UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

CORE MUSCLE ACTIVATION DURING STAND-UP PADDLEBOARDING IN COMPARISON TO TREADMILL RUNNING

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Clinical Exercise Physiology

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CORE MUSCLE ACTIVATION DURING STAND-UP PADDLEBOARDING IN COMPARISON TO TREADMILL RUNNING

By Autumn R. Vogel

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology

The candidate has completed the oral defense of the thesis.

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ABSTRACT

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The main purpose of this study was to determine if the core muscles are sufficiently activated to provide strength benefit during stand-up paddleboarding (SUP). A secondary purpose was to compare activation of the core muscles during SUP to treadmill running. Thirteen subjects performed SUP and treadmill (TM) running at RPE's of 11, 13, and 15. Surface electromyography (EMG) was recorded for the external oblique (EO), rectus abdominus (RA), erector spinae (ES), latissimus dorsi (LD), gluteus maximus (GM), and vastus lateralis (VL). Electromyography between the two conditions was compared using a two-way ANOVA with repeated measures. Significance was found between the muscles using a Fisher's LSD post-hoc test. The results of this study indicate that training at a moderate to vigorous intensity on SUP can activate the EO, RA, LD, and ES musculature. Therefore, SUP can be recommended to people looking to train and strengthen core musculature and the LD. However, SUP does not provide sufficient activation to the VL and GM muscles. Treadmill running would be the preferred method to train these muscles.

ACKNOWLEDGEMENTS

I would like to thank Dr. John Porcari, Dr. Clayton Camic, and Dr. Attila Kovacs for being very helpful and active committee members and helping me with this thesis. You all took a lot of time out of your busy schedules to answer all of my questions and teach me how to use the EMG software as well as electrode placement and writing assistance. It was greatly appreciated. A special thank you to Maria Cress for all of your assistance with, coming up with a set-up for testing as well as assisting with the testing and writing processes. Thank you to Chelsea Hahn and Kimberley Radtke for your assistance with set-up as well as testing. Lastly, thank you to all of my participants in this study, especially my classmates. Finally, I would like to thank my parents for all of the support they have given me throughout my education.

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INTRODUCTION

Stand-up paddleboarding (SUP) is increasing in popularity in the United States, and in 2009 SUP was the fastest growing paddle-sport in North America (SUPWorldMag.com). Stand-up paddleboarding originates from ancient cultures in Africa and South America. These cultural people were known for various modes of water transport including boards and canoes, which they used to stand on to fish and for transportation. Modern day SUP in America came from the Hawaiian Islands. The Hawaiian people used SUP as a popular alternative to surfing when the surf was down. In 2004, Rick Thomas brought a paddleboard back to his home in California, where its popularity grew as a navigational vessel for rivers and lakes. Today, SUP is a sport enjoyed by people of all skill levels, whether they live on the coast, near the ocean, or inland near a river.

Proponents of SUP claim there are many benefits provided by this sport, including muscle strengthening and increased balance. In order to maintain balance on the board, the body recruits and activates the majority of the core muscles. Schram, Hin, Climstein, and Walsh (2014) tested the balance of eight elite SUP athletes, performing different types of balancing exercises. Balance was measured using a center of pressure force platform to track postural sway. The study found that the elite SUP athletes had greater dynamic balance than other aquatic athletes. They attributed this to the need for maintaining balance on the unstable surface of the water.

Because the abdominal and back muscles are constantly working to maintain balance, SUP is also purported to provide a good core workout. Ruess et al. (2013) conducted a study that measured core muscle activation on a SUP ergometer compared to performing SUP on the open water. Muscle activation was determined using electromyography (EMG). They tested both modalities at three different power outputs. The data showed clear activation of the hard to train core muscles on both modalities, although activation of the latissimus dorsi muscle was greater on open water.

Stand-up paddle boarding is considered a low-impact sport due to the joints not being subjected to repetitive impact with the ground (Schram et al., 2014). Many people may find SUP to be a more accommodating form of exercise than running or walking due to the low-impact mechanisms of the sport. Stand-up paddleboarding is a sport suitable for all ages and people with lower body orthopedic problems that inhibit them from running or even walking comfortably.

Proponents of SUP claim it provides a great core workout. Since there is limited data to support these claims, the purpose of this study were to 1) determine if the core muscles are sufficiently activated to provide a strength benefit during SUP, and 2) to compare activation of the core muscles during SUP to treadmill running.

METHODS

Subjects

Subjects were 13 self-reported healthy volunteers (six men and seven women) between the ages of 21 and 25 years. All subjects had experience with SUP and treadmill running (TM) and all were free of any known cardiovascular and musculoskeletal issues. This study was approved by the University of Wisconsin- La Crosse Institutional Review Board for the Protection of Human Subjects prior to testing. All subjects provided written informed consent prior to the start of testing.

Procedure

Prior to testing, subjects attended practice sessions to familiarize themselves with SUP. They then completed two days of testing. One day was for SUP and one day was for TM. Treadmill was chosen for comparison because it is a common modality used for exercise.

On the initial day of testing, subjects had EMG electrodes placed on six different muscles: the rectus abdominis (RA), external oblique (EO), latissimus dorsi (LD), erector spinae (ES), gluteus maximus (GM), and vastus lateralis (VL). All electrodes were placed according to SENIAM recommendations (SENIAM.org) on the right side of the subject's body. Placement sites were shaved, abraded, and wiped with isopropyl alcohol prior to electrode placement. Placement of the electrodes for the RA, EO, LD, and VL was done while the subject was standing, while electrode placement of the GM and ES was done while the subjects was prone. To keep the electrode placement as uniform as possible between testing days, the electrodes were traced along the edges with a permanent marker on the subject's skin.

After electrode placement, subjects were required to perform six different manual muscle exercises (one for each muscle) to elicit a MVC. These exercises were performed on all six muscles on both days prior to testing. All contractions were held for 3 seconds.

1. Rectus Abdominis (RA): Subjects were asked to lie down on an incline bench. The tester than pushed down on the subject's shoulders while the subject tried to complete a sit-up.

2. External Oblique (EO): Subjects were asked to lie down on an incline bench. The tester than pushed down on the subject's right shoulder while the subject tried to sit-up and twist to the right against the resistance.

3. Erector Spinae (ES): Subjects were asked to lie facedown on the ground. The subjects were then asked to lift their arms and legs up in the superman pose, contracting their lower back as hard as possible.

4. Latissimus Dorsi (LD): Subjects were asked to grab a pole with their right hand while bending their elbow at a 90-degree angle. Keeping that elbow at a 90-degree angle and by their side, the subject was asked to pull back as hard as possible on the pole while focusing on the LD muscle.

5. Gluteus Maximus (GM): Subjects were asked to lie facedown on the ground with their right knee bent at a 90-degree angle. The tester than pushed down on the subject's foot while the subject tried to kick up against the tester.

6. Vastus Lateralis (VL): Subjects were asked to sit on a table. The subject was then asked to bend their right knee at a 120-degree angle with the tester holding their ankle. The tester pushed on the subjects' leg while the subject pushed out as hard as possible.

After the MVC's were completed on day 1, the subjects were asked to perform the SUP testing. The paddle-boarding portion of the test was performed on the University of Wisconsin- La Crosse track in the steeplechase pit. The Surftech 10' 6" board (Surftech, Santa Cruz, CA) and the BIC sport Alu ML SUP paddle (BIC Sport, Vannes, France) were then placed on the water in the pit. The paddleboard leg strap was attached to two weight sleds loaded with weights placed between the two sleds (see Figure 1). This served to keep the paddleboard in the middle of the pit as well as served as resistance for the subjects to paddle against. The subjects were helped onto the paddleboard and given the paddle. The subjects were given the opportunity to familiarize themselves with the testing set-up to determine intensity to paddle at in order to elicit rating of perceived exertion (RPE) levels of 11, 13, and 15. Once the subjects had determined these levels they paddled at an RPE of 11 for 30 seconds. They were then asked to paddle at an RPE of 13 for another 30 seconds. Lastly, they were asked to paddle at an RPE of 15 for 30 seconds.

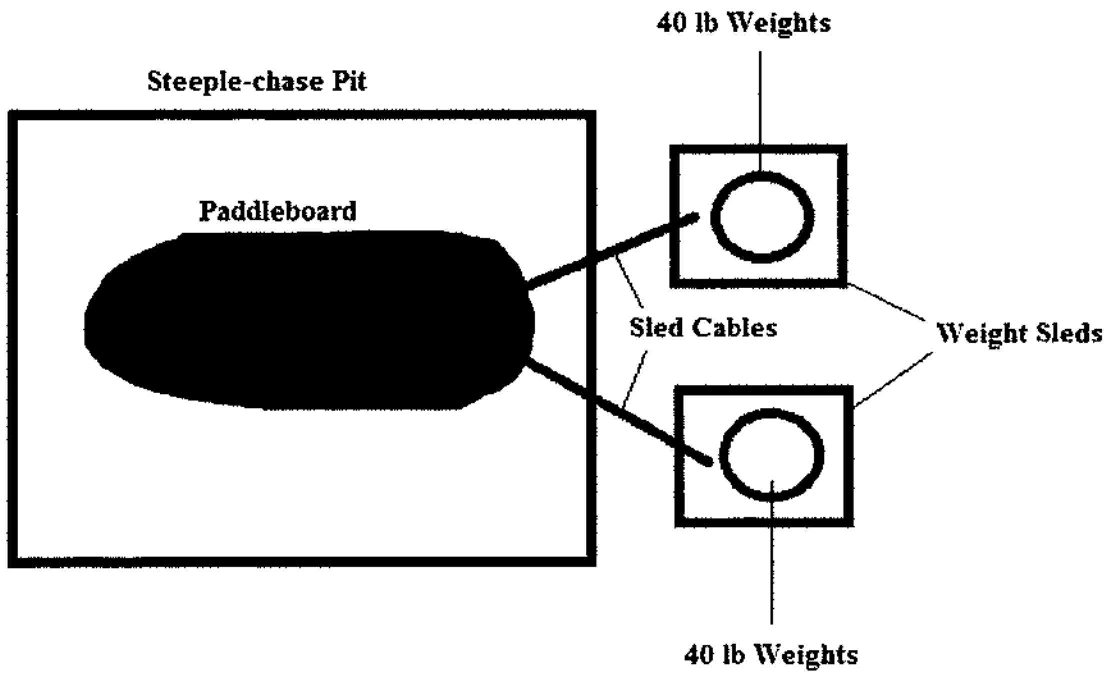

Figure 1. Testing set-up for the stand-up paddleboarding portion of study.

Within 48 hours of the SUP testing, the subjects returned to the Human Performance Laboratory on the UW-L campus to perform the TM portion of the study. The electrodes were placed in the same location as for the SUP testing and the six MVC tests were repeated. After the MVC tests were completed, subjects ran on a motorized treadmill (Woodway, Waukesha, WI) at speeds that corresponded to RPE levels of 11, 13, and 15. Subjects performed a warm- up run for 5 minutes prior to testing. For testing subjects ran on the treadmill at an RPE of 11 for 30 seconds, RPE of 13 for 30 seconds, and an RPE of 15 for 30 seconds. After the RPE 15 trial, subjects walked on the treadmill for 1 minute to cool-down.

Electromyographic Analysis

The raw EMG signals for the muscles studied were digitized at 2000Hz and stored on a personal computer. The EMG signal was preamplified using a differential amplifier (Delsys Trigno Wireless Systems, Boston, MA; bandwidth 20-450 Hz). All signal processing was performed using EMGWorks Analysis (Version 4, Delsy Inc, Boston, MA). The EMG signals were digitally bandpass filtered at 20-450 HZ. The MVC contraction values were calculated using the middle two-seconds of the three-second contractions cutting out the first and last 0.5 second of data. Root mean square was found in microvolts for each of these three contractions and then averaged to find the MVC for each muscle. This was repeated and a new MVC was found for each day of testing. The EMG amplitude (microvolts root mean square [uVrms]) values were found during the middle 20-seconds of each 30-second trial. The three greatest activation measurements were taken from the 20-seconds of data and averaged to find the peak RMS for each muscle. Percent MVC was found by dividing the RMS by the MVC for that muscle.

Statistical Analysis

A two- way ANOVA with repeated measures was used to compare the normalized EMG between conditions at each RPE, for each of the muscles (%MVC). Fisher's LSD was used to detect differences between the EMG levels of SUP and TM at each RPE. Alpha was set at 0.05 to achieve statistical significance. The data was analyzed using the IBM Statistical Package for the Social Sciences software (version 19.0; SPSS Inc., Chicago, IL).

RESULTS

Subjects for this study were 13 apparently healthy young adults (7 females and 6 males). Descriptive characteristics of the subject population are presented in Table 1.

Table 1. Descriptive characteristics of subjects (N=13).

Variables	Female (n = 7)	Male (n = 6)
Age (yrs)	23.7 ± 1.21	23.7 ± 0.95
Height (in)	62.7 ± 7.56	80.5 ± 9.77
Weight (kgs)	65.3 ± 1.60	71.2 ± 3.13

Values represent mean ± standard deviation.

Electromyography was used to measure total muscle activation from the EO, RA, ES, LD, GM, and VL during both SUP and TM. Subjects performed both activities at self-perceived workloads corresponding to RPE levels of 11, 13, and 15 on the 6-20 Borg Scale. Results are presented in Figures 2-6, respectively. For both SUP and TM, EMG showed muscle activation increased linearly with an increase in RPE, for all muscles. There was no significant difference in activation for SUP compared to TM for the EO and RA at each RPE. For the ES and LD, SUP elicited significantly greater muscle activation than TM at all three RPE levels. For the GM and VL, TM elicited significantly greater muscle activation than SUP at all three RPE levels.

Previous research has concluded that muscle activity above 45% MVC should result in strength improvements (Ekstrom et al., 2007). For SUP, muscle activation was above this threshold at all RPE levels for the RA, ES, and LD muscles. For the EO, only muscle activation at RPE 15 was above this threshold and for the VL, muscle activation at an RPE of 15 was above this level. Electromyography of the GM was not above 45% MVC for any RPE.

For the TM, EMG was above this threshold at all RPE levels for the RA, GM, and VL. For the EO, only EMG at RPE of 15 was above this threshold. Electromyography of the ES and LD were not above 45% MVC for any RPE.

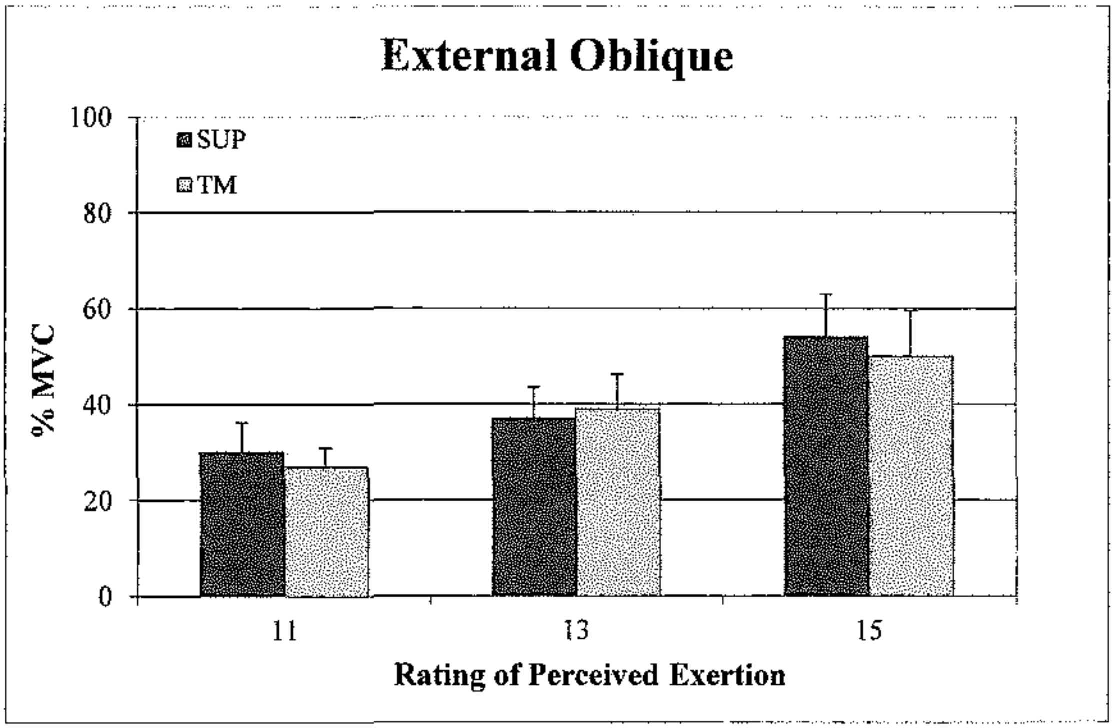

Figure 2. Comparison of the EO muscle activation for SUP compared to TM.

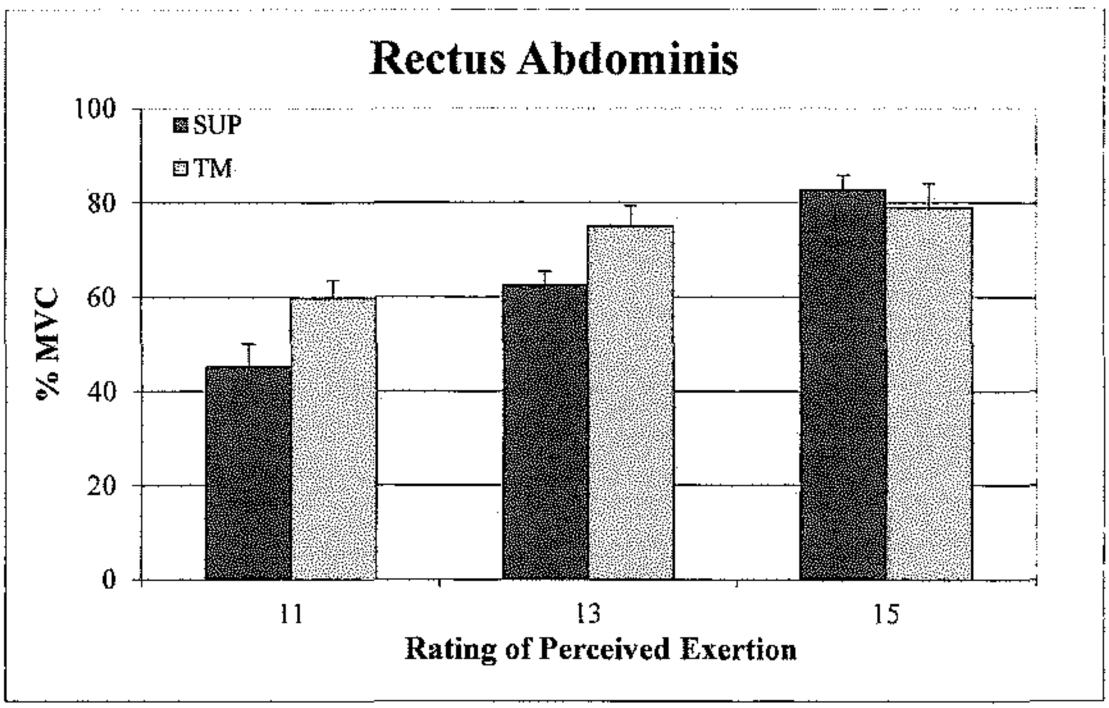

Figure 3. Comparison of the RA muscle activation for SUP compared to TM.

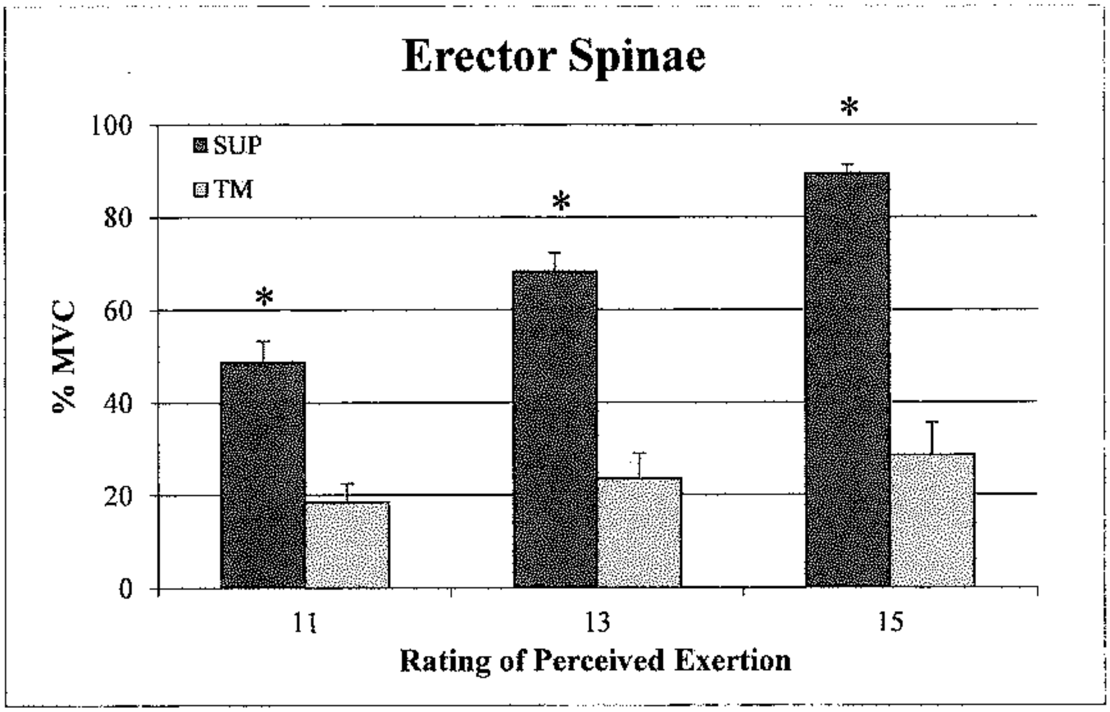

Figure 4. Comparison of the ES muscle activation for SUP compared to TM.
*Significantly greater than TM ($p < .05$).

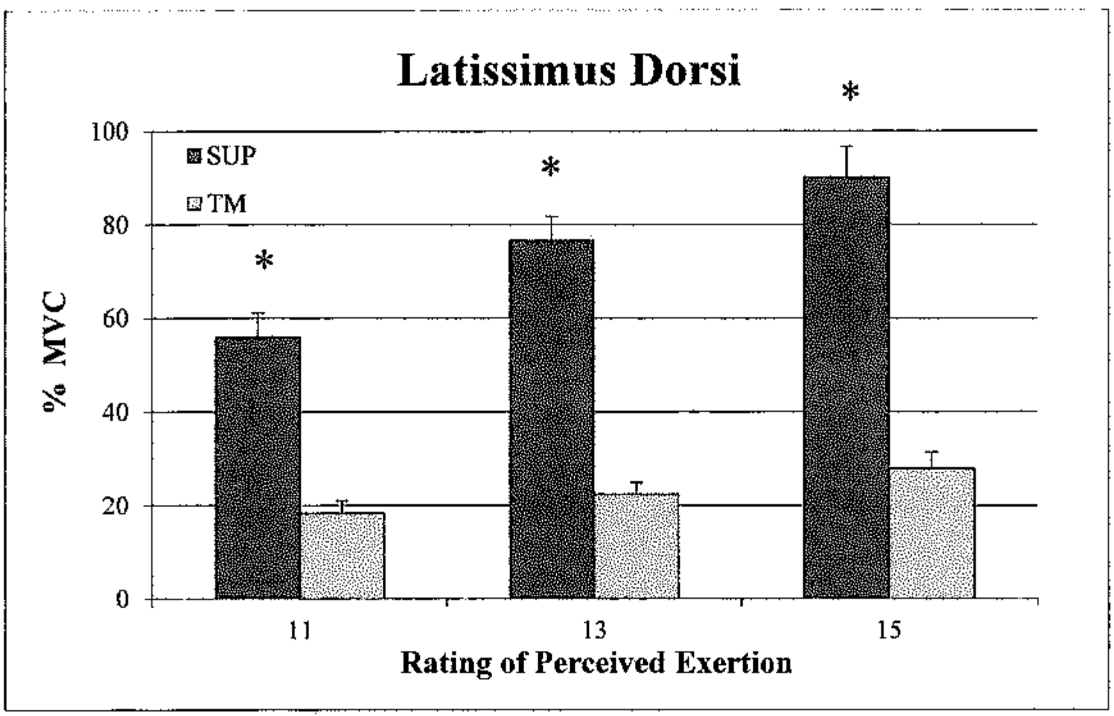

Figure 5. Comparison of the LD muscle activation for SUP compared to TM.
*Significantly greater than TM ($p < .05$).

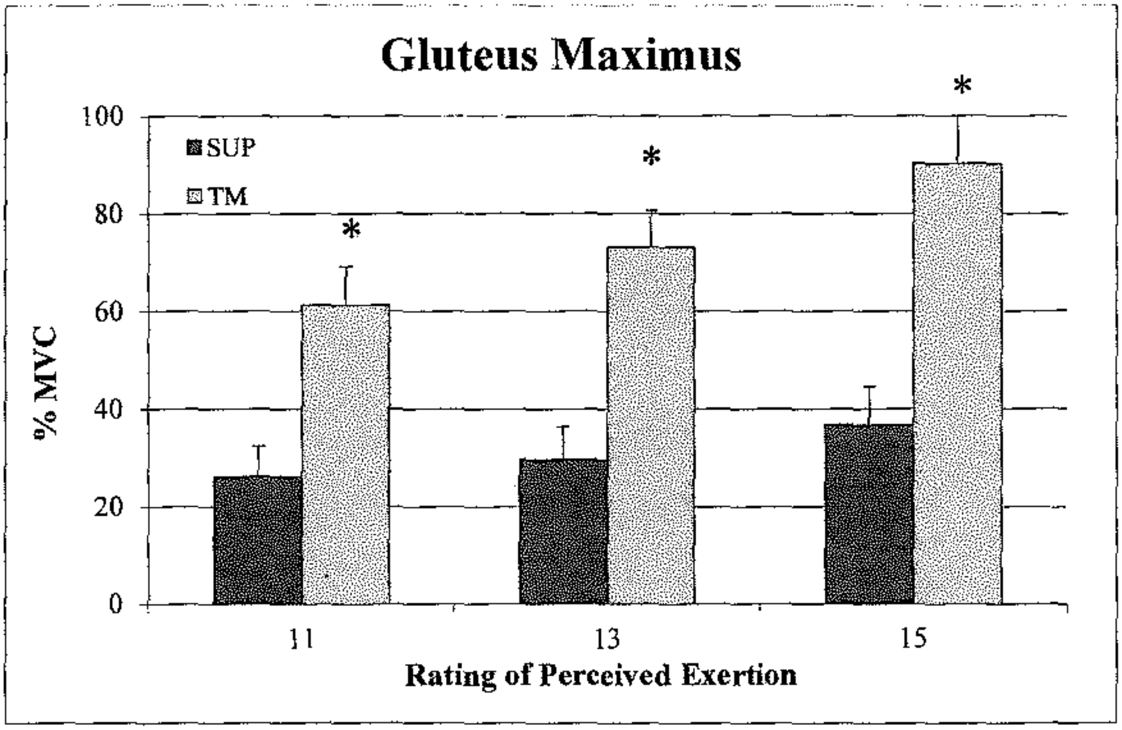

Figure 6. Comparison of the GM muscle activation for SUP compared to TM.
*Significantly greater than SUP ($p < .05$).

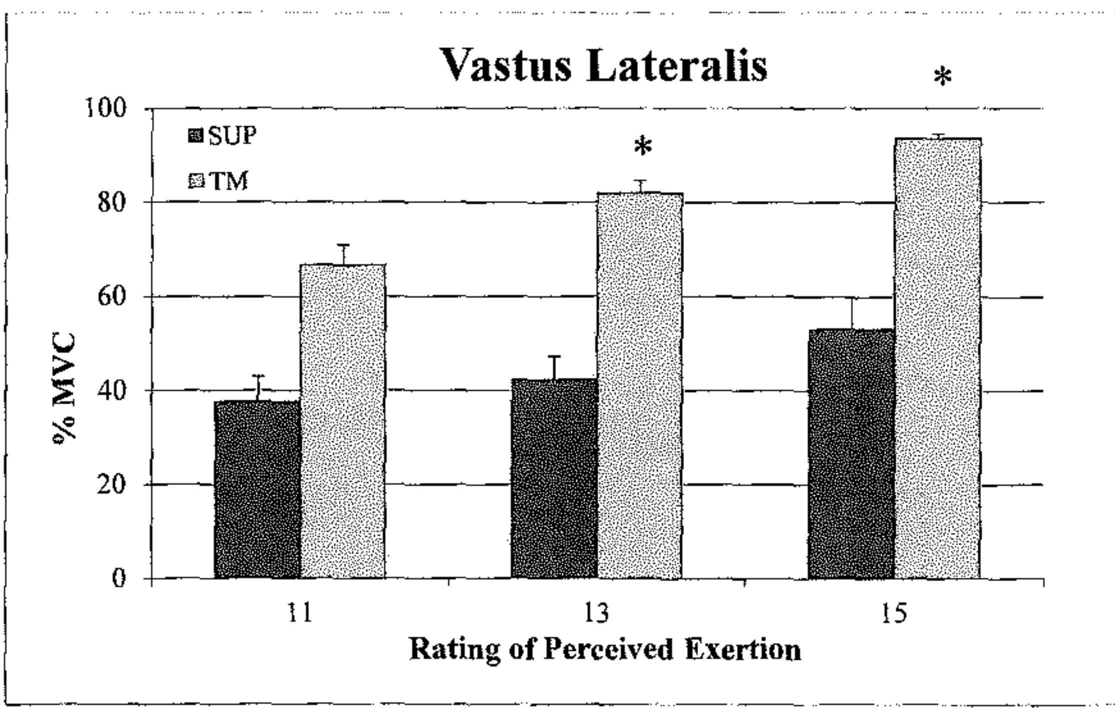

Figure 7. Comparison of the VL muscle activation for SUP compared to TM.
*Significantly greater than SUP ($p < .05$).

DISCUSSION

The major purpose of this study was to determine if SUP provides an adequate stimulus to increase core strength. Previous research has concluded that muscle activity above 45% MVC should result in muscular strength improvements (Ekstrom et al., 2007). The core muscles evaluated in this study were the RA, EO, and ES muscles. The results of the current study indicate that SUP provides sufficient stimulus to strengthen ES and RA muscles. However, only during RPE 15 was the stimulus great enough to increase EO strength during SUP. This could be due to increase twisting of the core, which increases torque, which is needed to increase speeds to propel the board at a faster pace. This agrees with the findings of Ruess et al. (2013) who tested EMG activation of the core muscles while performing SUP on-ergometer and on-water. They found clear activation of the abdominal and back muscles, especially during on-water trials, indicating that SUP may be an adequate activity to train core musculature.

Stand-up paddleboarding shares a lot of the similar movement patterns with rowing. In a study done by Pollock et al. (2010) it was found that in a race situation the EO, RA, and LD muscles were activated above 45% MVC. Additionally, the ES muscles were just below this threshold at 44% of MVC. This supports the results of the current study suggesting that rowing-like activities are sufficient at strengthening the core musculature as well as the LD muscle. In our study the LD muscle was adequately activated to increase strength during SUP at every RPE.

A secondary purpose of this study was to compare EMG activation of the EO, RA, ES, LD, VL, and GM musculature during SUP versus TM running. The results indicated that during SUP and TM running there were no significant differences in muscle activation for the EO and RA muscles between the two conditions, whereas the ES had significantly greater muscle activation during SUP versus TM running. The LD muscle was activated during SUP significantly greater versus TM running, suggesting that SUP would be a preferred option for training the LD muscle.

Additionally the current study evaluated the activation of the VL and GM muscles. The results indicate EMG activation of the VL and GM muscles were significantly greater during TM running when compared to SUP. This is most likely due to different demands placed on these muscles during TM running when compared to SUP. During TM running subjects use their legs as force generators to propel themselves forward. The body relies on the GM and VL muscles to contract more forcefully during full extension of the leg to push off the ground and to extend the hip and control flexion of the trunk during landing (Lieberman, Raichlen, Pontzer, Bramble, & Cutright-Smith, 2006). During SUP, the GM and VL muscles are primarily used as stabilizers during the stroke motion to generate force and maintain balance. Therefore, TM running would be the suggested activity to train the GM and VL muscles over SUP. This is supported by a study done by Kyrolainen, Avela, and Komi (2005), which evaluated the EMG activation of the leg muscles during running. The researchers recorded EMG values of greater than 45% MVC during running for both GM and VL muscles.

In conclusion, the results of this study indicate that training at a moderate to vigorous intensity on SUP can activate the EO, RA, LD, and ES musculature. Therefore, SUP can be recommended to people looking to train and strengthen the core musculature and the LD. However, SUP does not provide sufficient activation to the VL and GM muscles. Treadmill running would be the preferred method to train these muscles.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

CORE MUSCLE ACTIVATION DURING STAND-UP PADDLEBOARDING IN COMPARISON TO TREADMILL RUNNING

I, ______________________________, volunteer to participate in a research study being conducted at the University of Wisconsin-La Crosse. Autumn Vogel, a graduate student in the Clinical Exercise Physiology Program, is conducting this study under the supervision of Dr. John P. Porcari, a Professor in the Department of Exercise and Sport Science.

PURPOSE

The purpose of this study is to determine the activity of certain muscles during SUP compared to running on a treadmill. The SUP will be conducted on a Surftech stand-up paddleboard equipped with a paddle. All SUP practice testing will be conducted in the steeplechase pit of the outdoor track at the University of Wisconsin- La Crosse campus. My participation in this study will require me to:

Complete 3-5 practice sessions in order to become proficient at SUP.
Participate in one test session of SUP on the UWL steeplechase pit.
Participate in one session of treadmill running.
Wear electromyography electrodes placed on several muscles on the right side of my body.

POTENTIAL RISKS

I may experience muscle fatigue, muscle soreness, and possible musculoskeletal injuries from participating in SUP. Additionally, shortness of breath, irregularities in heart rhythm, heart attack, stroke, and even death are possibilities of vigorous exercise. However, the risk of serious or life-threatening complications is very low (<1/10,000 tests) in apparently healthy adults.

All testing will be stopped immediately if there are any complications.

Individuals trained in CPR, and Advanced Cardiac Life Support (ACLS) will be available during all testing sessions. There will also be a certified Lifeguard on scene at all times. Additionally, an Automatic External Defibrillator (AED) will be available during all testing.

BENEFITS

As a participant in this study, I will learn which muscles are used during SUP compared to running.

RIGHTS AND CONFIDENTIALITY
My participation in this study is entirely voluntary. I may choose to discontinue my involvement in the study at any time, for any reason, without penalty.

The results of this study have the potential of being published or presented at scientific meetings, but my personal information will be kept confidential and only group data will be presented.

I have read the information provided on this consent form. I have been informed of the purpose of this study, the procedures, the expectations of myself and the testers, and of the potential risks and benefits that may be associated with volunteering for this study. I have asked any and all questions that concerned me and received clear answers so as to fully understand all aspects of this study.

If I have any other questions that arise I may feel free to contact Dr. John P. Porcari, the principal investigator, at (608) 785-8684 (office) or (608) 386-5416 (cell). Questions in regards to the protection of human subjects may be addressed to the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects at (608)785-8124.

Subject: ______________________________ Date: __________________

Investigator: __________________________ Date: __________________

APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Historically, American society has been obsessed with fitness. The epitome of sexy in both genders is the coveted "six-pack," which is often used as a trademark of fitness. People think if they have defined core musculature they must be in peak physical condition. This being the thoughts of the everyday American, they are always looking for new ways to train the abdominal musculature with the least amount of work. This belief has led to million dollar industries promoting the newest equipment or fad for toning the abdominal musculature. A relatively new exercise that claims to help strengthen and tone the abdominal muscles is Stand-Up Paddle Boarding (SUP). Stand-Up Paddle Boarding is an exercise done on a long board, like a surfboard, performed on the open water. The participant is balanced on the middle of the board and uses a paddle to propel himself or herself forward. Proponents of SUP claim that it trains the entire body, especially the core musculature, while providing a fun and engaging workout. The purpose of this paper is to determine if the core muscles are sufficiently activated to provide strength benefits during SUP. A secondary purpose is to compare muscle activation of the core muscles during SUP to treadmill (TM) running.

Basics of Electromyography

Electromyography (EMG) is used to study the function and activation of muscle through the analysis of electrical signals emanating from the muscle (Basmajian & De Luca, 1985). Electromyography is used to study skeletal muscle and the level of contraction it performs (Reaz, Hussain, & Mohd-Yasin, 2006). Contraction of the skeletal muscle is initiated by voluntary impulses sent from the brain to the muscle via the neurons. The neurons are attached to the muscle fibers forming a motor unit. The motor unit is necessary for the impulse to reach the muscle cells allowing the action potential to be received and cause muscular contraction (Reaz et al., 2006). Motor units are comprised of a neuron and the multiple muscle fibers it innervates. It is impossible to stimulate just one muscle fiber (Kamen & Gabriel, 2010).

EMG Electrodes

In electromyography, two main types of electrodes are used. Surface electrodes, are placed in a specific location on the skin over the muscle, and intramuscular electrodes, which are inserted into the muscle belly via a needle (Kamen & Gabriel, 2010). The type of electrode used is dependent upon the situation and skill level of the applicator. Surface electrodes are non-invasive and are easier to apply than indwelling electrodes. A disadvantage to using surface electrodes is they can only be used on large superficial muscles and their signal can be impaired by moderate amounts of fatty tissue overlaying the muscle (Basmajian & De Luca, 1985). When a muscle is stimulated, a signal transducer is used to convert electric action potential into an electrical signal (Schanke, 2012).

Electrode Placement

Placement of EMG electrodes is essential for reliable EMG measurement. If electrodes are not placed in the correct site on the muscle, EMG readings can be inaccurately recorded (Merletti, Rainold, & Farina, 2005). Proper preparation of the site is also an important part of electrode placement. Cleaning and abrading the skin, to remove dead skin and oils, allows for better conduction of electrical signals (Merletti et al., 2005) and decreases the impedance between the muscle and the electrode. When placing the electrodes, the proper placement site must be found using articulations and anatomical landmarks of the body. These sites can be identified using SENIAM Guidelines (SENIAM.org). The electrode should be placed parallel to the muscle fibers, in the middle of the muscle belly. Surface electrodes should be placed anywhere from 5 to 20 millimeters apart from each other. The space needed is dependent upon the muscles that are of interest (Kamen & Gabriel, 2010).

Muscles of Interest

Stand-Up Paddle Boarding purportedly activates core muscles, which are the external oblique, rectus abdominis, internal oblique, transverse abdominis, multifidus, and the erector spinae group. The external oblique originates on the lower eight ribs and inserts on the linea alba and iliac crest. The external oblique is responsible for compression of the abdomen, depression the ribs, and flexion or bend of the spine (Martini & Timmons, 1995). The rectus abdominis originates on the superior surface of the pubis around the symphysis and inserts on the inferior surface of the costal cartilages (5-7) and xiphoid process of the sternum. The rectus abdominis is responsible for depression of the ribs and flexion of the vertebral column. The internal oblique originates on the lumbodorsal fascia and the iliac crest. Its insertion is located on the lower ribs, xiphoid of the sternum, and linea alba. The internal oblique muscle is responsible for compression of the abdomen, depression of the ribs, and flexion and bending of the spine. The transverse abdominis originates on the cartilages of the lower ribs, iliac crest, and lumbodorsal fascia and inserts on the linea alba and pubis. The transverse abdominis muscle is responsible for compression of the abdomen. The multifidus muscle originates on the transverse processes of vertebrae and posterior surface of the sacrum. The multifidus inserts on the spinous processes of the cervical vertebrae and the muscle is responsible for stabilization, rotation, and extension of the spine. The last core muscle called the erector spinae, is actually a grouping of muscles: spinalis dorsi, longissimus dorsi, and iliocostalis lumborum. The spinalis dorsi originates on the lower thoracic spinal processes and the upper lumbar vertebrae (Martini & Timmons, 1995). It inserts on the spinal processes of the upper thoracic vertebrae and is responsible for extension of the spinal column. The longissimus dorsi originates on the broad aponeurosis at the transverse processes of the lower thoracic and upper lumbar vertebrae where it joins the iliocostalis to form the sacrospinalis. It inserts on the transverse processes of the higher vertebrae and inferior surface of the ribs and is responsible for extension and lateral flexion of the ribs from side to side. Lastly, the iliocostalis lumborum originates on the sacrospinal aponeurosis and the iliac crest. It inserts on the inferior surfaces of the lower 7 ribs near their angles and is responsible for depression of the ribs and extension of the spine.

Other muscles that may have increased activation during SUP are the latissimus dorsi, gluteus maximus, and vastus lateralis. The latissimus dorsi originates on the spinal processes of the lower thoracic vertebrae (ribs 8-12), the spine of the lumbar vertebrae, and the lumbodorsal fascia (Martini & Timmons, 1995). It inserts on the lesser tubercle and the intertubercular groove of the humerus. It is responsible for extension, adduction, and medial rotation of the humerus. The gluteus maximus originates on the iliac crest of the ilium, sacrum, coccyx, and lumbodorsal fascia. The gluteus maximus inserts along the iliotibial tract and the gluteal tuberosity of the femur. It is responsible for extension and lateral rotation of the thigh. Lastly, the vastus lateralis originates from the anterior and inferior greater trochanter of the femur and along the linea aspera. The vastus lateralis inserts along the tibial tuberosity via the patellar ligament, and is responsible for extension of the leg.

Training Ability of Stand Up Paddle Boarding (SUP)

Stand-Up Paddle Boarding is a relatively new sport in the United States. There have been very few studies done on the sport and it's effectiveness as a training exercise. The few studies that have been done have shown promising data related to SUP's ability to be used as a training tool for balance, as well as strengthening of the abdominal trunk musculature. Ruess et al. (2013) performed a study comparing a SUP ergometer to performing SUP on the open water. It evaluated activation of the pectoralis major, rectus femoris, gluteus maximus, and latissimus dorsi, as well as core musculature such as the external oblique, rectus abdominis, multifidus, and the erector spinae. They measured the activation of the muscles at three separate power outputs: 3 Watts for beginner, 10 Watts for intermediate, and 30 Watts for expert. They found significant activation in all of the muscles tested throughout the majority of the activity. Ruess et al., (2013) found that at muscle activity patterns where similar at regardless of the power output. They also found muscle activation increased in a linear fashion as power output increased. This supports that all muscles show an increase in activation during SUP regardless of power output. This suggests that at different ratings of perceived exertion (RPE), similar patterns of muscular activation will be seen at the lower RPE as well as the highest RPE. The only difference will be the amount of activity expressed as % MVC, with the highest activity or % MVC being recorded at the highest RPE. The study saw clear activation of the hard to train core muscles throughout the study. To maintain balance on unstable surfaces the body recruits and activates the majority of the core muscles. Schram et al. (2014) tested the balance of eight elite SUP athletes, performing different types of balancing exercises in the laboratory. The study found that the elite SUP athletes had greater dynamic balance than other aquatic athletes. They attributed this to the need for maintaining balance on the unstable surface of the water.

Other studies have also suggested that the EMG activity of the abdominal muscles during SUP will be similar to treadmill running due to the unstable surfaces in both exercises (Kang & Kim, 2014). The researchers studied 12 healthy males who performed exercises on stable and unstable surfaces, and studied the effects on muscle activation of the rectus abdominis, external oblique, internal oblique, transverse abdominis, and the erector spinae using EMG. Electromyography levels in the rectus abdominis were significantly higher for the unstable surface compared to a stable surface. The EMG results for the transverse abdominis-internal oblique were also significantly higher on the unstable surface. The results showed the unstable surface also caused the abdominal muscles to stay contracted for longer periods of time without rest.

The results of a study Saeterbakken and Fimland (2011) support these findings, as they found exercises performed standing required more muscle activation of the erector spinae, external oblique, and rectus abdominis than the same exercises seated. They found an 81% decrease in EMG activity in the rectus abdominis while performing an exercise seated versus standing. They also found a 58% decrease in EMG activation for the external oblique when performing an exercise seated versus standing. The authors suggested this was due to the seated exercises having a wider, more stable base versus the smaller, less stable base while standing. Standing gives you a smaller base, therefore your body compensates by using your core musculature as stabilizers, eliciting more EMG activation.

EMG Studies of Rowing Activities

Pollock, Jones, Jenkyn, Ivanova, and Garland (2010) performed a study to compare the muscle activation of the trunk musculature in female rowers during a race. They wanted to compare the differences in EMG activity at the beginning of the race and the end of the race to see if there was a change with fatigue. Electromyography was recorded in the erector spinae, latissimus dorsi, gluteus maximus, rectus abdominis, external oblique, biceps femoris, transverse abdominis, and internal oblique. They found the muscle activity of the trunk flexors, external oblique, and rectus abdominis increased by 5.9% and 2.8% over the course of the race. The researchers felt this increase of the trunk flexors muscle activity may be due to the increased demand placed on the abdominal muscles to stabilize the trunk throughout the race. This trunk activation should be similar to SUP since SUP is performed while standing, meaning the athlete will have a harder time balancing on a smaller base.

Bazzucchi et al. (2012) compared muscle activation responses to on-water rowing versus a rowing ergometer in nine internationally competitive rowers. Electromyography of the trapezius superior, latissimus dorsi, biceps brachii, rectus femoris, vastus medialis, vastus lateralis, biceps femoris, and tibialis anterior muscles were examined. Root mean square (RMS) values were found at three separate times throughout the race. All of the muscles showed greater activation on the ergometer rather than the on-water trial at heart rates ranging from 80 bpm to 180 bpm.

A study by Fleming, Donne, Fletcher, and Mahony (2011) studied the EMG activity of the anterior deltoid, triceps brachii, latissimus dorsi, and vastus lateralis for elite male flatwater kayakers. The EMG activity was recorded during trials on-water and on-ergometer. Mean RMS data was found for four muscles during each trial. They found the latissimus dorsi had a higher RMS for the on-water compared to the on-ergometer trial. The vastus lateralis had similar activation for both trials. Root mean square for the tibialis anterior was higher on-water and the anterior deltoid RMS was higher on-ergometer. The results showed that EMG activity of the triceps brachii, anterior deltoid, and latissimus dorsi was significantly higher during the on-water kayak trials. This is contradictory to the findings of Bazzucchi et al. (2012) who studied the RMS of the latissimus dorsi in elite female rowers. The differences could be due to differing kinematics of rowing between rowing and kayaking as well as gender differences. Since SUP is also a paddle sport, results seen in the muscles used for paddling may be similar to those seen in SUP.

EMG Studies of Walking and Running

Walking and running are two of the most commonly performed exercises. Almost everyone at some point in their day performs one of these tasks to ambulate and perform everyday tasks of daily living. ACSM guidelines (Pescatello, 2014) recommend people should perform 30 minutes of moderate-intensity exercise, such as walking, five days a week, or they should perform 20 minutes of vigorous-intensity exercise, such as running, three times a week. A study by Capellini, Ivanenko, Poppele, and Lacquantit (2006) analyzed the EMG activation of 32 different muscles during walking and running. They recorded the EMG activation of every muscle at speeds of 3 km/h, 5 km/h, 7 km/h, and 9 km/h for walking and at speeds of 5 km/h, 7 km/h, 9 km/h, and 12 km/h for running. They found all of the muscles tested were activate during every power output during both walking and running. They also found that as speed increased, muscle activation increased. It is known that since walking and running activate the core musculature and are done upright on an unstable surface, there may be similar core activation responses seen in SUP.

In a study done by Behm, Cappa, and Power (2009), EMG activation of the external oblique, lower abdominals, the muscles of the erector spinae grouping where studied to compare activation during a curl-up to activation during moderate (60%) and high (80%) intensity running (percentages being based off of maximum heart rate reserve). Seventeen male subjects were used, seven of which were highly trained triathletes, while the other 10 were highly active non-run-trained individuals. The resaerchers found the external oblique had less activation during moderate-and high-intensity running than curl-ups. For the upper erector spinae and lower erector spinae muscles, the back extension exercise and curl-up showed less activation than the moderate- and high-intensity runs. The back extension exercise and curl up resulted in 5-15% MVC versus the 30-40% MVC seen with the 60% and 80% runs. During running, % MVC of the trunk muscles were recorded ranging from 10%-100% of MVC. This study indicates that running provides adequate activation of the erector spinae muscles that is sufficient to improve muscular endurance. The external oblique was activated between 20-33% MVC with the 60% and 80% runs. For the curl-up exercise, the average was 61% MVC, which is 30-40% higher than running. Therefore, running may be a good way to train the erector spinae muscles, but not the external oblique when compared to a conventional strength training regiment.

EMG Studies of the Core Muscles

Ekstrom, Donatelli, and Carp (2007) completed a study to determine what basic trunk, hip, and thigh muscle exercises are best for strengthening these muscles. They tested nine basic exercises: the side bridge, unilateral bridge, lateral step-up, quadruped arm/lower extremity lift, active hip abduction, dynamic edge, lunge, bridge, and prone-bridge. They measured the EMG activation of the gluteus medius, gluteus maximus, vastus medialis obliquus, hamstrings, longissimus thoracis, lumbar multifidus, external oblique abdominis, and the rectus abdominis. A linear relationship between EMG signal amplitude and increasing force production during isometric contractions has been reported by Basmajian and De Luca (1985). Marris and Davis (2001) found a strong linear relationship for the erector spinae, rectus abdominis, external oblique, and internal oblique muscles during isometric flexion and extension exercises. Based on these and other investigators findings, Ekstrom, Donatelli, and Carp (2007) determined that loads of 45% to 50% of 1 repetition maximum effort (1RM) have been shown to increase strength in previously untrained individuals. Therefore, the exercises that produced EMG signals of greater than 45% MVC could provide sufficient stimulation for strength gains in some individuals. If a muscle produces EMG signals of less than 45% MVC they would be considered most beneficial for endurance training. Using these guidelines, Ekstrom, Donatelli, and Carp (2007) determined that the bridge, unilateral-bridge, side bridge, prone-bridge on elbows and toes, and the quadruped arm/lower extremity lift exercises provided muscle activation endurance and stabilization training of the back and hips. This was decided based on the % MVC for a majority of the muscles being less than 45% MVC for those exercises.

Willet, Hyde, Uhrlaub, Wendel, and Karst (2001) conducted a study to determine the activity of the upper and lower rectus abdominis and the external oblique muscles during five common abdominal strengthening exercises. They compared the five exercises under isometric and dynamic conditions. The four exercises performed were the regular curl-up, the reverse curl-up, the twist curl-up, and the v-sit. They found the reverse curl-up had the greatest amount of lower rectus activity, the v-sit and reverse curl exercises had the greatest amount of external oblique activity, and the trunk curl with a twist and v-sit had similar amounts of upper rectus EMG activity. All of the muscles in this study had EMG activation greater than 50% MVC which according to Ekstrom et al. (2007) suggests that these would provide a strength training benefit in these core muscles.

Escamilla et al. (2010) performed a study to compare core muscle activation during swiss ball abdominal exercises to the traditional crunch and bent knee sit-up. They tested eight swiss ball exercises: roll-out, pike, knee-up, skier, hip extension (left and right), decline push-up, and the sitting march right. They found the pike and the roll-out exercises on the swiss ball to be the most effective exercises to activate the upper and lower rectus abdominis, external and internal oblique, and the latissimus dorsi, while limiting the activation of the lumbar paraspinalis and rectus femoris muscles. The EMG activation during the pike exercise for the various muscles was 47% MVC and 55% MVC for the upper and lower rectus abdominis, 84% MVC and 56% MVC for the external and internal oblique, 25 % MVC for the latissimus dorsi, and 8% MVC and 24% MVC for the lumbar paraspinalis and rectus femoris, respectively. The EMG activation during the roll-out exercise for the various muscles was 63% MVC and 53% MVC for the lower and upper rectus abdominis, 46% MVC for both the external and internal obliques, 12% MVC for the latissimus dorsi, and 6% MVC and 8% MVC for the lumbar paraspinalis and rectus femoris muscles. Based on these results, these two exercises are of sufficient intensity to result in strength improvement in the abdominal muscles.

Summary

Previous studies have shown that SUP does seem to work as an abdominal training exercise. Electromyography analyses have shown clear activation of core muscles while performing SUP. When looking at exercises similar to that of SUP, such as rowing, kayaking, running, and walking, muscle activation is adequate enough to stimulate muscle training. Although they are not exactly the same as SUP, they provide a generalization for what to expect during SUP.

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