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Testing the Validity and Reliability of Electromyography Acquisition Capabilities of a Wearable EMG Device, Sense3, by Strive

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TESTING THE VALIDITY AND RELIABILITY OF ELECTROMYOGRAPHY ACQUISITION CAPABILITIES OF A WEARABLE EMG DEVICE, SENSE3, BY STRIVE

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Abstract

There is a growing demand in the sports world for wearable technology, particularly those with electromyography acquisition capabilities. Electromyography (EMG) is technique for measuring the electrical activity that occurs during muscle contraction and relaxation. Basic practical applications of EMG use in sports include, but are not limited to: measuring activation timing of a muscle, measuring levels of activation, and detecting fatigue. The sports performance company Strive has designed an EMG wearable, called Sense3, that targets the following muscles of the lower limb: Quadriceps, Hamstrings, and Glutes. Sense3 must pass reliability assays to determine the validity of the EMG system in order for Sense3 to be accessible as a commercialized product. This study was designed to compare the EMG acquisition performance of Sense3 to the performance of a traditional EMG acquisition device, MA-300, during slow and controlled movements, simulated by use of a dynamometer, and during dynamic movements. Statistics from the reliability assays showed Sense3 to be reliable in the Rectus Femoris and Biceps Femoris during dynamometer trials. Sense3 was unable to consistently record useable EMG signals for analysis during dynamic exercise trials. The ability to record EMG signals during dynamic movement was the main determinant for validity of Sense3's EMG acquisition system. The results suggest that Sense3 is not a valid EMG acquisition system for sports-based, dynamic use.

Chapter 1. Introduction

Professional sports are a beloved cultural influencer that generate a huge economic market with estimated revenues of over a trillion dollars in the US alone. Over the decades, we have been able to push the limits of human athleticism and mastery of technical skills through the progression of medical practices, technological advancements, and research cultivated over the years. With the continuing growth of the sports industry, sports scientists, coaches, and athletes are investing in technology in order to gain the competitive advantage. Wearable technology has become the latest revolutionary technological means in sports. The growing trend is to monitor human physiological function and performance during physical activity in real-time (Li et al. 2016). As a result, sensors integrated into wearable devices are receiving considerable attention from the athletic community and companies are furthering research and production of these devices. Objectively quantified data collected from wearables can be used to predict outcomes and minimize risks by supporting decision-making with real data. Through the implementation of wearables, athletes are better equipped to track changes in athletic performance and movement in addition to monitoring workload and biometric markers that may be a pre-cursor to injury. Commonly used external load (movement) sensors include pedometers, accelerometers/gyroscopes, and global positioning satellite (GPS) devices. Generally used internal load (physiological) sensors include heart rate monitors, sleep monitors, and temperature sensors (Li et al. 2016). There are already established devices that permits the recording of such physiological markers, however, wearables present distinct advantages. Generally, wearables are intended to be worn comfortably by an athlete without limiting or affecting the execution of otherwise normal movement. Development of wearable devices could expectedly employ a smaller design than the standard testing equipment. Smaller designs are conceivable by incorporating smaller versions of the necessary components, which may have negative implications on the quality of testing results. The smaller versions tend to require less power consumption and are usually available at a relatively lower price, however, here presents the tradeoff between energy efficiency and performance (Benatti et al. 2017). The designing of wearable sensors is driven by the increased availability, lower cost, and advancements of personal computing devices such as smart phones and digital watches (Li et al. 2016). Being able to view data away from a stationary computer desktop assists in maximizing the potential of true mobile wearable devices.

Clinical and sports settings are having a growing demand for wearable devices with capabilities to perform electromyography (EMG). Surface electromyography (sEMG), in particular, is a non-invasive diagnostic technique for measuring the electrical activity that occurs during muscle contraction and relaxation cycles (Ltd. 2010). An

EMG signal denotes the electrical activity that is generated by motor unit action potentials occurring inside the muscles of interest (Lynn et al. 2018). "Electromyography is unique in revealing what a muscle actually does at any moment during movement and postures. Moreover, it reveals objectively the fine interplay or coordination of muscles… (Ltd. 2010)". Generally, electromyographic studies help us understand the location of the problem or opportunities for improvement in movement strategies and execution (Sozen and Turker 2013). The ability for sEMG to explore the relationship between muscle activation, movement, and force has made it more desirable in sports for athletic training and maintenance (Lynn et al. 2018). Organizing the utilization of muscles in a "optimal" and economical fashion helps improve athletic performance and minimize the risk of injury (Sozen and Turker 2013).

Basic practical applications of sEMG signals include, but not limited to:

- To measure the activation timing of a muscle
- To measure the level of activation of a muscle
- To measure the resting level of a muscle
- To monitor the fatigue of a muscle

Surface electromyography use in sports applications already exists. However, sports scientists, coaches, trainers, and athletes are requesting production of practical sEMG wearables due to the limitations that exist with current standard sEMG testing procedures. Issues that arise when considering sEMG use are total cost, time logistics, equipment restrictions, and expertise required for sEMG data acquisition (Freed et al. 2012). Utilizing a traditional EMG acquisition system is a lengthy endeavor. Setup begins with skin preparation; the skin is cleaned with alcohol and shaved to reduce electrode-skin impedance. Following preparation, electrodes must be carefully and securely placed on the appropriate muscles based on anatomical landmarks. "A whole session, including setup, system calibration, and patient assessment can take two to four hours (Freed 2012)." Trained personnel are required for preparation and operation of the acquisition system, verification of the signal quality, and interpretation of the results. Scheduling of EMG test sessions must be coordinated around the availability of the trained personnel, which may be a time constraint. Conventional sEMG systems tend to be heavy, bulky devices that limit data acquisition to a laboratory setting. These systems have long wires that connect the electrodes to the signal processor. This makes it difficult for patients to move freely, influencing normal movement, as well as tethering the patient to a confined space (DesMarais and Giess 2017). The equipment and associated personnel costs can be an issue. To own an EMG acquisition system and all its necessary parts cost thousands of dollars. To rent lab space, the required personnel, and the EMG system can be pricey as well, particularly if testing should be repeated.

Chapter 2. Review of Literature

Having wearable devices with the capabilities to perform surface electromyography presents a much more appealing option for those interested in sports performance. Advances in technology have allowed athletes to monitor player movements, workload, and certain biometric markers in attempts to maximize athletic performance and minimize injury (Li et al. 2016). The popularity of wearable sport devices incorporating sensor technology is driven by increased availability, lower costs, and the advancements of personal computing devices such as smart phones, tablets, and digital watches (Li et al. 2016). Unfortunately, wearable devices with EMG capabilities are not as prevalent as those using other sensor types. The current EMG wearables on the market show a trend towards cable-free systems, which allow greater freedom and range of motion, with wireless data transfer functions infused in athleticwear (Kugler et al. 2013). A wearable biosensor device that has been designed for long term use needs to be unobtrusive, lightweight and generally not cause disturbance to the user. The wireless capabilities permit quick and easy data transfer and possibly live monitoring which makes teaching and providing feedback quicker and more practical. Integrating sEMG into a wearable is advantageous because proper placement of electrodes is challenging for an untrained user, as the location and spacing between electrodes affects the resulting sEMG signal. But if the sEMG sensors are integrated into a wearable platform, such as clothing and textile, these difficulties could be reduced, then the user will only have to wear the textile as intended and the sensors would already be placed in the correct positions (Shafti et al. 2016). Development of wearable, textile-embedded sEMG acquisition devices would provide benefits including (i) much shorter setup time (a few seconds to put on garment), (ii) continuous, remote monitoring of muscle activity, and (iii) comfort and movement freedom when wearing (Shafti et al. 2016).

2.1. Traditional EMG System Basic Configuration

Most traditional EMG acquisition systems follow this basic design configuration, shown in Figure 2.1. Electrodes are placed on the skin at the appropriate position above the muscle(s) of interest. These electrodes detect the electrical activity that occurs within the muscle. Pre-amplifiers amplify the original signal. They are stationed very closely to the electrodes to help mitigate the effects of noise and motion artifact (Freed 2012). The signal continues through sheathed wires to a stationary central hub for further amplification and signal filtering. Filtering is applied to eliminate high-frequency and low-frequency noise. Noise is defined as electrical signals that are not a part of the desired EMG signal. Noise detected in EMG signal can be categorized into

the following types: the inherent noise generated by all electronic equipment (cannot be eliminated, reduced by using high-quality equipment), ambient noise (electromagnetic radiation from bodies and/or powerline interference), and motion artifacts (skin-electrode interface and movement in electrode cable) (Reaz et al. 2006). The signal must then be converted from an analog signal to a digital signal in order to be sent to a computer for signal analysis.

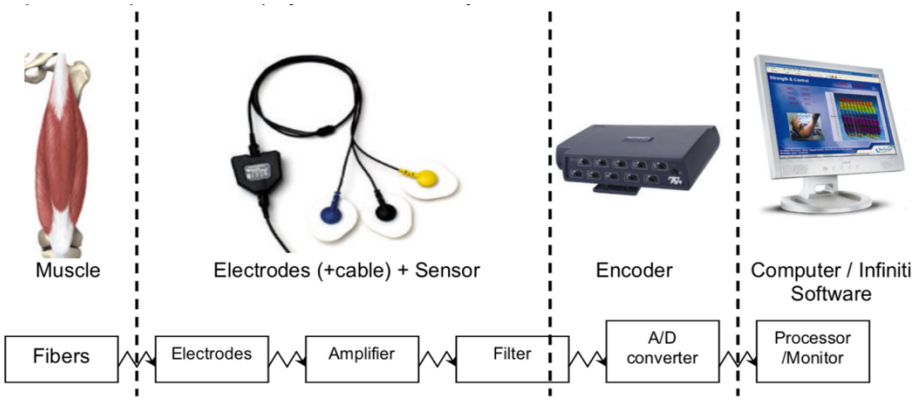


Figure 2.1. Basic EMG acquisition system design configuration

2.2. Electrical Activity Within a Muscle

An EMG signal is the summation of detected Motor Unit Action Potentials (MUAP) showing the muscle response to neural stimulation (Reaz et al. 2006), see Figure 2.2. The nervous system uses neurons to communicate with skeletal muscle using neural impulses that excite the motor unit. When a motor unit is activated, electrical action potentials are generated at the neuromuscular junctions and propagate along the associating muscle fibers (Sozen and Turker 2013). A wave of depolarization occurs and these neural impulses generate electrical signals, see Figure 2.3. The EMG system detects the electrical activity that occurs from exciting or relaxing the muscle.

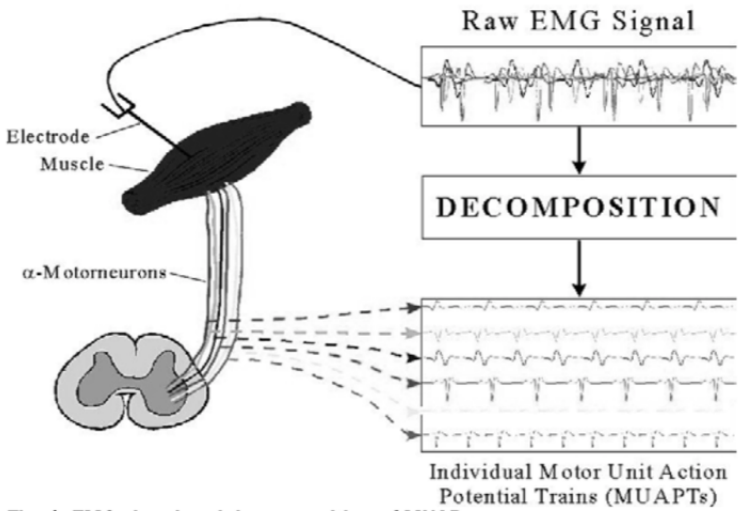


Figure 1.2. Summation of the Motor Unit Action Potentials detected from composes a raw EMG signal (Techniques of EMG signal analysis/detection)

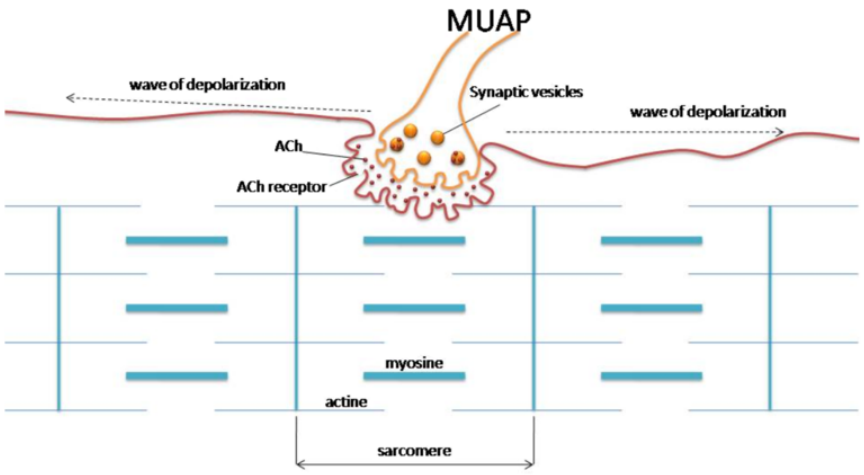


Figure 2.3. Depolarization that occurs from a Motor Unit Action Potential (Source: Sozen H, 2013)

2.3. The Process of Collecting and Processing an EMG Signal

Traditional surface EMG collection utilizes electrical detection sensors coming in the form of an electrode or electrode array. The surface electrodes come in two types: wet electrodes and dry electrodes. Wet electrodes have a gel-like, sticky substance (e.g., Ag/AgCl) on the skin-contact side which gives it the advantages of providing reduced motion artifact and reduced contact impedance and typically costs less than

dry electrodes. Dry electrodes (e.g., stainless steel) present their own advantages as well. These electrodes provide comparable performance, in terms of recognizing electrical activity, to wet electrodes. Dry electrodes may be more expensive initially but the cost differences could be realized overtime. Dry electrodes are resilient and reusable while the performance of wet electrodes degrade over time and are usually disposable. Electrode arrays can be used as an adequate substitute for wet or dry electrodes. A two-dimensional electrode array is a series of evenly spaced electrode consisting of m rows and/or n columns. This array can reduce the setup time and complexity of electrode placement by being able to be quickly placed over the muscle area to collect data across the whole array (Freed 2012).

The amplitude of the original raw EMG signal can range from about 6 microvolts to 200 microvolts and the frequency band can extend from about 10hz to 50hz (Kundu et al. 2011). Pre-amplifiers are implemented to strengthen the amplitude of the relatively weak signal. Situating the pre-amplifiers closely to the electrode improves the signal-to-noise ratio of the signal by minimizing the effect that noise factors may have further down the signal acquisition process.

The individual electrodes or electrode arrays are connected via wires to an interface unit typically situated at a nearby fixed location (e.g., desktop). This unit controls an assortment of settings involved with EMG data collection (e.g., recording bandwidth, adjustable gain switches, channel switching) and provides signal quality functions such as signal filtering and converting the EMG signal from analog to digital. Most electromyography acquisition systems support multichannel recording. Multichannel EMG acquisition systems allow simultaneous detection from many muscles at the same time, using a fraction of the available channels on each muscle, or they can be used for more in-depth assessment of a single muscle (Pozzo et al. 2004). Multi-channel EMG systems that are designed to be operated concurrently with motion capture may utilize a mobile unit that the subject wears on a vest or belt. The mobile unit is advantageous because it serves as a relay to the desktop-bound interface unit. The electrodes plug directly into the mobile unit and then a single (long) wire connects to the desktop unit. This extends the range of use and minimizes obstruction of the participant's intended movements. The mobile unit may also provide additional features or adjustable settings, or inherit some of the responsibilities of the desktop interface unit. The high-performance & high-quality data acquisition capabilities of these systems require a significant amount of reliable power. The usual source for power is obtained from a wall outlet, which is ultimately why the EMG system is stationary and lacks versatility. Furthermore, the interface unit will predictably be located near a desktop computer to where it must send the EMG signal for final processing and analysis.

2.4. Benefits of an EMG Wearable

Incorporating EMG sensors into a wearable design drastically minimizes the setup time necessary to perform electromyography. Normally, electrodes must be expertly placed and fastened to the appropriate muscle(s) for high-quality EMG acquisition. Pre-installed electrodes for smaller, intricate muscles or electrode arrays for larger, broad muscles would reduce setup time to the time needed to put on the device. Implementing a wearable for EMG acquisition also allows greater freedom and range of motion to the user. A cable-free system permits a more accurate assessment of movement performance and strategy since user can execute movements without restraint. Testing would no longer be restricted to a specific setting or time frame. Monitoring and recording of muscle activations, fatigue, and workload would be possible even in remote environments and at any time of the day.

2.5. Designing and Constructing an EMG Wearable

Development of a wearable multi-channel EMG acquisition system must consider the overall configuration of a traditional sEMG acquisition system while combining all the necessary parts into a single compact design. An acceptable wearable system for commercial mobile sports performance analysis of EMG signals consists of four major components: the wearable EMG sensors that acquire the raw signal, a device to receive and process the data, signal analysis algorithms that execute on the device, and a form of wireless data transfer (Kugler et al. 2013). Refer to Figure 2.4, while reading further description of wearable EMG design.

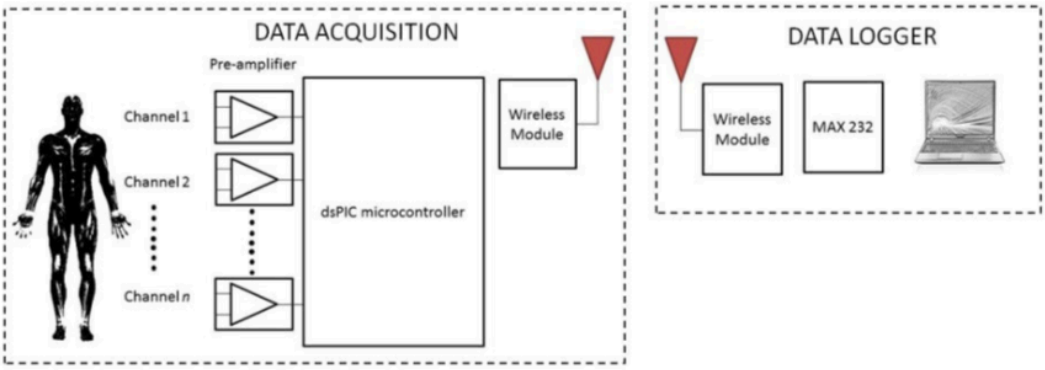


Figure 2.4. General wearable EMG device configuration (Source: Jamaluddin FN, 2014)

The design of wearable EMG device begins with the layout and construction of the garment. Considerations must be made when selecting the garment that will infuse the entirety of the EMG acquisition system. The garment must be functionally conducive to the desired movement objectives. Since a wearable would be reused,

flexible dry electrodes or electrode arrays should be integrated at the necessary locations inside the housing garment. Each accompanying channel of the EMG signal is to be intercepted by a biopotential pre-amplifier unit. Biosensors are challenged with high contact impedance between the skin and the electrode which makes the already weak EMG signal very sensitive to noise. The essential function of the biopotential amplifier units is to take the weak electric signal of biological origin and increase its amplitude so that it can be further processed, recorded, or displayed (VLAB, 2011). Due to the microvolt-level input signals and very high input impedance, pre-amplifier units utilize certain types of low noise amplifiers then apply notch filters following amplification (Jamaluddin et al. 2014). Instrumentation amplifiers are a form of differential amplifier that are commonly employed to satisfy the role of low noise amplifier in biopotential circuits. Differential amplifiers are a type of electronic amplifier that amplifies the difference between two input voltages but suppresses any voltage common to the two inputs. Instrumentation amplifiers supply great accuracy and stability to the biopotential circuit by having the following characteristics: low drift, low noise, very high common-mode rejection ratio, and very high input impedances to combat the high impedance between skin and the electrodes. At the least, simple notch filter circuits are added after the amplifiers to eliminate powerline interference (50hz) (Jamaluddin et al. 2014). Notch filters are band reject filters. These filters remove some frequency portion of a signal by attenuating a specific range of frequencies to very low levels (Jamaluddin et al. 2014).

The EMG signals depart from the pre-amplifier units and arrive at the microcontroller. The microcontroller is the brain of the wearable EMG system. The amplified and filtered analog EMG signal needs to be digitized for further signal processing. The microcontroller must have built-in digital signal processor (DSP) functions and offer analog-to-digital signal conversion. After converting the signal from analog to digital, digital signal processors take the biopotential signals and measure, filter and/or compress them, then apply the designed analysis algorithms. Particularly with a sports performance wearable training device, the signals need to be processed and analyzed so targeted information can be displayed and applied in real-time (Analogy Devices). Signal processing algorithms need to be able to be programmed on and ran by the DSP to present useful information. Examples of typically used processing algorithms for EMG signal include algorithms for pre-processing (high-band and low-band pass filter), event detection (Pan-Tompkins), feature extraction (FFT, Wavelets, statistics) and classification (Linear Discriminant Analysis, Support Vector Machine) (Kugler et al. 2013). Dedicated digital processors that are reduced to an application specific computational task have shown better power efficiency, which would make them more suitable in portable devices such as a wearable device because of the power consumption constraints (Verbauwhede et al. ; Mayer-Lindenberg 2003).

It is almost a requirement for biosensor wearables, designed for sports performance and rehabilitation applications, to have reliable and high-speed wireless data transmission. The purpose of such wearable is to obtain quality data in a wider range of settings and to be able to utilize that data in real time. To accomplish that and eliminate the need to plug the wearable into an external device, wireless LAN or Bluetooth technology need to be integrated into the wearable. Implementation of a wireless module into an EMG wearable design increases physical mobility and allows mobile access to information. For a coach or athlete, it may even be more advantageous to utilize Bluetooth technology (Kugler et al. 2013). Training is more likely to take place in an environment free of a computer and Wi-Fi, and Bluetooth permits direct data transmission to compatible devices like smartphones and tablet computers. However, wireless LAN use does present the advantages of quicker data transfer and the ability to connect with multiple devices.

While designing wearable systems, wearability is an essential factor to consider. Wearability is defined as the "interaction between the human body and the wearable object"(Freed 2012). If a biological signal acquisition device is to be worn for long term use, it needs to be unobtrusive, be compact and lightweight, and generally not cause disturbance to the user (Shafti et al. 2016). The challenge to wearable sensor design is to encompass all these features while still providing quality processed information. Unobtrusiveness in an EMG wearable is accomplished by eliminating the wires from the electrodes to the processing unit. By integrating the EMG acquisition circuitry into the textile frame of the wearable, users' movements are not impeded or restricted. The device needs to be light enough to be worn for an excessive amount of time without causing fatigue. Additionally, the device needs to be sleek enough to allow maximum flexibility of movements. Both can be accomplished by incorporating smaller versions of the components necessary to operate an EMG data acquisition system. Technology continues to advance by designing electronics that continue to get smaller while steadily improving performance. Smaller sizes correlate with lighter weight. Another strategy to reducing weight is by combining several components into a single device. In EMG wearable designs, pre-amplifier units combine series of amplifiers and notch filters into a single entity. Most microprocessors utilized in these designs have A/D converter capabilities along with its expected DSP functions. While smaller sizes do not necessarily correlate with less power consumption, there are versions of these devices that require less power by sacrificing performance capabilities. Minimizing power consumption is crucial to allow the wearable to be mobile and powered by a battery.

2.6. Factors Influencing the Mass Commercialization of EMG Wearables

There are technical, schematic and functional limitations that have hampered the mass growth and development of mobile wearable biological sensor devices, primarily those encompassing EMG technology. Physiological sensor or measuring devices that were once limited in use due to their large size, lack of mobility, or bulk have evolved to become much smaller and portable (Montes et al. 2018). The professional sport and recreation exercise communities desire accurate and consistent measurement devices that are small, unobtrusive, and comfortable to wear. Current technology allows for various systems and measurement units to be integrated together into a wearable system, however the challenge to an acceptable design is to encompass all features comfortably while providing quality processed information. Typically, smaller or mobile (battery operated) versions of technology have shown to perhaps cost less but may have poorer performance quality when compared to its gold-standard counterpart. As it pertains to a wearable EMG device, the challenge arises when attempting to satisfy the accuracy and consistency of EMG signal detection and analysis as well as providing a comfortable design (Belbasis and Fuss 2018). With sacrifices to component performance in exchange for size, mobility and low power consumption, complications arise when testing the validity and reliability of wearable EMG devices. Investigators report mixed reliability conclusions with some reporting low to moderate reliability while other demonstrate higher reliability. The mixed results arise from attempting to measure a highly sensitive and variable biological factor, such as muscle activation, using relatively poorer measurement quality equipment. Further, the data being used by investigators are largely dependent on the measures investigated, the muscle(s) of interest, and the methods by which reliability is quantified (Brown). Also, inconsistent methodological approaches, for example, different manufacturers utilizing different algorithms for signal processing, affects result interpretation (Zulkifli et al. 2019).

2.7. Sense3 by Strive

With advancements including component miniaturization, material development and improved manufacturing methods, new technologies for measuring human physiology are emerging that may reduce the setup cost and complexity of measuring sEMG of athletes in training or competition settings (Lynn et al. 2018). These advancements are being applied to the development of wearable EMG acquisition systems for clinical and sports purposes. Sports performance company Strive has designed and constructed Sense3 to be a commercial mobile multi-channel EMG acquisition system used by athletes of all ages, pictured in Figure 2.5. Sense3's EMG acquisition system has been integrated into the construction of athletic compression

shorts and has the full ability to acquire, process, analyze electromyographic signals and send the results wirelessly to a personal account on the company's associated website (Lynn et al. 2018). Sense3 is an athletic performance movement monitoring system that provides coaches and athletes with performance metrics derived from sEMG measurements, but aside from its EMG acquisition and processing capabilities, Sense3 can track and monitor several heart parameters pertaining to heart rate, as well as, motion parameters like distance traveled, accelerations, and jump heights. To be considered a viable option as a wide-spread commercial wearable EMG acquisition system, or performance monitoring system as a whole, the validity and reliability testing of the system needs to be completed. Validity and reliability testing will be performed on two monitoring systems of Sense3: EMG acquisition and motion detection (jump heights and average acceleration).

Figure 2.5. Prototype Sense3 worn on athlete (left). Front view of the integration of EMG system into garment (center). Rear view of the integration of EMG system into garment (right).

Access to specific component details utilized in the construction of Sense3 is limited. Sense3 uses a culmination of dry sEMG sensors located to align with the designated muscle groups of interest: Hamstrings, Glutes, and Quads. The EMG signals are recorded with a sample rate 1024 hz. The analog signal is amplified and passes through a bandpass filter of 70hz – 500hz (3dB points). It then reaches the microprocessor and is digitally converted by a 12-bit analog-to-digital converter. The EMG signal completes processing and is sent through analysis algorithms to provide all the performance metrices available.

Sense3 utilizes a small detachable housing device titled "the puck", located on the front of the waistband shown in Figure 2.5, that holds the EMG processing

hardware, the accelerometer and gyroscope, and the wireless transmission module. The accelerometer has a 100hz sampling frequency and the gyroscope has a 100hz rotational velocity. The puck uses a Bluetooth Low Energy Transmitter that transmit the data to a mobile data box that, with an internet connected, sends the data to the associated company website.

Chapter 3. Purpose

The electromyographic study of athletes is becoming more prevalent in sports. Using surface EMG to improve athletic performance and minimize the risk of injury is a luxury that many coaches, trainers, and athletes desire to be readily accessible. The sports performance market is pushing for wearable EMG acquisition systems. Establishment of a functional EMG wearable expands the range of practical applications from passive monitoring of muscle activation and fatigue to active training or optimization of movement strategies. The sports performance company Strive has designed athletic compressive shorts integrated with a multi-channel EMG acquisition system coupled with an external load monitoring system called Sense3. Although traditional surface EMG systems provide high quality interpretations of muscle activity which makes it suitable for clinical use and research, EMG data can be variable. Even EMG data collection of the same subject, performing the same movement, with the same collection device, will likely show some sort of variance. A wearable EMG acquisition system is likely to demonstrate variance as well, however, to what degree and how do the EMG signals quantitatively compare to a traditional sEMG system. The purpose of this thesis to test the validity and reliability of Sense3's EMG acquisition system by comparing Sense3 sEMG measurements to those collected by a traditional surface EMG acquisition system (Motion Lab Systems, MA300). Validity and reliability will also be examined of the Sense3's acceleration and jump height calculations to calculations made from the results of a motion capture system (Codamotion). The validity of the Sense3 EMG system will be evaluated by first comparing sEMG signal characteristics recorded by both systems of the quadriceps, hamstrings, and glutes on participants attempting to perform the same movements (Lynn et al. 2018). There are two movement conditions in which the EMG measurements will be recorded to determine validity: contractions during isolated joint movements and contractions during dynamic exercise. Through the use of a dynamometer, participants will perform selected uni-joint exercises intended to isolate activation to the designated muscle. The dynamometer helps determine repeatability by allowing the participants to perform, seemingly, the exact same movement which permits more objective quantitative comparison amongst both systems and all participants. "Repeatability of EMG data is established for many isometric exercises but less is known about the reliability of this method of analysis during dynamic exercise" (Sozen and Turker 2013). Validity and reliability testing of Sense3 during dynamic movements would be insightful since the expectation is for the product to utilized in environments exclusive to dynamic movement. Muscle activation strategies and intensities vary from person to person when performing dynamic, multi-joint exercises. Muscle activation variance and motion artifacts experienced during movement is expected to make validity

conclusions more up to interpretation. The external load measurements of Sense3 needs to be tested as well. Sense3 offers to calculate average acceleration of a particular sprint and the heights reached in a particular jump. Motion capture will be used to analyze these parameters and compare to Sense3.

3.1. Research Question

To be considered a viable option as a wide-spread commercial wearable EMG acquisition system, or performance monitoring system as a whole, validity and reliability testing of Sense3's measuring systems need to be completed. The EMG acquisition system of Sense3 will be tested for reliability. Sense3's motion detection system, designed to report jump height and average horizontal acceleration, will be tested for validity.

3.2. Rationale

The electromyographic study of athletes is becoming more prevalent in sports. sEMG is a tool used to improve athletic performance and to minimize injury risks. Many coaches, trainers, and athletes desire for its abilities to be readily accessible. The sports performance market is pushing for wearable EMG acquisition systems. Establishment of a functional EMG wearable expands the range of practical applications from passive monitoring of muscle activation and fatigue to active training or optimization of movement strategies. The sports performance company Strive has designed athletic compressive shorts integrated with a multi-channel EMG acquisition system coupled with a motion detection system called "Sense3". Although traditional surface EMG systems provide high quality measurements of muscle activity which makes it suitable for clinical use and research, inconsistencies with electrode placement, the natural variability of the participant's movement execution, and other factors, cause these measurements not be uniform, i.e., reducing reliability of the measurements. Even the EMG signal measurements of the same subject, performing the same movement, with the same collection device, will likely show some degree of variance. A wearable EMG acquisition system is likely to demonstrate that variance as well. This experiment is designed to test how the EMG signals from Sense3 compare quantitatively to a traditional sEMG system.

The purpose of this project is to test the validity and reliability of Sense3's EMG acquisition system by comparing Sense3 sEMG measurements to those collected by a traditional surface EMG acquisition system (Motion Lab Systems, MA300) through quantitative and qualitative analysis methods. Reliability will be evaluated by comparing sEMG signal characteristics recorded by both EMG systems of the Rectus Femoris, Biceps Femoris, and Gluteus Maximus on participants attempting to perform

the same movements (Lynn et al. 2018). There will be two movement conditions in which the EMG measurements will be recorded: contractions during isolated joint movements and contractions during dynamic exercise. Through the use of a dynamometer, participants will perform selected uni-joint exercises intended to isolate activation to the designated muscle. The dynamometer helps minimize variability by allowing the participants to perform, hypothetically, the exact same movement which permits more objective quantitative comparison amongst both systems and all participants. Using isometric and isokinetic exercises on the dynamometer is an established method of analysis to provide repeatability to EMG data, which makes it effective in comparing EMG acquisition systems. However, less is known about the reliability of this method of analysis during dynamic exercise (Sozen and Turker 2013). The muscle activations produced by the Rectus Femoris, Biceps Femoris, and Gluteus Maximus would be observed throughout the entirety of a series of different movement tasks (jump, squat, walk). The variations between the neuromuscular strategy each participant chooses to use in order to execute the movement task provides a situation comparative to would-be real-world experiences. Validity and reliability testing of Sense3 during dynamic movements would be insightful since the expectation is for the product to be utilized in environments exclusive to dynamic movement. Muscle activation strategies and intensities vary from person to person when performing dynamic, multi-joint exercises. Muscle activation variance and motion artifacts experienced during movement is expected to make validity and reliability conclusions more up to interpretation. The movement measurements of Sense3 needs to be tested as well. Reliability will be examined of the Sense3's average horizontal acceleration and jump height calculations to calculations made from the results of a motion capture system (Codamotion). Sense3 offers to calculate average acceleration of a particular sprint and the heights reached in a particular jump. Motion capture will be used to analyze these parameters and compare to Sense3.

Chapter 4. Methodological Design

4.1. Participants

Ten healthy males consented to this study. Participants' mean (SD) age and weight were 24.2 (±4.96) years old and 191.3 (±36.3) lbs respectively. All participants were right leg dominant and recreationally active with no history of lower limb and lower back injury in the last six months.

4.2. Experimental Procedure

Prior to data collection, each participant had their anthropometric data recorded to be used in kinetic and kinematic analyses. This experimental protocol consists of testing the performance of two systems on Sense3: the EMG acquisition system and the external movement measurements (average acceleration & jump height). The EMG data measurements of Sense3 was compared to the EMG data measurements of a conventional EMG acquisition system under the same conditions. Each participant was tested by both systems under two testing conditions: using a dynamometer and performing dynamic exercise. Participants started data collection using Sense3. Once all trials of the initial testing condition was completed, the participant was setup for conventional EMG acquisition. After the trials for both systems were completed, the participants proceed to the next testing conditions to be measured by both systems. The order of the initial testing condition was randomized. Jump height and average acceleration calculations measured by Sense3 was compared to the calculations from motion capture analysis.

4.2.1. Surface Electromyography

The performance of the EMG acquisition was tested under two conditions: uniform isometric & isokinetic movements and dynamic exercise. Data collected from EMG acquisition and analysis is characteristically variable by nature. In attempts to minimize variability, a dynamometer was used by each participant for the isometric and isokinetic condition. The dynamometer guides the movement pattern by controlling angle, timing and speed of the movement and permits the maximum voluntary contraction of a specified muscle. This representation of uniformity amongst all participants, in terms of levels of muscle activation, provides a basis to quantitatively compare the EMG signals of both systems across all participants. Dynamic exercise allows us to see how Sense3 performs in scenarios likely to be seen in the field. Each athlete has adopted and learned his/her own muscular activation strategy in order to

perform a particular movement pattern. As a result, EMG signal comparison between two athletes performing "identical" movements will likely show differences in signal amplitudes and frequencies, depending on the activation strategy utilized. This variability can be seen within the same subject, particularly when performing more complex movements that demand a more complex organization of degrees of freedom. Dynamic exercise is meant to investigate how the EMG acquisition system of Sense3 performs in these dynamic scenarios. EMG data was acquired by each EMG acquisition system separately under both conditions. Sense3 was worn throughout the duration of session, however, Sense3 did not record when testing with the traditional EMG system. EMG signal recordings are designated for the following muscles, shown in Figure 4.1, of the dominant leg: Rectus Femoris (Quadriceps), Biceps Femoris (Hamstrings), and Gluteus Maximus (Glutes). The Sense3 system records EMG data at a frequency of 1024hz. Raw signal data could not be provided from the Sense3. Only the unspecified filtered and processed signal could be used for analysis and comparison. This experiment used the MA-300 EMG system, created by Motion Lab Systems, as the traditional EMG system. The MA-300 system, pictured in Figure 4.2, recorded EMG data at a frequency of 2000hz. High-pass and low-pass second-order Butterworth filtering and a zero-phase filter was applied to the raw signal collected from the MA-300 system. A notch filter at 120 hz was then applied to the filtered signal to eliminate powerline interference. EMG signal analysis determined the EMG signal amplitude and mean and median frequency of each muscle.

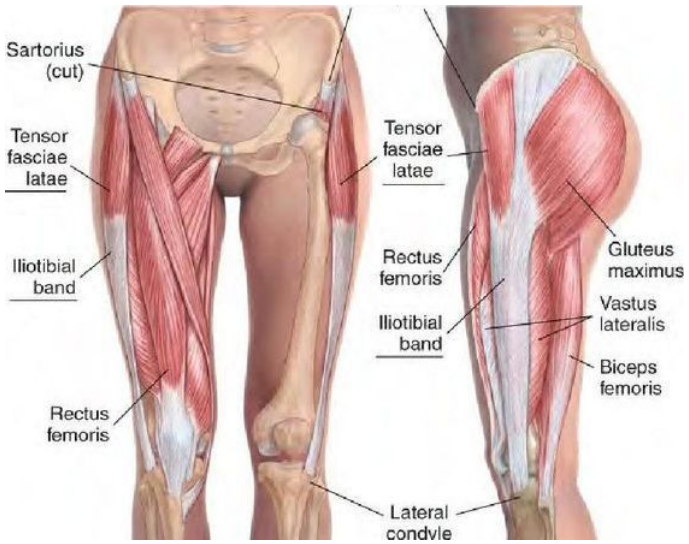


Figure 4.1. Diagram of the lower muscles recorded by EMG (Rectus Femoris, Biceps Femoris, Gluteus Maximus) https://sbrsport.me/2017/07/23/one-tensor-fasciae-latae-without-sugar-please/

Figure 4.2. MA-300 EMG acquisition system created by Motion Lab Systems

4.2.1.1. Dynamometer

Dynamometer testing includes two testing conditions: isometric (3 sec. maximum voluntary contraction) and isokinetic (60°/s for knee extension/flexion and 15°/s for standing hip extension). The speeds used for isokinetic condition was calculated to produce muscular contractions that lasted between 1–1.5 seconds when going throughout the full range of motion of the exercise (70°=knee extension/flexion & 25°=hip extension). Each muscle of interest has its own movement to test muscle activation. Activations of rectus femoris is recorded during knee extension. Activations of biceps femoris is recorded during knee flexion. Activations of gluteus maximus is recorded during standing hip extension. Participants was secured into Biodex System 3 dynamometer, shown in Figure 4.3, using standard protocol. Each muscle of the participant performed three individual trials of each testing condition. Trials under these conditions were repeated while using either Sense3 or the conventional EMG system. Participants were given approximately 1 min rest between trials (Mau-Moeller et al. 2019).

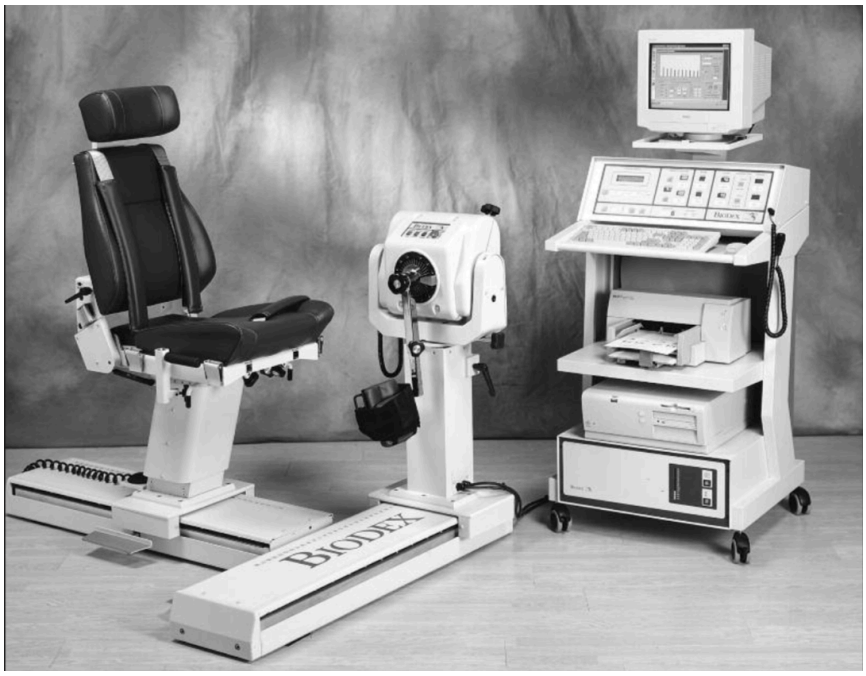


Figure 4.3. Biodex Systems 3 dynamometer

4.2.1.2. Dynamic Exercise

The dynamic exercise portion of the session included six trials in total per movement task: three trials recording EMG with Sense3 and three trials recording with the conventional sEMG acquisition system. Each trial requires the subject to perform a series of individual movements (3 in total). The movements are as follows: a body weight squat, a standing vertical jump, and a walk (~4m). The order of the movement pattern was randomized to account for learning effects. Throughout the session, motion capture was recorded in all trials to compare motion data and calculate kinematic data. Each participant performed three trials of each movement, totaling nine trials per participant starting with one randomized EMG system then switching to the other EMG system and completing the same order of movement tasks. Data was collected from all ten participants, resulting in ninety trials to look at all three muscle activations. Force plates were used to acquire forces that will subsequently be used in calculating joint moments using an inverse dynamics approach.

4.2.2. Motion Capture

During the dynamic exercise condition, each subject was set up for motion capture analysis using the Coda Motion Solutions motion capture system. Using double sided

tape, infrared markers will be placed on designated anatomical landmarks. Those landmarks on the dominant leg include: Iliac crest of the hip, lateral knee, lateral Malleolus, heel, 5th Metatarsal, the sacrum, and Cervical Vertebrae 7. From these, hip, knee, and ankle joint kinematics can be calculated and further used for inverse dynamics. Calculating joint kinematics is used for dynamical analysis and to analyze whether variations of EMG signals are due to the acquisition system or alterations in movement performance. Motion capture is also used to calculate external measurements. Jump height was calculated from vertical movement of the sacrum marker. Following the EMG acquisition portion of the session, participants detached from everything besides sacrum marker to perform bursts. Horizontal accelerations were calculated from horizontal movement of the sacrum marker. Acceleration and jump heights were calculated and compared to the accelerometer's readings in the Sense3 shorts.

4.2.3. Force plates

Force plate data was only be recorded during the squat, jump, and walk movements. For the squat and jump movements, participants started with the foot of the dominant leg on a force plate then performed the movement. For the walk movement, the participants walked and stepped fully onto the plate. Participants practiced the walk before recording to ensure that the foot lands within the boundary of the plate without altering the natural walking gait. Force plate data was used to calculate joint kinetics.

Chapter 5. Data Analysis

5.1. EMG Signal Analysis

Testing the reliability and determining the validity of the Sense3 EMG system involves examining the signal amplitudes and frequencies that result from recording muscle activations. The EMG signals collected by Sense3 and the conventional EMG acquisition system (MA-300) will be compared to the other trials of the same testing condition to determine the variance within each system. Then the EMG signals from Sense3 will be compared to the EMG signals of MA-300 to determine differences in the EMG signal data, under the presumptions that the MA-300 system is both valid and reliable. Testing reliability and determining validity will utilize the EMG signal analysis techniques are Root Mean Square (amplitudes) and Frequency Domain/Power Spectrum (frequencies). Due to the variance involved with EMG signal acquisition, analysis will always be qualitative in nature. Getting the participants to perform "uniform" movements via a dynamometer is meant to present more of the quantitative element to signal analysis and comparison. Recording EMG during dynamic exercise expected to increase variance thus increasing qualitative inspection.

Statistical analysis was performed using Microsoft Excel. To determine and compare inter-rater reliability of both sEMG acquisition machines, two-way random average measures absolute agreement intra-class correlation ICC (2,k) and coefficient of variance (CV) was used. ICC and CV will be calculated on the testing variables: mean frequency, median frequency, 95th percentile of sEMG signal amplitude, and the max force produced. In dynamometer testing, the max force is rotational and unidirectional; in dynamic exercise, the max force is a vector and is most likely multidirectional. For the dynamometer testing results, the ICC and CV will be calculated into three groups, using all trials of the following testing conditions: isokinetic, isometric, and both. For dynamic exercise, the ICC and CV will all be calculated into three groups, using all trials of each dynamic exercise: squat, jump, and walk.

The coefficient of variation is defined as the ratio of the standard deviation to the mean and is typically expressed as a percentage. The coefficient of variance formula is shown in Figure 5.1. In this study, CV is used to analyze the distribution and variance of the measurements of each testing variable amongst all participants' trials in each testing condition. Since EMG testing of both EMG systems was not performed concurrently, using the CV statistic is a way to see if the variation of measurements is due to the

$$CV = \frac{\text{std dev}}{\text{mean}} = \frac{s}{\bar{y}}$$

Figure 5.1. Formula for Coefficient of Variance

participants as a whole not performing similarly when in both systems. Similar CVs for both systems can give the assumption that participants performed similarly while performing in both systems. Dissimilar CVs can be an explanation for poor ICC scores.

Intraclass correlation is a descriptive statistic that can be used when quantitative measurements are organized into groups that describes how strongly the measurements resemble each other. In ICC (2,k), specifically, each subject (muscle activation) is measured by each rater (EMG system) and reliability is calculated by the average of k (3) raters' measurements (N/A). The ICC (2,k) formula is shown in Figure 5.2. In this study, the measurements of the testing variables are reported in different scales between the two systems. Each system recorded sEMG signals at different recording frequencies (1024hz = Sense3, 2000hz = MA300) which skewed MA300's mean and median frequencies to higher values. Further, the EMG signal amplitude recorded by Sense3 is reported their own processed unitless value, while MA300 reports amplitude in

$$\text{ICC } (2,k) \qquad \frac{MS_R - MS_E}{MS_R}$$

Figure 5.2. Formula for ICC (2,k)

microvolts. This statistic is being used in this study to determine reliability because it shows correlation based on data structured as groups, despite difference of scale, rather than paired observations of the same scale. Additionally, direct correlations, like Pearson's correlation, cannot be performed because no one can reproduce the exact same forces (i.e. muscle activation) repeatedly; ICC considers the variability that is sure to exist. The ICC and its 95% confidence limits were calculated in Microsoft Excel using between-subject standard deviation and within-subject standard deviation obtained through ANOVA one-way tests (Hopkins 2009). Munro's descriptors for reliability coefficients were used to index the degree of reliability: very high correlation, 0.90–1.00; high correlation, 0.70–0.89; moderate correlation, 0.50–0.69; low correlation, 0.26–0.49; and little or no correlation, 0.00–0.25 (Jang et al. 2018).

Reliability statistics will be collected and validity will be determined by using these statistics in addition to the qualitative inspection needed to infer and put the statistics in perspective. Coefficient of Variance is used to test reliability within each system and to assist in testing reliability between the systems. Conclusions drawn from

the CV values will be in terms of pass/fail. Each system for each participant will produce a CV value. CV values of 15% or less will be deemed passing; greater than 15% is failing. The number of pass/fail participants will be counted and compared to the other system. Intra-class correlation is used to test reliability between the two systems. Each participant in each condition will produce an ICC value falling under one of the categories mentioned previously. The totals will be counted to show how often each level of reliability was demonstrated. Aside from the differences in scales of the signal amplitudes and the skewedness of the frequencies, qualitative inspection is required because muscle activations (EMG measurements) are hard to reproduce. The variability that results should be put in perspective by looking at the torque/kinetics and kinematics to see if differences in the EMG measurements are due to changes in the individual participant's movement strategy, by looking at kinematics, or effort, by looking at the produced torques and forces, or the performance of the EMG system.

5.2. Motion Data Analysis

Calculated horizontal average accelerations from motion capture will be compared to the reported average accelerations from Sense3. Calculated jump heights from motion capture will be compared to the reported jump heights from Sense3.

The validity of the motion system is Sense3 will be determined by calculating the percent differences of jump heights and average accelerations reported by Sense3 to those variables measured by Codamotion.

Chapter 6. Results

6.1. EMG Analysis

6.1.1. Dynamometer

Nine participants' trials were analyzed from isokinetic and isometric trials of isolated muscles (RF, BF, GM) performed on the dynamometer. Ten participants performed trials but EMG data from one participant was lost and full analysis could not be executed. Two strategies were employed when calculating the ICC and CV values between the two EMG systems for the four variables (intensity, 95th percentile amplitude, mean & median frequency). The first strategy calculated the ICC and CV based on the summation of all the participants' trials grouped together from each testing condition. Using this strategy, ICC and CV values were grouped into: JUST isokinetic, JUST isometric, and BOTH; resulting in three ICC and six CV values for each muscle within each testing variable. The second strategy, calculated one ICC and two CV values for each participant for each testing condition for each muscle. For example, the knee extension isokinetic condition provided nine ICC values and eighteen CV values (n subjects = 9). Second strategy was more appropriate than the first to determine reliability and validity. The first strategy reported very poor ICC and CV values for all variables and conditions except mean and median frequency of the Rectus Femoris during the JUST isokinetic, JUST isometric, & BOTH conditions. By using the second strategy, it eliminated the variability that exists between the participants and provided more useful data.

6.1.1.1 Intensity

Nine participants completed three trials of each movement. Figure 6.1 shows the average peak torque (N*m) values of each isokinetic and isometric muscle contraction (knee flexion=BF; knee extension=RF; hip flexion=GM) recorded by the MA-300 EMG acquisition system and the Sense3 system. The peak torques recorded between each system demonstrate poor correlation. Figure 6.2 illustrates that among all testing conditions, 74% of intraclass correlations are deemed to have little or no correlations (ICC<0.25=37/50). Despite poor correlations, participants did well in recreating peak torque values (CV <15%=67/100).

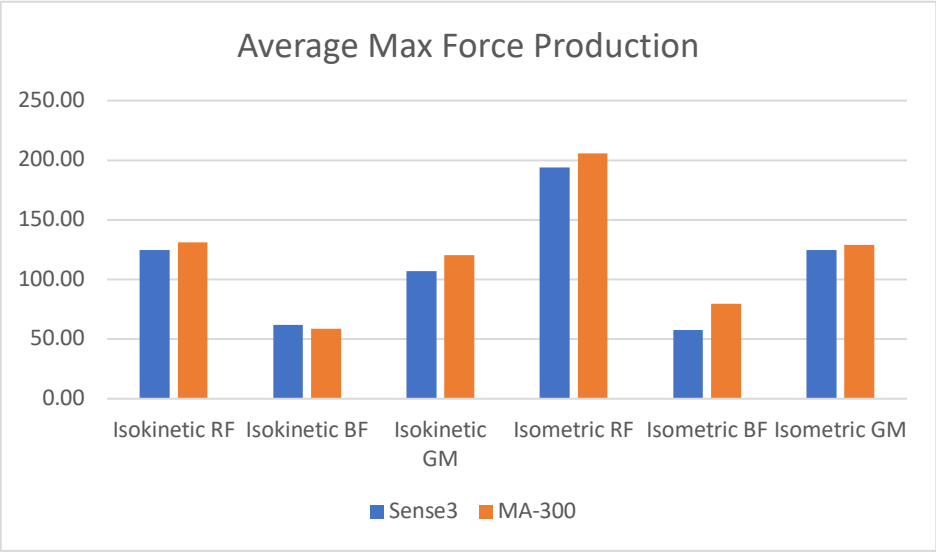


Figure 6.1. Comparison of the average max force produced during each muscle condition when using Sense3 and MA-300

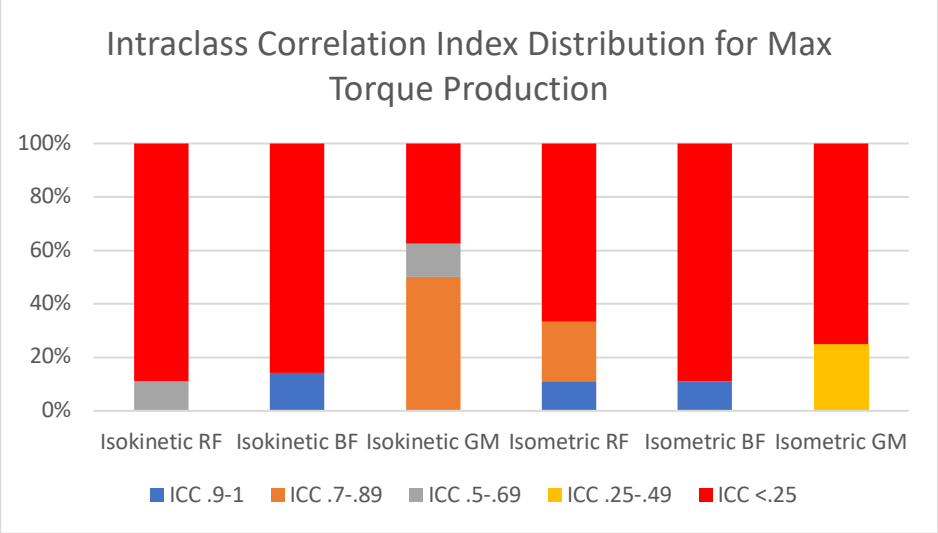
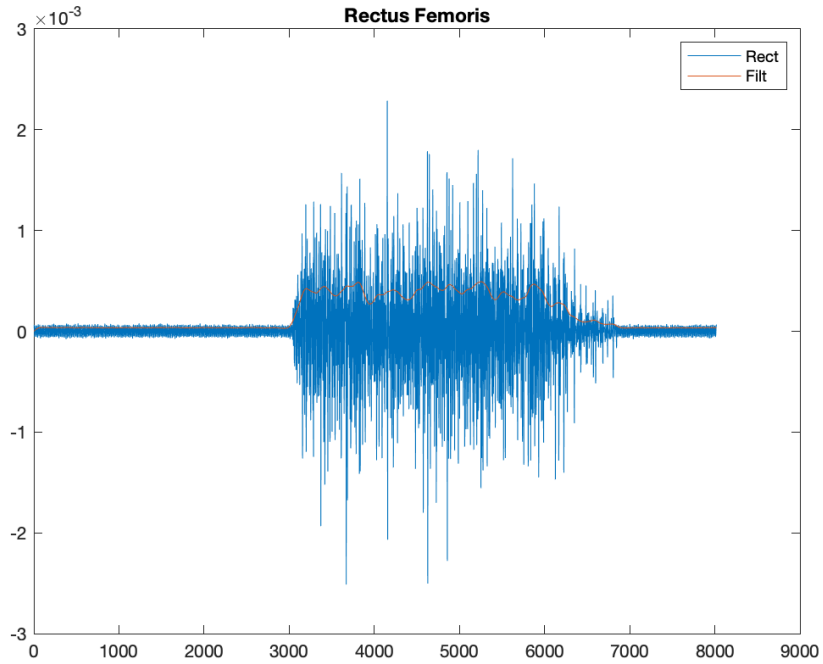


Figure 6.2. Percentage of participants that demonstrated each level of the Intraclass Correlation index for max torque production

6.1.1.2. Ninety-Fifth Percentile Max Signal Amplitude

The EMG signals from the MA-300 system were filtered and processed, using Matlab, and reported in millivolts. The Sense3 system reported its amplitudes values in units specific to an undisclosed formula. The ninety-five-percentile peak EMG amplitude values tend to show "high" to "very high" relative reliability in all muscles during both isokinetic and isometric contractions. Figure 6.3 shows an isometric activation from each muscle during dynamometer trials recorded by the MA-300 system. Figure 6.4

shows the same activations but from the Sense3 system. Figure 6.5 shows the ICC distribution among all participants for each condition. Data from Rectus Femoris contractions demonstrated very high correlations in the majority of participants (very high ICC: isokinetic=7/9 & isometric=8/9). The coefficient of variance was calculated for each participant to be used to determine individual system reliability. The average coefficient of variance per system for each condition is shown in Figure 6.6. The CVs were almost consistently lower from the MA-300 system than from Sense3. When using the Sense3 system, five out of nine participants reported acceptable average CV values of less than 15% in both isokinetic and isometric contractions (cumulative CV average: isokinetic=14.43% & isometric=18.29%). A higher percentage of participants reported acceptable CV values when using the MA-300 system (isokinetic=6/9 & isometric=8/9), which would be expected from a standard EMG acquisition system (cumulative CV average: isokinetic=15.91% & isometric=10.36%). Data from Biceps Femoris also showed very high correlations in the majority of participants (very high ICC: isokinetic=8/9 & isometric=7/9). Both systems reported slightly less acceptable CVs from participants when recording BF contractions than RF contractions. Cumulative averages of the MA-300 system are better than those reported by Sense3. Amplitudes from the gluteus maximus are the least correlated and reliable among the three muscles in both systems. Figure 15 shows that the GM still showed high to very high correlation though correlation was not as strong as the other two muscles. Larger CV values were also recorded in the gluteus maximus, significantly from the Sense3 system (cumulative CV average: isokinetic=26.25% & isometric=29.40%).



(fig. cont'd)

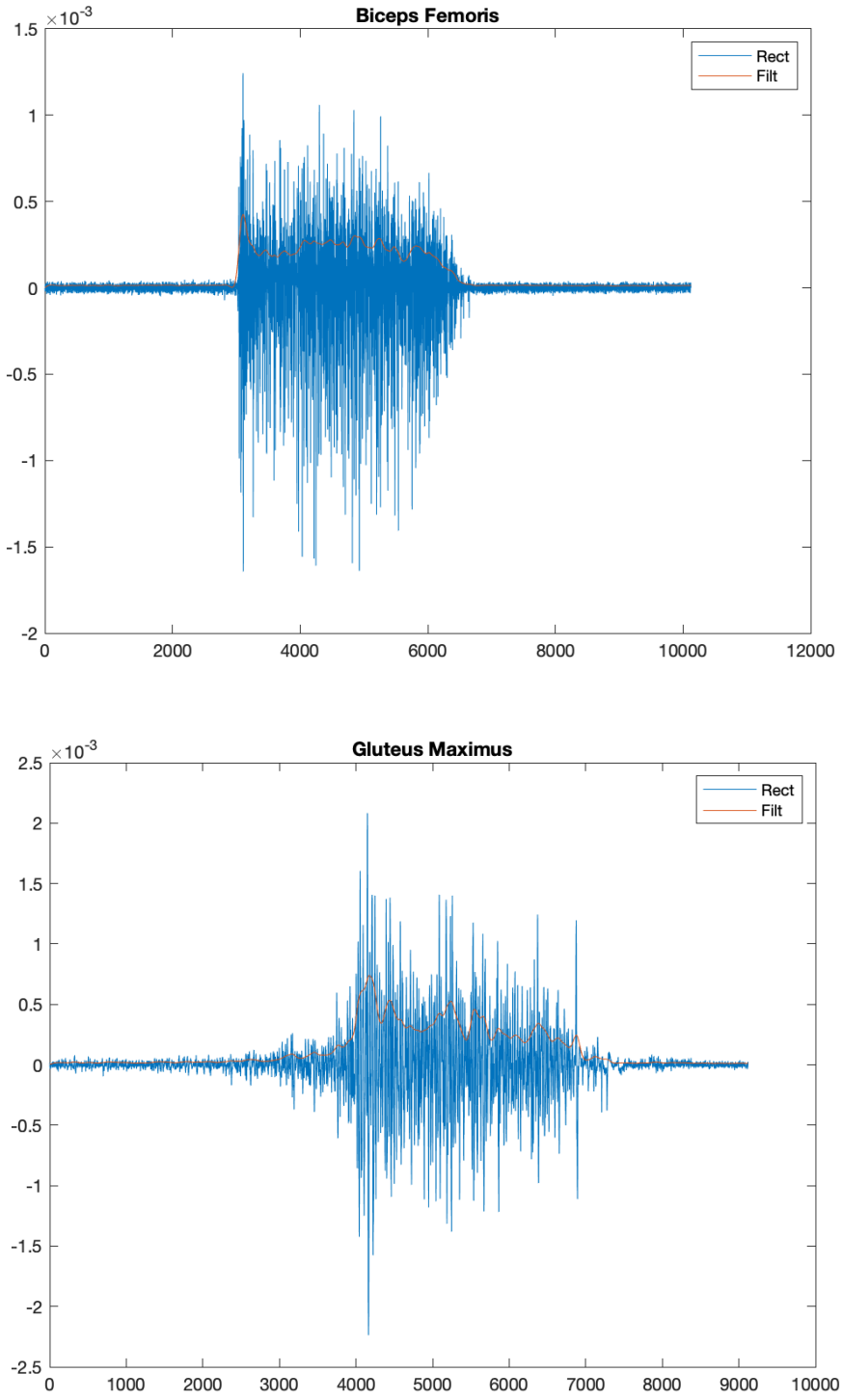


Figure 6.3. EMG signal from isometric activations of Rectus Femoris, Biceps Femoris, and Gluteus Maximus recorded by MA-300 system

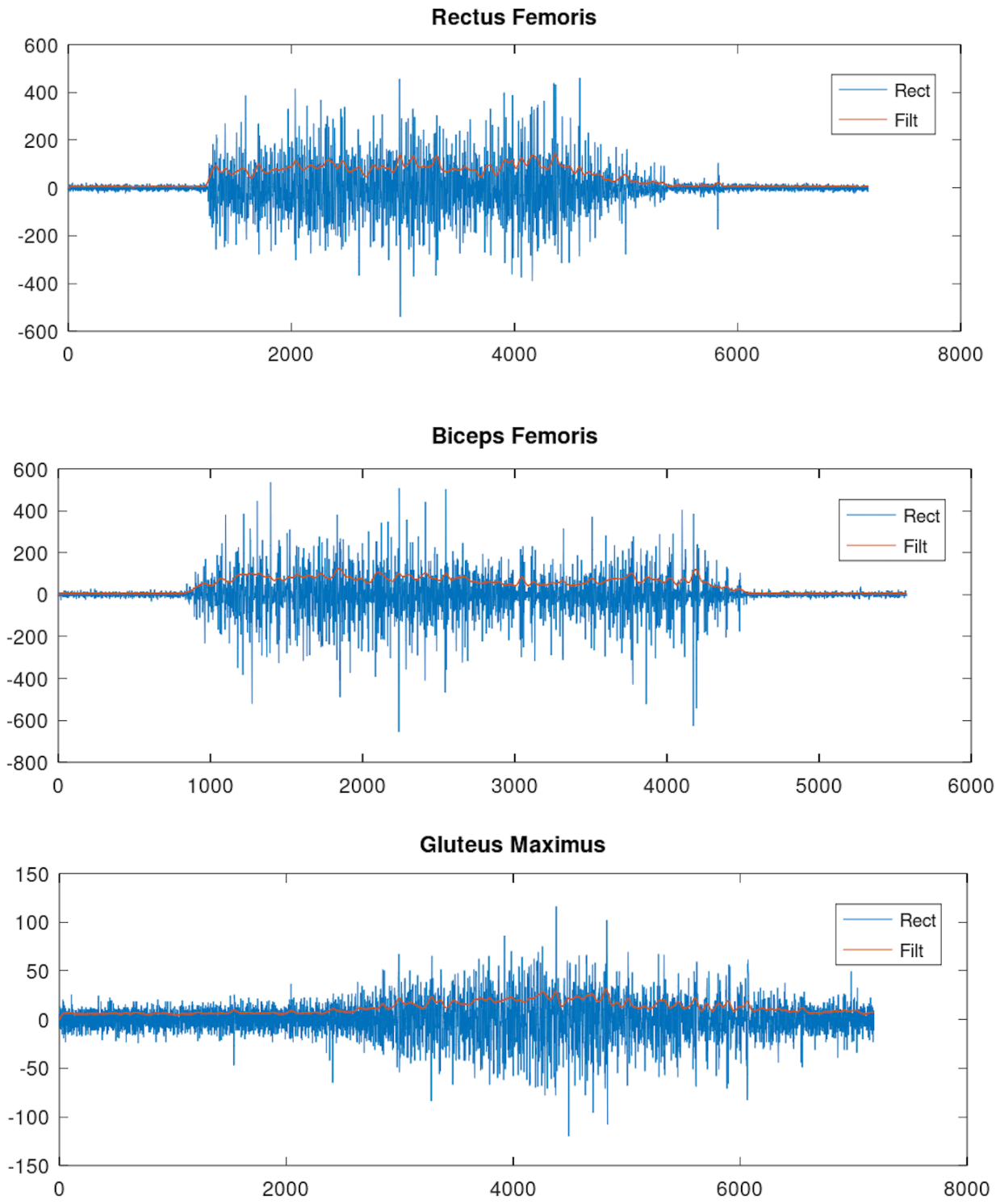


Figure 6.4. EMG signal from isometric activations of Rectus Femoris, Biceps Femoris, and Gluteus Maximus recorded by Sense3 system

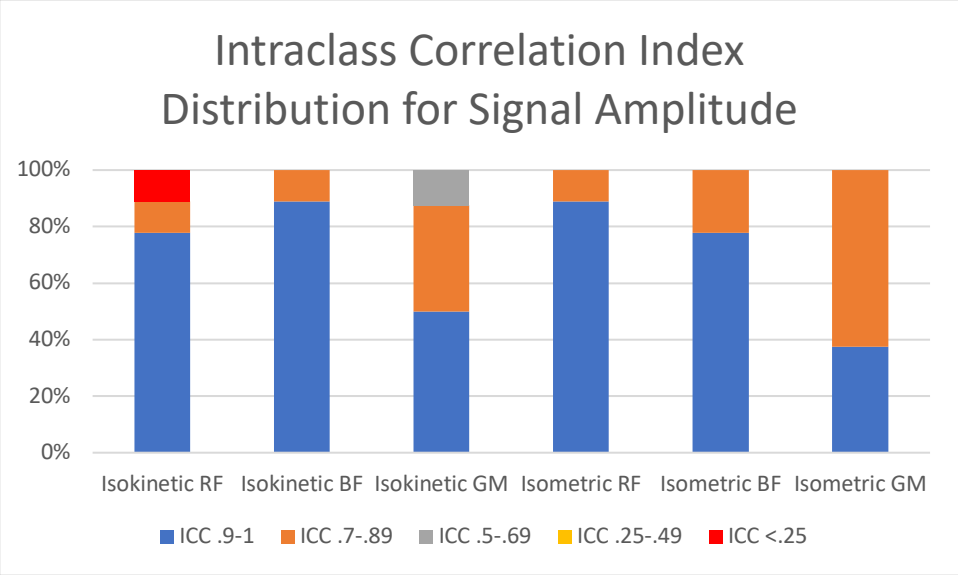


Figure 6.5. Percentage of participants that demonstrated each level of the Intraclass Correlation index for 95th percentile max amplitude reporting

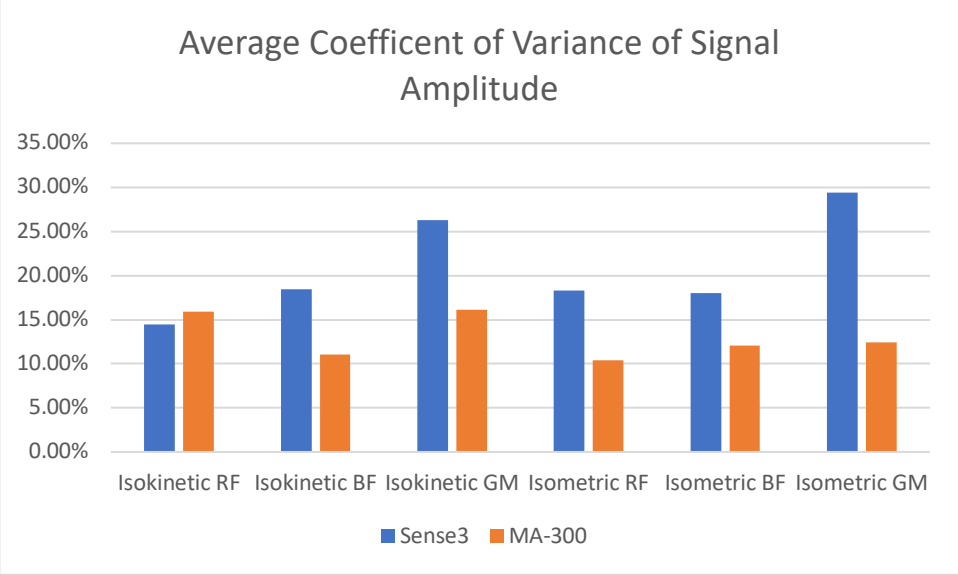


Figure 6.6. Average Coefficient of Variance demonstrated by both EMG systems when reporting 95th percentile max amplitude

6.1.1.3. Mean Frequency

The Sense3 and MA-300 systems showed nearly unanimous very high correlations of mean frequency values in the Rectus Femoris and Biceps Femoris. Figure 6.7 shows that all participants reported very high correlations in RF isokinetic and isometric contractions. All but one participant reported very high correlations in BF isokinetic and isometric contractions. Among all participants, nearly all CV values of mean frequency values reported were acceptable from both systems during BF and RF contractions. The cumulative averages of CV values, shown in Figure 6.8, from Sense3 RF and BF (isokinetic & isometric) contractions are 8.82% & 4.38% (RF) and 8.82% & 1.85 (BF), respectively. Coefficient of variance values from MA-300 were even more repeatable, reporting cumulative averages of 3.77% & 1.95% (RF) and 3.27% & 3.29 (BF), respectively. The differences between the cumulative CV averages for each condition was calculated to highlight the disparities in reliability. The differences between the systems' averages in BF and RF conditions were around 5% or lower. When looking at the GM conditions, the differences in CV were closer to 8%. Out of eight participants in the GM conditions, only four had acceptable CV values in the isokinetic condition and six had acceptable CV values in the isometric condition. Not as many participants showed very high levels of correlations in the gluteus maximus conditions (very high ICC: isokinetic=4/8 & isometric=3/8). Aside from those with very high correlations, the other participants showed moderate to little or no correlation.

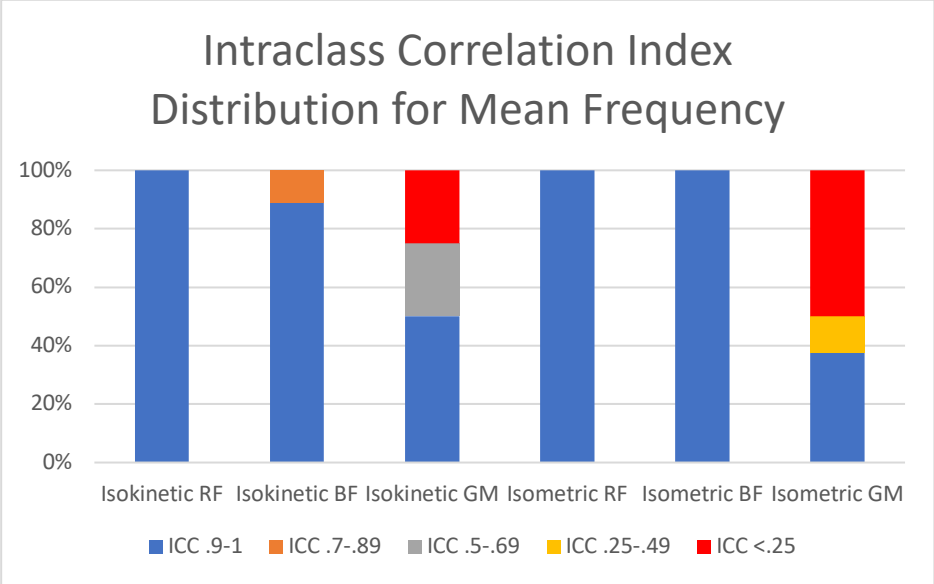


Figure 2. Percentage of participants that demonstrated each level of the Intraclass Correlation index for mean frequency reported

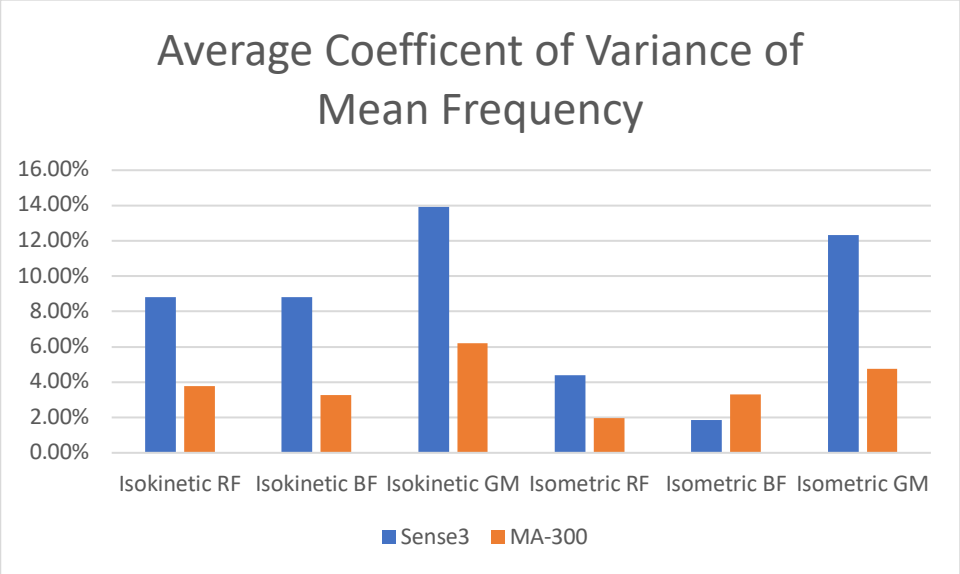


Figure 3. Average Coefficient of Variance demonstrated by both EMG systems when reporting mean frequency

6.1.1.4. Median Frequency

The ICC and CV values from the median frequency values are similar to those gathered from the mean frequency values. Figure 6.9 shows "high" to "very high" interclass correlations between both EMG systems for the BF and RF muscles. Correlations for GM conditions vary from "little to no" to "very high" correlation. Coefficient of variance values reported by the MA-300 were nearly all in the acceptable range for all testing conditions (51/52 of participants' trials). The Sense3 system had more acceptable CV values during the isometric trials than isokinetic (isokinetic=16/26 & isometric=24/26). To be expected, cumulative averages of CV for each condition was lower when recorded by the MA-300 system than when recorded by Sense3, shown in Figure 6.10. The differences between the averages of the two system are about 3% or lower in RF and BF conditions and 6% - 8% in GM conditions.

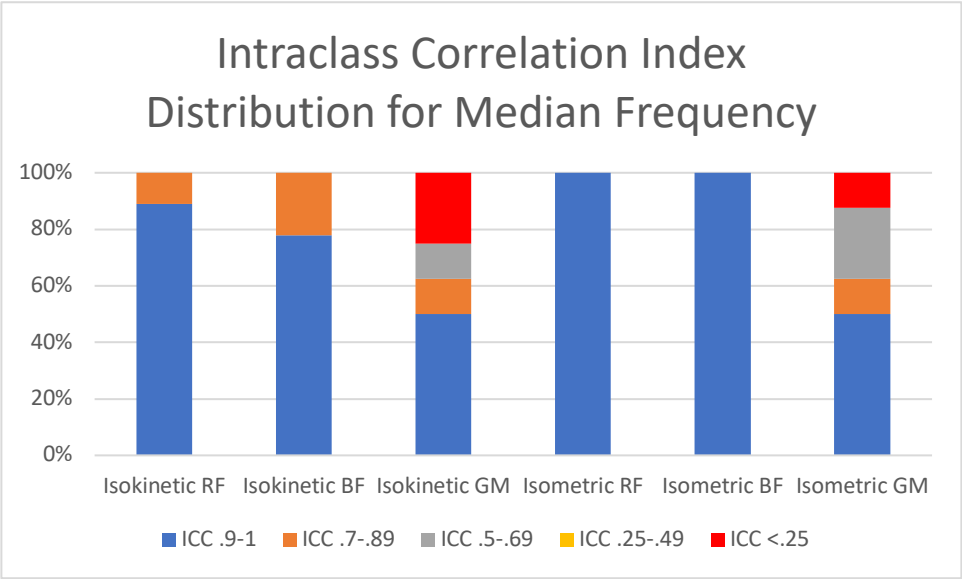


Figure 5. Percentage of participants that demonstrated each level of the Intraclass Correlation index for median frequency reported

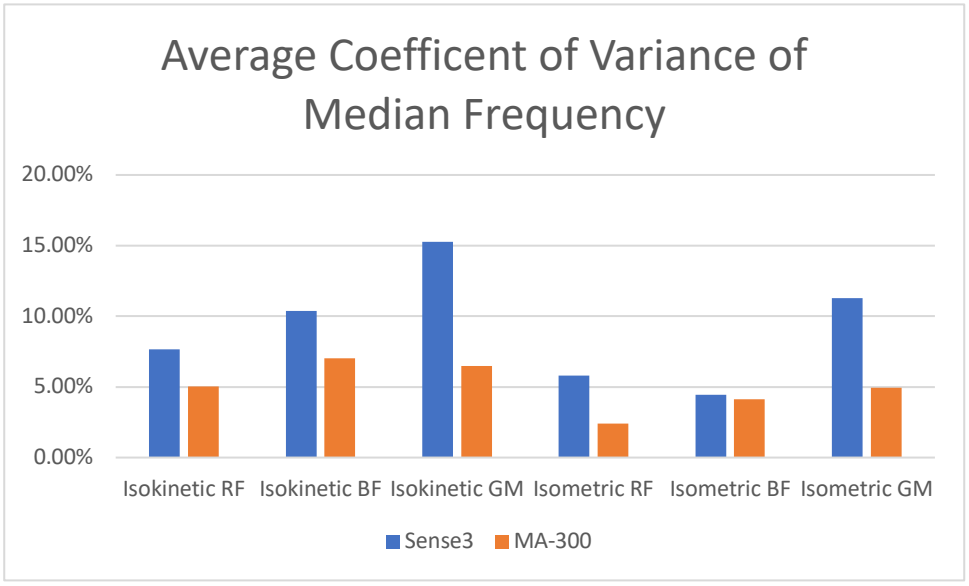


Figure 4. Average Coefficient of Variance demonstrated by both EMG systems when reporting median frequency

Table 6.1. Count of Participants Passing the Sub-15% CV Threshold

95 Percentile Signal Amplitude			Mean Frequency			Median Frequency		
Condition	**System**	**Count**	**Condition**	**System**	**Count**	**Condition**	**System**	**Count**
Isokinetic Rectus Femoris	Sense3	5/9	**Isokinetic Rectus Femoris**	Sense3	8/9	**Isokinetic Rectus Femoris**	Sense3	7/9
	MA-300	6/9		MA-300	9/9		MA-300	9/9
Isokinetic Biceps Femoris	Sense3	4/9	**Isokinetic Biceps Femoris**	Sense3	9/9	**Isokinetic Biceps Femoris**	Sense3	5/9
	MA-300	7/9		MA-300	9/9		MA-300	9/9
Isokinetic Gluteus Maximus	Sense3	3/8	**Isokinetic Gluteus Maximus**	Sense3	4/8	**Isokinetic Gluteus Maximus**	Sense3	4/8
	MA-300	4/8		MA-300	8/8		MA-300	8/8
Isometric Rectus Femoris	Sense3	5/9	**Isometric Rectus Femoris**	Sense3	9/9	**Isometric Rectus Femoris**	Sense3	9/9
	MA-300	8/9		MA-300	9/9		MA-300	9/9
Isometric Biceps Femoris	Sense3	5/9	**Isometric Biceps Femoris**	Sense3	9/9	**Isometric Biceps Femoris**	Sense3	9/9
	MA-300	6/9		MA-300	9/9		MA-300	9/9
Isometric Gluteus Maximus	Sense3	2/8	**Isometric Gluteus Maximus**	Sense3	6/8	**Isometric Gluteus Maximus**	Sense3	6/8
	MA-300	5/8		MA-300	8/8		MA-300	8/8

6.1.2. Dynamic Exercise

Sense3 did not acquire enough successful trials to do proper EMG analysis. A component of the research experiment was to witness the performance of Sense3's EMG acquisition in dynamic movement situations. The inability to record an acceptable EMG signal during the movement correlates to a fail if Sense3 were to be used in a real world, dynamic scenario. While observing each muscle activation in each trial, the activations were classified into a category (YES, NO, MAYBE), in reference to if the activation is acceptable to be analyzed. Selection to YES category was dependent on if a clear beginning and ending to the activation was observed. Activations placed in the MAYBE category was due to the recorded signal having minimal parts of the activation not captured by the electrodes and/or not being able to confidently determine the beginning or ending of the activation. People implement different movement strategies in order to perform dynamic movements or exercises. This results in different muscles being utilized more or less in one participant versus the next. Issues that placed activations in the NO category was due to large holes in the signal, massive noise, the activation being poorly measured or not measured at all, or unable to determine the beginning or ending of the activation. Figures 6.11, 6.12, & 6.13 represent actual activations from participants in the study recorded by Sense3. Out of the ninety trials, only 23% of Rectus Femoris (MAYBE=8%; NO=69%) activation signals from Sense3 were in the YES category, while only 3% of activations from the Biceps Femoris (MAYBE=7%; NO=90%) and Gluteus Maximus (MAYBE=13%; NO=83%) were

in the YES category. Only one trial had useable signals for each of the three muscles. Since a large percentage of signals could not be analyzed, validity and reliability analysis assays could not be performed nor compared to the MA-300 system. As a result, kinetics and kinematics were no longer necessary.

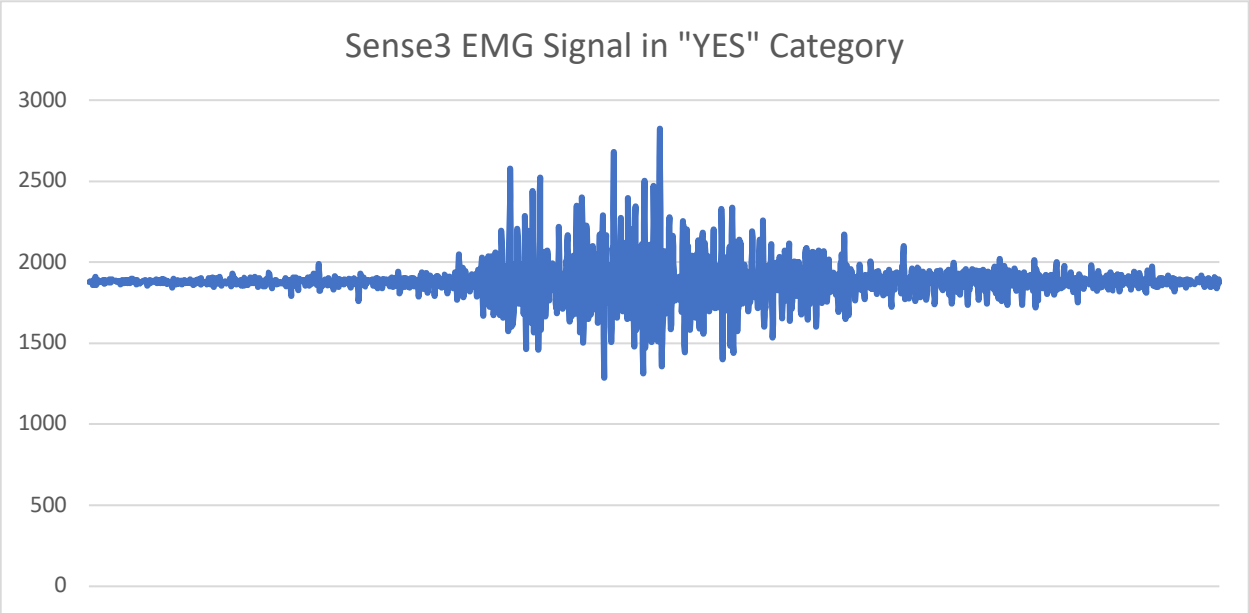


Figure 6.11. Example of a Sense3 recorded muscle activation that fell into the "YES" category. This is the EMG signal from the right Rectus Femoris of participant 108 during "Squat Trial 1".

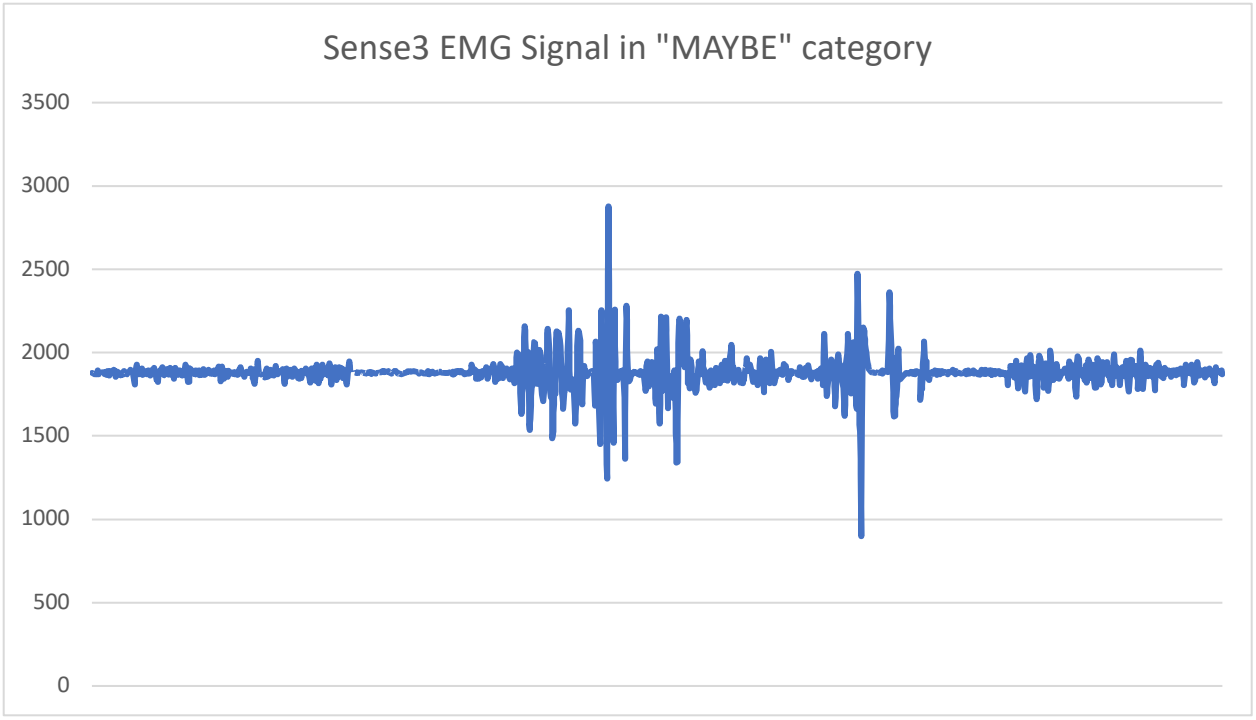


Figure 6.12. Example of a Sense3 recorded muscle activation that fell into the "MAYBE" category. This is the EMG signal from the right Rectus Femoris of participant 110 during "Jump - Trial 2".

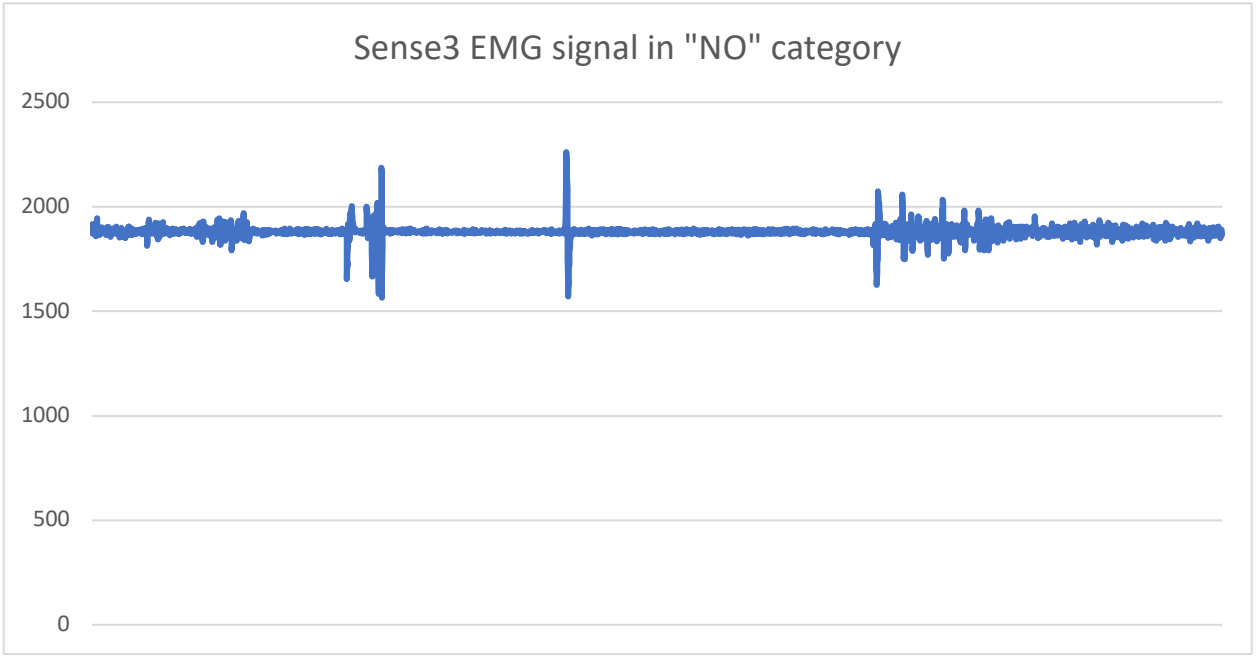


Figure 6.13. Example of a Sense3 recorded muscle activation that fell into the "NO" category. This is the EMG signal from the right Rectus Femoris of participant 112 during "Squat - Trial 3".

6.2. Motion Analysis

Motion capture was done during dynamic exercise trials. Certain software needed to be ran during jump and burst trials, in order to collect the jump height and acceleration data from Sense3. This software was not executed for a sufficient amount of participants and trials to be acceptable for analysis and for conclusions to be made. There were sessions where the software was operating during these trials but problems arose when attempting to download the data. The motion analysis of horizontal acceleration and jump height could not be completed in this study. The inability to perform motion analysis acceptable since motion analysis was not the main purpose of the study.

Chapter 7. Discussion

This study was designed to test reliability and determine the validity of a textile-infused wearable EMG system, Sense3, in a controlled and dynamic environment. Due to differences in the scale or units used in measuring the EMG signal characteristics, alternative methods of measurement comparison and statistical analyses needed to be performed. Since a measuring device can be reliable and not be valid, by testing and confirming reliability and combining that with verification from qualitative inspection, validity of the system can be assumed. Reliability analysis results show that the EMG data measurements are highly correlated between both systems when using the dynamometer, supporting reliability in these controlled environments. The repeated inability for Sense3 to record useable and decipherable EMG signals represented poor reliability in these more dynamic environments.

7.1. Reliability

In order to determine the reliability of the Sense3 EMG acquisition system, EMG data collected from Sense3 was correlated and compared to EMG data collected from the MA-300 system. Intra-class correlation (ICC) and Coefficient of Variance (CV) was calculated on the data collected for the following variables: max torque recorded during contraction, 95^{th} percentile peak EMG signal amplitude, mean frequency, and median frequency. The CV is being utilized to show how reliable each system is compared to itself. ICC is being used in reliability analysis to compare EMG measurement performance of Sense3 to the performance of a standard EMG system (MA-300). ICC statistics were calculated for each condition using all the three trials performed by each participant. Research shows that the average of repeated sEMG measurements demonstrate higher reliability than from single measurements (Jang et al. 2018). Muscular contractions and the corresponding EMG signal are inherently variable and the average of multiple trials would be a better representation to compare across systems. The two EMG systems did not collect EMG data concurrently, which I believe had a negative influence on the correlations seen between the two systems. The variability that exists when attempting to recreate muscular contractions would be expected not to have as much influence if the two EMG systems recorded at the same. Essentially, for a given condition, the participant would create three muscular activations and six EMG signals would be produced (three from Sense3 and three from MA-300). However, in this experiment, the participant created six muscular activations resulting in the six EMG signals used in this analysis. It would have been more appropriate to perform the EMG recordings at the same time, to ensure that the systems were recording the same performances.

The correlations from the recorded peak torques were shown to be very poor in all isometric conditions (RF, BF & GM) and in the Rectus Femoris and Biceps Femoris isokinetic conditions. According to Figure 6.12, at least 66% of participants recorded ICC values less than 0.25 (very poor correlation) in each of these conditions. The isokinetic GM condition was the only condition with less than 38% of participants showing very poor ICC values and at least 50% of participants with ICC values greater than 0.7. As previously stated, muscular contractions are difficult to reproduce perfectly, thus poor torque correlation values are not completely unexpected. Performing EMG recordings concurrently would have eliminated these discrepancies. Additionally, it should be noted that the dynamometer system is old and some measured torques appeared to be not correct. Torque measurements within the same participant would be significantly different despite the same apparent amount of effort. Collecting ICC values from the peak torque variable was necessary to determine, in the event that the other variables poorly correlated within and/or between EMG systems, if the poor correlations were due to changes in the participant's effort or poor reliability performance of the EMG system. If improper torques were reported by the dynamometer's software, then this would have an impact on the ICC values collected during data analysis. However, either way, Figure 6.1 shows the average torques produced among the participants for each condition and the figure shows that peak torques produced were consistent, with the MA-300 system having the slightly higher torques. So, for this variable, the values from the two systems did not correlate but they are sufficient enough to believe that exertions put into the muscular activations were alike within each participant. It is valuable to look at the torques created however torque is not perfectly correlated with effort (EMG amplitude). Analysis of 95th percentile peak EMG signal amplitude values showed more promising results that suggest acceptable reliability of the system. In all isokinetic and isometric conditions, at least 87.5% of participants' trials demonstrated "high" to "very high" correlation values. Figure 6.5 shows that the Rectus Femoris and Biceps Femoris contractions (isokinetic/isometric) having higher percentages of very good ICC values than contractions of the gluteus maximus. A theory for the greater variance shown in Gluteus Maximus values is due to the design to isolate GM activations. Based on the hip extension protocol, it was observed that participants could and would recruit the hamstrings to assist in the movement. The recruiting of additional muscles not only affects the torques produced but the EMG signal amplitudes as well. The greater variance of the GM is also shown when looking at CV values. The averaged CV values from MA-300 amplitude measurements (isokinetic: 15.91%, 11.07%, 16.15%; isometric: 10.36%, 12.06%, 12.45) are smaller and more consistent among the RF, BF, and GM than Sense3 measurements (isokinetic: 14.43%, 18.45%, 26.25%; isometric: 18.29%, 18.01%, 29.40%), yet the CV values of the GM are consistently the highest of the three

muscles in both the isokinetic and isometrics and in both EMG systems. The largest increase of variance between the two systems is shown in the GM of Sense3 during isokinetic and isometric trials. The differences between MA-300 average CV to Sense3 average CV for GM contractions are 10.10% (isokinetic) and 16.95% (isometric) which suggests that Sense3 measuring of GM is not as reliable as MA-300. Figure 6.6 shows the differences of CV between each system. Research suggested that CV values of acceptable reliability for EMG signal measurements to be less than 15%, which are satisfied in almost all standard EMG acquisition system (MA-300) conditions. On the other hand, when all participants' CV are averaged together, almost none of the Sense3 conditions satisfied this condition. However, I believe that since the standard EMG system is expected to be more reliable than the developing EMG wearable, it is necessary to look at the differences in average CV between the two systems, which are shown in Figure 6.6. Percent differences of less than 8% in the RF and BF conditions are more acceptable for reliability than the differences shown for GM conditions (10.10% & 16.95%). Also, the greater CV averages in Sense3 could be due to difference in scale of the measuring units; MA-300 presented amplitude in millivolts (calculated in sub-1, decimal form) as Sense3 presented amplitude in on an arbitrary scale (calculated through unique algorithm processing) with ranges up to almost 500 units. The discrepancies in CV values due to differences in scales is further supported since correlations of this variable were almost unanimously "high" to "very high" despite the higher CV values. Statistical analysis of mean and median frequencies presented similar results (Figure 6.7 & Figure 6.9). In both categories, 100% of participants garnered "highly" to "very highly" correlated ICC values during isokinetic and isometric RF and BF conditions. CV averages for these conditions all fell below 10%, which satisfies the acceptable CV limit (15%). The MA-300 system consistently had better CV average values than Sense3, but the differences between the two averages were all less than 5% (for RF and BF conditions). Poorer performance was shown by Sense3 in GM conditions. From the analysis of mean frequencies, less than 50% of participants showed "high" to "very high" correlation for this muscle. The CV averages were the largest in the GM out of three muscles for both systems in isokinetic and isometric conditions, however, Sense3 produced CV values higher than 10%. This resulted in much higher CV average differences between the systems in GM compared to RF & BF, shown in Figure 6.8. In analysis of median frequencies, less than 63% of participants showed "high" to "very high" correlation for the GM in comparison to the 100% of participants with "high" to "very high" correlations in the RF & BF muscles. CV averages were again largest in GM conditions and produced the highest CV average differences. Despite CV averages of the GM not being as impressive as in RF or BF, the measurement of mean and median frequency by Sense3 still satisfies the acceptable CV limit of sub-15%.

7.2. Validity

Validity was expected to be determined through quantitative analysis and qualitative inspection of the EMG signal characteristics. Statistical analysis using the coefficient of variance provided the foundation of quantifying the reliability of the Sense3 EMG system. This statistic further allowed the reliability of Sense3 to be compared to that of a standard EMG acquisition system (MA-300), under the presumption that the standard machine is highly reliable. The reliability of Sense3 using the coefficient of variance could be determined without comparing to those of the MA-300, however, it was beneficial to see how much of a difference the performance of Sense3 was compared to the gold standard. Confirming reliability of a system within one of the conditions for any of tested EMG signal characteristics was uncertainly determined by a 15% average coefficient of variance threshold. Meaning, if the average of all participants' CV when using one of the systems is greater than 15%, then it has insufficient reliability, but if the average CV is less than 15% then the system has acceptable reliability. In this instance, this threshold is weakly determinant, which is why comparison of the CV between systems was necessary, because the average CV of Sense3 may be near or greater than the 15% threshold for CV but still relatively close to the CV of MA-300. This threshold is also indeterminant because it represents the average of all the participants of the testing condition. If multiple participants individually achieved CV values higher than the threshold then the average CV for the system may surpass the threshold as well, designating insufficient reliability for the system used. This was shown to occur in the data. When looking at data from the signal amplitude, shown in Table 6.1, not all participants passed the threshold. The actual amount in all conditions varied around 50% of participants passing for Sense3 and MA-300 would have more participants passing than Sense3. When looking at the individual CV values for mean and median frequencies using Sense3, the number of passing participants were almost unanimous in all conditions except those the isokinetic conditions for median frequency and the gluteus maximus in the isokinetic condition for mean frequency, see Table 6.1. This is not too big of a surprise since Sense3 performed well and passed the average CV threshold in all conditions including those of the gluteus maximus, yet these conditions had the largest disparity between the two systems, refer to Figure 6.8 and Figure 6.10. The Coefficient of Variance values were also used to support the Intra-class correlation values between Sense3 and MA-300. Almost unanimous "high" to "very high" correlations were seen in the Rectus Femoris and Biceps Femoris for all three variables, signal amplitude and mean and median frequencies. These high correlations support acceptable reliability and a claim for the validity of Sense3 EMG capabilities. The correlations are not as strong in the

Gluteus Maximus. Multiple participants actually showed little to no correlation for the mean frequency and median frequency variables in this muscle. The poorer performance of Sense3 in Gluteus Maximus conditions, shown by the Coefficient of Variance values and Intraclass correlation, suggests that improvements need to be made. If the ability to monitor Gluteus Maximus activations were similar to its ability to monitor the activations of the Rectus Femoris and Biceps Femoris, Sense3 should be confirmed as valid in these slow controlled movements simulated by the dynamometer.

The ultimate validation of Sense3's EMG capabilities was expected to be tested and determined by its ability to record muscular activations during dynamic movements. Sense3 was tested using a protocol that simulated real-world applications of the product. Sense3 failed at its attempts to record muscular activations during these situations. Parts of and whole activations were missing from the EMG signal in most trials, prohibiting the ability to analyze the EMG signals during these trials. No other conclusion can be made except the invalidity of Sense3 EMG acquisition capabilities during dynamic movement.

Chapter 8. Limitations

There were limitations in the design and execution of this study that hindered the ability to give a stronger determination of the validity and reliability of Sense3 EMG acquisition system and motion tracking system. Isolating the activation of the Gluteus Maximus was a bit of a challenge given the design and limitations of the structural and software components of the dynamometer. The dynamometer had protocols already in place to examine isolated quadricep and hamstring performance, however, the machine's hip extension protocol did not induce high levels of muscular activation in the Gluteus Maximus. A manipulation of the system's standard protocol was executed to induce to isolate activation in this muscle. Much greater amplitude levels were seen, but I noticed that small but detectable levels of activation was seen in the hamstring of most participants. Recruitment of the hamstring, even minimal and variable amounts, could have led to the more variable results seen in the Gluteus Maximus EMG signal variables than in Biceps Femoris and Rectus Femoris. Another limitation of the study was due to the Sense3 shorts that were used in the study. Only three shorts were provided to be used in the study. Two of the shorts were relatively the same size and the third was slightly larger. Essentially, the shorts didn't fit each participant uniformly. It is expected to see differences in the strength of signal between participants due to factors such as muscle size and muscle activation and overlying fat levels, but shorts would need to be customized for the individual for proper alignment of the electrodes in order to see optimal results. I would also suggest some way to prevent sliding and bunching up of the shorts during movement. Aside for the fitting of the shorts, Strive advised applying water to the electrodes before testing to optimize results. Applying water was not implemented until after the first couple of participants. This continued for a few participants, but then was aborted for the remaining participants. Nevertheless, a noticeable difference between results were not seen between the middle participants with the beginning and ending participants.

A theory for poorer performance of Sense3, primarily in the Gluteus Maximus, is due to improper placement of electrodes on the belly of the intended muscle. There were three Sense3 shorts used in the study by the ten participants, each participant self-selected which pair they would use for testing. The shorts would fit the participants differently: tighter, looser, electrodes placed higher or lower. The Gluteus Maximus is the largest muscle on the human body which gives it the highest chance for improper electrode placement. Another theory is that the electrodes used in Sense3 are not as high quality as the standard EMG system, MA-300.

Along with a proper warmup to prepare the muscles for maximum voluntary contractions, participants should have been better familiarized with executing the movements on the dynamometer. Going through the beginning trials of each

movement, participants would commit errors in execution. This could be also due to the old machine and associated software. Another limitation may be apparent during the trials of knee flexion. Between each of these trials, the participant would have to hold their leg up in a knee extended position for a time frame between a few seconds to a minute. This may have caused fatigue in some instances and affected the proceeding muscle activation.

More limitations were seen during the recording of the EMG signal in the Sense3. The MA-300 system and Sense3 recording the EMG signals of equivalent muscular contractions at different recording frequencies. The MA-300 system recorded at a frequency of 2000hz which Sense3 recorded at a frequency of 1024hz. This caused the frequency spectrums presented by the MA-300 system skewed higher, presenting mean and median frequency values roughly 100hz higher than those presented by Sense3. Intra-class correlation needed to be used to compare these frequencies instead of a more direct correlation approach. Measuring the activations at the same recording frequency would have shown if Sense3 is recording the same frequencies as MA-300 or not. Also, Sense3 does not present its EMG signal amplitude in voltages units. After measuring the signal, Sense3 processes the signal and presents the amplitude in range dependent on an algorithm in the processing code. This too required assumptions made through intraclass correlation instead of more direct comparisons. Lastly, Sense3 was unable to record an acceptable amount of sufficient EMG signals from dynamic exercise trials. Since so much of that data was unusable, validity and reliability analyses could not be performed thus resulting unacceptable validity and reliability conclusions.

Chapter 9. Conclusion

The Sense3 EMG acquisition system showed high reliability in activations of the RF and BF during dynamometer trials, determined by the high to very high ICC values and the comparable CV values between the two systems. Activations in the GM also presented high to very high correlations, though not in as many participants, as well the CV values not being as small as those shown in RF and BF signals. Validity of Sense3 as a sports performance-based EMG wearable cannot be recommended due to its inability to record acceptable EMG signals during dynamic movement in addition to many of the limitations stated above. Testing reliability of the Sense3 EMG system during dynamic movement could not be attempted since a small percentage of the collect signals, from dynamic exercise trials, were useable for analysis. Performance during dynamic exercise is important to be used as an athletic performance device. The inability to record acceptable EMG signals in these situations is of major concern, since athletic performance involves dynamic movements, not isolated, simple movements replicated by the dynamometer use.

Appendix A. IRB Approval Sheet

Application for Approval of Projects Which Use Human Subjects

This application is used for projects/studies that cannot be reviewed through the exemption process.

Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/research

– Applicant, please fill out the application in its entirety and include parts B-F listed below. Once the application is completed, please submit to the IRB Office by e-mail (irb@lsu.edu) for review and allow ample time for the application to be reviewed. Expedited reviews usually take one month. Carefully completed applications should be submitted three weeks before a meeting to ensure a prompt decision.

– A Complete Application Includes All of the Following:
- [A] This completed form
- [B] A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1&2)
- [C] Copies of all instruments to be used.
  - *If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment material
- [D] The consent form that you will use in the study (see part 3 for more information.)
- [E] Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB. Training link: (http://phrp.nihtraining.com/users/login.php)
- [F] Signed copy of the IRB Security of Data Agreement: (https://sites01.lsu.edu/wp/vred/files/2013/07/IRB-Security-of-Data.pdf)

1) Principal Investigator*: Arend W. A. Van Gemmert Rank: Associate Profes

*PI must be an LSU Faculty Member

Dept: Kinesiology Ph: 225-578-9142 E-mail: gemmert@lsu.edu

2) Co-Investigator(s): please include department, rank, phone and e-mail for each.
If the co-investigator resides in the EU, a GDPR consent form must be signed by the co-investigator prior to study submission for IRB approval.

Stanley Smith, Graduate Student, School of Kinesiology, ssmi226@lsu.edu, 504-312-2614
Erika Garcia Mora, Graduate Student, School of Kinesiology, egarc23@lsu.edu, 714-357-5446

3) Project Title: The comparison of electromyography readings of "Sense3" athletic compression shorts with an integrated EMG system to a conventional EMG system.

4) Proposed Start Date: 1/10/2018 5) Proposed Duration Months: 24

6) Number of Subjects Requested: 50 7) LSU Proposal #:

8) Funding Sought From: N/A

9) Is your project regulated by the FDA? Y/N No ; If unsure, click here for a checklist.

10) Does your study include participants (counting MTurk) in the 28 member states of the EU or the three additional countries? (Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, UK, Norway, Iceland, Lichtenstein) ☐ Yes ■ No

ASSURANCE OF PRINCIPAL INVESTIGATOR named above
I accept personal responsibility for the conduct of this study (including ensuring compliance of co-investigators/co-workers) in accordance with the documents submitted herewith and the following guidelines for human subject protection: The Belmont Report, LSU's Assurance (FWA00003592) with OHRP and 45 CFR 46 (available from http://www.lsu.edu/irb). I also understand that copies of all consent forms **must be maintained at LSU for three years after the completion of the project.** If I leave LSU before that time, the consent forms should be preserved in the Departmental Office.

Signature of PI _____ Date 1/4/2019

ASSURANCE OF STUDENT/PROJECT COORDINATOR named above. If multiple Co-Investigators, please create a "signature page" for all Co-Investigators to sign. Attach the "signature page" to the application.

I agree to adhere to the terms of this document and am familiar with the documents referenced above.

Signature of Co-PI (s) _____ Date 1/4/2019
1/7/2019

Continue on the next page

Part 1: A. Is a HIPAA Agreement Needed?

Are you obtaining any health information **from a health care provider or participant** that contains any of the identifiers listed below?

A. Names
B. Address: street address, city, county, precinct, ZIP code, and their equivalent geocodes. Exception for Zip codes: the initial three digits of the ZIP Code may be used, if according to current publicly available data from the Bureau of the Census: (1) The geographic unit formed by combining all ZIP codes with the same three initial digits contains more than 20,000 people; and (2) the initial three digits of a ZIP code for all such geographic units containing 20,000 or fewer people is changed to '000'. (Note: The 17 currently restricted 3-digit ZIP codes to be replaced with '000' include: 036, 059, 063, 102, 203, 556, 692, 790, 821, 830, 831, 878, 879, 884, 890, and 893.)
C. Dates related to individuals
   i. Birth date, admission date, discharge date, or date of death
   ii. And all ages over 89 and all elements of dates (including year) indicative of such age. Such ages and elements may be aggregated into a single category of age 90 or older.
D. Telephone numbers or fax numbers;
F. Electronic mail addresses;
F. Social security numbers;
G. Medical record numbers; (including prescription numbers and clinical trial numbers)
H. Health plan beneficiary numbers;
I. Account numbers;
I. Certificate/license numbers;
K. Vehicle identifiers and serial numbers including license plate numbers;
L. Device identifiers and serial numbers;
M. Web Universal Resource Locators (URLs);
N. Internet Protocol (IP) address numbers;
O. Biometric identifiers, including finger and voice prints;
P. Full face photographic images and any comparable images;
Q. Identification card numbers
R. Cookie Id
S. Race or origin
T. Sexual life or orientation
U. Political opinions, religious, or philosophical beliefs
V. Any other unique identifying number, characteristic, or code; except a code used alone or in combination with other information to identify an individual who is the subject of the information.

☐ YES Your study falls under the HIPAA (Health Information Privacy and Accountability Act) and you must obtain either a limited data set use agreement or a HIPAA authorization agreement from the health care provider. This agreement must be submitted with your IRB protocol.

☒ NO You do not need a HIPAA agreement.

B. Are pregnant women specifically excluded from participation on the consent form?

☒ YES Skip to Part C

☐ NO You need to document the following:

☐ 1. Is the purpose of the activity to meet the health needs of the mother and

   ☐ a. Fetus will be placed at risk only to minimum to meet mother's needs.

   ☐ b. Fetus risk is minimal.

☐ 2. Have mother and father given informed consent including potential affects on the fetus?

☐ 3. Father's consent to be omitted when:

   ☐ a. Purpose of activity is to meet health needs of the mother

   ☐ b. His identity can not be ascertained

   ☐ c. He is not reasonably available

   ☐ d. Pregnancy is from rape

Continue on the next page

C. Are any of your participants incarcerated?

☐ **YES** - You must document the following information:

- ☐ 1. Is the study minimal risk? (it must be)
- ☐ 2. Research fits one of the allowed categories below
  - ☐ Causes or effects of incarceration
  - ☐ Study of prisons or prisoners
  - ☐ Conditions affecting prisoners as a class
  - ☐ Practices that may improve health or well-being of subjects
- ☐ 3. Are the risks commensurate with risks accepted by non-prisoners?
  - ☐ Selection of subjects is fair - controls random
  - ☐ Language is understandable
  - ☐ Study does not affect parole
  - ☐ If necessary, follow up care will be provided

■ **NO**

D. Are children involved?

☐ **YES** - You need both parental consent form and a child assent form

- ☐ If the study has greater than minimal risk and no direct benefits, then you must show that the risk is only a minor increase above minimal, and it involves experiences that are commensurate with ordinary medical, psychological, social or educational situations

■ **NO**

Part 2: Project Abstract - Provide a brief abstract of the project

■ I have attached a project abstract to this application

Part 3: Research Protocol

A. Describe study procedures

Describe study procedures with emphasis on those procedures affecting subjects and safety measures. Also, provide script for telephone surveys.

■ I have attached a description of my study procedures to this application

B. Answer each of the following questions

1. Specify sites of data collection

All data will be collected in the School of Kinesiology Biomechanics Laboratory (Gym Armory, B-2).

Continue on the next page

2. If surgical or invasive procedures are used, give name, address, and telephone number of supervising physician and the qualifications of the person(s) performing the procedures. Comparable information when qualified participation is required or appropriate.

N/A

3. Provide the names, dosage, and actions of any drugs or other materials administered to the subjects and the qualifications of the person(s) administering the drugs.

N/A

4. Detail all the physical, psychological, and social risks to which the subjects may be exposed.

The potential risks involved as a research participant in this study are minimal. Participants face a small risk of injury when performing the sprint, walking and/or jumping motions, however, they are not more risky than motions they perform in normal everyday exercises. Additional risks may include skin irritation due to the use of tape and fatigue. There is also the inadvertent risk that anonymity of participants will not be kept. However, every effort will be made to maintain confidentiality. The collected data and participants' information will be held on a computer protected by a password. Their consent forms will be locked away.

5. What steps will be taken to minimize risks to subjects?

The risk of skin irritation will be minimized with the use of hypoallergenic tape. As well, rest periods will be provided throughout the experiment to prevent fatigue. The research staff for this study is prepared to make suitable accommodation to all the participants to avoid any kind of injury. The collected data and participants' information will be held on a computer protected by a password. Their consent forms will be locked away.

Continue on the next page

6. Describe the recruitment pool (community, institution, group) and the criteria used to select and exclude subjects.

Young adults (males and females) between the ages of 18 and 35 from the Baton Rouge community, including the college community. Individuals need to be free of any orthopedic, cardiovascular, and neuromuscular health problems (as determined using the PAR-Q questionnaire). The participants must also have the capability to provide informed consent. Individuals who are pregnant are excluded.

7. List any vulnerable population whose members are included in this project (e.g., children under the age of 18; mentally impaired persons; pregnant women; prisoners; the aged.

N/A

8. Describe the process through which informed consent will be obtained. (Informed consent usually requires an oral explanation, discussion, and opportunity for questions before seeking consent form signature.)

Prior to participation in the study, participants will be provided with an informed consent form. This form will outline the procedures to be expected throughout the study and the measurements that will be taken. Participants will be free to ask questions at any time to make sure they are fully aware of the experimental procedures. Participants can withdraw from the study at any point for any reason without penalty.

9. (A) Is this study anonymous or confidential? (Anonymous means that the identity of the subjects is never linked to the data, directly or indirectly through a code system.)

(B) If a confidential study, detail how the privacy of subjects and security of their data will be protected

This study is confidential. Results of the study may be published; however, no names or identifying information will be included. The identities of participants and their data will be kept confidential unless release is legally compelled. The collected data and participants' information will all be stored on a password protected computer. Their consent forms will be stored in a locked cabinet in a locked room.

Continue on the next page

Part 4: Consent Form (including assent form and parental permission form if minors are involved)

- **Please note:** The consent form must be written in non-technical language, which can be understood by the subjects. It should be free of any exculpatory language through which the participant is made to waive, or appears to be made to waive any legal rights, including
- For example consent forms and a complete checklist of required items, please refer to our website, www.lsu.edu/irb. Remember, **IRB contact information must be included on the consent form!**
- To waive signed consent. **IRB must be provided with the consent script** that will present the informed consent information to human subjects regarding the study/research. Also, note that waiving signed consent requires full IRB approval, which may delay approval of your study.

I am requesting waiver of signed Informed Consent because:

☐ (a) Having a participant sign the consent form would create the ***principal risk*** of participating in the study. or that

☐ (b) The research presents ***no more than minimal risk*** of harm to subjects and involves no procedures for which having signed consent is normally required.

Expedited reviews usually take one month. See our website for information about meeting dates. Carefully completed applications should be submitted three weeks before a meeting to ensure a prompt decision.

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

Appendix B. Physical Activity Readiness Questionnaire (PAR-Q)

Physical Activity Readiness Questionnaire (PAR-Q)

For most people, physical activity should not pose any problem or hazard. This questionnaire has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the suitable type of activity.

1.	Has your doctor ever said you have heart trouble?	Yes	No
2.	Do you frequently suffer from chest pains?	Yes	No
3.	Do you often feel faint or have spells of severe dizziness?	Yes	No
4.	Has a doctor ever said your blood pressure was too high	Yes	No
5.	Has a doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by, or might be made worse with exercise	Yes	No
6.	Is there any other good physical reason why you should not follow an activity program even if you want to?	Yes	No
7.	Are you 65 and not accustomed to vigorous exercise	Yes	No

If you answer "yes" to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary.

I have read this questionnaire, I understand it does not provide a medical assessment in lieu of a physical examination by a physician.

Participant's signature_____ Date _____

Investigator'signature_____ Date_____

Adapted from PAR-Q Validation Report, British Columbia Department of Health, June, 1975.

Reference:
Hafen, B. Q. & Hoeger, W. W. K. (1994). Wellness: Guidelines for a Healthy Lifestyle. Morton Publishing Co: Englewood, CO.

Appendix C. Consent to Participate

CONSENT TO PARTICIPATE IN A RESEARCH STUDY
INFORMED CONSENT

Study Title: The comparison of electromyography readings of "Sense3" athletic compression shorts with an integrated EMG system to a conventional EMG system.
Performance Site: School of Kinesiology, Biomechanics Laboratory (Gym Armory, B-2)
Investigator: If you have any questions regarding the study, please contact

Arend Van Gemmert, Ph.D. Phone: 225-578-9142 Email: gemmert@lsu.edu
Stanley Smith, M.Sc. Phone 504-312-2614 Email: ssmi265@lsu.edu
Erika Garcia Mora, M.Sc. Phone: 225-578-9142 Email: egarc23@lsu.edu

Purpose of the Study:

The proposed project will be to observe whether EMG integrated in shorts (Sense3) allow for consistent and accurate measurements of muscle activity of groups of muscles and kinematics of joint and limb movements of the pelvis and/or legs during a motor task. The purpose of the present study will be to determine whether the EMG shorts produce equivalent results as standard EMG (sEMG) and kinematic recording procedures.

Participant Information:

Thirty healthy young adults (male and female) between the ages of 18 and 40, who are free of any orthopedic, cardiovascular, and neuromuscular health problems (as determined using the PAR-Q questionnaire), will be recruited for this study. Participants must also have the ability to provide informed consent to the study.

Equipment / Study Procedures:

The study will involve one laboratory testing session with 4 motor tasks and they are asked to perform 3 trials/task. The motor tasks are squats, standing vertical jumps, normal walking, and approximately 30 ft sprints. Participants should wear their normal comfortable training shoes. Participants will begin the motor task with integrated EMG short – Sense3 (Strive Tech Inc., Bothell, WA) or with the standard EMG system – sEMG (Motion Lab Systems Inc., Baton Rouge, LA) and then switch. Additionally, three-dimensional (3-D) motion will be recorded using markers. Markers will be placed on Cervical Vertebrae 7, sacrum, hips, knees, ankles, and feet using double-sided tape. Like previously stated, muscle activities will be recorded in two ways: 1) using an electromyography system (sEMG) which consists of placing electrodes on the: Rectus Femoris, Biceps Femoris, and Gluteus Maximus muscles; 2) wearing compression shorts with electrodes embedded into the Sense3 shorts. In preparation for sEMG electrodes' placements, participants may be shaved (if needed) and will be cleaned with alcoholic wipes to remove any dry skin or cream around the desired muscle location. Participants will perform four motor tasks, 3 trials per motor task, per EMG system type. The four motor tasks include: (1) body weight squat, (2) walk of 5 meters at comfortable pace, (3) bilateral max effort jump and land, and (4) the takeoff phase of a sprint. Participants will wear Sense3 shorts throughout all trials for convenience. The laboratory session will last approximately 1.5 hours.

Access to Select Medical Information:

The participants participating in this study should be free of any orthopedic, cardiovascular, and neuromuscular health problems.

Benefits:

The study does not have any direct benefits to participants. The results of this study will be useful for coaches and training professionals in planning programs to maximize performance in training and athletic populations.

Risks/Discomfort:

The potential risks involved as a research participant in this study are minimal and may include skin irritation due to the use of tape and/or fatigue due to performing the motor tasks. The risk of skin irritation will be minimized with the use of hypoallergenic tape. As well, rest periods will be provided throughout the experiment to prevent fatigue as result of exertion during performance of the motor tasks. The research staff for this study is prepared to make suitable accommodation to all the participants to avoid any kind of injury.

Right to Refuse:

Participants may choose to not participate or withdraw from the study at any time without any penalty.

Privacy:

Every effort will be made to maintain the confidentiality of your study records. Results of the study may be published; however, we will keep your name and other identifying information private. If you agree, video data of your participation may be used in the scientific presentation of the study, and measures will be taken to keep your participation anonymous. Your identity will remain confidential unless disclosure is required by law.

Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about participants' rights or other concerns, I can contact Dennis Landon, Chairman, LSU Institutional Review Board, (225)-578- 8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the researchers' obligation to provide me with a copy of this consent form if signed by me.

Participant Signature: _____

Date: _____ Participant's Date of Birth: _____

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Vita

Following graduation, Stanley Smith intends to continue the pursuit of becoming a sports science researcher. Currently, he is interning at a number of sports performance and fitness training facilities. There, he is learning various training techniques and principals, as well as, how to communicate and coach athletes of all ages and backgrounds. Being able to communicate with trainers and athletes the knowledge gathered from scientific research would make him more useful in a wider range of environments. By being a former collegiate athlete, he can provide a more insightful perspective for potential solutions to problems that exist in the sports world.