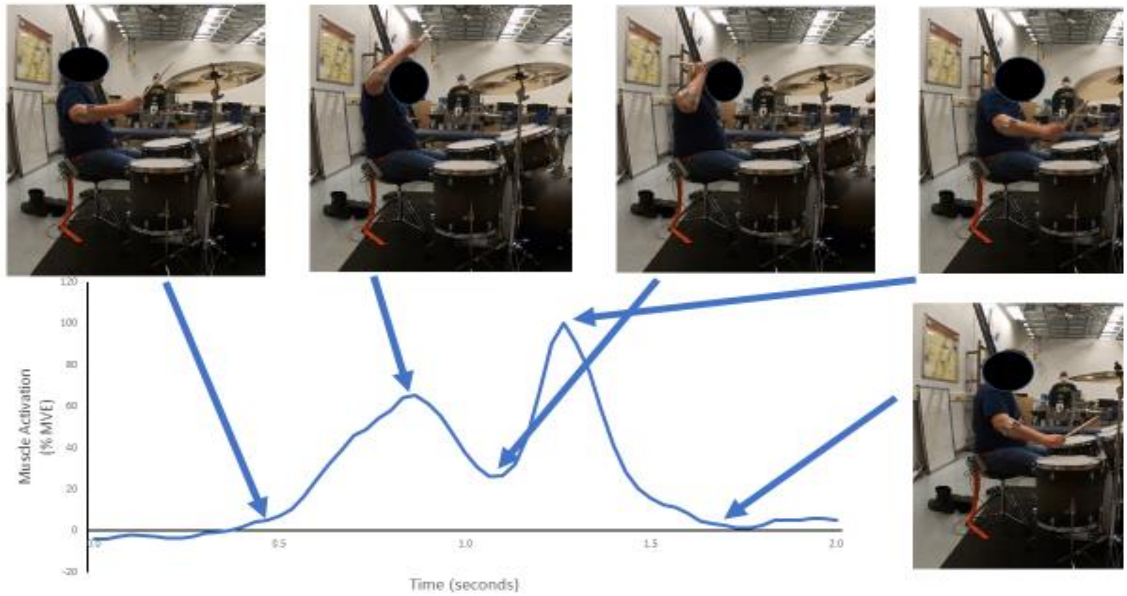

Figure 10. Video frames associated with key moments of the DP muscle DPMA of Drummer A during the MVE 3 trial. The first pulse occurred near the time of peak shoulder flexion and the second occurred near the time of impact with the crash cymbal.

Due to technical difficulties, Drummer A had to perform the pattern trial four separate times with breaks in between. The pattern was repeated nine times and 10 crashes were recorded. When examining the EMG traces for all eight muscles, possible DPMAs appeared in the TB, DP, and TM muscles (Table 3). No DPMAs were observed in the LD, ES, or RA muscles. The substantial muscle activity observed in the FCU and ECR muscles made observing DPMAs during the cymbal crashes unachievable. Examples of the FCU and ECR muscle EMG traces can be observed in Figure 11. The DP exhibited the most DPMAs across the nine repetitions, with five that met the >10 % criterion and two that were inconclusive upon visual inspection but met the >5 % criterion. The TM exhibited three DPMAs that met the >10 % criterion and two that were inconclusive upon visual inspection but met the >5 % criterion. The TB exhibited two DPMAs that were

Table 3. Drummer A DPMA observations for pattern trial. DPMAs occurred most frequently in the DP and TM muscles but video analysis confirmed that the timing of the first pulse was not associated with the crashing ('YES': DPMA present, 'X': DPMA not present, '--': inconclusive).

Trial	Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
Crash 1	Visual	X	X	X	X	X	X	X	X
	5%	X	X	X	X	X	X	X	X
	10%	X	X	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 2	Visual	X	--	X	X	X	X	X	X
	5%	X	YES	X	X	X	X	X	X
	10%	X	YES	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 3	Visual	X	X	X	X	YES	YES	X	X
	5%	X	X	X	X	YES	YES	X	X
	10%	X	X	X	X	YES	YES	X	X
	20%	X	X	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 4	Visual	X	X	X	X	YES	--	X	X
	5%	X	X	X	X	YES	YES	X	X
	10%	X	X	X	X	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 5	Visual	X	X	X	X	--	YES	X	X
	5%	X	X	X	X	YES	YES	X	X
	10%	X	X	X	X	X	YES	X	X
	20%	X	X	X	X	X	X	X	X
Crash 6	Visual	X	X	X	X	YES	--	X	X
	5%	X	X	X	X	YES	YES	X	X
	10%	X	X	X	X	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 7	Visual	X	--	X	X	YES	X	X	X
	5%	X	YES	X	X	YES	X	X	X
	10%	X	YES	X	X	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 8	Visual	X	--	X	X	YES	X	X	X
	5%	X	X	X	X	YES	X	X	X
	10%	X	X	X	X	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 9	Visual	X	--	X	X	X	X	X	X
	5%	X	X	X	X	X	X	X	X
	10%	X	X	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 10	Visual	X	--	X	X	--	YES	X	X
	5%	X	X	X	X	YES	YES	X	X
	10%	X	X	X	X	X	YES	X	X
	20%	X	X	X	X	X	X	X	X

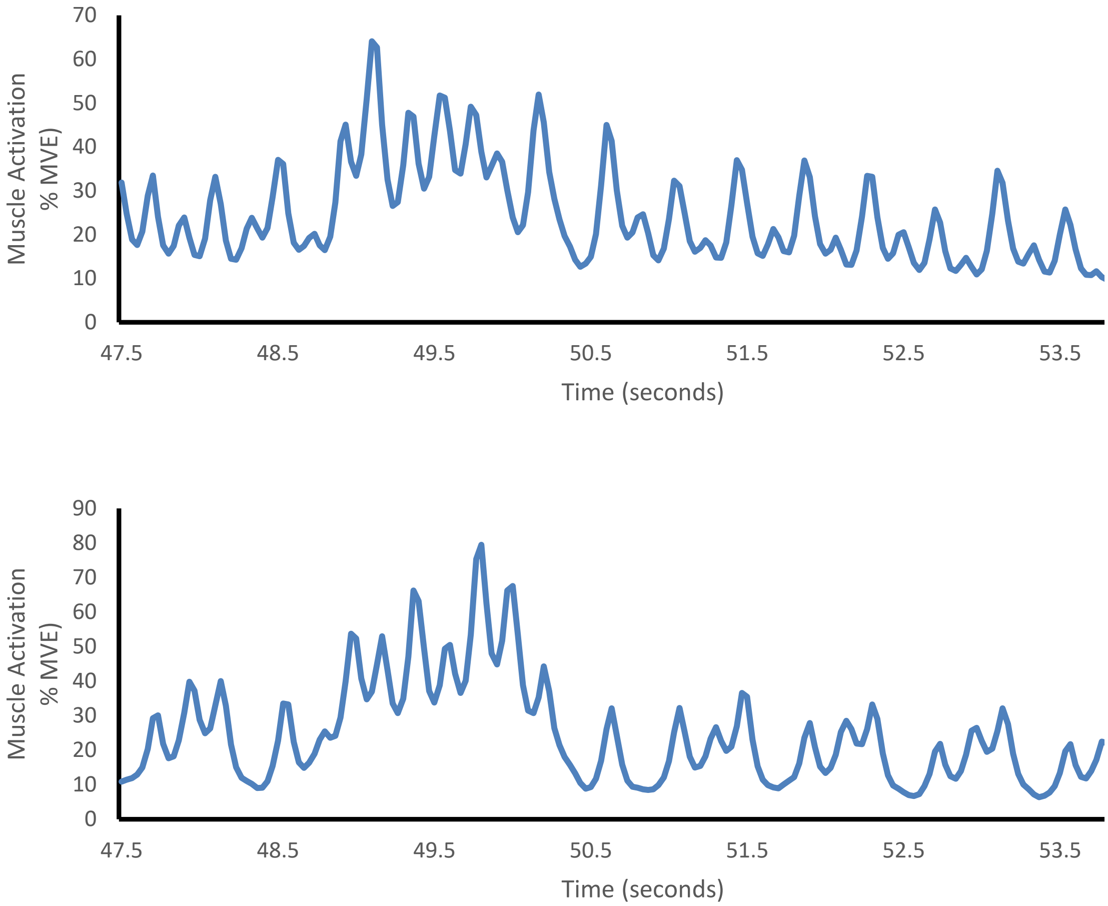

Figure 11. Sample FCU (top) and ECR (bottom) traces during a crash within the pattern trial for Drummer A. These muscles were too active to observe DPMAs during the crashes.

inconclusive upon visual inspection but met the >10 % criterion. The EMG traces for the DP and TM were inspected along with video analyses for crashes three, seven, and eight. In all cases, the timing of the first pulse occurred before the crash during the snare drum roll followed by the second pulse that occurred during the crashing motion on the cymbal. Since the first pulse was not associated with the crashing motion, it was not deemed a “true” DPMA for the purposes of this study. A peak decibel reading of 100.6 dB and average decibel reading of 92.5 dB was recorded for the pattern trial.

Drummer A played for two minutes and 10 seconds during the free play trial. The video recording and EMG traces were searched for cymbal crashes where a DPMA might have occurred. Three such instances were further examined for DPMAs under visual inspection and then evaluated against the change in %MVE criteria (Table 4). Under visual inspection, the LD, TB, and DP all exhibited DPMAs twice and the TM, once. Both DPMAs for the TB met the >20 % criterion, and the TB exhibited one DPMA that was inconclusive upon visual inspection but met the >10 % criterion. Both DPMAs for the DP met the >10 % criterion. The LD exhibited one DPMA that met the >20 % criterion and one that met the >10 % criterion. The TM exhibited one DPMA that met the >10 % criterion and one DPMA that was inconclusive upon visual inspection but met the >5 % criterion. The ES and RA did not show any evidence of DPMAs and the FCU and ECR muscles were too active for a DPMA to be observed. When analyzing the video, the two

Table 4. Drummer A DPMA observations for free play trial. The LD, TB, DP, and TM exhibited DPMAs that met at least the >10 % criterion, but none of these could be confirmed as "true" DPMAs through video analysis ('YES': DPMA present, 'X': DPMA not present, '—': inconclusive).

Trial	Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
Crash 1	Visual	YES	YES	X	X	YES	--	X	X
	5%	YES	YES	X	X	YES	YES	X	X
	10%	YES	YES	X	X	YES	X	X	X
	20%	YES	YES	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 2	Visual	X	YES	X	X	YES	X	X	X
	5%	X	YES	X	X	YES	X	X	X
	10%	X	YES	X	X	YES	X	X	X
	20%	X	YES	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 3	Visual	YES	--	X	X	X	YES	X	X
	5%	YES	YES	X	X	X	YES	X	X
	10%	YES	YES	X	X	X	YES	X	X
	20%	X	X	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X

pulses from the DPMAs of all muscles were associated with separate strikes on the drums or cymbals; thus, these could not be considered “true” DPMAs. A peak decibel reading of 100.8 dB and average decibel reading of 96.8 dB was recorded for the free play trial.

4.3 Drummer B

4.3.1 Intake Summary

Drummer B is a 37-year-old male rock-and-roll drummer who started playing the drums at 15 years of age. He took formal drum lessons for two years and has played the drums in five different bands for the last 10 years. He is right hand dominant, uses a matched grip, plays with a closed hi-hat/snare pattern, and uses a single bass drum kick pedal. He plays up to 10 hours/week in two-hour sessions and has been playing more than five hours/week for the last 10 years. He reported no injuries that prevented him from playing to the intensity and skill levels to which he is accustomed. Drummer B used ProMark drumsticks (he did not provide the model, only the brand). Drummer B requested to kick the bass drum pedal while crashing on the cymbal during the MVE trials, because that is his usual practice when crashing on cymbals.

4.3.2 Muscle Activation Patterns

The mean RMS amplitude of the baseline signals for all eight muscles was 2.4 ± 0.1 µV (range: 2.1 – 2.4). These baseline RMS values fall within the ideal range provided by Konrad (2005). The peak values for normalization occurred during the free play trial for most muscles except the TB (MVE 2) and the RA (pattern trial). Table 5 presents the results of the DPMA inspection for Drummer B during the MVE trials. DPMAs occurred most frequently in the FCU muscle, which exhibited two DPMAs that met the >20 %

Table 5. Drummer B DPMA observations for MVE trials. DP and FCU muscle DPMAs were the only ones that could be confirmed with video analysis ('YES': DPMA present, 'X': DPMA not present, '--': inconclusive).

Trial	Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
MVE 1	Visual	--	X	X	--	--	--	YES	YES
	5%	YES	X	X	X	YES	YES	YES	YES
	10%	X	X	X	X	X	X	YES	YES
	20%	X	X	X	X	X	X	YES	X
	Video Analysis	X	X	X	X	X	X	YES	X
MVE 2	Visual	X	X	YES	X	YES	X	YES	X
	5%	X	X	YES	X	YES	X	YES	X
	10%	X	X	YES	X	YES	X	YES	X
	20%	X	X	X	X	X	X	YES	X
	Video Analysis	X	X	X	X	YES	X	YES	X
MVE 3	Visual	--	--	X	X	--	X	--	--
	5%	YES	YES	X	X	YES	X	YES	YES
	10%	YES	YES	X	X	X	X	YES	YES
	20%	YES	X	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	YES	X

criterion and one that was inconclusive upon visual inspection but met the >10 % criterion. The ECR exhibited one DPMA that met the >10 % criterion, and one that was inconclusive upon visual inspection but met the >10 % criterion. The LD exhibited two DPMAs that were inconclusive upon visual inspection, one of which met the >20 % criterion and one that met the >5 % criterion. The TB and the TM each exhibited one DPMA that was inconclusive upon visual inspection but met the >10 % and >5 % criteria, respectively. The ES exhibited one DPMA that met the >10 % criterion. The DP muscle exhibited one DPMA that met the >10 % criterion (Figure 12) and two that were inconclusive upon visual inspection but met the >5 % criterion. The RA was the only muscle to never display a DPMA. The timing of the DPMAs exhibited by the LD, TB, ES DP, FCU, and ECR muscles were inspected under video analysis. The timing of the LD, TB, and ECR DPMAs indicated that the first pulse was associated with the instant of impact on the crash cymbal and the second with a movement after the crash and were therefore not considered "true"

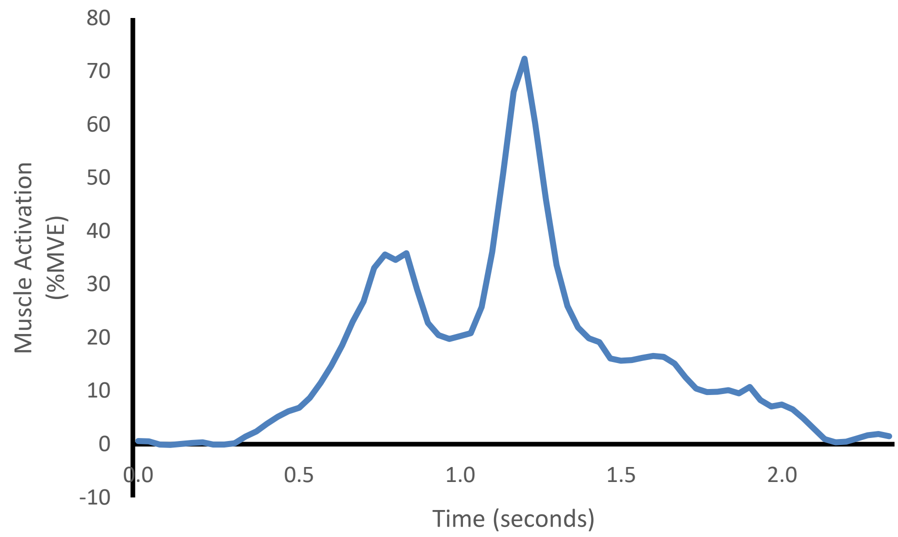

Figure 12. DPMA waveform in the deltoideus posterior of Drummer B during the MVE 2 trial. Each pulse lasted approximately 0.5 seconds with >10% change in MVE between the lowest peak and the valley.

DPMAs. The DPMAs of the DP and FCU had similar timing, with the first pulse occurring towards the top of arm elevation and the second occurring at the instant of cymbal impact (Figure 13). There does not appear to be any major wrist flexion during the movement, thus the participant could simply have been tensing the FCU muscle to grip the stick more tightly. The peak decibel reading for the MVE trials was 100.9 dB.

Drummer B played 11 repetitions of the pattern with 11 crashes and potential DPMAs were observed in five muscles: the LD, TB, RA, DP, and TM (Table 6). No DPMAs were observed in the ES, and the FCU and ECR were again too active to observe any DPMAs. There were four DPMAs in the LD and two in the TM that were inconclusive upon visual inspection but all of which met the >10 % criterion. The RA exhibited two DPMAs that met the >20 % criterion, and another that was inconclusive upon visual inspection but met the >20 % criterion. Eight DPMAs were observed in the TB, two of which met the >5 % criterion, and five of which met the >10 % criterion. The TB also

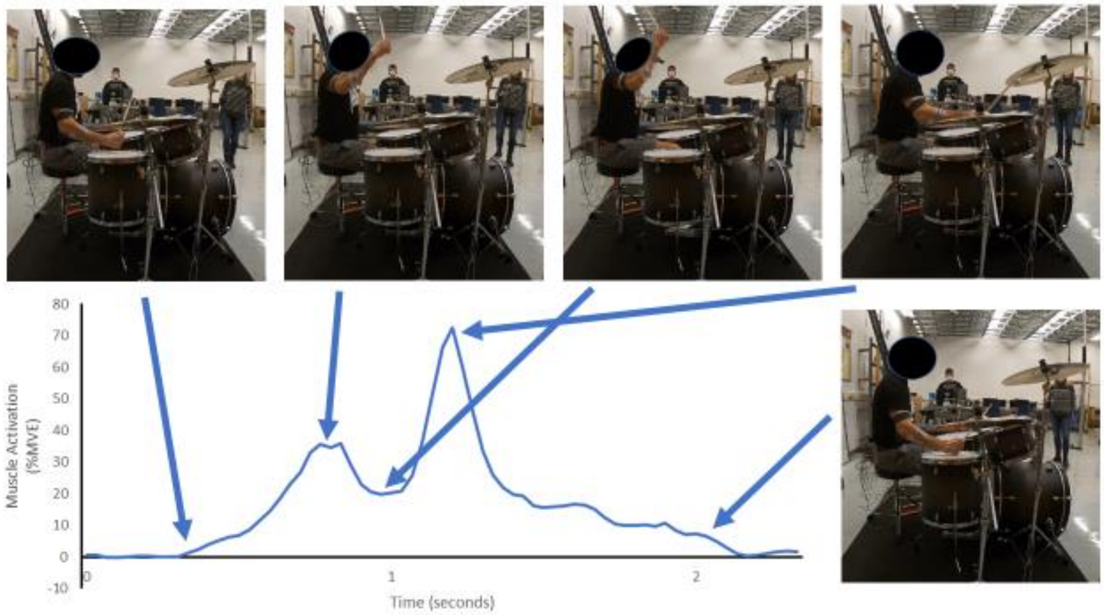

Figure 13. Video frames associated with key moments of the DPMA in the deltoideus posterior of Drummer B during the MVE 2 trial. The first pulse occurred near peak shoulder flexion and the second occurred near the moment of cymbal impact.

exhibited one DPMA that was inconclusive upon visual inspection but met the >5 % criterion. Six DPMAs were observed in the DP, four of which met the >10 % criterion and two which met the >5 % criterion. The DP also exhibited one DPMA that was inconclusive upon visual inspection but met the >5 % criterion. Crashes one, two, and ten were chosen for video analysis and the DPMAs of the LD, TB, RA, DP, and TM were inspected. Similar to Drummer A, the first pulse was associated with the snare roll movements and the second with the cymbal crash, and so these could not be considered “true” DPMAs. The peak and average decibel readings during the pattern were 101.7 dB and 94.8 dB respectively.

Drummer B played for 2 minutes and 25 seconds during the free play trial. The EMG traces were searched for cymbal crashes where a DPMA might occur. Three such instances were further examined for DPMAs under visual inspection and then evaluated against the change in %MVE criteria (Table 7). The LD, TB, DP, and TM muscles were

Table 6. Drummer B DPMA observations for pattern trial. No DPMAs from the LD, TB, RA, DP, and TM muscles could be confirmed to be "true" DPMAs with video analysis ('YES': DPMA present, 'X': DPMA not present, '--': inconclusive).

Trial	Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
Crash 1	Visual	--	YES	X	YES	YES	X	X	X
	5%	YES	YES	X	YES	YES	X	X	X
	10%	YES	YES	X	YES	YES	X	X	X
	20%	X	X	X	YES	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 2	Visual	X	YES	X	--	YES	X	X	X
	5%	X	YES	X	YES	YES	X	X	X
	10%	X	YES	X	YES	YES	X	X	X
	20%	X	X	X	YES	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 3	Visual	--	YES	X	X	--	X	X	X
	5%	YES	YES	X	X	YES	X	X	X
	10%	YES	X	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 4	Visual	--	YES	X	X	--	X	X	X
	5%	YES	YES	X	X	X	X	X	X
	10%	YES	YES	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 5	Visual	X	--	X	X	X	X	X	X
	5%	X	X	X	X	X	X	X	X
	10%	X	X	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 6	Visual	X	X	X	X	YES	X	X	X
	5%	X	X	X	X	YES	X	X	X
	10%	X	X	X	X	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 7	Visual	--	--	X	X	YES	--	X	X
	5%	YES	YES	X	X	YES	YES	X	X
	10%	YES	X	X	X	X	YES	X	X
	20%	X	X	X	X	X	X	X	X
Crash 8	Visual	X	YES	X	X	X	X	X	X
	5%	X	YES	X	X	X	X	X	X
	10%	X	X	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 9	Visual	X	YES	X	X	YES	X	X	X
	5%	X	YES	X	X	YES	X	X	X
	10%	X	YES	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 10	Visual	X	YES	X	X	YES	--	X	X
	5%	X	YES	X	X	YES	YES	X	X
	10%	X	YES	X	X	YES	YES	X	X
	20%	X	X	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 11	Visual	X	YES	X	YES	X	X	X	X
	5%	X	YES	X	YES	X	X	X	X
	10%	X	X	X	YES	X	X	X	X
	20%	X	X	X	YES	X	X	X	X

Table 7. Drummer B DPMA observations for free play trial. The pulses from the LD, TB, DP, and TM muscles were from different movements and could not be considered "true" DPMAs ('YES': DPMA present, 'X': DPMA not present, '--': inconclusive).

Trial	Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
Crash 1	Visual	YES	X	X	X	YES	YES	X	X
	5%	YES	X	X	X	YES	YES	X	X
	10%	YES	X	X	X	YES	YES	X	X
	20%	YES	X	X	X	YES	YES	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 2	Visual	YES	YES	X	X	YES	YES	X	X
	5%	YES	YES	X	X	YES	YES	X	X
	10%	YES	YES	X	X	YES	YES	X	X
	20%	YES	YES	X	X	YES	YES	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 3	Visual	X	YES	X	X	YES	YES	X	X
	5%	X	YES	X	X	YES	YES	X	X
	10%	X	YES	X	X	YES	YES	X	X
	20%	X	YES	X	X	YES	YES	X	X
	Video Analysis	X	X	X	X	X	X	X	X

the only muscles to show potential for DPMAs. All observed DPMAs met the >20 % criterion. The LD and TB exhibited DPMAs in two of the crashes whilst both the DP and TM exhibited DPMAs in all three crashes. All DPMAs were inspected with video analysis, which revealed that the pulses were associated with separate crashes and therefore could not be considered "true" DPMAs. The peak and average decibel readings during the pattern were 101.2 dB and 99.4 dB, respectively.

4.4 Drummer C

4.4.1 Intake Summary

Drummer C is a 24-year-old male drummer who started playing the drums at 12 years of age and has been a touring drummer in a rock band for four years. He is right-hand dominant, uses a variety of matched grip styles (i.e., French, German, American), plays with a closed hi-hat/snare pattern, and uses a double bass drum kick pedal. He plays an average of five hours/week in one-hour sessions and has done so for one year. He has taken formal drum lessons for one year. He had experienced an injury that affected his ability to play the drums to the skill and intensity levels to which he was accustomed within the last 12 months, but he had returned to pre-injury playing intensity and skill levels more than 30 days prior to data collection. Drummer C used Vater 5B drumsticks and used his own double kick pedal and throne. Given that the study was focusing on upper limb and trunk activity, and the participant's throne was the same make and model as the lab's drum throne, the participant was granted permission to use his own throne and double kick pedal to feel more comfortable while playing.

4.3.2 Muscle Activation Patterns

The mean RMS amplitude of the baseline signals for all eight muscles was 2.1 ± 0.5 μV (range: 0.9 – 2.6 μV) which is within the ideal range for baseline RMS values (Konrad, 2005). The free play trial was not used for data analysis due to abnormalities seen across all EMG channels and the light signal. The peak values for normalization occurred during MVE 3 for the LD, ES, DP, and TM, and in the pattern trial for the TB, RA, FCU, and ECR. Table 8 presents the results of the DPMA inspection for Drummer C during the MVE trials. The DPMA occurred most frequently in the DP, which exhibited DPMAs in all three trials (two that met the >20 % criterion and one that met the >5 % criterion: Figure 14). The LD exhibited one DPMA that met the >5 % criterion and one that was inconclusive upon visual inspection and did not meet any of the %MVE criteria. The TB, ES, RA, TM, and ECR each exhibited one DPMA, all of which were inconclusive upon visual inspection and did not meet any of the %MVE criteria. The RA also exhibited one DPMA that appeared conclusive upon visual inspection but did not meet any of the %MVE

Table 8. Drummer C DPMA observations for MVE trials. DPMA were only observed and confirmed by video analysis in the DP muscle with >20% criterion ('YES': DPMA present, 'X': DPMA not present, --': inconclusive).

Trial	Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
MVE 1	Visual	X	--	X	X	YES	X	X	X
	5%	X	X	X	X	YES	X	X	X
	10%	X	X	X	X	YES	X	X	X
	20%	X	X	X	X	YES	X	X	X
	Video Analysis	X	X	X	X	YES	X	X	X
MVE 2	Visual	--	X	X	YES	YES	--	X	--
	5%	X	X	X	X	YES	X	X	X
	10%	X	X	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
MVE 3	Visual	YES	X	--	--	YES	X	X	X
	5%	YES	X	X	X	YES	X	X	X
	10%	X	X	X	X	YES	X	X	X
	20%	X	X	X	X	YES	X	X	X
	Video Analysis	X	X	X	X	YES	X	X	X

criteria. The DP was the only muscle to undergo video analysis. In all cases, the first pulse occurred at the middle to top of arm elevation and the second pulse coincided with the cymbal crash (Figure 15). Drummer C impulsively kicked the double kick pedal while crashing during the MVE trials. The peak decibel reading for the MVE trials was 101.0 dB.

Drummer C played 10 repetitions of the pattern (10 crashes) and DPMAs were observed in five muscles: the LD, TB, RA, DP, and TM (Table 9). No DPMA activity was seen in the ES, and the FCU and ECR were again too active to observe any DPMAs. The DP and TB exhibited the most obvious DPMAs waveforms. The DP exhibited four DPMAs, two that met the >20 % criterion and two that met the >10% criterion. The DP also exhibited three DPMAs that were inconclusive upon visual inspection but two of which met the >10 % and one that met the >10 % criteria. The TB exhibited two DPMAs that met the >20 % criterion and five that met the >10 % criterion. The TB also exhibited

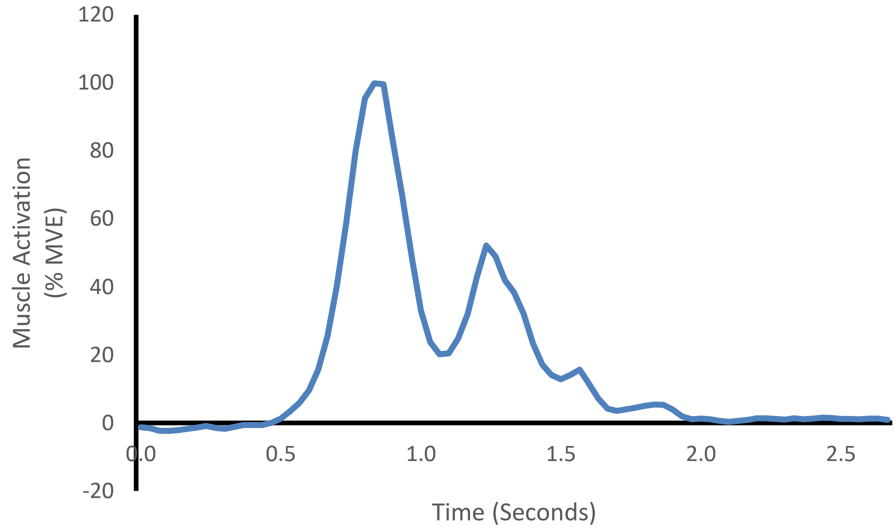

Figure 14. DPMA waveform in the deltoideus posterior of Drummer C during the MVE 3 trial. Each pulse lasted approximately 0.5 seconds with >20% change in MVE between the lowest peak and the valley.

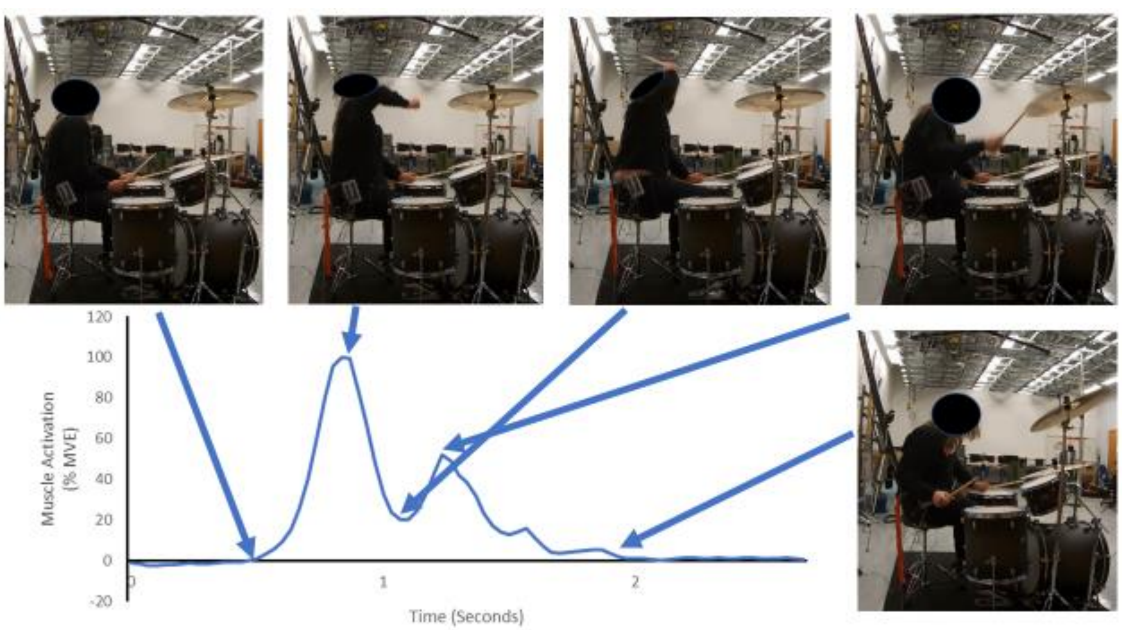

Figure 15. Video frames associated with key moments of the DP muscle DPMA of Drummer C during the MVE 3 trial. The first pulse occurred at mid-to-top shoulder flexion and the second one occurred at impact.

four DPMAs that were inconclusive upon visual inspection, one of which met the >5 % criterion and three that met the >10 % criteria. The RA exhibited three DPMAs, two that met the >10% criterion and one that met the >5% criterion. The RA also exhibited five DPMAs that were inconclusive upon visual inspection, one of which met the >10 % criterion, two that met the >5 % criterion, and two that did not meet any of the %MVE criteria. The LD and TM exhibited many DPMAs that met the >5% criterion with a variety of positive, negative, and inconclusive visual readings between them. Crashes three, four, and five were chosen for video analysis for the TB, RA, and DP muscles. The first pulse was again associated with the snare roll preceding the second pulse for the cymbal crash. The peak and average decibel readings during the pattern were 101.5 dB and 96.2 dB, respectively.

Table 9. Drummer C DPMA observations for pattern trial. No DPMAs from the TB, RA, and DP muscles could be confirmed with video analysis and were therefore not considered "true" DPMAs ('YES': DPMA present, 'X': DPMA not present, '--': inconclusive).

Trial	Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
Crash 1	Visual	--	--	X	X	YES	--	X	X
	5%	X	YES	X	X	YES	YES	X	X
	10%	X	YES	X	X	YES	X	X	X
	20%	X	X	X	X	YES	X	X	X
Crash 2	Visual	YES	YES	X	--	YES	--	X	X
	5%	YES	YES	X	X	YES	YES	X	X
	10%	X	YES	X	X	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 3	Visual	--	YES	X	YES	YES	--	X	X
	5%	X	YES	X	YES	YES	X	X	X
	10%	X	YES	X	YES	YES	X	X	X
	20%	X	YES	X	X	YES	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 4	Visual	YES	YES	X	YES	YES	YES	X	X
	5%	YES	YES	X	YES	YES	YES	X	X
	10%	X	YES	X	YES	YES	X	X	X
	20%	X	YES	X	X	YES	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 5	Visual	YES	YES	X	--	--	YES	X	X
	5%	YES	YES	X	YES	YES	YES	X	X
	10%	X	YES	X	YES	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
	Video Analysis	X	X	X	X	X	X	X	X
Crash 6	Visual	YES	--	X	YES	--	YES	X	X
	5%	YES	YES	X	YES	YES	YES	X	X
	10%	X	YES	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 7	Visual	--	X	X	--	YES	--	X	X
	5%	X	X	X	YES	YES	YES	X	X
	10%	X	X	X	X	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 8	Visual	YES	--	X	--	--	X	X	X
	5%	YES	YES	X	YES	YES	X	X	X
	10%	X	YES	X	X	YES	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 9	Visual	X	X	X	X	X	X	X	X
	5%	X	X	X	X	X	X	X	X
	10%	X	X	X	X	X	X	X	X
	20%	X	X	X	X	X	X	X	X
Crash 10	Visual	--	--	X	--	YES	YES	X	X
	5%	YES	YES	X	X	YES	YES	X	X
	10%	YES	X	X	X	YES	X	X	X
	20%	X	X	X	X	YES	X	X	X

4.5 Inter-rater Reliability Analysis

The inter-rater reliability analysis included a total of 24 waveforms from three randomly chosen MVE trials from Drummers A and B. Both raters agreed on the presence/absence of a DPMA in 20 waveforms, yielding a percentage agreement of 83.3 %. Table 10 provides the results of the inter-rater reliability study. The four waveforms where the raters did not agree occurred in the TB, ES, TM, and ECR. In those disagreements, one rater chose an inconclusive rating whereas the other rater gave a rating of YES. In general, a percentage agreement above 75% is considered acceptable in most fields (Goodier, 2011).

Table 10. Inter-rater reliability results. Agreement on the presence/absence of a DPMA upon visual inspection was achieved in 20 out of 24 EMG traces (83.3%) (‘YES’: DPMA present, ‘X’: DPMA not present, ‘—': inconclusive).

Trial	Rater	LD	TB	ES	RA	DP	TM	FCU	ECR
Drummer A MVE 3	1	X	--	X	X	YES	--	X	X
	2	X	YES	X	X	YES	YES	X	X
Drummer B MVE 2	1	X	X	--	X	YES	X	YES	X
	2	X	X	YES	X	YES	X	YES	X
Drummer A MVE 1	1	X	YES	X	X	YES	YES	X	YES
	2	X	YES	X	X	YES	YES	X	--

4.6 Results Summary

Table 11 presents the frequencies with which each muscle displayed a DPMA that met the >10 % criterion or higher out of 46 crashes and across all three participants. This criterion was chosen as it seemed to coincide most consistently with a positive visual inspection. There were many instances where a DPMA with an inconclusive visual inspection would meet the >5 % criterion only or none at all. The DP and TB exhibited

DPMAs the most frequently, followed by the LD and TM. The ES, RA, FCU, and ECR muscles very rarely displayed a DPMA, and in the cases of the FCU and ECR, there was frequently too much muscle activity to make detection of a DPMA possible.

Table 11. Total number of DPMAs that met the >10 % criterion across all participants. DPMAs occurred most frequently in the DP, TM, and LD (shoulder extension) and the TB (elbow extension).

Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
10%	8	16	1	3	16	7	1	2
20%	3	5	0	3	11	6	2	0
Total	11	21	1	6	27	13	3	2

When reviewing the videos synchronized with the EMG traces, similar patterns were seen across all participants. During the MVE trials, the first pulse would occur between the middle and the peak of the upper limb raise before lowering and extending the arm and forearm to crash on the cymbal, where the second pulse would occur. Table 12 presents the total number of DPMAs observed for each muscle during the MVE trials with a positive video confirmation. For the pattern trial, the first pulse was frequently associated with the snare drum roll preceding the cymbal crash, where the second pulse would emerge. Lastly, the DPMAs observed in the free play trials for Drummers A and B appeared to be related to separate consecutive crashes on the cymbals and drums. In both the pattern and free play trials, the two pulses of the DPMA waveforms were associated with different movements, and thus could not be considered “true” DPMAs.

Table 12. Total DPMAs observed across all participants during MVE trials with video confirmation. Many DPMAs were not considered “true” DPMAs after video analysis, but the DP muscle exhibited “true” DPMAs most frequently.

Decision Criterion	LD	TB	ES	RA	DP	TM	FCU	ECR
10%	1	1	0	0	2	1	1	0
20%	0	0	0	0	4	2	2	0
Total	1	1	0	0	6	3	3	0

CHAPTER 5: DISCUSSION

The purpose of this study was to examine the muscle activation patterns of skilled drummers during high velocity cymbal crashes for DPMAs. Elite athletes in the sports of MMA, golf, and baseball have all exhibited DPMAs, which are believed to be a strategy to increase the velocity and force of striking movements (McGill et al., 2010; Silva et al., 2013; Ball et al., 2019). In many ways, skilled drummers have been shown to be physically and cognitively similar to elite athletes, and they have quicker muscle activation and relaxation rates than non-drummers (Azar, 2021; Bianco et al., 2017; Fujii et al., 2009a). Therefore, drummers may also utilize the DPMA to enhance striking velocity and force when performing cymbal crashes. This study used EMG to monitor the muscle activation patterns of three skilled drummers during high velocity cymbal crashes.

DPMAs were observed in all three participants. They were observed most frequently in the DP and TB followed by the LD and TM. The main actions of these muscles include extension at the shoulder joint (LD, DP, TM) and at the elbow joint (TB) (Tortora & Derrickson, 2018). When delivering crashes, drummers must first flex the shoulder to raise the upper limb above their heads, then extend the shoulder and elbow joints to lower the upper limb down upon the drums and cymbals. The faster and harder they extend the shoulder and elbow joints; the more force will be transferred to the drums and cymbals for louder dynamic levels. The DP, TB, LD, and TM muscles will all assist in the crashing action of the upper limb and, in theory, the DPMA would help them to produce more velocity and force. The core muscles (RA and ES) did not exhibit many DPMAs, nor did the forearm muscles (FCU and ECR). The forearm muscles were not expected to display the DPMA to the same extent because their actions were not consistent with the motion needed to perform a cymbal crash. Based on previous studies (McGill et al., 2010; Silva et al., 2013; Ball et al., 2019), the core muscles were expected to display the DPMA and were considered main muscles of interest for this study. The RA and ES muscles function to flex the torso and extend the spine (respectively) while also bracing the core to stabilize the body (Tortora & Derrickson, 2018). Drumming involves a lot of movement of the upper limbs and feet, and it appears that these core muscles were primarily used to stabilize the body with tonic activation, rather than for power with phasic activation as seen with other sports. The FCU and ECR muscles function to flex and extend the hand at the wrist (Fujii & Oda, 2006). Quick alternation between wrist flexion and extension is very important in the regular time-keeping aspect of drumming but was not seen in the big crashes that were investigated in this study.

After examining all DPMAs using the >5 %, >10 %, and >20 % criteria based on their change in MVE, the >10% criterion was deemed the most appropriate for identifying DPMAs. There was too much inconsistency between the results of the visual inspection for DPMAs and the >5 % criterion, and therefore this criterion was determined to be inappropriate for the context of this study. This incongruence did not occur as often using the >10 % criterion. The >20 % criterion was decided to be too large of a range for the consideration of a DPMA because there were many obvious DPMAs that did not meet the >20 % criterion but did meet the >10 % criterion. Therefore, the >10 % criterion was selected as the minimum to be considered a DPMA. This study has attempted to set an objective numerical criterion to define a DPMA as previous studies did not use any objective criteria for identifying a muscle activation pattern as a DPMA (McGill et al., 2010; Silva et al., 2013; Ball et al., 2019). These studies simply stated that double pulses were observed when examining muscle activation patterns. By establishing an objective criterion for identifying DPMAs, future studies can utilize this criterion to objectively identify DPMAs beyond visual inspection of EMG traces. A change of at least 10 %MVE was consistently seen in DPMAs identified through visual inspection and is therefore the recommended objective criterion by which to define a DPMA.

Following visual inspection and DPMA criteria selection, the video analysis was conducted to ensure the pulses in muscle activation were associated with the movements of one single high velocity cymbal crash. To compare the drummers to the athletes in previous studies, the double pulses must represent the same specific instances of movement (i.e., initiation of movement and impact). The MVE trials consisted of one crash only, however, the first pulse was seen at the middle-to-top of the upper limb elevation stage of the movement before crashing down on the cymbal with the drumstick. Previous studies indicated that the first pulse represented the muscle activation that initiated movement towards the target. Contrary to previous studies' findings, the first pulse observed in Drummers A-C did not quite coincide with the initiation of the downward arm movements; instead, the data suggests that the drummers were eccentrically contracting to slow the limbs' flexion trajectories, followed closely by concentric contraction to accelerate in the opposite direction (i.e., extension). Given that the MVE crash movement was one quick fluid movement, it would be very difficult to separate the two phases of the muscle contraction without a more detailed kinematic analysis. If this pulse was associated with upper limb elevation exclusively, the muscle activation would occur at the beginning of the flexion movement and not the end. The second pulse occurred at or slightly before contact between drumstick and cymbal, which suggests that the drummers were preparing for impact by stiffening the arm to transfer force. The relaxation in muscle activity between the two pulses was used to accelerate the limb to increase impact velocity. The DP is the main muscle responsible for shoulder extension (Tortora & Derrickson, 2018), and the DPMA was observed most frequently in this muscle across all trials. The TM and LD muscles also exhibited the DPMA after video confirmation and they function similarly to each other in extending the upper limb from a flexed position at the shoulder joint (Tortora & Derrickson, 2018). These findings match expectations as the DP, TM, and LD all assist in the motion of crashing on a cymbal from a raised arm position as performed during the MVE trial.

Drummer B displayed unexpected results by also showing DPMAs in the FCU muscle in all three of his MVE trials. The timing of the pulses was consistent with those of the DP indicating that he activated the muscles at the same time. The first pulse in the FCU would not have the same function as the DP (i.e., to decelerate arm flexion), however, the second pulse would still function to stiffen the forearm/wrist for impact to increase force transfer. The first pulse could simply be a unique muscle activation of wrist flexor that Drummer B developed while learning to play, given that a review of the videos from the MVE trials showed no notable differences in wrist positioning or stick grip style between the three drummers. Another unique finding between Drummer A and Drummers B-C was observed in the MVE trials. Drummers B-C used the kick pedal when delivering the crash and Drummer A did not. When observing the ES and RA muscle waveforms, differences in activation were observed. Drummers B-C had larger increase in % MVE when crashing compared to Drummer A. When kicking the bass drum while crashing, it appears that the core muscles would increase in activation due to the increased instability from the drummer raising both the arm and the leg. Even with the additional muscle activation, still no DPMA was observed the ES and RA muscles of Drummers B and C.

The video analysis of the pattern and free play trials indicated that the DPMAs observed in the EMG traces were not related to one singular cymbal crash, and therefore, could not be considered “true” DPMAs. In the pattern trial, the DP, LD, TB, and TM muscles would activate first to bring the arm to the snare drum for the snare roll and then the second pulse would extend the arm crashing down on the cymbal. While reviewing the video, it was observed that the participants did not perform a cymbal crash with a large arm flexion above their head leading to extension on the cymbal as they did in the MVE trials. Instead, they extended the arm at the elbow with shoulder abduction to reach the cymbal as quickly as possible from the snare drum to the cymbal with little movement. Drumming at 144 bpm is a highly dynamic activity and may not have allowed enough time for large dramatic and forceful crashes on the cymbal. The DPMA has only been observed in individual ballistic movements such as punching, kicking, batting, and golfing where maximizing force quickly is essential. This is consistent with the observations made by McGill et al (2010): In moments when producing large forces is not the objective, such as a left jab before a right hook, the left jab would not exhibit a DPMA. The free play trial was included to represent more authentic drumming conditions, however, the pulses observed were associated with separate crashes on the same or different cymbals and drums. The drummers would play at a high tempo involving many strikes to the drums and cymbals. In regular performance there would be little time between crashes to raise their arms to a height obtained in the MVE trials. Quick movements were made between drums and cymbals, which did not allow enough time for large amounts of force to be created and therefore, DPMAs were not observed. It is possible that DPMAs would be more readily apparent in different styles of drumming, such as the Japanese style Taiko drumming where gross motor movements with grand gestures involving shoulder flexion/extension are used more often than the traditional rock drumming used in this study.

Most previous studies (McGill et al., 2010; Silva et al., 2013; Ball et al., 2019) used EMG to examine a variety of trunk muscles during strikes in their respective sports (i.e., MMA, golf, and baseball). Rotation of the trunk and activation of trunk muscles forming a strong kinetic chain is essential to enhance effective mass in all these respective sports (Pinto Neto et al., 2007). The athletes use the trunk as a fulcrum around which they rotate their limbs, creating as much force as possible (Winter, 2009). The muscle activation patterns of the trunk muscles of Drummers A-C suggested that the trunk muscles are not as important as the upper limb and back muscles when creating cymbal crashes in drumming. There is less of a need to rotate the trunk to enhance effective mass when going from one drum or cymbal to another. The muscle activation for the crashes in the pattern and free play trials suggested that quick movements from the shoulder and elbow joint are more important to deliver crashes under these playing conditions. Furthermore, the drummer sits on a throne (i.e., a stool without a back) when playing, restricting the amount of movement that is possible at the trunk. The drummer also does not need to activate their core muscles as much to initiate movements and brace for impact when delivering strikes with the right arm while sitting. Rather, the core muscles would function more to stabilize the body to help the drummer stay in position on the throne. It is understandable, therefore, that the trunk muscles did not exhibit DPMAs during high velocity impacts on a cymbal.

The muscles controlling the movement of the arm at the shoulder and elbow joint were far more likely to exhibit DPMAs.

The trials of all the previous studies of the DPMA only included MVE-type movements. For example, the MMA fighter delivered one singular kick or punch, and the golfer and baseball player would hit the ball in one movement. These movements are all similar to the MVE trial of the drummers in this study crashing on one cymbal with one motion. In baseball and golf, there is only ever one movement to contact with the ball. However, MMA, like drumming, is a highly dynamic activity where the body is in constant motion and the athlete must adapt to changing situations. The research completed by McGill et al. (2010) did not include any trials that simulated fight conditions, where the athlete would be in a constantly evolving situation. In the current study, true DPMAs (i.e., confirmed via video analysis) were observed in drummers during the MVE trials, but not in the pattern and free play trials. It is possible that in real fighting situations, the MMA athletes also would not have enough time to produce a DPMA when striking, similar to what was observed in the drummers in this study during the pattern and free play trials.

5.1 Limitations

The safety regulations imposed by the SARS-CoV-2 pandemic created many obstacles in the completion of this study. Data collection was delayed by approximately 13 months, due to restrictions placed on face-to-face research with human participants involving extended breaches of physical distancing. Also, the drum set could only be used once every 72 hours, to minimize the risk of exposure to the virus from the drum set surfaces, which could not be cleaned with harsh disinfectants. This limited the number of participants that could be included in the study while still completing it within a reasonable time frame. Participant recruitment became limited to the point where the sample size was adjusted to include three drummers in a multiple case study design. Thus, the goal of the study became to obtain a proof of principle that a DPMA would emerge in the EMG profiles of a limited number of highly skilled drummers. This was a significant shift from the original design, which was intended to include participants of varying degrees of skill to compare results across groups. Statistical analysis would have been possible with a larger participant sample size, which would have allowed for further investigation into the production of DPMAs between highly skilled and novice drummers. Furthermore, the original aim was to keep the participant pool consistent to avoid potential differences across genres, however, the inclusion criteria had to be expanded to include drummers of all genres. Even with the expanded inclusion criteria, Drummers A-C did all identify performance genres within the rock category.

The results of the video analysis in the MVE trial indicated that the first pulse typically occurred toward the end of the upward motion of the arm, before the downward crashing motion was initiated. This pulse likely represented both the eccentric action to slow down shoulder flexion and the concentric action to initiate shoulder extension, but the lack of precision of the qualitative video analysis made it impossible to pinpoint the transition between these two phases of muscle contraction. Analyzing 3-dimensional (3-D) joint kinematics quantitatively using a motion capture system would have assisted in the interpretation of the EMG profiles by being able to tell more precisely what the associated joints were doing at the moments of the pulses of the DPMA.

To limit the number and duration of breaches of physical distancing during data collection, maximal voluntary contraction (MVC) trials were not collected. The investigator would have had to assist in providing the resisting force for the participant, which could only be done with close physical contact. Instead, MVE trials were conducted. MVEs were considered a reasonable substitute because the motion for an MVE is more realistic to true drumming performance than a static contraction against resistance. In many cases, peak muscle activation levels will occur during the task under investigation rather than the MVC trials (Halaki & Ginn, 2012). However, the movement performed in the MVE trials did not provide ideal conditions to enable interpretation and display of a DPMA. It would have been more beneficial to have the participant raise their arm, then pause for a moment before crashing down upon the cymbal. That way, it would be very clear what the purpose of the first pulse in the MVE trial was. By restricting the crash to a singular unidirectional motion, the initiation of the downward movement would have more distinguishable from the upward arm motion. The study design included a one fluid motion MVE as that is what is generally used in performance.

Finally, all participants used their own drumsticks, which they brought to the data collection. This allowed for an additional variable between participants rather than standardizing the drumsticks by providing them to the drummers. Drumsticks are made with different materials, at different diameters and lengths causing varying weights. The different weighted drumsticks could require more or less effort to crash, and one stick could provide more rebound off the cymbal than others. In this study, drumsticks were not standardized so that the drummers were not using an unfamiliar pair of sticks during data collection, which could have changed their mechanics when performing.

5.2 Future Directions

The DPMA was observed in the EMG profiles of drummers during singular ballistic cymbal crashes but more research is needed to fully understand its use in drumming, particularly within more musical contexts. The limitations of this study provide an excellent starting point when considering the future directions for this line of research. The most beneficial addition to this study would be 3-D motion capture. Using motion capture to create a 3-D model to gather quantitative kinematic data such as segment accelerations, joint kinematics, and body orientation would allow future investigators to better understand the timing and purpose of the muscle activation patterns of drummers during a high velocity cymbal crash. More accurate synchronization of the motion capture data to the EMG could also be achieved by collecting both the motion capture and EMG data through the same computer system. By comparing the timing of muscle activation to the movements of the body, a more objective interpretation of the movements would be possible. The phases of raising the arm during flexion and lowering the arm onto the cymbal during extension would be clearer if joint accelerations could be calculated. This research team has previously used the Xsens™ motion capture system, therefore, it would be an easy addition to the study for future data collection.

The data collected from the wrist flexors and extensors was too active to properly identify DPMAs in the pattern and free play trials. However, the data may still be useful to make comparisons to the results from the series of studies by Dr. Shinya Fujii (e.g., Fujii et al., 2009a; Fujii et al., 2009b; Fujii & Moritani, 2012). The muscle contraction and relaxation rates would be readily available to make comparisons in future analyses of the results from this study.

Collecting data on more participants to increase the sample size would also add to the study. The goal was to obtain at least six participants for a multiple case study design but only four could be recruited within the time frame of the study, and only three yielded useable data. Increasing the sample size would increase the chance for interesting individual findings that could lead to further research questions and a more thorough understanding of the research area. For example, comparisons between novice and highly skilled drummers could be made to gain more information on the population of people that produce DPMAs. With a large enough participant pool, statistical analysis will be possible, which would allow for generalizations to be made about the larger drumming population. Furthermore, with additional participants, an intervention group could be created to see if the DPMA can be trained in novice drummers. By providing a training regimen and asking drummers to practice producing separate pulses in muscle activation, they may be able to begin exhibiting DPMAs.

Future studies should also include maximal voluntary contractions (MVC) as well as modified MVE trials. MVCs would consist of separate isometric exercise trials for each muscle to obtain the maximal amount of force production and activation for each muscle. Comparisons between the muscle activation levels during crashing can be made to the MVCs to better understand how much effort each muscle produces when crashing. The MVE trials should be modified to include a pause at the top of the arm elevation, so that the crashing motion is limited to a single direction of motion. That pause would force the participant to initiate the crash as a separate movement so muscle activations can more effectively interpreted. In this study, the eccentric muscle contraction to slow shoulder flexion and prepare for shoulder extension did not provide a clear indication on the purpose of the pulses of the DPMA.

Lastly, different muscles should be selected to be monitored in future studies. The core (ES and RA) and forearm (FCU and ECR) should be eliminated in favour of more deltoid and rotator cuff muscles. Based on the observations of the participants in this study, shoulder and elbow joint movements are most important when delivering crashes, and so they should be examined in more depth. During the pattern and free play trials, arm abduction was more common than arm extension, so capturing more of the abductors (i.e., middle deltoid and supraspinatus) and adductors (i.e., anterior deltoid) would be beneficial. It may also be beneficial to observe more “push” muscles such as the pectoralis major. After reviewing the video, it appeared all participants use more of a push action to go from drums to cymbals as quickly as possible during the pattern and free play trials. By adding these additional muscles, along with quantitative kinematic analyses, a greater understanding of the mechanics of high velocity cymbal crashes will be possible. Despite the limitations, this study has contributed to the literature on the biomechanics and motor control of drumming while also providing many possibilities for future research on the use of the DPMA in drummers.

CHAPTER 6: CONCLUSION

The current study has demonstrated that the DPMA does occur within the EMG profiles of drummers during singular ballistic movements like high velocity cymbal crashes. When crashing on a cymbal during an MVE trial, the DP, TM, LD, TB, and FCU muscles exhibited a DPMA, with the DP muscle doing so the most consistently. The first pulse typically coincided with the eccentric contraction to stop shoulder flexion but also likely captured the initiation of extension. The second pulse frequently coincided with preparation for contact with the cymbal to transfer force. The relaxation in between likely allowed the limb to accelerate to increase striking velocity and effective mass. The DPMA has been previously observed in quick striking ballistic sports such as MMA, golf, and baseball. Prior research has demonstrated that drummers have similar physical and cognitive attributes as athletes such as speed, coordination, precision, consistency, and increased sensory-motor abilities such as reaction time. They also have faster muscle activation and relaxation rates than non-drummers while being able to strike faster and harder. This is the first time the DPMA pattern has been observed in drummers and its appearance opens the possibility of more research in this field. Suggestions for future studies include 1) adding motion capture to enable quantitative analysis of 3-D joint kinematics, 2) modifying procedures for MVE trials and include MVC trials, and 3) changing which muscles are monitored by removing the trunk muscles and adding shoulder adductors. All of these will enable a better understanding of the use of the DPMA by drummers. Overall, this study provides a foundation for further study of the DPMA in drummers, which will add to the literature on the biomechanics and motor control of drummers while continuing to bridge the gap between drummers and athletes.

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APPENDICES

Appendix A: Informed Consent Forms

University of Windsor

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **An Investigation of Drummers' Trunk and Upper Limb Muscle Activation Profiles during High-Velocity Cymbal Crashes**

You are asked to participate in a research study conducted by **Nicolas Latreille (graduate student) and Dr. Nadia Azar (faculty)** from the **Department of Kinesiology** at the University of Windsor**. The results will contribute to Nicolas' Master's degree program.**

If you have any questions or concerns about the research, please feel to contact:

Nicolas Latreille, primary investigator:	latreil1@uwindsor.ca	
Dr. Nadia Azar, faculty supervisor:	azar5@uwindsor.ca	519-253-300 ext. 2473

PURPOSE OF THE STUDY

The purpose of this study is to examine the muscle activation patterns of highly skilled drummers for evidence of a double peak during high velocity cymbal crashes. The double peak in muscle activation may be a strategy used by skilled drummers to increase striking velocity and effective mass, just as athletes do in other sports. This study will bridge the gaps in the drumming research by using electromyography (EMG) to examine muscle activation patterns to explain how skilled drummers produce large forces quickly and efficiently during high velocity cymbal crashes.

PROCEDURES

If you volunteer to participate in this study, you will be asked to:

Prior to Meeting the Investigators:

- contact Nicolas and/or Dr. Azar through email to ensure you fall within the inclusion/exclusion criteria and select a mutually convenient data collection time slot
- review and practice the standard drum beat to be used in the study (provided by Nicolas or Dr. Azar)
- NOTE – removal of body hair in the areas where the EMG electrodes will be attached will be necessary, to make sure the devices are firmly secured to the skin. You will be asked to do so in the privacy of your own home prior to attending your data collection session, and you will be provided with a diagram indicating the areas that must be shaved. If adjustments must be made to the size or location of the shaved areas, you will be provided with a disposable razor and asked to shave those areas (we can assist with hard-to-reach areas, if you are comfortable with this).
    - Please avoid using any lotions, oils, etc. on the shaved areas on the day of your data collection
- Review this Informed Consent Form, the Consent for Still Photography and Audio/video Recording, and the Consent Addendum for COVID-19 Risks and Procedures for In-Person Research at the University of Windsor, and contact Nicolas or Dr. Azar should you have any additional questions

On the Day of your Data Collection:

- complete the Safe Lancer App or the on-line fillable document within one hour prior to coming to campus and forward the results to the researcher (if you need instructions for downloading the app or the fillable form, please see the instructions on the last page of the *'Consent Addendum for COVID-19 Risks and Procedures for In-Person Research at the University of Windsor'*).
- meet the investigators at the front entrance of the University of Windsor's Human Kinetics building (2555 College Ave, Windsor, ON N9B 2Z5) wearing loose/comfortable clothing. They will take you to room 242, where data collection will occur
- wear a 3-ply surgical mask and eye protection (e.g., safety glasses or face shield) at all times in while you are in the lab. These will be provided to you unless you prefer to use your own.
- Wash and/or sanitize your hands upon entering and exiting the building, and at regular intervals while you are in the building
- bring the headphones/in-ear monitors or hearing protection you normally use (if any)
- bring at least one pair of the drumsticks you normally use
- complete a short intake form including questions about your demographic information (e.g., age, preferred gender pronouns, etc.), playing history, injury history, and performance style
- adjust the standardized drum kit provided so it feels comfortable for you to play
- be instrumented with up to 17 EMG electrodes (sensors to detect muscle electrical activity, which will be placed in specific positions on the right side of your trunk and your right upper limb) to monitor the electrical activity of up to four muscles
- lay on your back on a therapy table and relax all your muscles completely for approximately 2 minutes
- complete a brief warm-up (10 minutes) to ensure you are comfortable with the drum kit and EMG electrodes
- strike the crash cymbal with maximal effort three times with 30 seconds rest between strikes
- play the given drum beat for 10 repetitions
- after a break of your desired length, you will be asked to play whatever you would believe contains high velocity crashes that might elicit and double peak in muscles activation (can be patterns/fills or part of a song)
- after data collection, you will be asked to gently remove preamplifier cables and position them on a nearby table

You will also be asked to:

- consent to the publication of the EMG data (i.e., muscle activation patterns) and photos/videos in any, or all, of several forums. Examples include, but are not limited to:
  - Summary on the University of Windsor's Research Ethics Board website
  - Conference or other academic presentations (e.g., teaching, guest lectures, speaking engagements, etc.)
  - Academic publications (e.g., master's thesis document, peer-reviewed journals)
  - Online (e.g., investigator's website, online drumming communities, blogs and/or vlogs)
  - Summaries and/or case studies shared through social media (e.g., Facebook, Twitter, Instagram, etc.)
  - Articles in popular drumming magazines (e.g., Modern Drummer, Drum! Magazine, etc.)
  - Media appearances (e.g., radio, television, or online interviews such as podcasts, vlogs, and/or blogs)
  - Drummer Mechanics and Ergonomics Research Laboratory (DRUMMER Lab) promotional purposes (e.g., future study recruitment initiatives)

Publication in these forums can be achieved confidentially, if you wish. In those cases, no identifying information will be disclosed, and your face will be covered in any photos/videos (or, your photos/videos won't be used). **Please refer to the audio/video/still photography consent form at the end of this document to indicate your desired level of confidentiality.**

It is estimated that the process in the data collection room will take approximately 2 hours.

INCLUSION AND EXCLUSION CRITERIA

You ***can*** participate in this study if you:

- are 18 years of age or older
- are located in, or willing to travel to, the Windsor-Essex area (Human Kinetics Building at the University of Windsor)
    - NOTE – travel expenses will not be reimbursed
- use a closed hi-hat/snare drumming pattern
- fit the profile of highly skilled drummer (i.e., professionally established, touring/recording artist, or regularly perform in public)
- regularly play the drums for at least 5 hours per week
- have been free from any injuries/ailments that affected your ability to play the drums to your accustomed level of skill and/or intensity for the last 30 days.
    - If you have sustained such an injury/ailment within the last 12 months, you are eligible to participate if you have returned to your pre-injury/ailment drumming skill and intensity levels for at least 30 days.
- are fully vaccinated against COVID-19 (i.e., you have received two doses and the second dose was administered at least 2 weeks prior to your data collection)

You ***cannot*** participate in this study if you:

- are younger than 18 years of age
- are not located in/not willing to travel to Windsor-Essex County (Human Kinetics Building at the University of Windsor) at your own expense
- do not have adequate experience on the drum kit
- do not regularly play the drums for at least 5 hours per week
- are currently injured, or have suffered any injury/ailments that affected your ability to play the drums to your accustomed level of proficiency and/or intensity within the last 30 days.
- Have suffered any injuries/ailments within the last 12 months and have not yet returned to your pre-injury/ailment drumming skill and intensity levels.
- are allergic to the ingredients in the adhesive tape used to secure the electrodes or the electrodes themselves
  are not fully vaccinated against COVID-19 (i.e., you have not received any doses, you have only received a single dose, or you have received both doses but the second dose was administered within the last 2 weeks)

POTENTIAL RISKS AND DISCOMFORTS

- As with any physical activity, there is a risk that you might develop muscular fatigue and/or soreness or a muscle or joint injury. The drumming you will do for this study will be similar in duration and intensity level to what you would typically experience in your own day-to-day playing, and so the risk of experiencing muscle fatigue/soreness or a muscle or joint injury is no different than the risk you take when playing on your own time. Any muscle soreness that might occur is expected to be mild and should subside within a few days.
- The adhesive tape used to secure the sensors and minimize the movement of the sensor cables may chafe or irritate the skin, or they may become uncomfortable if they are secured too tightly. This irritation is similar to that which may develop from the use of commercially available bandages and is expected to disappear within a few days. Care will be taken to secure the tape strips in such a way that the adhesive surfaces are comfortable when touching the skin. You are encouraged to let the investigators know if the tape is too tight or uncomfortable, or if it is irritating the skin (redness, rash, inflammation, etc.), so the tape can be adjusted or removed.
- The skin where the EMG electrodes will be placed will need to be shaved to improve the adhesion and signal quality. This could cause some skin irritation, similar to what you would experience with dry-shaving, and is expected to disappear within a few days.
- Due to the nature of the instrument, the volume in the data collection room will increase when you are playing. You will be required to wear your own in-ear monitors/headphones or hearing protection throughout the data collection.
- You may feel uncomfortable with the physical contact required during the application of the electrodes and the tape strips. If you are uncomfortable with the application of the tape strips by Nicolas or a member of the research team, you will be shown how to apply the tape yourself, and then it will be adjusted as necessary by Nicolas or a member of the team. If you are uncomfortable with the application of the EMG electrodes, you can choose to withdraw from the study.

- You may feel uncomfortable with the idea of shaving patches of hair on your body. If you do not want these areas to be shaved, you can choose not to.
- You may feel uncomfortable disclosing the demographic information that is requested. This information is required to ensure the validity of the study and to ensure you meet all inclusion criteria. This information will remain confidential – it will only be tied to your randomized participant number, not your name. If you do not want to disclose this information you can choose to withdraw from the study.
- You may feel anxious or concerned about potential exposure to COVID-19 from your participation in this study. Research staff will follow multiple safety precautions, including wearing N95 masks and eye protection, wearing gloves while we apply the EMG electrodes, routine and frequent handwashing and sanitizing, and spacing data collections by at least 72 hours. Your participation in this study is completely voluntary, and you are free to withdraw from the study at any time by following the procedures outlined below.
- Although the data collection will occur in a private room, it will occur in a public building, so you may be seen walking into the building by members of the public. Furthermore, the door to the lab must remain propped open to enhance air circulation (a barrier will be put in place to eliminate a direct line of sight into the lab). If you are concerned about the possible loss of status, privacy, and/or reputation you can choose to withdraw from the study.

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

While we do not anticipate any direct benefits to the participants, you may benefit from knowing that you contributed to research in an emerging field (and, being a drummer yourself, one in which you have a vested interest). Your contributions will also help to benefit the drumming community and the common interests of the investigators and participants. This study will provide benefits for drummers of all skills as well by providing practical implications for helping drummers excel. Knowledge of to produce more efficient forceful strikes can be incorporated into the training of drummers by helping skilled drummers refine their skills and giving novice drummers a visualization and a goal on how to excel in their drum training. The field of drummer biomechanics and motor control is very new therefore there are many gaps in the literature. The results from this study will expand and bridge the gaps in the literature. This study will also further the idea of drummers as athletes leading to further "sport like" research on drummers allowing the field to grow. Finally, this research will help foster a relationship between the Department of Kinesiology and School of Creative Arts that will be built upon in the future.

COMPENSATION FOR PARTICIPATION

You will receive either a Kinesiology Research t-shirt or a DRUMMER Lab t-shirt as a token of gratitude for your time.

CONFIDENTIALITY

Participant anonymity is not possible with this research as the data collection is required to occur in person, with you and the investigators and occasionally other members of the research team (i.e., other lab members who are there for training or to provide assistance) in the same room. However, only members of the research team will be present during data collection. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

Data confidentiality will be handled as follows:

1. EMG data and intake forms will be collected and stored in a de-identified manner (i.e., by participant code only). These data will also be disseminated in a de-identified manner unless you indicate that you consent to non-confidential dissemination on the last page of this informed consent form (i.e., the audio/video/still photography consent form).
2. All audio-visual files will be collected and stored in a de-identified manner (i.e., by participant code only). Video/photos will only be used for dissemination if you indicate your consent for

partially confidential or non-confidential use of your photos/videos on the last page of this informed consent form (i.e., the audio/video/still photography consent form).

3. A file linking participant names to their participant codes will be encrypted, password protected, and stored on the investigators' password-protected computers and/or OneDrives.

Raw data are valuable for future studies, and therefore the data collected in this study will not be destroyed. Hard copies of the signed informed consent forms and the de-identified intake forms will be kept in a locked filing cabinet in the Biomechanics Lab and will be labelled with individualized participant codes until the conclusion of the study, when they will be moved to a locked filing cabinet in the faculty supervisor's office and stored indefinitely. The de-identified digital data and the photos/videos will be stored indefinitely on the investigators' password-protected computers and/or OneDrive. All data recorded will be labelled with the participants' unique identifying code and not their name. A document linking participants' names and unique identifying codes will be encrypted, password protected, and kept on the investigators' password-protected computers and/or OneDrives. At the end of the study, Nicolas will surrender this file to Dr. Azar and will delete it from his computer. However, he will retain the right to keep a copy of the de-identified data and the photos/videos. Dr. Azar will keep the file linking participant names to their codes indefinitely (i.e., encrypted, password protected, and kept on a password-protected computer and/or OneDrive). The GlobalProtect Virtual Private Network (VPN) will be used on all computers that are used to access the data.

PARTICIPATION AND WITHDRAWAL

You will be able to withdraw from the study at any point up until two weeks following your date of data collection. After this two-week period, it will be assumed that you consent to the use of your data and digital audio-visual recordings in any or all of the forums listed above.

If you want to withdraw from participation during the data collection period, you can let the research team know verbally and the study will be stopped immediately. If you decide you want to withdraw from the study after your data has been collected, you can contact Nicolas Latreille by email (latreil1@uwindsor.ca) within two weeks of the date of your data collection with your request to withdraw.

As soon as you withdraw from participation (either verbally or in writing within two weeks of the date of your data collection) your digital data (including digital audio-visual recordings) will be promptly deleted from all electronic devices and databases and hard copies will be destroyed.

The investigators may withdraw you from this research if circumstances arise which warrant doing so. These circumstances may include, but are not limited to, the determination that you do not fall within the inclusion criteria.

All participants who schedule and show up to their assigned data collection time slot will receive and be welcome to keep a Kinesiology Research t-shirt and drumsticks as our token of gratitude for their time.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

A summary of the findings of this research will be made available to participants and the general public upon completion. It will be posted on the University of Windsor's research website (address below) and on Dr. Azar's social media pages.

Web address: https://scholar.uwindsor.ca/research-result-summaries/
Social Media Handle: @DrNadiaAzar (Facebook, Instagram, Twitter)
Date when results will be available: December 31st, 2022

SUBSEQUENT USE OF DATA

These data and photos/videos may be used in subsequent studies, in publications, and in presentations, as described above and on Consent for Still Photography and Audio/video Recording form.

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: The Office of Research Ethics, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study **An Investigation of Drummers' Trunk and Upper Limb Muscle Activation Profiles during High-Velocity Cymbal Crashes** as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

☐ I would like Dr. Nadia Azar to retain my contact information so that I can be contacted with information about the possibility to participate in future DRUMMER Lab research studies.

____
Name of Participant

______________________________________ ___________________
Signature of Participant Date

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____________________________________ ____________________
Signature of Investigator Date

CONSENT FOR STILL PHOTOGRAPHY AND AUDIO/VIDEO

RECORDING

Research Participant Name: ______________________________

Title of the Project: An Investigation of Drummers' Trunk and Upper Limb Muscle Activation Profiles during High-Velocity Cymbal Crashes

This study will involve the use of still photography, video, and/or audio recording. I understand these are voluntary procedures and that I am free to withdraw at any time by requesting that the recording and/or photography be discontinued.
All recordings and photographs will be stored on password-protected computers and OneDrives. The GlobalProtect Virtual Private Network (VPN) will be used on all computers that are used to access the recordings/photographs.
I understand these recordings/photographs may be used for dissemination of the results of the study in any, or all, of several forums. Examples include, but are not limited to:

- Summary on the University of Windsor's Research Ethics Board website
- Conference or other academic presentations (e.g., teaching, guest lectures, speaking engagements, etc.)
- Academic publications (e.g., master's thesis document, peer-reviewed journals)
- Online (e.g., investigator's website, online drumming communities, blogs and/or vlogs)
- Summaries and/or case studies shared through social media (e.g., Facebook, Twitter, Instagram, etc.)
- Articles in popular drumming magazines (e.g., Modern Drummer, Drum! Magazine, etc.)
- Media appearances (e.g., radio, television, or online interviews such as podcasts, vlogs, and/or blogs)
- Drummer Mechanics and Ergonomics Research Laboratory (DRUMMER Lab) promotional purposes (e.g., future study recruitment initiatives)

I have indicated my level of consent to the use of audio/videotaping and/or photography of study procedures while wearing the research equipment, using the check boxes below:

☐ **Non-confidential use**: I give the investigators permission to use my likeness in the manners listed above without any masking, such that I will be fully identifiable in the photos/videos.

☐ **Partially confidential use**: I give the investigators permission to use my likeness in the manners listed above, provided that my face is masked. I understand that any visible tattoos or other markings may not be able to be masked, and so I may still be identifiable based on these features.

☐ **Fully confidential use only**: my videos and/or photos may only be viewed by the research team during data analyses. I do not wish for them to be used in any public presentations of the data.

This research has been cleared by the University of Windsor Research Ethics Board.

______________________________ ____________________

(Research Participant Signature) (Date)

Consent Addendum for COVID-19 Risks and Procedures for In-Person Research at the University of Windsor

Title of Research Project: An Investigation of Drummers' Trunk and Upper Limb Muscle Activation Profiles During High-Velocity Cymbal Crashes

You have already been invited to participate in a research study conducted at the University of Windsor and have given your consent to participate. This additional consent form is intended to bring your attention to important information related to the COVID-19 pandemic and risks associated with in-person participation in research. This form also informs you about the strategies that researchers will implement in this project to modify their procedures in light of the pandemic.

Due to the current global COVID-19 pandemic, Canadian public health authorities have strongly recommended that everyone (especially high-risk individuals or those in contact with high-risk individuals) take additional precautions. The University of Windsor is attempting to limit the risk of exposure to COVID-19 by using reasonable efforts to follow the health and safety guidelines recommended by the federal, provincial and local health authorities (https://www.wechu.org/). Nevertheless, there remains a risk that by coming onto the University of Windsor campus or any of the University of Windsor study sites, you may contract the virus that causes COVID-19.

You are reminded that your participation in this research is voluntary and you can withdraw from the research per the terms as set out in the main consent agreement for this research. Please feel free to ask questions and express any concerns as you read through the information in this form by contacting the individuals noted in the main consent form. **If you are feeling unwell or experiencing any potential COVID-19 symptoms, please do not come to campus and notify a member of the study team that you cannot attend**. Contact information can be found on the consent form that has been shared with you.

In order to help reduce the risk of spreading COVID-19, the University of Windsor is following Public Health Ontario directions in addition to taking the following safety precautions:

What you will be asked to do:

- Complete the Safe Lancer Application or the on-line fillable document. On the day of your visit, no more than an hour before you come to campus, you must complete the Safe Lancer Application (https://www.uwindsor.ca/campuspolice/safelancer) or the on-line fillable document (https://www.uwindsor.ca/returntocampus/sites/uwindsor.ca.returntocampus/files/0042_rtc_questionnaire_safe_lancer_-_final.pdf). Once you have completed this activity, you must forward the results to the researcher prior to arriving on campus. If you do not receive a positive confirmation, please contact the research team to reschedule your appointment. For further instructions on how to use the on-line applications, please see below.
- Wear PPE while at the study site: Wear the mask, face shield, goggles or any other personal protective equipment (PPE) provided by the researchers during the entire time you are at the study site. The face covering provided to you should fully cover your mouth and nose.
- Provide information on your vaccination status, if asked. The research team may ask you for your vaccination status if this is part of their approved screening protocol. If they do ask, they will want to know if you have had both vaccinations and the date of your last shot.

What the researchers will do:

- Follow the guidance provided by the University of Windsor for conducting research on campus. All research team members will follow the University of Windsor COVID-19 Research and Innovation Guidance (**https://www.uwindsor.ca/vp-research/353/covid-19-research-and-innovation-guidance**).
- Wear PPE at all times during the data collection. All researchers will be required to wear a N95 mask, and participants will be required to wear a 3-ply medical grade mask, as well as a face shield

or goggles if physical distancing cannot be maintained. These personal protective equipment (PPE) will be provided to you by the research team.

- Sanitize all surfaces. The research team will ensure that all surfaces and/or shared equipment will be sanitized between participants' appointments. The researchers will use disposable equipment as much as possible.
- Maintain physical distancing unless approved for close contact. All researchers and participants must maintain a physical distance between them of 2 metres or more, unless some study procedures require closer distance or contact (for example, taking saliva or blood samples), applying or fitting equipment, or other preparation for participation that requires close contact or touching. If 2 metres of distance is not possible, the study procedures will include additional safety measures that were approved by the University of Windsor's Research Safety Committee and cleared by the Research Ethics Board.

In addition to the above, the University of Windsor will be collecting personal contact information. The purpose of this information is to be retained and used only to follow up with you in cases where you may have been exposed to COVID-19 at the study site. Your contact information may be shared with public health authorities for the purpose of contact tracing. Contact information will be stored securely and separately from research data. Your information for contact tracing will be destroyed as soon as permitted by public health authorities (usually after 14 days).

The Government of Canada provides information on COVID-19 risks and prevention and on taking care of your mental health during the COVID-19 pandemic.

You are asked to acknowledge and accept the information outlined above regarding the risks of COVID-19 exposure and the related safety measures that have been put in place. By signing this document, you confirm that you have read the information above and have had an opportunity to ask questions.

☐ I acknowledge (check box if all of the following are true)

- I have completed the Safe Lancer App or the on-line fillable document prior to coming to campus and have forwarded the results to the researcher (if you need instructions for downloading the app or the fillable form, please see the instructions below).
- I am not experiencing any potential Covid-19 symptoms (e.g., fever, cough, trouble breathing);
- In the last 14 days, I have not travelled outside Canada or had close contact with anyone who has any of the symptoms listed above or a confirmed or presumed case of COVID-19.

If requested:

☐ I acknowledge:

- I have received both vaccinations for COVID19
- My second vaccine was on (**DATE**): __________________

I understand the COVID-19 information including risks and mitigation strategies and their limitations provided for the study. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Participant

______________________________________ ___________________
Signature of Participant Date

Instructions for using the Safe Lancer App:
Within an hour before arriving to the research site:

Step 1: On the Safe Lancer App main page click the “COVID-19 Updates & Self-Assessment”
Step 2: Click “Self-Assessment Tool”
Step 3: Click “Start Self-Assessment”. Read the questions carefully and answer “Yes” or “No” and click “Continue”.
Step 4: Confirm answers and submit.
Step 5: Upon completion of the screening questions, you must show confirmation, of a green badge to enter the research site. Click on the QR code and send via email to the researcher’s email listed on the consent form (To forward your badge, tap the QR code once. At the top of the badge screen, copy the URL link and paste it into an email to forward).

If you do not have a phone or tablet to download the Safe Lancer App:
On-line fillable self-assessment form:

- Within an hour before arriving to the research site, download the self-assessment questionnaire using the following link: https://www.uwindsor.ca/returntocampus/sites/uwindsor.ca.returntocampus/files/0042_rtc_questionnaire_safe_lancer_-_final.pdf
- Complete this form and e-mail it to the researcher using the address provided by the researcher.

Paper version of the self-assessment form:

Ask the researcher for a hard copy of the self-assessment tool, which you’ll have to complete immediately before coming onto campus, and then give the completed self-assessment paper to researcher when you arrive at the

Appendix B: Participant Intake Form

Participant Identification Number: ____________________________________
Date/time/location: ____

Date of Birth: ____
Sex: ____________________
Preferred pronouns: ____________________
Allergic to latex, adhesives, etc?
____
Fully vaccinated against COVID-19? _______________
Date second dose was administered: _______________

Performance Style

Main musical genre:	
Dominant hand:	**RIGHT / LEFT**
Common grip style(s) used:	
Do you play an open-handed or closed-handed hi-hat/snare pattern?	**OPEN / CLOSED**
Do you play a single or double bass drum pedal?	**SINGLE / DOUBLE**
Make/model of the drumsticks you are using today	

Playing History

At what age did you start playing the drums?	
How long have you been playing the drums for at least 5 hours per week?	

How many hours do you play the drums per week?	
What is the average duration of a playing session (e.g., practice or performance)?	
Have you ever taken formal drum lessons?	**YES / NO**
If yes, for how long?	
Describe the extent of your drumming experience and career. For example, "touring drummer for 10 years, playing since the age of 7 years".	

Injury History

Do you currently have (or have had within the past 30 days) an injury/ailment that affected your ability to play the drums to the skill and/or intensity levels to which you are accustomed?	**YES / NO**
Have you experienced an injury/ailment that affected your ability to play the drums to the skill and/or intensity levels to which you are accustomed, more than 30 days ago but within the last 12 months?	**YES / NO**
What part of the body did this injury/ailment affect?	
Has this injury/ailment resolved to the point where you have returned to the intensity and skill levels at which you were playing prior to your injury/ailment?	**YES / NO**
Have you ever had an injury or ailment that interfered with your ability to play the drums at the skill and/or intensity levels to which you are accustomed?	**YES / NO**

What part of the body did this injury/ailment affect?	
Approximately how long ago/When did this injury/ailment occur?	

Appendix C: EMG Traces

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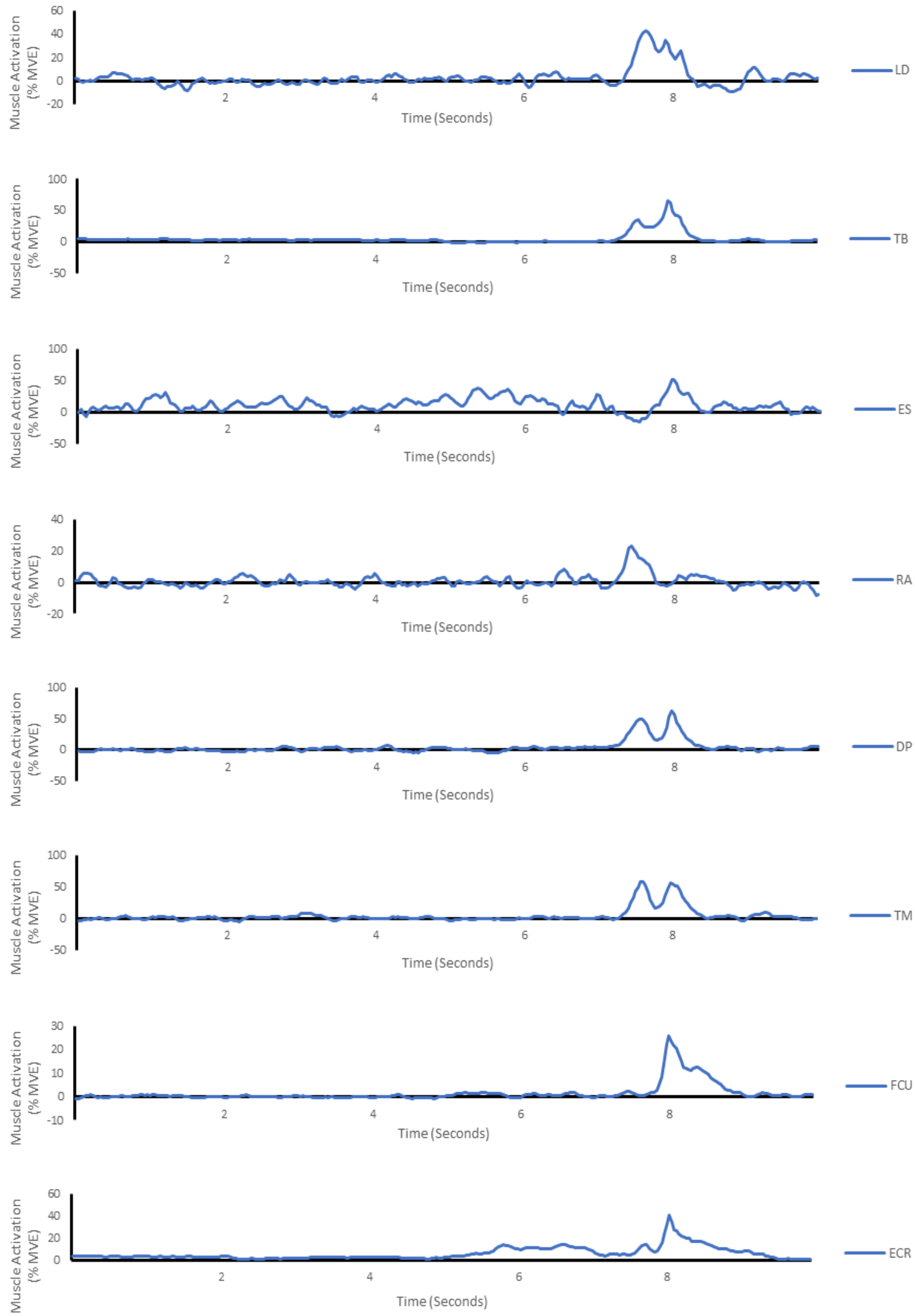
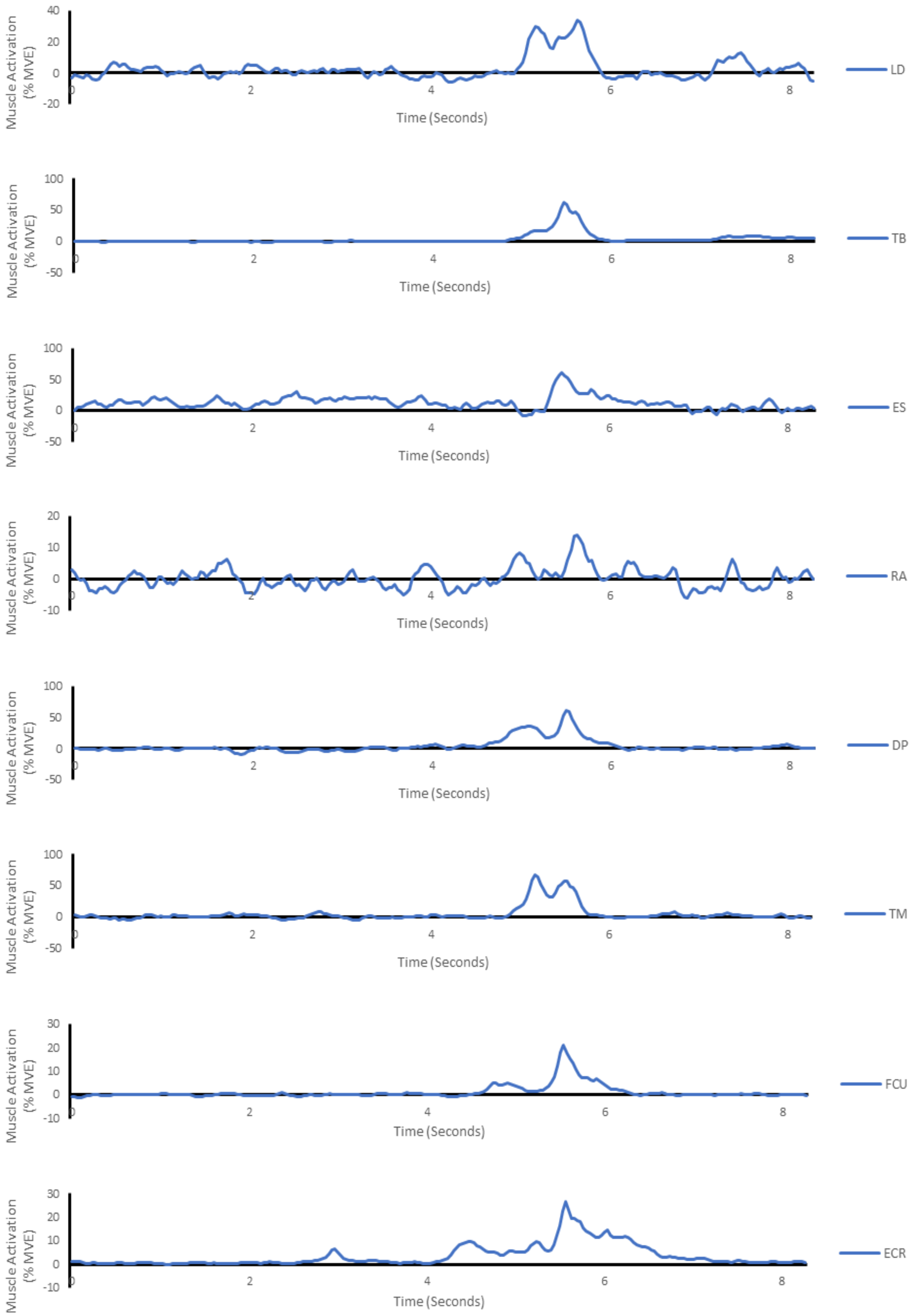
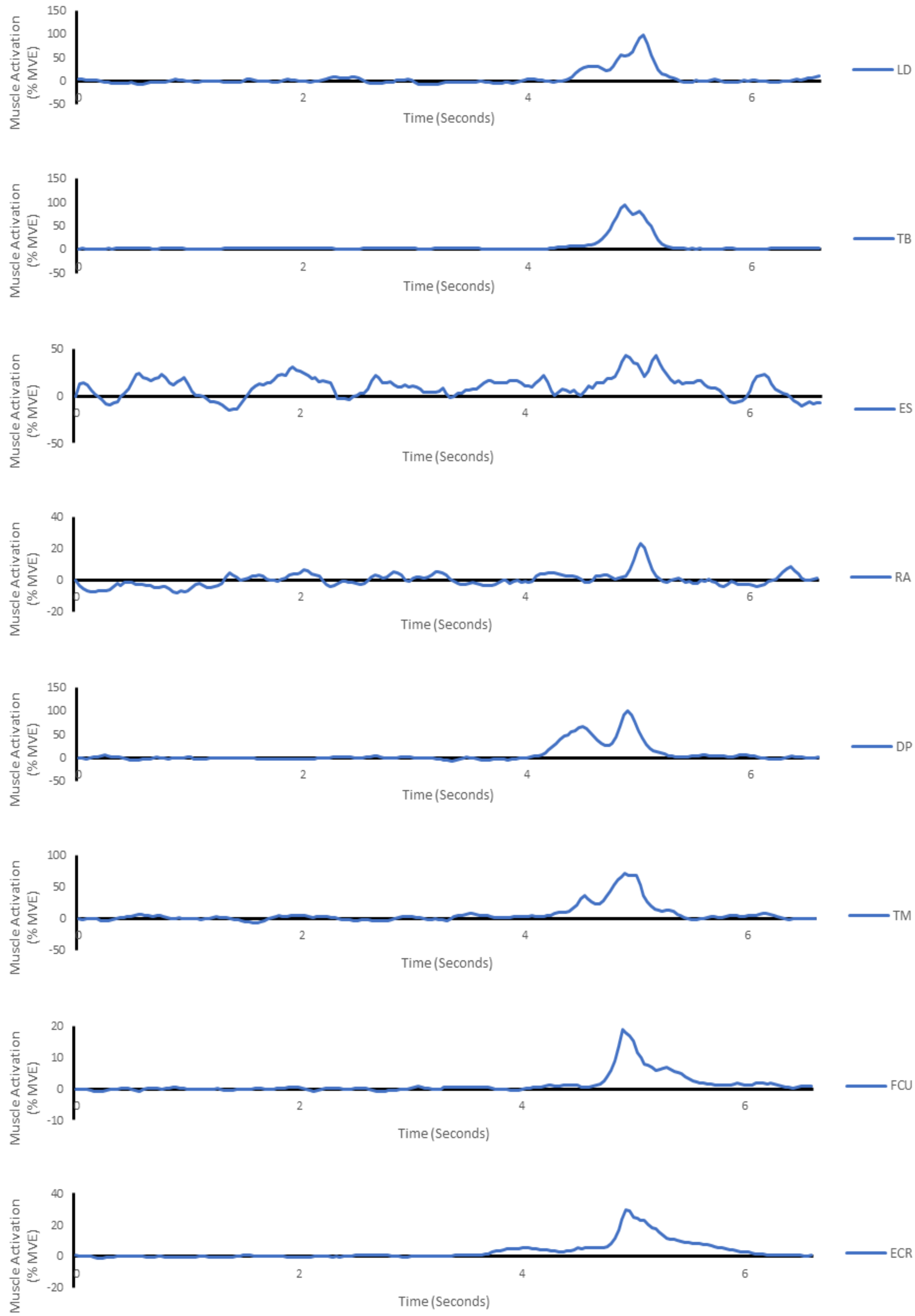
Drummer A MVE 1



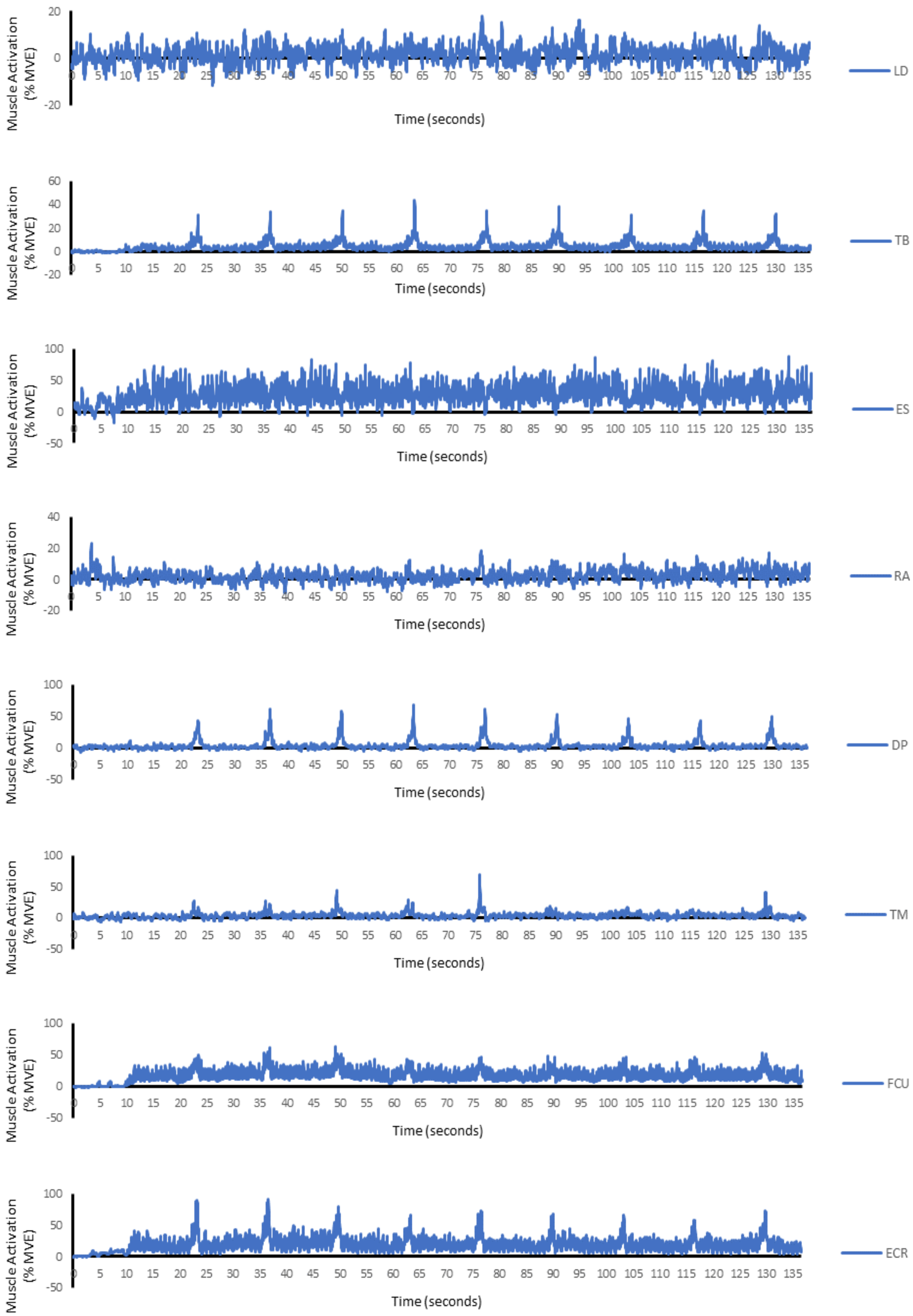
Drummer A MVE 2



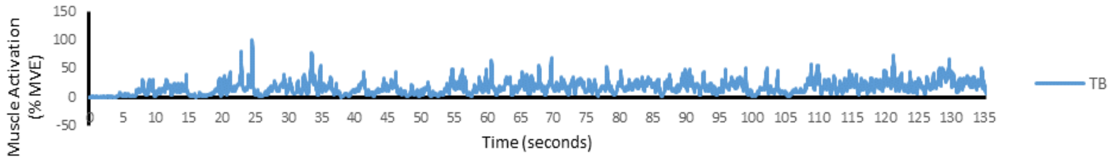
Drummer A MVE 3

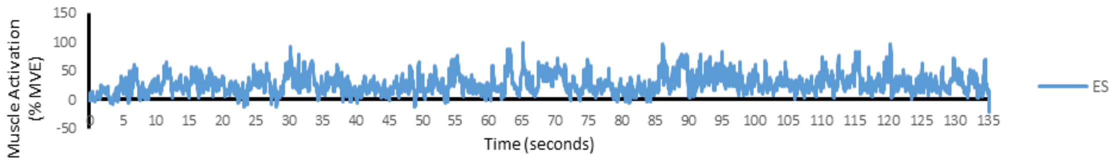


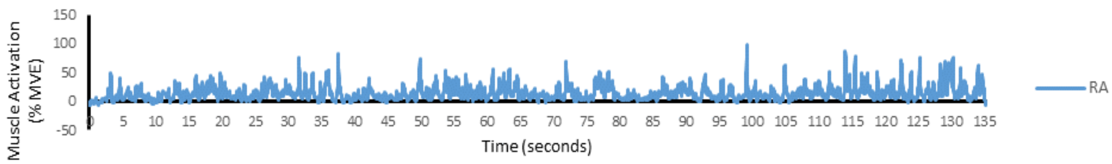
Drummer A Pattern

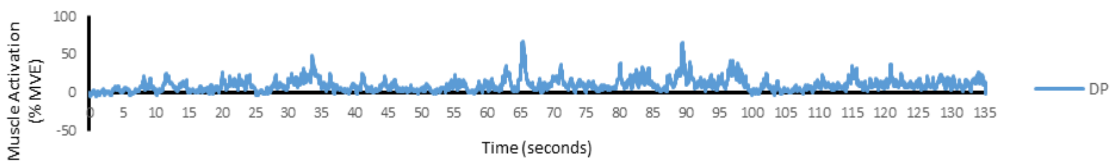


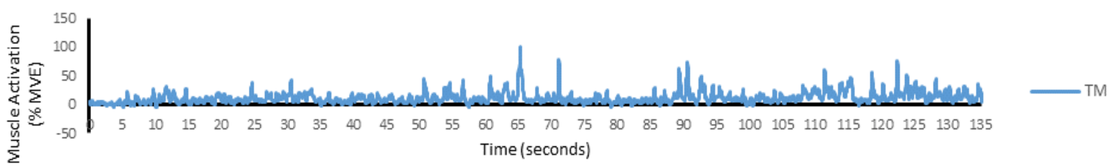
Drummer A Free Play

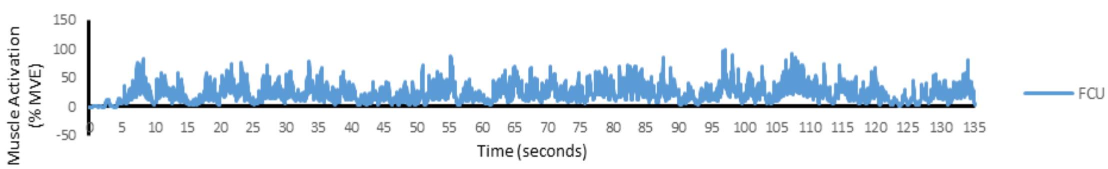


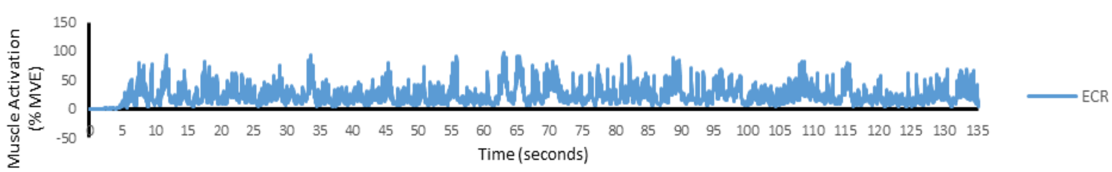




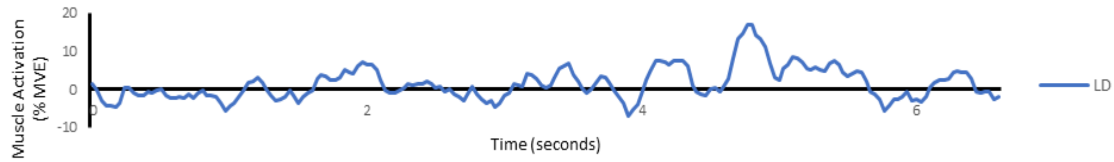


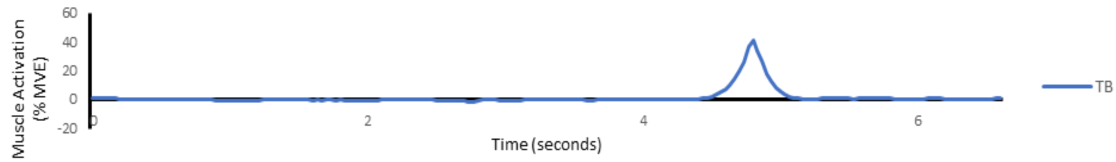


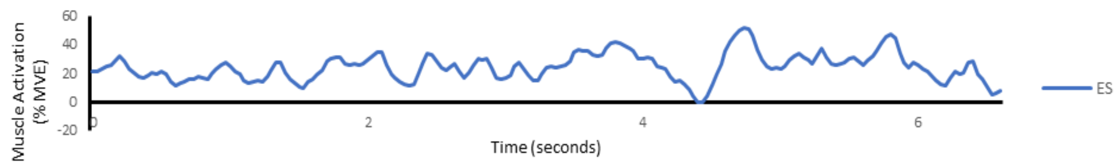


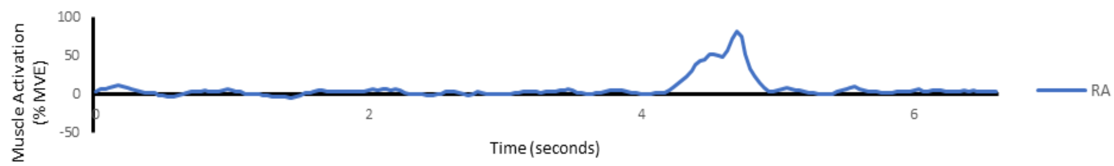


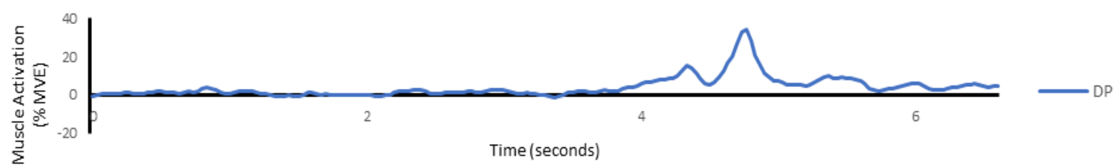
Drummer B MVE 1

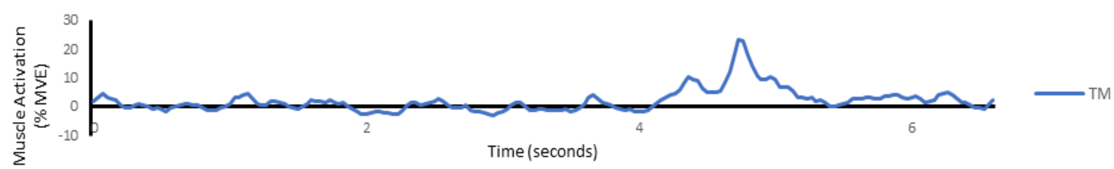


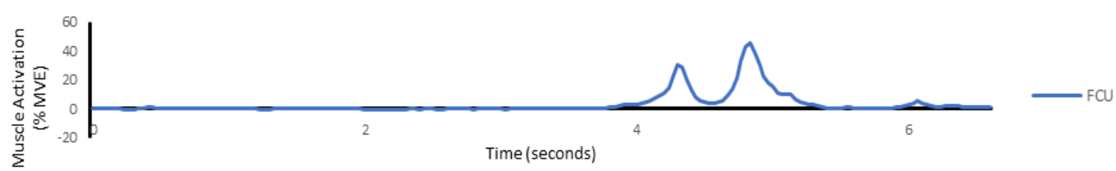


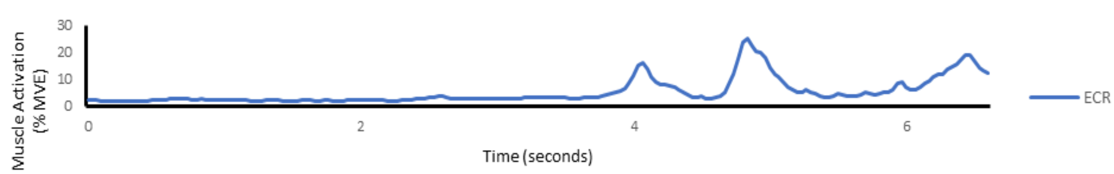












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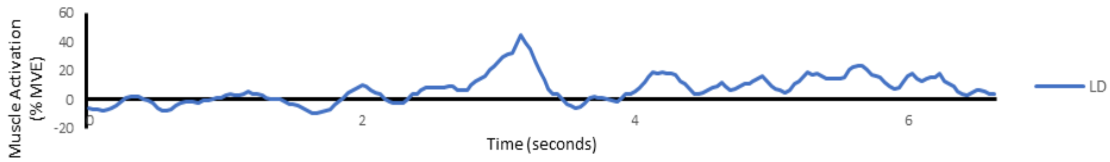
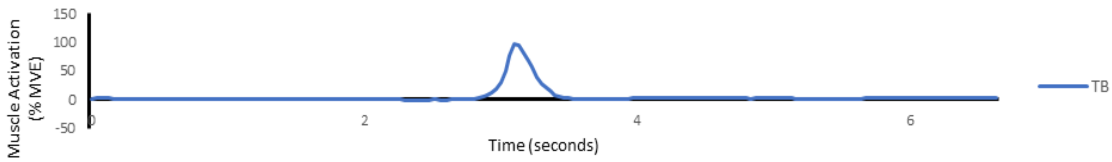
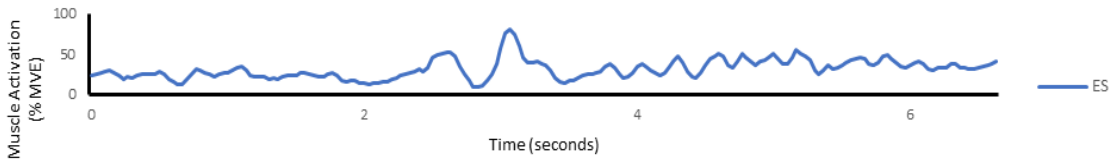
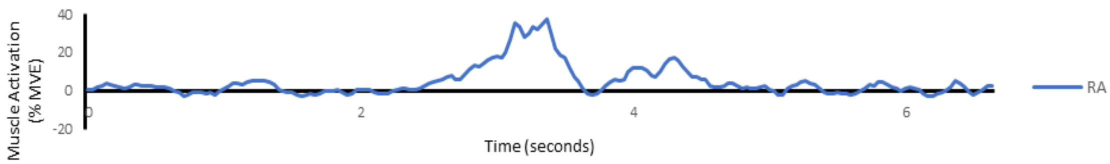
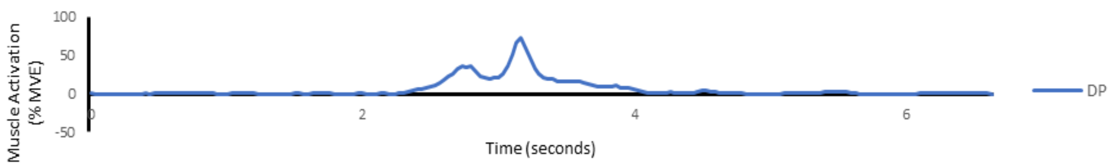
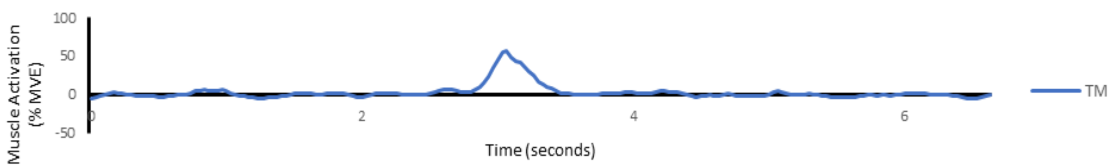


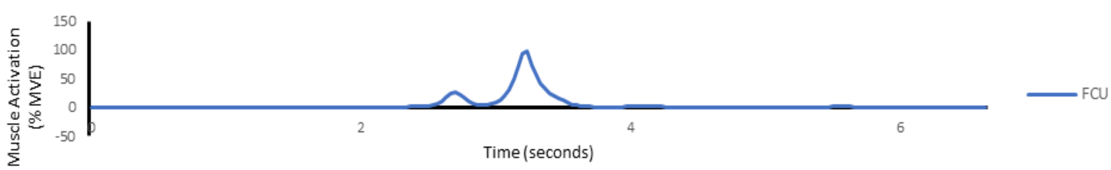


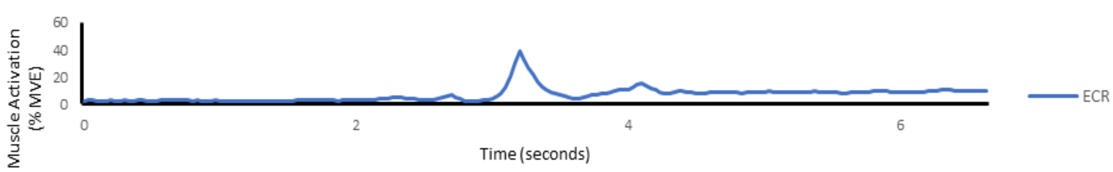




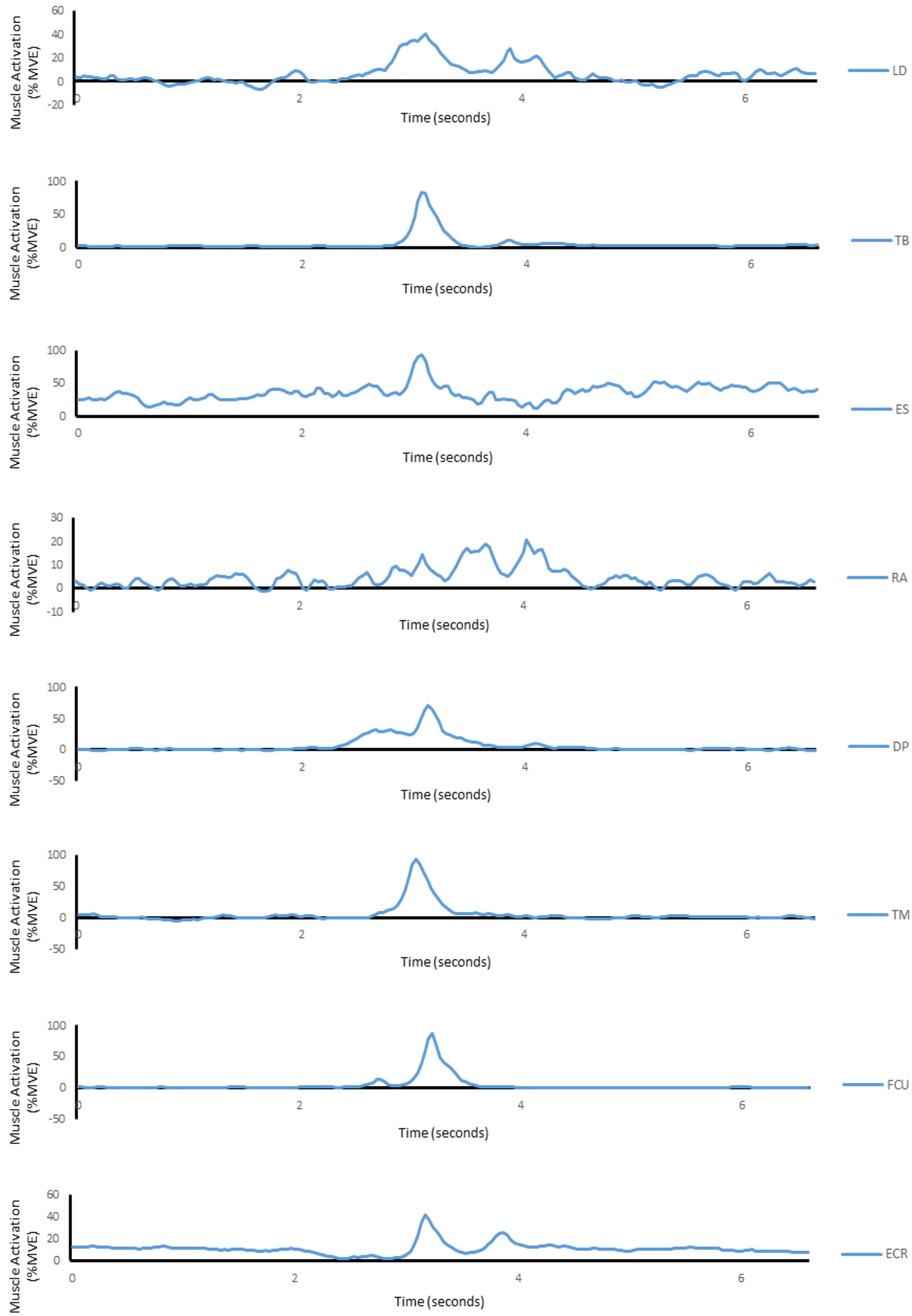




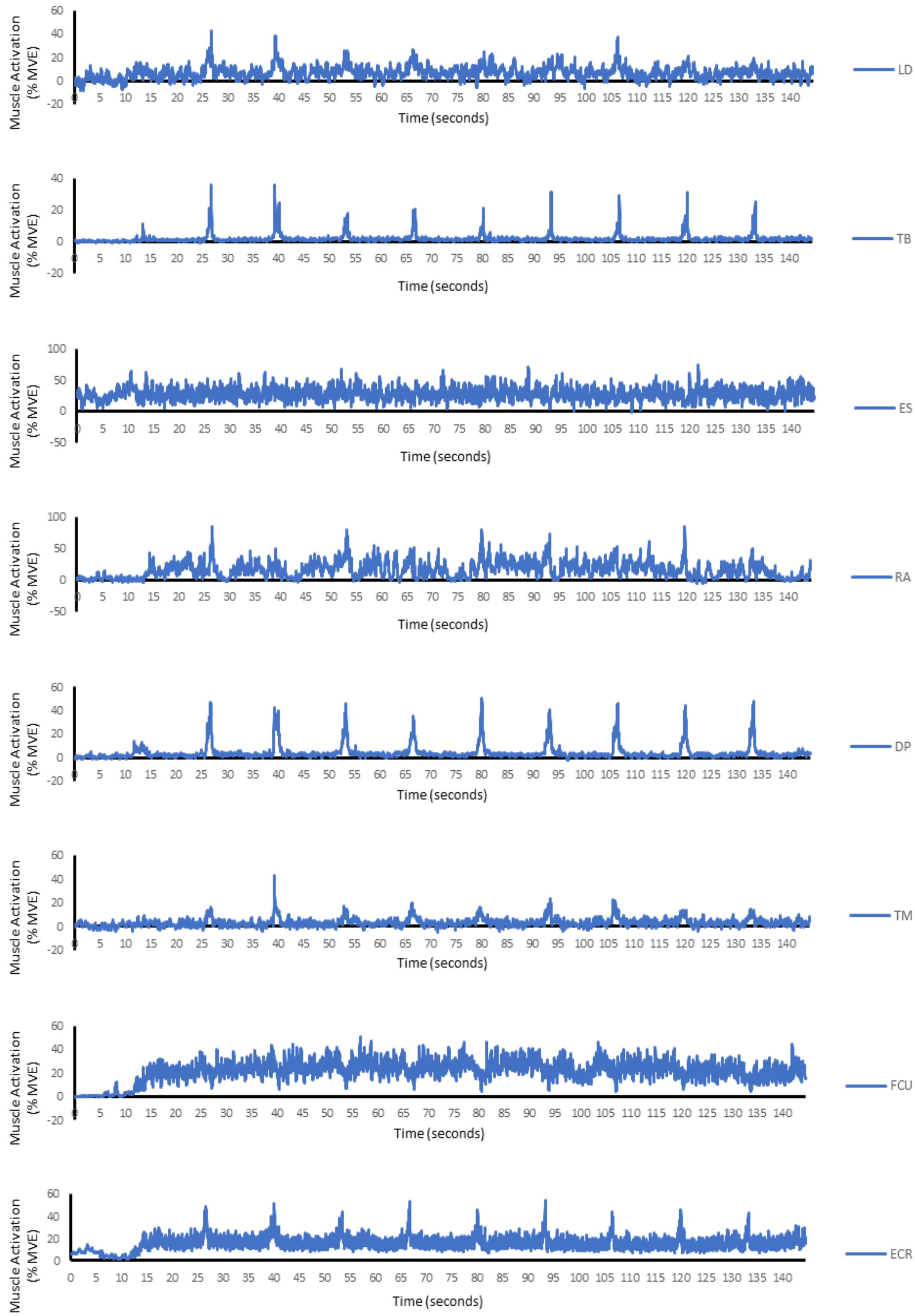




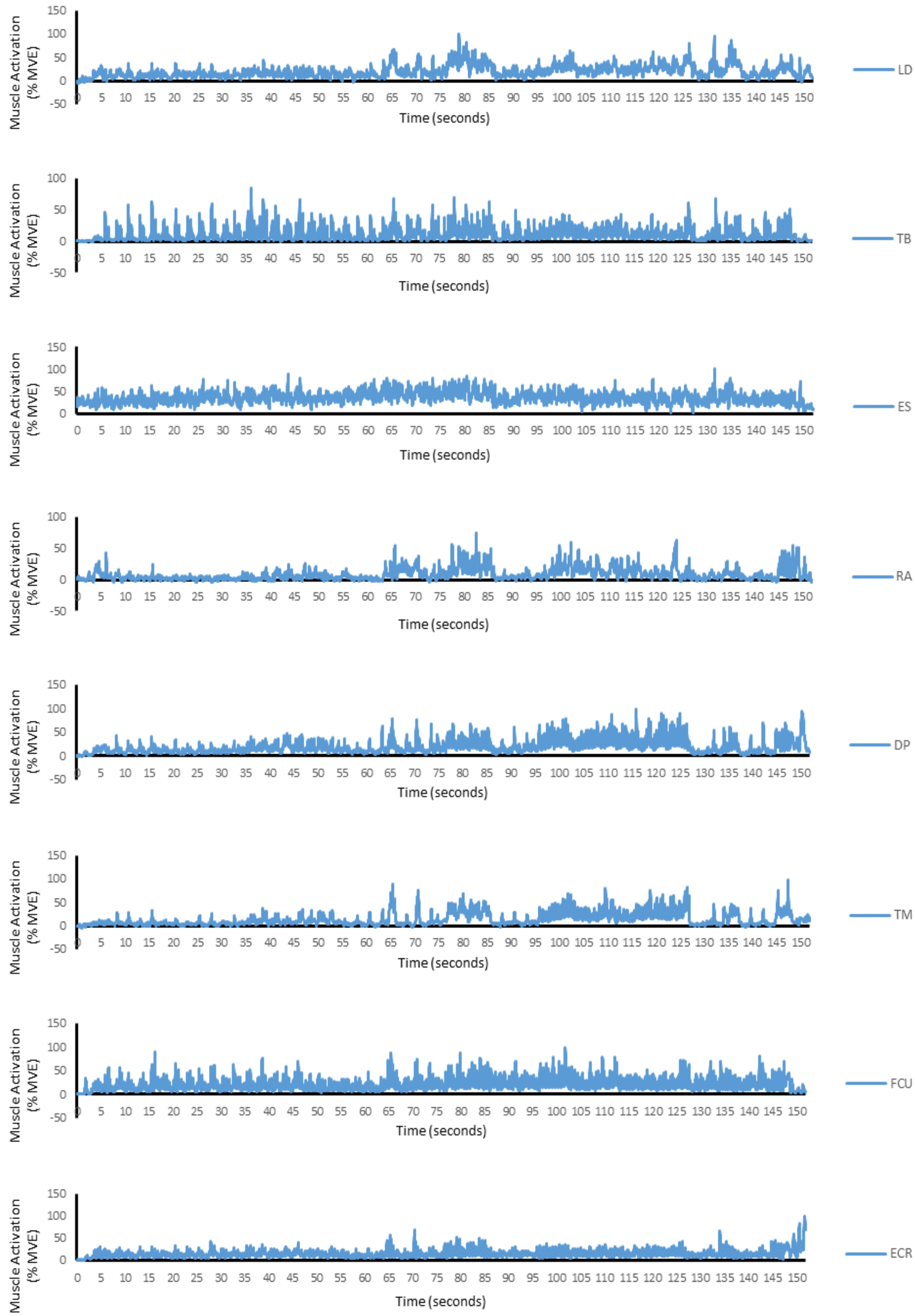
Drummer B MVE 3



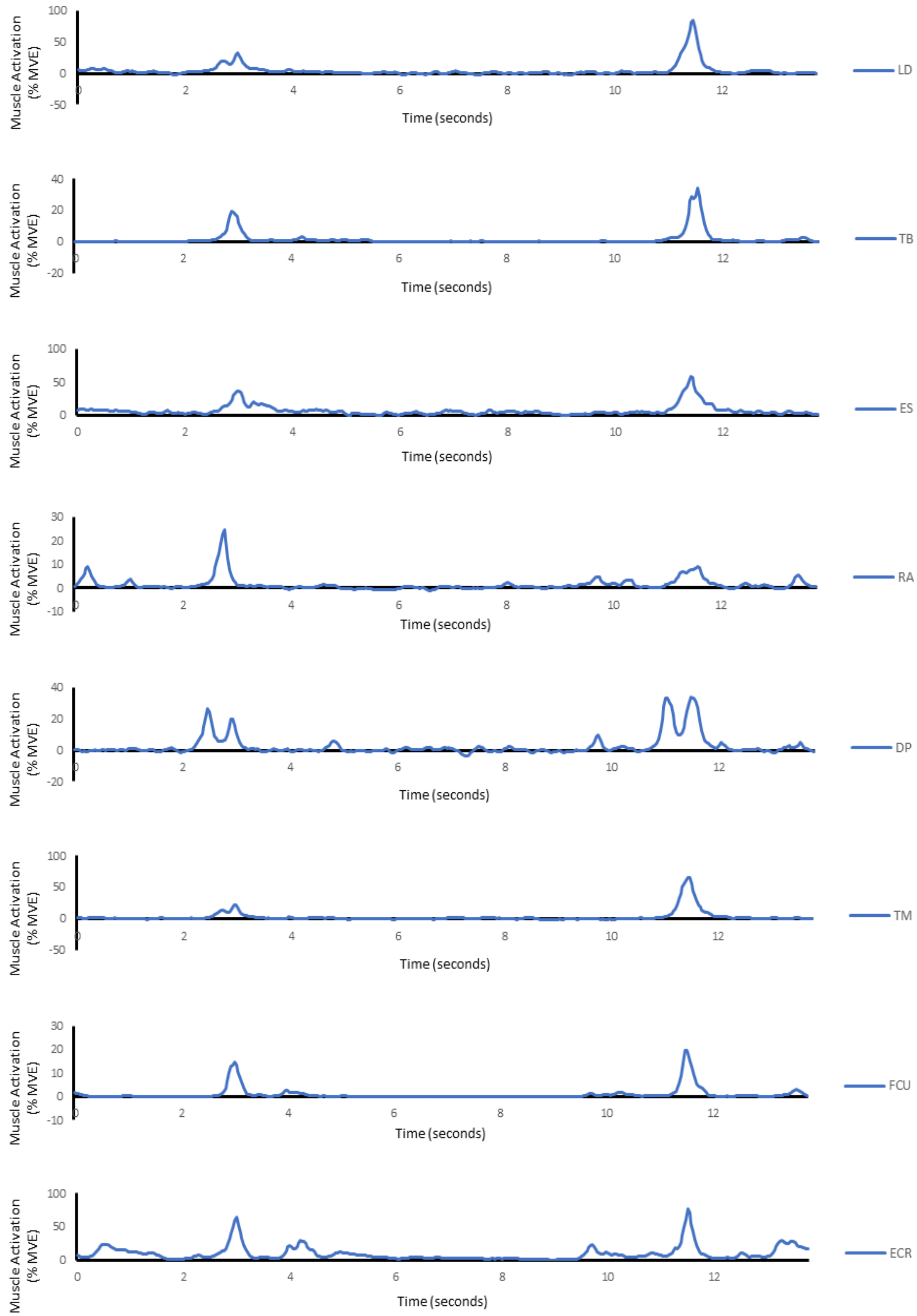
Drummer B Pattern



Drummer B Free Play



Drummer C MVE 1



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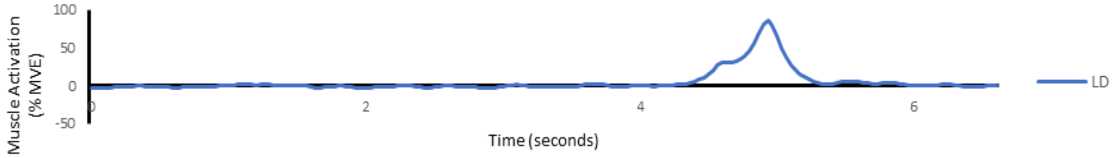
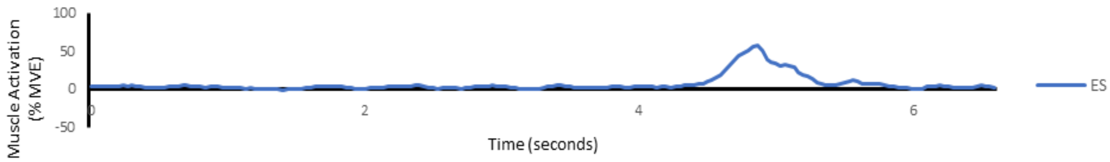
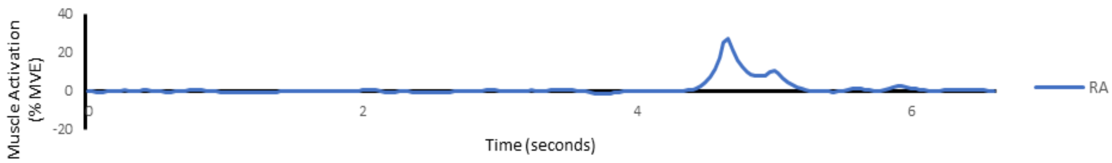
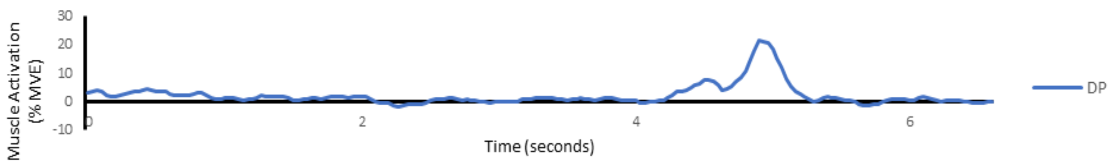
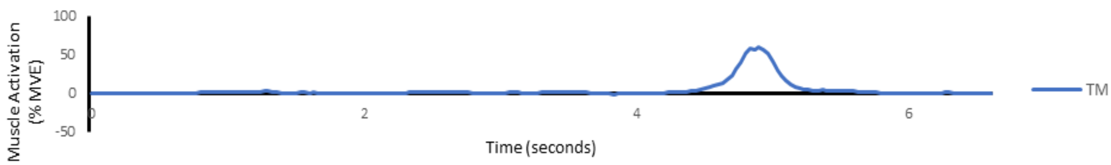
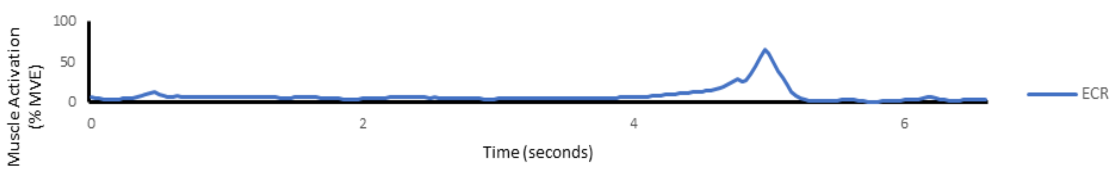




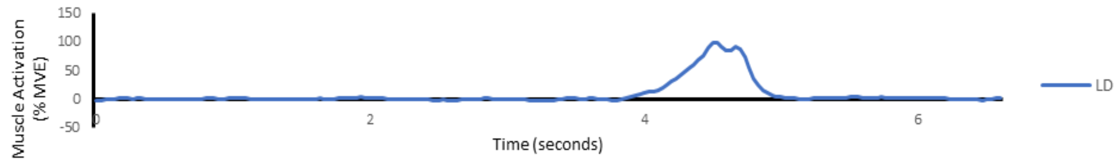


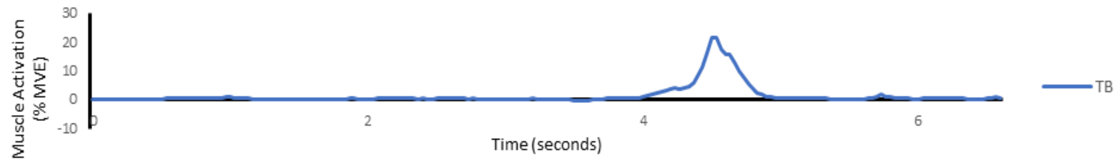


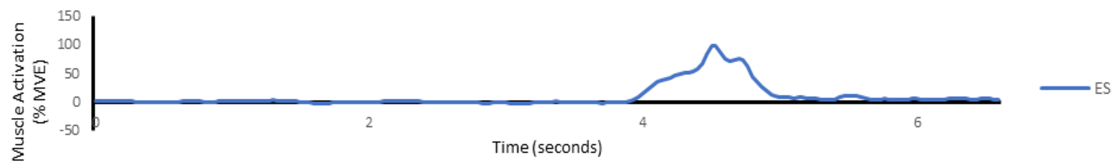


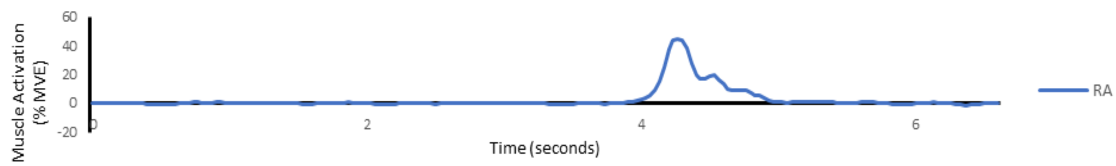


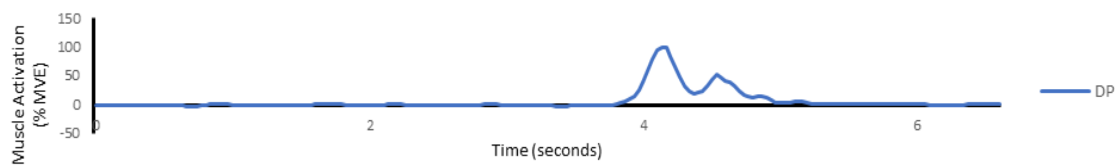
Drummer C MVE 3

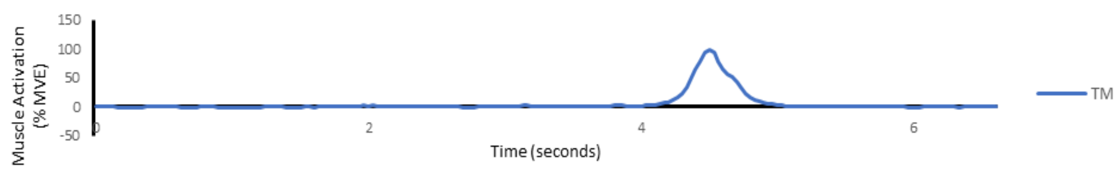


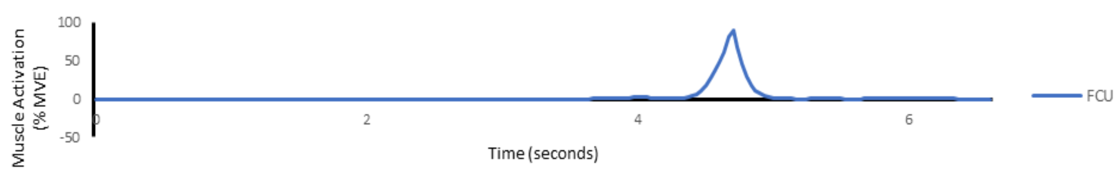


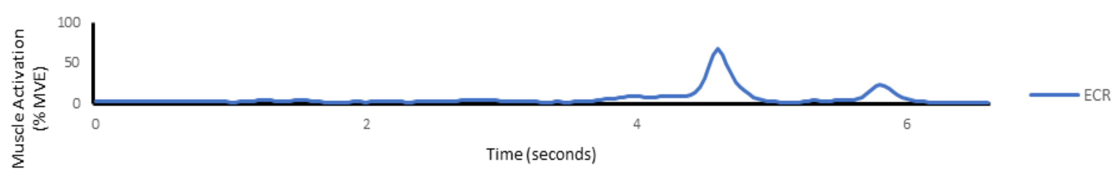




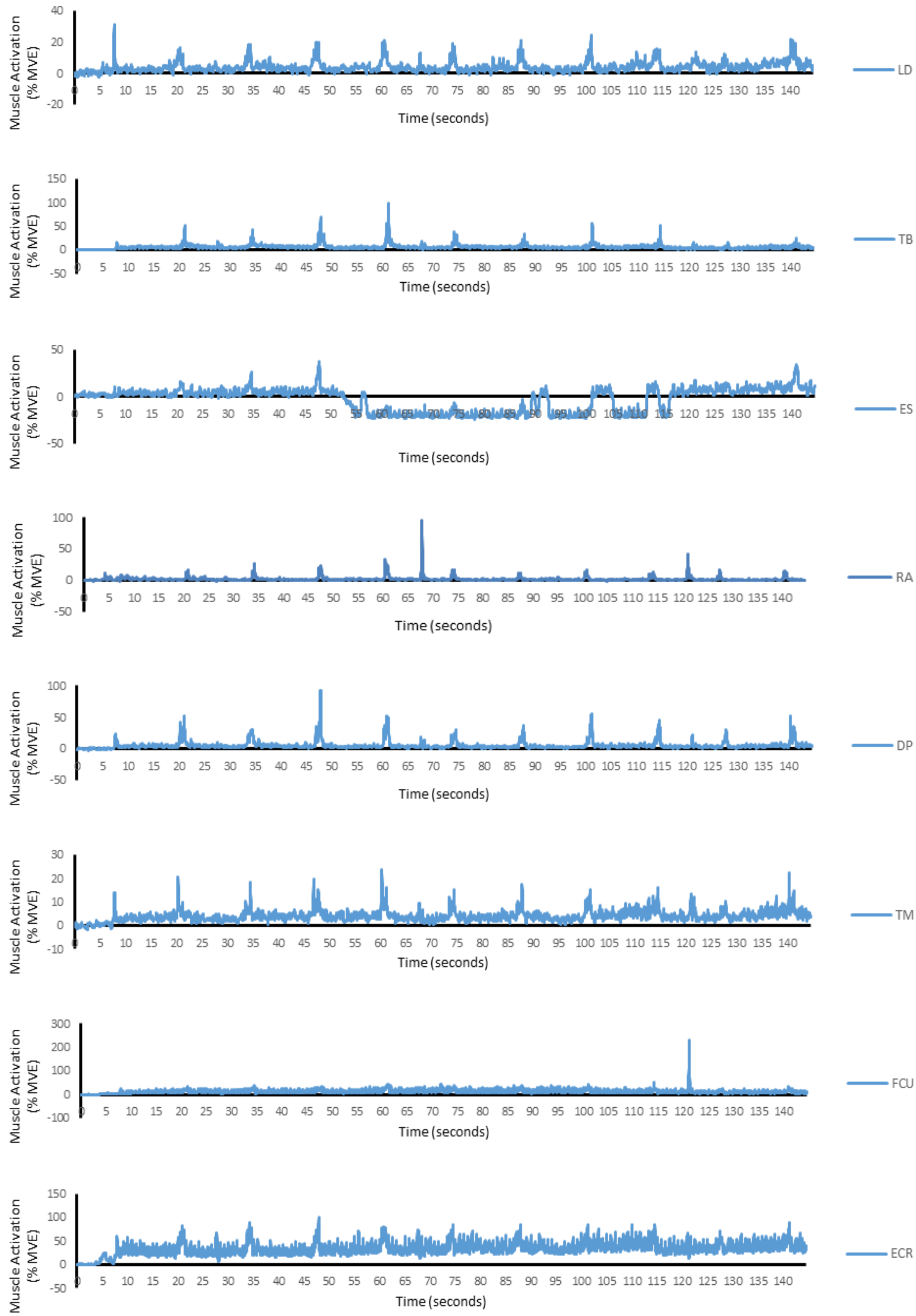








Drummer C Pattern



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