ELECTROMYOGRAPHY ANALYSIS OF LOWER BODY MUSCLE MECHANICS DURING MAXIMAL VERTICAL JUMPS ON A RIGID AND SAND SURFACE

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By

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Wisdom lies neither in fixity nor in change, but in the dialectic between the two.
- Octavio Paz

DEDICATION

I would like to dedicate this thesis to my grandparents, Mayo Harris, Leonard Harris, and Pauline Guerrero. Their love and support throughout my life has inspired me to achieve my dreams. I hope that the completion of this thesis and ultimately receiving my master's degree symbolizes how much I appreciate being their grandson.

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ABSTRACT

ELECTROMYOGRAPHY ANALYSIS OF LOWER BODY MUSCLE MECHANICS DURING MAXIMAL VERTICAL JUMPS ON A RIGID AND SAND SURFACE

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Objective: **Design and Setting**: All data were collected in the Jowers Center Biomechanics Supplemental Research Lab, Texas State University-San Marcos. **Subjects**: Sixteen healthy, physically active males and ten healthy, physically active females (age = 26.9 ± 6.5 yrs, height = 177.2 ± 10.6 cm, and weight = 79.1 ± 15.1 kg) with no reports of current lower limb or low back injuries. **Measurements**: All subjects performed three short step countermovement jumps each on a sand surface and a rigid surface. A 4-channel electromyography (EMG) system recorded output from the rectus femoris, vastus lateralis, biceps femoris, and gastrocnemius muscles of the right leg. A wireless waist belt accelerometer obtained subject jump height. Mean and mean peak EMG data from the lower extremity muscles was compared between the two surfaces along with jump height. **Results**: Analysis using an ANOVA was conducted between the two surfaces. There was a significant difference between jumping surfaces for the normalized mean and mean peak percentage EMG output measures. The rectus femoris and vastus lateralis muscles of the quadriceps registered significantly higher normalized mean and mean peak percentage EMG output measures on a sand surface. The biceps femoris and gastrocnemius muscles were significantly higher on a rigid surface for both the normalized mean and mean peak percentage EMG output measures. **Conclusion**: Jumping from a sand surface requires more output from the quadriceps muscles than jumping from a rigid surface.

CHAPTER I

ELECTROMYOGRAPHY ANALYSIS OF LOWER BODY MUSCLE MECHANICS DURING MAXIMAL VERTICAL JUMPS ON A RIGID AND SAND SURFACE

The 2008 Beijing Olympics exposed the sport of beach volleyball to millions worldwide.[1] Estimates of 800 million people play volleyball recreationally.[9] Indoor volleyball represents the second ranked sport in the National Collegiate Athletic Association (NCAA).[21] Recently the NCAA pursued the option of accepting sand volleyball as an intercollegiate sport.[23] Sand volleyball provides a versatile style of play that helps develop all skills necessary in the game.[15]

Research has identified that one particular skill, the jump, can differentiate between a stable and unstable surface.[3,10,20] Extension of the knee and hip joints on a stable surface provides an efficient force application during jump takeoff.[24-25] A sand surface represents an unstable surface that requires a mechanical adjustment in movement. Several studies have identified a reduction of jump height on a sand surface compared to a rigid surface.[3,10,20] Sand surfaces create a challenge in developing ground reaction forces necessary to plant the foot during takeoff.[25] Movement in the sand causes a decreased center of mass which creates an increased energy expenditure.[17] Running on a sand surface reveals greater hamstring activity and a significant increase in hip and knee flexion kinematics.[22] Analysis using electromyography during a vertical leap will contribute to information on differences in jumping from both a rigid and sand surface.

Purpose

The purpose of the study will be to analyze electromyography activity between jumping on a rigid and sand surface. Lower extremity muscles including the hamstring, quadriceps, and calf muscle groups will be measured during maximal voluntary contractions required in a vertical leap test.

Research Hypothesis

It is hypothesized that electromyography activity of the lower extremity muscles, the hamstrings, quadriceps, and calf muscles, will register a higher activity level in the sand surface due to stabilizing factors developing ground reaction forces.

Operational Definitions

1. Rigid surface- A firm, hard surface that maintains force application.[10]
2. Ground reaction force- The force application that the ground applies to an object at rest or in motion.[24]
3. Center of mass- Center of mass of the whole body relative to its surroundings.[17]
4. Energy expenditure- The metabolic cost of the amount of work produced while in motion.[17]
5. Electromyography- A recording of the signal activation in muscles.[22]
6. Kinematics- The mechanics that describe motion.[22]
7. Lower extremity- Refers to the leg of the human body consisting of the gluteal, hamstring, quadriceps and calf muscle groups.

8. Maximal voluntary contraction- The maximal level voluntarily attempted to reach peak physical performance of an activity.

Delimitations

This research will be delimited or incur certain boundaries that will affect data collection and interpretation.

1. The subjects will be physically active individuals between the ages of 20 and 45 years old.
2. Participants who are currently active will be allowed to participate.
3. Subjects will be asymptomatic of any lower extremity injury or trauma in order to insure maximal voluntary contraction.
4. A BIOPAC 4-Channel Electromyography Telemetry System will monitor muscle output.

Assumptions

Basic assumptions for the study include:

1. Subjects selected to participate will be randomly selected.
2. All subjects will perform the tests under the assumption that the exercise will be a maximal effort.
3. Medical health questionnaire and questions involving activity levels will be completed by the subjects accurately.
4. Subjects will follow all instructions prior to testing to allow for proper setup and administration of testing procedures.

Significance of the Study

The research conducted in this study will attempt to further interpret the differences between jumping on a rigid and sand surface. Electromyography readings will provide information of lower extremity muscle output between the two surfaces while jumping. Results of this study will provide specific information on how the lower body muscles respond to jumping in the sand. Strength and conditioning professionals can take into account the kinematic features discovered in this study. In addition, identification of muscular output can potentially aid healthcare professionals in developing rehabilitative techniques that involve jumping on a sand surface.

CHAPTER II

REVIEW OF RELATED LITERATURE

An individual's jumping ability can provide information regarding lower body muscular strength. The vertical jump test assesses the kinetic variables involved in developing the power to takeoff from a surface. Research on surface type utilized to push-off during a jump has provided information on rigid, sand, and aquatic reaction forces. Evaluation of vertical jump data on various surfaces can lead to modification of strength training and therapeutic intervention protocols. Investigation on the kinetics, type of jump, surface type, and electromyography output will outline previous literature and detail the need for further research.

Vertical Jump Kinetics

The initiation of dorsiflexion at the ankle, and flexion of the knee and hip, creates the downward movement necessary to conduct a countermovement jump. Optimal jumping performance maintains when the prestretch occurs slowly with a relative low average force.[31] Performances that occur with a fast prestretch under a high force that lasts longer produce a suboptimal jump.[31] A longer prestretch effect relates to an extended push-off phase and time to peak force.[16] The rate of force decreases with more time and can develop greater variation in ground reaction force production.[16]

The time element represents a critical factor in the ground reaction force equation.[16] Vertical displacement requires an effective and sufficient amount of force.[16] Smooth coordinated movements enable an amount of peak power to create a jump height.[16] The amount of peak power must equate to two times the body weight for the highest possible jump height.[8] Peak power represents the single predictor of jump height performance.[8] Analysis of peak power depends on the type of jump performed and can aid in setting up a specific training regimen.

Jump Type

Jump height can be measured through various types of jumps. Commonly jump height assessment involves a countermovement jump. The jump begins from an upright position, followed by a downward action prior to pushing off with the feet, in order to generate a takeoff motion.[4] Another type of jump height assessment involves the squat jump. Squat jump positioning sets up in a semi-squatted stance, and jumps without countermovement.[4] Jump strategies between the countermovement and squat jump revealed that training background was not related.[31]

Countermovement jump height is significantly greater than squat jump height.[4] Research credits the greater amount of work individual muscles are able to complete for joint motion at takeoff.[4] Another factor to consider for jump height with a countermovement jump involves arm swing. The upward movement of the arms slows down the lower body muscles to exert more ground reaction force.[12] Arm movement accounts for an average 10 percent increase in jump height due to increased takeoff velocity.[12]

Squat jump height is reduced compared to the countermovement jump.[13] A pre-movement silent period while in the squat jump position limits the response of lower body muscle function.[13] Positioning in the squat jump utilizes small, rapid stretch-shortening cycles that may affect jump height.[13] Jumping from the squatted position sustains the time at the deepest knee flexion and negative power transfer activity.[31] Hip to knee joint power transfer in both the countermovement and squat jump exhibit negative activity.[31] The countermovement jump differentiates through the transfer of momentum downward and then back up for takeoff.[31]

Countermovement jumps can be either one or two-legged. The one-legged countermovement jump represents a higher level of gastrocnemius muscle activation.[30] Two-legged jump neural mechanism reflects lower muscle activation.[30] This decrease can be attributed to training effects that occur with habituation.[30] Emphasis on strength and technique through neuromuscular training may help in reducing injury.[27] A further understanding of movement on a sand surface may provide a source for neuromuscular training.

Sand Surface

Jumps on a sand surface result in a reduction of jump height.[3,10,20] Ground reaction forces determine the peak vertical impulse of a jump created with extension of the legs and plantar flexion of the ankles.[6] Ground reaction force is reproducible and reliable on a firm surface when jumping.[6] A sand surface absorbs the energy of a jump into the sand and reduces the ground reaction force.[3] The displacement of the sand in order to create a ground reaction force affects the physiology, mechanics, and musculoskeletal systems of the body.

The feeling of more exertion required to move on the sand compared to a firm surface provides potential to strength train. Energy expenditure on sand is higher compared to a firm surface.[20] Both oxygen uptake and the amount of kilocalories burned, increased significantly after 30 total jumps on the sand.[20] The increase in energy expenditure on a sand surface may be due to a decrease in exercise efficiency.[20] The reduction of coordinating factors required to move the body with normal mechanics differentiates the two surface conditions.

Movement on the sand requires an excess amount of internal work to create work externally on the environment.[17] The ground reaction force produced on a sand surface creates a downward sagittal movement.[17] Lateral forces are displaced resulting in a passive transfer of energy.[17] Mechanically the body increases the musculotendon work while the sand decreases the efficiency of the musculotendon work.[17] A decrease in musculotendon efficiency affects the range of motion of the joints when moving on a sand surface.

Sand surfaces show an increase in range of motion while running.[22] Pinnington et al.[22] reported that both the knee and hip increased in flexion through the range of motion. The initial foot contact causes the trunk of the body to lean and move the center of gravity forward to support the foot early in the stance.[22] Following takeoff, the foot requires a secondary burst from the hamstring muscle to clear the sand surface.[22] Finally, in the late swing phase, knee flexion increases in order to control the eccentric phase of knee extension.[22]

Force measurement can also provide information on the differences in jumping between a rigid and sand surface. Results of the study by Giatsis et al.[10] indicated a difference between the starting positions of the ankle in sand compared to a rigid surface. At takeoff, the angle of the hip was greater in the sand because of the increased angle of the ankle.[10] Giatsis et al.[10] credits the increase in angle to the instability of the sand at takeoff creating a force that causes the toes and feet to sink. The body tries to equalize and balance, which results in more hip extension at takeoff.[10] Finally, an increase in contraction time occurs, allowing more of an active state of force prior to shortening to contract the muscle.[3] Measurement of contractions can be conducted through electromyography of muscle activity.

Surface Electromyography

Surface electromyography tests while vertical jumping proves to be reliable with specific parameters used for examination. Electromyography integration during the entire propulsion phase demonstrates a reliable assessment.[11] Avoidance of electromyography integration analysis at the mid-propulsion phase will further ensure test reliability.[11]

Specific muscles of the lower limb elicit some variability during electromyography integration. Poor reliability occurred between the gastrocnemius and rectus femoris muscles.[11] The proximity of the leads to adjacent muscles makes the gastrocnemius and rectus femoris muscles subject to interference.[11] This also may be due to measurements taken from separate jumping sessions.[11] A reliable measure of electromyography while vertical jumping applies to the rectus femoris and vastus medialis.[11]

A study of female volleyball players' vertical jump and landing, positioned electrodes on the vastus medialis, hamstring, and lateral gastrocnemius muscles.[27] The hamstring electrode placement was 2.5 centimeters medial to the midpoint of the muscle.[27] Study results did not convey interference between the vastus medialis, hamstring, and lateral gastrocnemius muscle sites.[27]

An active warm-up on surface electromyography revealed an increase in median frequency and maximal instantaneous power.[26] The increase in median frequency can result in an enhanced muscle fiber action potential conduction velocity.[26] The heightened median frequency and muscle fiber action potential conduction velocity could potentially be attributed to an increase in body temperature.[26] Surface electromyography after dynamic stretching exhibited an increase in activity due to an enhanced neuromuscular response.[14] When static and dynamic stretching are combined, muscle activity of the gastrocnemius muscle was not influenced.[32]

Conclusion

Utilization of the sand for therapeutic intervention and strength training can supplement current protocols for training. A sand surface does not have the normal ground reaction forces created on a rigid surface.[25] Sand training can also be applied as an intervention for prevention of injuries. Common overuse injuries of the knee and ankle involving acute traumatic events may be effectively reduced through intervention.[2] Injury rates occur during the greatest total volume of vigorous physical training.[2] Stabilizing forces in the sand provide a unique technique for training mediolateral and anteroposterior movements as the foot sinks into the sand.[25] Similar forces are present with aquatic environments.

The buoyancy force in water while jumping acts similar to sand through the mediolateral and anteroposterior characteristics involved to stabilize the body, and generate power.[29] Significant improvements in vertical jump height were recorded after 6 weeks of aquatic plyometric training.[18] Research on the effects of a sand-based training program on vertical jump height have yet to be conducted. It is the goal of this thesis to enhance the literature on the electromyography differences between jumping on a rigid and sand surface. The knowledge gained from this study could potentially lead to further studies on training on a sand surface.

CHAPTER III

METHODOLOGY

Subjects

Twenty-six healthy male and female subjects between the ages of 20-45 participated in the study. Recruitment was open to all undergraduate and graduate students, and individuals recruited online through a website (www.atxvb.com). The website was originally constructed as an online forum to post messages about gathering interested people to play sand volleyball on specific dates in the Austin, Texas area. The site has approximately 500 registered participants, both male and female, of all ethnic backgrounds.

Inclusion criteria consisted of active individuals who participated in physical activity at least three times a week or a total of 90 minutes a week. Each participant received information about the components of the study (See Appendix A). A letter described the protocol and significance of the study, and provided an informed consent (See Appendix B). Subjects were required to sign informed consent and be screened for exclusionary criteria with a medical health questionnaire (See Appendix C). Criteria for exclusion included any current Anterior Cruciate Ligament injury, current ankle or hip injury, and any current low back pain or lower extremity injury. Incentives for participating in the study included knowledge of personal muscle electromyography (EMG) output while jumping on a rigid and sand surface. Each subject was issued a randomized number to differentiate results between subjects and to maintain subject confidentiality. In order to participate in this study, subjects recruited must sign the informed consent form in accordance with the Institutional Review Board at Texas State University-San Marcos.

Instruments

Testing was conducted in one individualized session for each subject at the Biomechanics Supplemental Research Lab located in Jowers Center on the campus of Texas State University-San Marcos. The research laboratory contained the required equipment necessary to test including a BIOPAC 4-Channel Electromyography Telemetry System (BIOPAC Systems Inc., Goleta, CA), an inForm Sport Training System accelerometer (6^{th} Dimension Devices, Canada and USA), a wooden pit (6'x4'x1') filled with dry, compact sand approximately 12 centimeters deep (QUIKRETE Premium Play Sand No. 1113, Atlanta, GA). General purpose BIOPAC EL503 1 centimeter diameter electrodes were used in conjunction with a BIOPAC MP 100 system and AcqKnowledge data acquisition software (BIOPAC Systems Inc., Goleta, CA). A BIOPAC TSD116B foot switch was used to trigger the electrodes prior to the execution of a jump (BIOPAC Systems Inc., Goleta, CA).

PROCEDURES

Electromyography

Data was collected from output results with a BIOPAC 4-Channel Electromyography Telemetry System. Electrodes were placed on the following four muscles of the right leg: rectus femoris, vastus lateralis, biceps femoris, and gastrocnemius. Location of the rectus femoris electrodes were placed anteriorly approximately half the distance between the knee and iliac spine.[7] Vastus lateralis electrodes were placed anteriorly 3 to 5 centimeters above the patella at an oblique angle just lateral to the midline.[7] Placement of the biceps femoris electrodes were put posteriorly on the lateral aspect of the thigh two thirds the distance between the trochanter and the back of the knee.[7] A general placement on the gastrocnemius was utilized by placing the electrodes proximally so that one electrode resided laterally and one medially on the muscle.[7] Each subject was marked and told to shave over the top of the marking. After shaving, subjects performed low-level plyometrics and dynamic stretches to warm-up. Alcohol wipes were then used to clean and abrade the skin tissue before electrode placement. All electrodes were placed 2 centimeters apart from each other.[7]

Jump Height

An inForm Sport Training System wireless accelerometer was secured around the waist of each participant with a belt. A wireless computer tablet controlled the activation of the accelerometer and processed the data after each jump. Subjects were instructed to remain still while the accelerometer activated before jumping. Once the device was active, subjects were allowed to perform the jump. After jumping, subjects were instructed to remain still while waiting for the data to download to the computer tablet. Data from the accelerometer provided information on jump height.

Jump Protocol

Three jumps were completed on each surface. Subjects were barefoot for both the sand and rigid surface jumps. Each subject performed three jumps on the sand surface first. After each jump on the sand, the sand was combed with a rake to insure consistency while the subject rested for 90 seconds between jump attempts. Subjects then jumped three jumps on a rigid surface and landed on a gymnastic mat placed in front of the jump area. Subjects executed a short step jump for each attempt. A short step jump was used to activate the foot trigger prior to jumping. The foot trigger construction consists of a two piece system with a flat lower foundation and an angled upper platform that depresses downward towards the base when pressed. Subjects were setup in a staggered stance with the right leg behind the body and foot rested above the trigger. When instructed, subjects clicked the foot trigger with the back of the right heel to activate the electrodes. After activating the foot trigger the subject then stepped forward with the right foot and performed a countermovement jump. Each jump was carried out with the subjects' hands on the hips throughout the duration of the jump.

Data Acquisition and Analysis

Statistical analysis of both surfaces was executed using an ANOVA. The dependent variables analyzed were jump height, EMG mean peak and mean normailized percentage levels of the rectus femoris, vastus lateralis, biceps femoris, and gastrocnemius. EMG collection was set at a gain of 500 with a common mode rejection ratio of 110dB. Raw data acquisition occurred with a band-width setting of 10 Hz to 500 Hz. Raw signal data was smoothed using Root Mean Square (RMS) within a 200 millisecond window. Mean output data was acquired in the 200 millisecond window. The mean peak activity was derived from an envelope of .25 seconds, .125 seconds before and after, the max activity. The highest mean peak output on a rigid surface represented the subjects' maximum voluntary contraction (MVC). Data were normalized by taking the MVC and dividing the three trial average of both the mean peak EMG and mean EMG activity levels on both surfaces to create a percentile. Calculations were computed using STATA software (version 11.0: StataCorp, College Station, TX). Statistical significance tests were conducted with an alpha level set at $p<0.05$.

CHAPTER IV

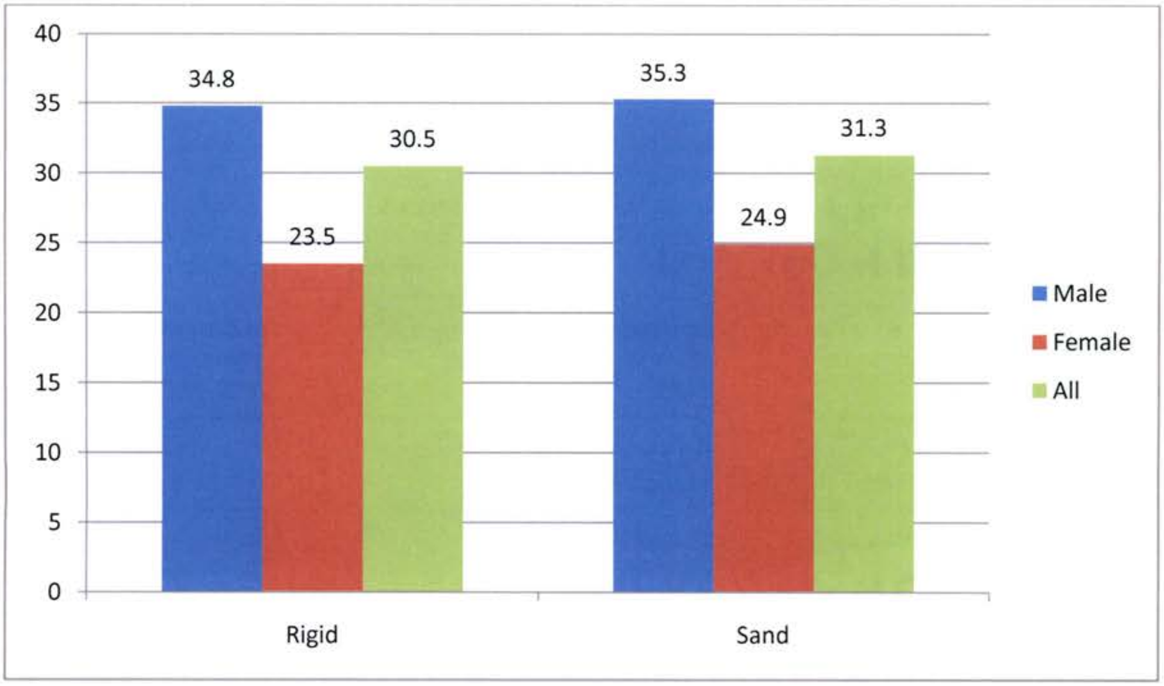
RESULTS

The subjects' mean age, height, and weight were 26.9 ± 6.5 years, 177.2 ± 10.6 centimeters, and 79.1 ± 15.1 kilograms respectively (Table 1). Males jumped significantly higher than females (Figure 1), $F(1,24) = 21.1$, $p = .0001$, for both the sand and rigid jumping conditions. There was no significant difference in jump height between the sand and rigid jumping conditions for both male and females combined (Table 1), $F(1,24) = 1.1$, $p = .295$.

Table 1. Descriptive values

	Male (n=16)	**Female (n=10)**	**All (n=26)**
Age	28.9 ± 7.6	23.7 ± 1.1	26.9 ± 6.5
Height (cm)	182.9 ± 7.5	168.1 ± 8.1	177.2 ± 10.6
Weight (kg)	84.1 ± 14.1	71.0 ± 13.4	79.1 ± 15.1
Rigid Jump Height (cm)	34.8 ± 7.2	23.5 ± 3.9	30.5 ± 8.3
Sand Jump Height (cm)	35.3 ± 7.6	24.9 ± 3.4	31.3 ± 8.1

Figure 1. Jump height (cm)



A significant difference was observed in rectus femoris mean peak EMG (Table 2), $F(1,24) = 12.7$, $p = .002$, with values for the sand jumping condition (62.99 ± 16.91) significantly higher than the rigid jumping condition (54.34 ± 11.08). For the normalized vastus lateralis mean peak EMG values, a significant difference between the jumping conditions was observed, $F(1,24) = 4.6$, $p = .043$. The sand jumping condition (62.76 ± 16.88) resulted in significantly greater mean peak EMG values (Table 2) than the rigid jumping condition (57.35 ± 10.81). For the normalized biceps femoris mean peak EMG values, a significant difference between the jumping conditions was observed, $F(1,24) = 4.7$, $p = .040$. The rigid jumping condition (60.89 ± 9.76) resulted in significantly greater mean peak EMG values (Table 2) than the sand jumping condition (55.90 ± 12.29).

A significant difference between the two jumping conditions was also observed in normalized gastrocnemius mean peak EMG values, F(1,24) = 9.4, p = .005. The rigid jumping condition (62.63 ±11.41) resulted in significantly greater mean peak EMG values (Table 2) than the sand jumping condition (56.33 ± 12.90).

Table 2. Mean peak EMG values (%)

	Rigid Surface (±SD)	**Sand Surface (±SD)**
Rectus femoris	54.34 ± 11.08	62.99 ± 16.91
Vastus lateralis	57.35 ± 10.81	62.76 ± 16.88
Biceps femoris	60.89 ± 9.76	55.90 ± 12.29
Gastrocnemius	62.63 ± 11.41	56.33 ± 12.90

For the normalized mean EMG measures, several significant differences between the sand and rigid jumping conditions were observed. For the rectus femoris muscle group, the sand jumping condition (56.05 ± 15.43) resulted in significantly higher mean EMG measures (Table 3), F(1,24) = 12.4, p = .002, than the rigid jumping condition (48.66 ± 10.45). For the vastus lateralis muscle group, the sand jumping condition (54.15 ± 14.24) again resulted in significantly higher mean EMG measures (Table 3), F(1,24) = 5.1, p = .034, than the rigid jumping condition (49.76 ± 10.17). The opposite effect was observed for the biceps femoris muscle group. The rigid jumping condition (53.40 ± 8.75) resulted in significantly higher mean EMG measures (Table 3), F(1,24) = 9.2, p = .006, than the sand jumping condition (49.03 ± 10.82). For the gastrocnemius muscle group, the same effect was observed as that for the biceps femoris. The rigid jumping condition (59.29 ± 9.68) resulted in significantly higher mean EMG measures (Table 3), F(1,24) = 8.7, p = .007, than the sand jumping condition (50.25 ± 11.20).

Table 3. Mean EMG values (%)

	Rigid Surface (±SD)	Sand Surface (±SD)
Rectus femoris	48.66 ± 10.45	56.05 ± 15.43
Vastus lateralis	49.76 ± 10.17	54.15 ± 14.24
Biceps femoris	53.40 ± 8.75	49.03 ± 10.82
Gastrocnemius	59.29 ± 9.68	50.25 ± 11.20

No gender differences in normalized mean EMG measures were observed for either the rectus femoris, $F(1,24) = 0.03$, $p = .857$, vastus lateralis, $F(1,24) = 0.11$, $p = .741$, biceps femoris, $F(1,24) = 03.3$, $p = .083$, or gastrocnemius, $F(1,24) = 0.03$, $p = .877$, muscle groups.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The purpose of this study was to examine the differences between jumping on a rigid surface compared to a sand surface using EMG. It was hypothesized that the EMG activity of the lower extremity muscles tested on the sand surface would register a greater output level compared to the rigid surface. The basis of this hypothesis was formulated through previous research by Giatsis et al.[10] who described the instability of a sand surface as an inhibitory environment resulting in a delayed appearance of maximum force. A delay in max force suggests more work for the muscles to complete and potentially exhibit a higher activity level when jumping out of the sand.

The type of sand has an effect on the output reading of the jump. Sand can resemble various types of texture depending on exposure and care. Dry, soft sand displaces when pushed downward and can be perceived as a damper, increasing the workload while reducing mechanical efficiency. Deep, easy moving sand replicates a similar but perhaps more difficult result as dry, soft sand. Firm, recently watered down sand seems to provide more of a reaction when pressing on top of the surface. Subjects participating in this study reported the sand to resemble a dry and soft texture. Several subjects described the sand as being one of the better quality sands to jump from when compared to other sand surfaces. The dry, soft sand used in this study exhibited a free moving type of sand that resulted in a harder workout for certain muscles.

The results of this study proved to exhibit a significant difference with higher activity levels for some, but not all muscles while jumping in the sand. The quadriceps group, specifically the rectus femoris and vastus lateralis muscles, resulted in significantly greater output in the sand for both mean peak and mean EMG measures when compared to the rigid surface. These results concur with a study by Pinnington et al.[22] who analyzed running on a sand surface compared to a firm surface. The rectus femoris muscle registered a greater peak activation output level on a sand surface during the weight acceptance phase of the stance while running.[22] Pinnington et al.[22] attributed the higher quadriceps muscle output in the sand to stabilization factors controlling the knee after initial foot contact. Net knee extensor EMG levels of the rectus femoris, vastus lateralis, and vastus medialis were higher on a sand surface as well.[22] Peak knee extension EMG activity levels registered a higher magnitude on a sand surface and continued for a longer duration when compared to a rigid surface.[22]

In contrast, the hamstrings and calf groups, specifically the biceps femoris and gastrocnemius respectively, revealed significantly greater output on the rigid surface for both mean peak and mean EMG measures when compared to the sand surface in this study. The hamstrings and gastrocnemius muscles recorded a lower net knee flexor EMG activation level on a sand surface in the Pinnington et al.[22] study. The same result occurred on the sand surface in this study with the biceps femoris and gastrocnemius muscles. However, in the Pinnington et al.[22] study, the gastrocnemius recorded a higher peak activation at the middle of the stride while running on a sand surface. The results from Pinnington et al. while running on a sand surface share related outcomes with the results of this study while jumping.

Running has a similar bouncing mechanism compared to a jump.[17&20] During locomotion, the work done on the body by the muscles and tendons in one phase must be absorbed by the muscles and tendons in the next phase.[17] At the beginning of the contact phase while running, the foot rests on the surface of the sand.[17] The stride continues on to the end of the stance phase and applies the horizontal ground force work downward, decreasing muscle tendon efficiency.[17] Contact phase accelerations reduce when the foot sinks into the sand and passively transfers energy to the center of mass.[17] The effect causes a pause between the eccentric to concentric muscle action and reduces the efficiency of the stretch shortening cycle.[17] This outcome can be applied to the ground reaction force while jumping.

A longer stretch shortening cycle affects the countermovement jump through the loss of energy as heat.[3] The energy production absorbs into the sand while trying to establish a ground reaction force and increases the time to contraction.[3] More time allows for the leg extensor muscles to build up an active state prior to shortening.[3] A well executed vertical jump requires elastic energy from the eccentric muscle action.[3] If the time is favorable between the eccentric to concentric stretch short shortening cycle the countermovement jump will be effective.[3] Successful jumps take advantage of the flexion range to produce a larger amount of stored elastic energy.[3] According to the results of this study, leg extensor muscle output elicits a greater active state in the sand than the plantar flexor muscles.

In soft sand, the ankle has a larger range of motion.[10] An increase in range of motion is due to the body attempting to establish balance.[10] In return, this causes the knee joint to take a lower squatted position creating a smaller angle.[10] This explains the higher activity level output by the quadriceps muscles in this study. More range of motion by the ankle and a reduced knee angle allows for a smaller amount of resistance, which diminishes the force or energy of the body to push along the vertical axis.[10] The ankle and knee movements in the sand alter the angle of the hip to a larger extension at takeoff.[10] These movements slow down the transition from eccentric to concentric work and reduces knee extension work at takeoff in the sand.[28]

EMG measures in this study reflected a greater output with both mean peak and mean activity levels for the knee extensor muscles of the quadriceps. This could be attributed to a longer duration of activity from the knee extensor muscles to stabilize the center of mass prior to jump takeoff. When jumping on a rigid surface the vertical velocity represents the decisive factor for jump height.[5] Mechanical efficiency improves with increased braking phase kinetics during the stretch-shortening cycle for greater amounts of elastic energy resulting in an effective jump.[19] This study demonstrated a greater amount of activity with the knee extensor muscle group while in the sand. The stretch-shortening cycle was not as effective in the sand as the rigid surface. The results from this study can be interpreted that data from the EMG measures demonstrate that jumping in the sand is not as mechanically efficient as jumping on a rigid surface.

Practical Application

The results of this study indicate that jumping in the sand is not as mechanically efficient as jumping on a rigid surface. This study did indicate that jumping in the sand provided a higher output of EMG activity for the quadriceps muscle group. Application of this aspect can be utilized for strength training the extensors of the lower body muscles. Potential benefits of jumping on the sand may include training the stabilizer muscles activated during the stretch-shortening cycle. Further research will help determine a specific training regimen to implicate for a specific protocol to apply when jumping in the sand.

Limitations

Limitations in this study included the utilization of subjects that were untrained in jumping from a sand surface. Jumpers were required to maintain hands on the hips throughout the duration of the jump. This method of jumping without the use of arms might not have been familiar to the participants and caused a suboptimal level of performance for this study. The style of jump with a short step from a staggered stance may have limited the ability of the jumper as well.

APPENDIX A

Texas State University Research Study

You are invited to participate in a study of the differences between jumping on a rigid and sand surface.

Seeking active males and females between the ages of 20-45 years

- The study will be conducted on the campus of Texas State University-San Marcos, Jowers Center, Biomechanics Supplemental Research Lab
- Testing will last approximately 30 minutes
- Participation involves jumping on both a rigid and sand surface
- Electrodes placed on the right leg will register muscle output
- Subjects will be informed of lower leg strength and jump height

If interested, please contact Mike Guerrero at jg1405@txstate.edu

APPENDIX B

Consent Form to Participate in Research

Electromyography Analysis of Vertical Jumps on a Rigid and Sand Surface

Principal Investigator and Contact Information:

Texas State University – Exercise Science Program

- Mike Guerrero, Graduate Student

  Phone: 512-585-6006 Email: jg1405@txstate.edu

Introduction

You are being asked to participate in a research study. This form provides you with information regarding the research being conducted. Please read this form and ask any questions you may have regarding participation in this study. Participation is entirely voluntary. You will be evaluated in the Biomechanics Supplemental Research Lab located in the Jowers Center at Texas State University-San Marcos. Read the information below and ask questions about anything you do not understand prior to deciding whether or not to participate.

Purpose

The purpose of this research is to analyze the effects of the lower leg muscles during a maximal voluntary jump on a rigid and sand surface.

Procedures

You must first fill out a form about your health history using the Medical Health Questionnaire Form attached to the back of this Consent Form. Participants may choose to not answer any of the Medical Health Questionnaire Form questions if they do not feel comfortable doing so.

Each subject will be instructed to wear athletic clothing including a t-shirt and gym shorts. Workout clothing is necessary for locating specific areas to attach electromyography leads for muscle output analysis. The following procedures will take about 30 minutes to complete.

1. Subject height and weight will be measured privately with only the principal investigator present.
2. The principal investigator will locate and mark specific areas of the right leg including the hip, hamstring, quadriceps, and calf muscles to measure muscle output.
3. Subjects will be given a new shaving implement to remove hair from specific marked spots on the right leg in order to place electromyography leads.
4. Prior to testing, subjects will complete a 5-10 minute warm up jogging on a treadmill machine and complete low-level plyometrics.

5. After warm up, subjects will clean with alcohol wipes the surface of the skin previously marked for electromyography leads.
6. Electromyography leads will be placed on the clean surface of the marked skin on the right leg.
7. Subjects will be instructed, by the principal investigator, on how to complete each jump that will be conducted.
8. Leads will be hooked up with conduction wires to the BIOPAC 4-Channel Electromyography Telemetry System.
9. An inForm Sport Training System accelerometer will be secured around the waist of the participant with a belt.
10. Subjects will jump a total of 6 jumps, 3 times each on both a rigid and sand surface.
11. Upon test completion, subjects will conduct a walking cool down around the laboratory and be instructed to stretch their leg muscles.

Potential Risks or Discomforts

The potential risks for this experiment are minimal because the subjects will be supervised by the principal investigator during the duration of the study; however, with any exercise there are potential risks for injury. Subjects will be required to jump vertically without any deviation or unusual discomforts associated with regular activity or recreational sport. Risks will be minimized by warming up prior to the testing protocol and cooling down after testing.

Measurements conducted on the sand surface will take place in a sand box. The box will have an adequate depth of 7 cm of dry, compact sand that will be raked evenly after each jump to ensure consistency and safety. The principal investigator will be present to tend to the sand box and spot participants during each maximal voluntary jump. Gymnastic mats will be placed around the testing surfaces to provide a cushioned support system.

If a medical emergency occurs during testing, emergency services will be contacted. The primary investigator will assist with all emergency situations until EMS arrives on scene. If a minor emergency occurs, the Biomechanics Supplemental Research Lab is located next to the Athletic Training Lab with on-site accredited Athletic Trainers available to provide support if needed. The primary investigator also has experience in conducting vertical jump tests through assisting research conducted by professors in the Health, Physical Education and Recreation Department at Texas State University-San Marcos.

Possible Benefits

The benefits of this investigation will provide you information about:

- Muscle output activity in the leg while jumping on a rigid and sand surface
- Jump height while jumping on a rigid and sand surface
- Force applied when jumping on a rigid and sand surface

Confidentiality

Each subject will be issued a number to differentiate results found between subjects and to maintain the confidentiality of subject's information. A subject's name, social security number, telephone number, etc. are not required to participate in this study. Results from the study may be used for future research. If consent form material is needed for research purposes, subjects will be contacted for additional release of consent of information. All data will be kept in the primary investigator's office for 2 years in a locked cabinet in order to preserve confidentiality of subjects.

Participation

Participation in the study is completely voluntary and you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at anytime without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed. You may request a copy regarding the results of this study anytime upon completion of the study. Please contact the principal investigator, Mike Guerrero at (512) 585-6006 or jg1405@txstate.edu in order to arrange delivery of the results. If you have any other questions regarding the research, research participants' rights, and/or research-related injuries to participants, please contact the IRB chair, Dr. Jon Lasser at (512) 245-3413, lasser@txstate.edu or to Ms. Becky Northcut, Compliance Specialist at (512) 245-2102.

Authorization

Texas State University-San Marcos, Department of Health, Physical Education and Recreation supports the practice of protection for human subjects participating in research and related activities. The consent form is provided so that you can decide whether or not to participate in the present study.

"I have read the above statement and have been fully advised of the procedures to be used in this project. I have been given sufficient opportunity to ask any questions I had concerning the procedures and know that I am free to ask questions as they may arise. I likewise understand that I can withdraw from the study at any time without being subjected to reproach."

______________________________ ______________
Participant Name Printed (18 years or older) Phone #

______________________________ ______________
Signature Date (mm/dd/year)

______________________________ ______________
Principle Investigator Signature Date (mm/dd/year)

APPENDIX C

Medical Health Questionnaire Form

Yes	No	Current Activity Level
❍	❍	Are you physically active (i.e., do you get at least 30 minutes of physical activity on at least 3 days per week)? Please list the activities that you do for physical activity (i.e., aerobic exercise, weights, sport activities, etc).
❍	❍	Have you participated in sand volleyball activities for at least once a week for the past 3 months?

Yes	No	Symptoms – Do you:
❍	❍	Experience chest discomfort with exertion?
❍	❍	Experience unreasonable breathlessness or unusual fatigue at rest, with mild exertion, or during usual activities?
❍	❍	Experience dizziness, fainting, or blackouts?
❍	❍	Experience difficulty breathing when lying flat or when asleep?
❍	❍	Experience ankle swelling?
❍	❍	Experience forceful or rapid heartbeats?
❍	❍	Experience numbness in legs or arms from time to time?

Yes	No	Other health issues that may warrant physician approval before engaging in physical activity.
❍	❍	Have you ever been told not to exercise by a health care provider?
❍	❍	Do you have problems with your muscles, bones, or joints?

Please provide an Emergency Contact: **Name**: ______________________________

Phone Number: ___________________________

I certify that the information included on this form is correct.

______________ ______________________________________

Date **Signature of Participant**

______________ ______________________________________

Date **Signature of Primary Investigator**

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VITA

James Michael Guerrero was born in Austin, Texas, on June 22, 1980, the son of Melanie Lyn Harris and Leonard Andrew Guerrero. After completing his Bachelor of Science in Exercise and Sports Science at Texas State University – San Marcos, San Marcos, Texas, in 2007, he entered the graduate program in Exercise Science at Texas State University – San Marcos. Throughout his three years at Texas State as a graduate student, Michael coordinated the Biomechanics and Motor Control Laboratory for undergraduate and graduate students, conducted his Thesis research and substitute taught PE 3320 undergraduate upper-division kinesiology. After Graduate school, he plans to enroll in a doctoral program in Biomechanics and pursue a career in academics and research as a professor.

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