ABSTRACT

ELECTROMYOGRAPHICAL COMPARISON OF THE ABDOMINAL CRUNCH TO PLANKS PERFORMED WITH AND WITHOUT A SUSPENSION TRAINER

Research has shown the importance of strengthening the abdominal muscles for increased stability, mobility, rehabilitation and prevention of lower back pain as well as increased athletic performance. Understanding the relative recruitment of the abdominal muscles during the performance of various abdominal exercises can aid rehabilitation specialists, personal trainers and athletic coaches in selecting appropriate exercises for clients and athletes with different needs and varying fitness levels. Eleven participants took part in a study which purpose was to compare the relative recruitment of the rectus abdominis (RA), external oblique (EO), and rectus femoris (RF) during the performance of six different exercises: the traditional abdominal crunch, an isometric plank (traditional and suspended), mountain climber plank (traditional and suspended) and a suspended plank with a knee tuck. Repeated measures ANOVA found a main effect for muscle and exercise ($p < 0.05$) as well as a significant interaction between these factors ($p < 0.05$). We found that the relative recruitment of the RA and EO was similar among the crunch, plank, and TRX plank. Our results also indicated that the TRX knee tuck produced significantly greater overall muscle activity than the other exercise conditions ($p < 0.05$). We conclude that for individuals wanting to develop the abdominal musculature, all plank variations (traditional and suspended) seem to be effective.

Sarah Elizabeth Pierce

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ELECTROMYOGRAPHICAL COMPARISON OF THE ABDOMINAL CRUNCH TO PLANKS PERFORMED WITH AND WITHOUT A SUSPENSION TRAINER

by

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APPROVED

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CHAPTER 1: INTRODUCTION

Strength coaches and fitness and rehabilitation professionals have long recognized that strength and endurance of the core muscles are an important component of both, health and sports performance fitness (Hildenbrand & Noble, 2004). The American College of Sports Medicine (ACSM) recommends incorporating core training into a regular fitness regimen at least twice a week because of its multiple benefits (ACSM, 2010). These benefits include improved mobility and spinal stability, decreased risk of injury, as well as rehabilitation and prevention of chronic lower back pain (Gottschall, Mills, & Hastings, 2013; Kibler, Press, & Sciascia, 2006). Additionally, recent studies have also shown a correlation between core strength and athletic performance (Shinkle, Nesser, Demchak, & McMannus, 2012).

One of the more traditional core conditioning exercises is the abdominal crunch which has been the standard for strengthening the abdominal muscles (Sternlicht, Rugg, Bernstein, & Armstrong, 2005). The main reason for this is because the main action of the rectus abdominis (RA) is flexion of the trunk (Thompson & Floyd, 2001). Recent research (e.g., Comfort, Pearson, & Mather, 2011; Snarr & Esco, 2014) has validated the claim that the plank is also an effective exercise to strengthen the abdominal muscles. Because of these results, there has been a recent surge in the popularity of plank exercises (as stressors of the midsection), including those performed with instability devices such as a suspension trainer (e.g., TRX). According to Snarr and Esco (2014), part of this popular trend is perhaps explained by a more specific carry-over of planking to activities of daily living. These authors also address the fact of decreased compressive loading on the spine while planking (Snarr & Esco, 2014). However, there is limited research comparing the abdominal crunch and planks (performed in a variety of ways) regarding their corresponding relative recruitment of the abdominal muscles. Research investigating the recruitment of abdominal muscles while planking using the TRX suspension trainer is even more limited. To date, only six published articles have addressed abdominal muscle recruitment using a suspension trainer (TRX). Only one of these investigations has compared TRX recruitment to recruitment during crunches (Snarr, Esco, Witte, Jenkins, & Brannan, 2013). Given the recent surge in the popularity of suspended planking (and associated variations), comparing the relative recruitment levels to that of crunches may help establish the prescription parameters (e.g., repetitions, time held) needed to induce equivalent training loads.

Statement of the Problem

It was the purpose of this study to compare the relative recruitment of the rectus abdominis (RA) and external oblique (EO) resulting from the performance of traditional abdominal crunches to that from planks performed with and without the use of a suspension trainer (TRX). In addition, the relative recruitment of the rectus femoris (RF) was evaluated to compare its engagement among various plank conditions (e.g., traditional and suspended, with and without leg movement) (Byrne et al., 2014). The muscles' relative recruitment was based on recorded surface electromyography (EMG) data.

Research Hypotheses

1. The traditional abdominal crunch will result in higher relative recruitment of the RA and EO when compared to that resulting from isometric planks performed with and without the use of the suspension trainer.

2. The suspended mountain climber plank and suspended plank with a knee tuck will result in the highest relative recruitment of the RA and EO when compared to that resulting from the other exercises.
3. The relative recruitment of the RF will be greater during suspended planks.

Significance of the Study

The findings of this study will help professionals in the fitness and rehabilitation industry (including sport coaches) make evidence-based decisions regarding the prescription of abdominal strengthening exercises. By establishing relative recruitment patterns among traditional crunches and planks (traditional and suspended), a health care provider may be able to design a plank-based midsection program (that imposes an equivalent mid-section stress) for someone who cannot perform a traditional crunch. For example, in cases where the abdominal crunch may place too much stress on the lumbar region due to previous injury (Snarr & Esco, 2014), a traditional plank might be more appropriate. For highly fit individuals, suspended (unstable) planking may be used to supplement and/or modify their abdominal training program according to pre-established relative recruitment stresses. However, relatively little research exists on how planks performed with and without a suspension trainer impacts muscle activation of the midsection as compared to a traditional abdominal crunch. Therefore, research evaluating the relative recruitment of each of the above mentioned midsection exercises was warranted.

In addition to investigating the relative recruitment of the RA and EO during the performance of the above-mentioned exercises, investigation of the RF was justified due to its noted synergistic activation with abdominal muscles

(Neumann, 2010). According to Byrne et al. (2014), the RF acts as a force couple to assist the pelvis in maintenance of a neutral position when the abdominals are activated strongly. This synergistic activation is required during the performance of a plank to prevent the pelvis from rotating posteriorly.

Delimitations

Only volunteers that self-reported being free of cardiorespiratory, neurological, and/or musculoskeletal disorders were allowed to participate.

Only volunteers that could display the required fitness and technique needed for proper and sustained execution of traditional crunches and suspended planks were allowed to participate.

Only volunteers with a body fat percentage 15% and below (for men) and 25% (for women) were allowed to participate. In addition, waist circumference had to be below 35.5 in (for men) and 32.5 in (for women). This was needed for the sake of controlling for the effect of excess adiposity on the surface EMG signal amplitude (Bartuzi, Tokarski, & Roman-Liu, 2010).

Limitations

The participants' lack of familiarity in performing maximal voluntary contractions (MVICs) of the midsection (RA, EO) and knee extensors (RF) muscles may have affected the normalization of the surface EMG data.

The participant's body fat content in the abdominal region may have affected the amplitude and/or frequency of the surface EMG signal recorded from the tested muscles (Bartuzi et al., 2010).

It is assumed that the participants were truthful in their answers to the questionnaires addressing their fitness level and/or health status.

The lack of linearity between muscle force and the associated surface EMG signal noted during dynamic muscle actions may have affected the comparisons of the EMG records between the crunches (dynamic) and planks (isometric) (Staudenmann, Roeleveld, Stegeman, & Dieen, 2009).

Definition of Terms

1. Abdominal crunch – an exercise performed while lying in a supine position with the knees flexed to 90°, feet flat on the floor, and the arms crossed over the chest. The spine is flexed by lifting the head and shoulders off the ground and then lowered back on the floor (Snarr et al., 2013).
2. Abdominal muscles – the rectus abdominis, external oblique, transversus abdominis, and internal oblique (Akuthota & Nadler, 2004).
3. Core – the aspect of the human body consisting of the spine, hips, pelvis and abdominal muscles (Kibler et al., 2006).
4. External oblique – a muscle located on the lateral side of the abdomen. Its main action is rotation and lateral flexion of the spine; assists the rectus abdominis (Akuthota & Nadler, 2004).
5. Plank – an exercise performed in a prone position in which the elbows and shoulders are flexed at 90˚, the legs are fully extended, and only the forearms and toes are contact with the ground (Snarr & Esco, 2014).
6. Rectus abdominis – a long, flat muscle that runs vertically on the anterior wall of the abdomen from the rib cage to the pubic bone. Its primary action is flexion of the spine (Akuthota & Nadler, 2004).

7. Rectus femoris – a muscle located on the center of the anterior surface of the thigh, approximately half the distance between the knee and the iliac spine (Cram, Kasman, & Holtz, 2011).
8. Surface Electromyography – a non-invasive technique used to measure and analyze the electrical activity associated with a contracting muscle (Sternlicht et al., 2005).
9. Suspension Trainer (TRX) – a device similar to Olympic gymnastics rings using hanging straps and handles to leverage gravity and the user's bodyweight to perform a variety of exercises (Snarr & Esco, 2014).

CHAPTER 2: REVIEW OF LITERATURE

Within fitness, sports and rehabilitation settings, the performance of a variety of abdominal strengthening exercises is encouraged. However, there is a current void in the published literature regarding the validity of which exercises induce the highest recruitment of the abdominal musculature. By establishing relative recruitment patterns among traditional crunches and planks (e.g., traditional and suspended), rehabilitation specialists, personal trainers, and athletic coaches may be able to design a midsection program that is appropriate for clients and athletes with different needs and varying fitness levels.

In the past, published literature has focused on comparing EMG data of abdominal muscles during the performance of a traditional abdominal crunch to that of popular home abdominal strengthening devices that mimic the action of the crunch (Beim, Giraldo, Pincivero, Borror, & Fu, 1997; Demont et al., 1999; Hildenbrand, & Noble, 2004; Sternlicht et al., 2005). More recently, investigations of abdominal recruitment between different plank variations (traditional and suspended) have surfaced, but comparisons between the traditional abdominal crunch and plank variations (traditional and suspended) are limited. Of the literature that has been published regarding suspended plank variations, the focus has been on planks held isometrically. To this author's knowledge, no published study has probed the relative recruitment of the abdominal muscles during the performance of a suspended plank (TRX) with the lower limbs engaged dynamically (mountain climbers, knee tuck). The following paragraphs will present some of the most current and pertinent literature addressing the above statements.

Abdominal Recruitment Between Different Plank Variations: Traditional vs. Suspended

A shift has taken place from the performance of the abdominal crunch for strengthening the abdominals to the performance of the plank. It is thought that when the body is in a prone plank-like position while exercising, the abdominals are activated to a higher degree than in a supine spinal flexion position, the abdominal crunch, for example. Furthermore, the performance of the plank for strengthening the abdominals has gained popularity because of its potential relevance to activities of daily living and decreased strain to the lumbar region. Planks have been shown to be a safer alternative for strengthening the abdominals in individuals with lower back issues. Planks are a bodyweight exercise designed to increase core muscular strength, endurance and stability (Snarr & Esco, 2014). In a study conducted by Snarr and Esco (2014), the EMG activity of the RA and EO was compared during different plank variations (feet in foot cradles, forearms in foot cradles) using a suspension trainer (TRX), and planks using a Swiss ball (elbows on Swiss ball and feet on Swiss ball) to a plank on a stable surface. Their study revealed that as instability increased with the performance of a plank, so did activity of the abdominal musculature. The traditional plank performed on a stable surface provided the lowest activity of the abdominals. The plank performed with the forearms placed in the foot cradles of the suspension trainer (TRX) had the highest EMG activity of the RA and EO. The author's explanation for this is because a plank performed in this manner placed the participant's center of mass farther away from the unstable surface than the other plank variations. Additionally, the participants had the lowest amount of surface area in contact with the ground. However, no comparison was made with regard to plank performance and the abdominal crunch nor did they investigate the relative recruitment of the RF during the performance any of these plank variations. The results of the previous study were validated by a study conducted by Byrne et al. (2014) where they compared a traditional plank to plank variations using the suspension trainer (TRX). The plank variations consisted of forearms in the foot cradles, feet in the foot cradles and feet and forearms in the foot cradles using two suspension trainers (TRX). Results revealed an increase in activity of the RA, EO, and RF while performing a suspended plank with the forearms in the foot cradles. All three plank variations had higher activity of the RA, EO, and RF than the traditional plank performed on a stable surface. These studies established higher relative recruitment of the RA, EO, and RF with the performance of a suspended plank compared to a traditional plank, but made no comparison to the traditional abdominal crunch. In a conflicting study, Atkins et al. (2015) compared a plank with hands on the ground (start of a push-up) to a plank with hands on a Swiss ball, and a plank with hands on the straps of a suspension trainer (TRX). Recorded EMG activity of the RA, EO, and ES were collected in a population of swimmers. The findings for the recorded EMG activity of the RA were similar to the studies by Snarr and Esco (2014) and Byrne et al. with the suspended plank having the highest EMG reading for the RA. However, unlike the previously mentioned studies, the EO had the highest activity for the plank with the hands on a stable surface.

Comparison of Plank Variations to a Traditional Abdominal Crunch

Three studies have been published comparing the relative recruitment of the abdominal muscles during the performance of a traditional abdominal crunch to that of a plank variation, but with conflicting results. Gottschall et al. (2013) compared EMG data during the performance of a traditional abdominal crunch and a diagonal mountain climber plank in six muscles including the RA and EO.

Contrary to the author's hypothesis, EMG data of both the RA and EO elicited higher activity during the diagonal mountain climber plank compared to the traditional abdominal crunch. The author's rationale for this higher activation is the increased balance required for the diagonal mountain climber plank. However, in this study no investigation of the RF was made.

In a separate study, Snarr, Hallmark, and Esco (2016) compared EMG data of four muscles which included the RA, EO and RF during the performance of a traditional abdominal crunch, pike, and towel pike (both plank variations). For the RA, the towel pike showed values significantly greater than the crunch and pike, but the EMG values for the crunch were significantly higher than the pike. The towel pike also had significantly greater EO values than the crunch or pike, but no statistical difference was found for the EO between the crunch and pike. For the RF, the towel pike elicited the highest activity, while the crunch elicited the lowest. The findings in this study for the RA and EO conflict with a study conducted by Schoffstall, Titcomb and Kilborune (2010) where no significant difference was found between the abdominal crunch and suspended pike (TRX) in the relative recruitment of the RA and EO. In this study these exercises were performed isometrically, whereas in the study done by Snarr et al. (2016), they were performed dynamically. These contrary results might be due to varying EMG activation between isometric and dynamic movements. However, EMG data for the RF during the performance of a traditional abdominal crunch and pike (towel pike and suspended pike) was consistent between the two studies with the crunch having significantly lower RF activation than all pike exercises performed.

Comparison Between Crunch and Push Up (Traditional And Suspended) In Recruitment of the RA

Several studies have investigated abdominal recruitment during the performance of a push-up (traditional and suspended). The starting point of a push-up is a plank, so the inclusion of these studies into this literature review is warranted. In one such study, Snarr et al. (2013) compared EMG data of the RA during the performance of a traditional abdominal crunch to a push-up (traditional and suspended). The traditional push-up performed without the suspension trainer (TRX) elicited the least amount of activity from the RA and the suspended (TRX) push-up had the highest RA activity among the three exercises.

Summary

In conclusion, research has shown the importance of strengthening the abdominal muscles for increased stability, mobility, rehabilitation and prevention of lower back pain as well as increased athletic performance. Understanding the relative recruitment of the abdominal muscles during the performance of various abdominal exercises can aid rehabilitation specialists, personal trainers and athletic coaches in selecting appropriate exercises for clients and athletes with different needs and varying fitness levels.

Among the studies comparing abdominal recruitment during isometric planks, the suspended version has consistently yielded higher recruitment scores (Atkins et al., 2015; Byrne et al., 2014; Snarr & Esco, 2014). In studies comparing the relative recruitment of the abdominal muscles during a traditional abdominal crunch and plank variations (traditional and suspended) results are conflicting with two studies reporting higher EMG activity of the RA during the plank variations (Gottschall et al., 2013; Snarr et al., 2013) and one study showing no difference in RA activity between the abdominal crunch and plank variation (Schoffstall et al., 2010). Additionally, no research has been performed on the relative recruitment of the abdominals during the performance of a suspended (TRX) plank variation where the lower limbs are engaged dynamically. Because the current void in the literature comparing the relative recruitment of the RA, EO, and RF between the performance of the abdominal crunch, isometric planks (traditional and suspended), and suspended planks (TRX) with leg motion, research addressing this question is warranted.

CHAPTER 3: METHODOLOGY

This chapter will describe the procedures employed to fulfill the objectives of this study. It is divided into participants, procedures, and the experimental protocol of the study.

Participants

Recruitment of participants for this study was based on word of mouth and flyers posted on various campus locations. Their descriptive statistics (mean ±*SD*) are presented in Table 1.

Table 1

Descriptive Statistics of the Study Participants

Descriptives	Men (n=8)	Women (n=3)	Overall (n=11)
Age (yr)	26.88 ± 4.94	27.67 ± 5.51	27.09 ± 4.82
Height (m)	1.76 ± 0.09	1.651 ± 0.01	1.72 ± 0.10
Body mass (kg)	70.41 ± 28.37	55.46 ± 3.27	66.34 ± 24.79
Body fat %	16.2 ± 6.13	20.3 ± 1.92	17.32 ± 5.54
Waist Circumference	33.72 ± 2.31	26.5 ± 0.5	31.75 ± 3.89
BMI	26.01 ± 1.71	21.42 ± 0.89	23.72 ± 1.30

To be considered for participation in the study, male and female subjects were required to display the musculoskeletal fitness and technique needed for proper and sustained execution of traditional crunches and planks (traditional and suspended). The above fitness and exercise technique requirements were established based on the answers to a questionnaire (see Appendix A) and the participants' ability to properly demonstrate to the investigator the aforementioned exercises. In addition, participants had to have a body fat percentage at or below 15% (for men) and 25% (for women). The expected percent fat was established via plethysmography (BOD POD; Life Measurement Instruments, Concord, CA USA) using procedures described by Dempster and Aitkens (1995). Participants' waist circumference also had to be below 35.5 in (for men) and 32.5 in (for women). Waist circumference was measured using a cloth measuring tape at the smallest part of the waist while the participant stood relaxed. Eligible participants were required to complete a Physical Activity Readiness Questionnaire (PAR-Q) to ensure a reasonable good health standing and physical preparedness (see Appendix B). Subjects were informed of the risks and benefits involved and were instructed to wear proper clothing that allows for ready access to EMG electrode placement sites. Participants were also required to sign a written consent prior to participation (Appendix C). The protocol for this investigation conformed to the California State University, Fresno (CSUF) policy on the use of human subjects.

Procedures

Familiarization Session

Participants visited the Human Performance Lab (HPL) at CSUF, Department of Kinesiology on two separate occasions. In the first (familiarization) session, the participants signed the informed consents, were introduced to the study's experimental protocol, as well as the equipment used for data collection. During this session the participants' height (m), mass (kg), age (yr), and body fat percentage were also measured. Next, the investigator illustrated the proper technique of the required exercises: traditional abdominal crunch (Figure 1), traditional plank (feet on the floor) (Figure 2), suspended plank (TRX plank)

(Figure 3), suspended plank with a knee tuck (TRX knee tuck) (Figure 4), mountain climber plank (traditional) (Figure 5), and mountain climber plank (suspended) (Figure 6). The following paragraphs describe these exercises.

During the abdominal crunch, the participants lie supine with knees flexed to 90°, feet flat on the floor, arms crossed over the chest (Figure 1). Participants flexed the spine by lifting their head and shoulders off the ground until the inferior angle of the scapula was off of the mat. Then, the participants returned to the starting position. The above was practiced for 15 repetitions at a rate set by a metronome of 4 s per repetition (2 s concentric, 2 s eccentric) as this was the pace required in the experimental session.

Figure 1. Abdominal crunch

During the traditional plank, participants were in a prone position with their elbows flexed at a 90° with only the forearms and toes in contact with the ground (Figure 2). The torso remained rigid with the legs extended and the head and spine in a neutral position. This plank position was held for 15 s. The latter was repeated as needed until mastery in the expected technique was achieved.

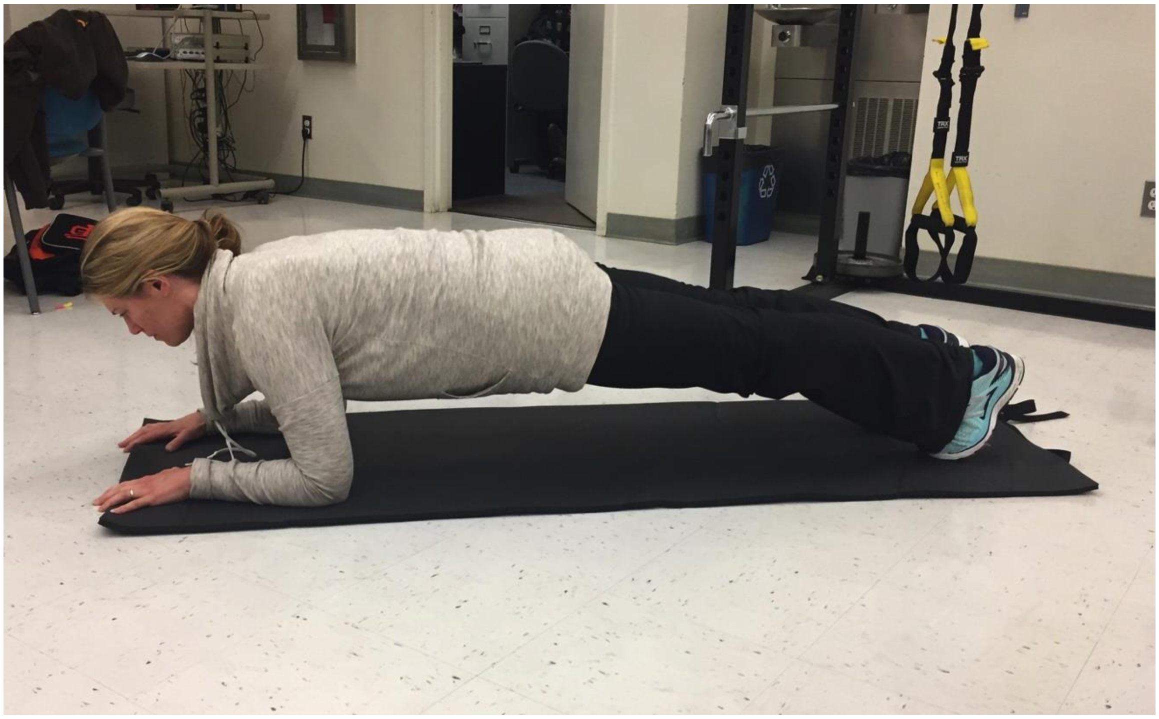

Figure 2. Traditional plank

During the suspended plank, the TRX device was anchored to a squat rack (Figure 3). The foot cradles were placed 8-12 in from the ground which is the manufacturer's recommended suspension height. Participants assumed a plank position. Forearms remained in contact with the ground and the feet were placed inside the foot cradles of the TRX (Snarr & Esco, 2013). This (suspended) plank position (TRX plank) was also held for 15 s. The latter was repeated as needed until mastery in the expected technique was achieved.

During the suspended plank with a knee tuck (TRX knee tuck), subjects assumed a plank position with the arms fully extended and hands on the ground slightly wider than shoulder width (Figure 4). Each foot was secured in the foot cradles of the suspension trainer (TRX). With the hips and knees fully extended,

Figure 3. Suspended (TRX) plank

participants were instructed to flex the hip and knee joints in one continuous and controlled motion pulling the knees toward the torso until they reached the upper abdominal region. This was followed by a return to the initial position. The hips and knees were simultaneously flexed and extended at a metronome cadence of one beat per second (Snarr & Esco, 2013). Subjects were asked to practice the exercise as needed until mastery in the expected technique was achieved.

During the traditional mountain climber plank, subjects started from a push-up position (arms fully extended and hands on the ground shoulder width apart; feet hip width apart) (Figure 5). They were instructed to bring in one knee at a time toward the chest at a metronome rate of one beat per second. During each 1-second period, the knee and hip for a given leg flexed and extended in an alternating fashion. Subjects were asked to practice the exercise as needed until mastery in the expected technique was achieved.

Figure 4. Suspended plank with a knee tuck (TRX knee tuck)

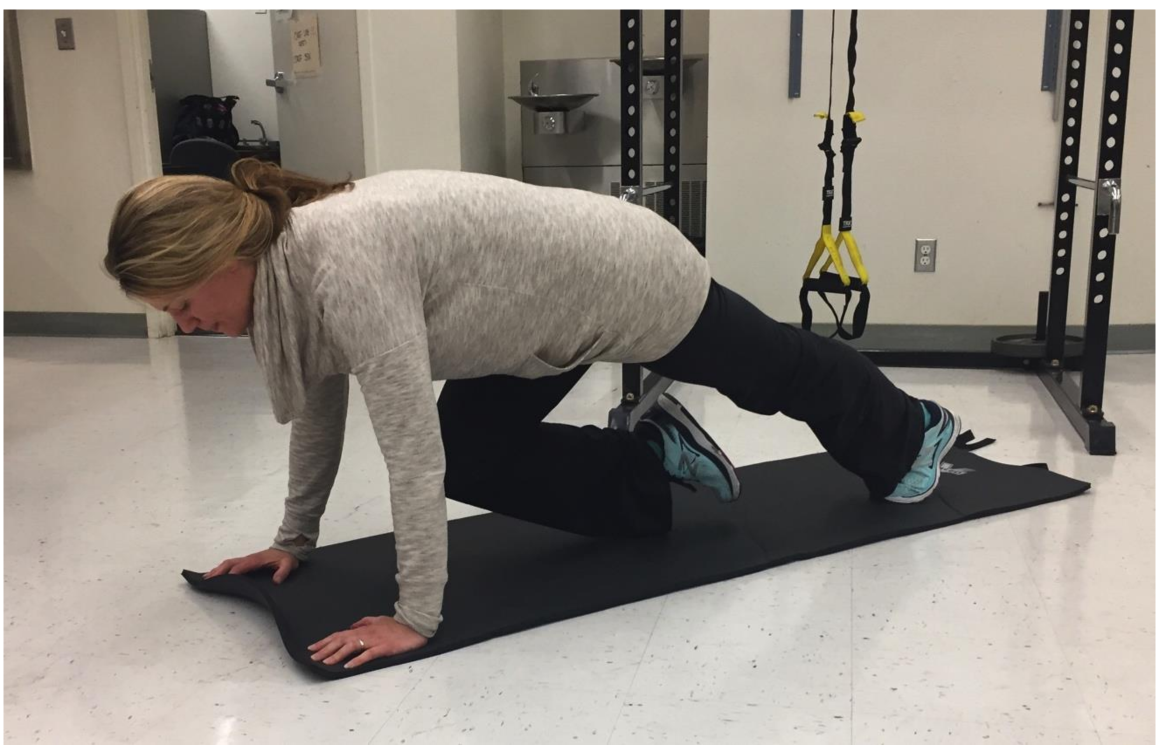

Figure 5. Traditional mountain climber plank

During the suspended mountain climber plank (TRX MC), subjects performed the previously described mountain climber plank, but this time with feet suspended in the foot cradles of the suspension trainer (TRX) (Figure 6). Subjects were asked to practice the exercise as needed until mastery in the expected technique was achieved.

Figure 6. Suspended mountain climber plank (TRX MC)

Once the investigator was satisfied with the participant's ability to perform these, the subjects were directed to perform a standardized warm up (see Appendix D).

Familiarization Session

Maximal voluntary isometric contraction (MVIC) Practice Trials – Before MVIC practice, subjects were directed to perform a standardized warm up (see Appendix D). After such, the MVIC of the RA was achieved by having the subject assume a supine position on a padded mat with the knees flexed to 90°, feet anchored, and the arms crossed over the chest. The subjects then attempted to perform a maximal-effort sit-up while the investigator provided a matched resistance at the shoulders to prevent the subject from moving upward (Snarr et al., 2013). The MVIC for the EO was accomplished by having the subjects assume a side-lying position, with the legs and hips restrained (Konrad, 2005). Next, the subject attempted to perform a maximal-effort lateral spinal flexion while the investigator provided a matched resistance at the shoulder (Snarr & Esco, 2014). For the RF, the subject was asked to extend his/her right thigh as forcefully as possible (sitting position; both legs hanging) while the investigator provided a matched resistance at the ankle (Byrne et al., 2014).

For each muscle, two to three 6 s MVICs were made, each separated by a 1-min recovery period. The multiple attempts were intended to teach subjects the proper execution and required effort of MVIC testing. Upon the conclusion of the familiarization session, subjects were asked to refrain from any strenuous physical activity for at least 24 hr before the experimental session. Attempts were made to have subjects perform the experimental session no later than 7 days after the familiarization session.

Experimental Session

EMG data collection and treatment. All surface EMG data were recorded using a BIOPAC Systems Inc. electromyograph (Santa Barbara, CA). The raw EMG signals were sampled at 1000Hz, amplified (x2000) and filtered (high pass=30Hz, low pass=500Hz, band stop=60Hz). The signals were then rectified and smoothed via a root mean square (RMS) algorithm using a 100-ms sliding window. The included Student Lab Pro Software (v3.7.2) was used to establish the mean RMS scores that became the study's dependent measures.

Skin preparation and electrode placement. Before skin preparation and electrode placement, subjects were asked to perform the same standardized warm up (see Appendix D) done in the Familiarization session. Upon conclusion of the warm-up, and prior to EMG data collection, the corresponding sites for the RA, EO, and RF (see below) were shaved, abraded, and cleansed with alcohol wipes before placement of the surface (bipolar) AG/AGCL pre-gelled electrodes. Electrode placement sites were determined per recommendations established by Cram, Kasman, and Holtz (2011). For the RA, electrodes were placed 2 cm to the right of the umbilicus and 3 cm apart (vertically) directly over the RA muscle fibers. For the sake of minimizing cross-talk between the tested muscles, electrodes for the EO were placed 15 cm left to the umbilicus, and halfway between the iliac crest and the bottom of the ribs at a slightly oblique angle (25º). Electrodes for the RF were placed vertically near the midline of the anterior aspect of the right thigh halfway between the anterior superior iliac spine and the superior border of the patella. The ground electrode for the RA was placed on the medial-most aspect of the eighth vertebrochondral rib (left side); for the EO, the same location was used, but on the right side. The superior-most aspect of the right ilium was the site for the ground electrode corresponding to the RF. Athletic tape or stretch tape was used to secure electrodes. The BIOPAC's electrode check feature was employed to ensure that impedance of the skin electrode interface was below 5,000 Ohms (Ω). Following electrode placement, baseline EMG signals (i.e., from MVIC trials) were collected.

MVIC trials. Once electrodes were in place, the subjects were once again requested to perform 2, six-second MVICs of the RA, EO, and RF as previously described in the familiarization session. From the collected EMG data, the mean RMS score (averaged over 6 s) for all MVIC attempts (RA, EO, RF) were determined; the highest score was used for normalizing the data. The maximal 6 s RMS scores were used to normalize the submaximal RMS amplitudes during the ensuing crunching and planking efforts.

Exercise trials. Following the MVIC efforts, the order of the exercises to be performed (i.e., crunches, planks, suspended planks) were randomly selected. The abdominal crunch was performed for five repetitions at a rate set by a metronome of 4 s per repetition (2 s concentric, 2 s eccentric). The traditional plank and suspended plank (TRX plank) were each held for 15 s. For the suspended plank with a knee tuck (TRX knee tuck) the performance was maintained for 10 s at a metronome cadence of one beat per second. During each beat of the metronome both hips and knees were either flexing or extending The mountain climber planks (traditional and suspended) were performed for 20 s at a metronome cadence of one beat per second; during each beat the hip and knee of a given leg was either flexing or extending. A 3 min recovery period was given between each exercise to allow for adequate recovery. During all exercises the surface EMG activity of the RA, EO, and RF were recorded during the respective time periods.

EMG variables. In order to obtain a 6 s sampling window during crunches, three consecutive, 2 s concentric efforts were pasted in sequence. Next, the mean RMS score was obtained for the resulting 6 s period. During all isometric planks (traditional, TRX), the mean RMS score was obtained from seconds 4-10 (of the 15 s sampling period). For the TRX knee tuck, the mean RMS score for the flexion and extension aspect of the plank were recorded from seconds 2-8 (of the 10 s sampling period). To obtain 6 s sampling windows for both, the traditional (MC) and suspended (TRX MC) mountain climber planks, the first and last 4 s of the respective 20 s sampling windows were removed. The remaining 12 s provided three, yet alternating 2 s windows for each leg (hip and knee flexion and extension = 2 s). For each leg, the three 2 s segments were pasted for the sake of composing a 6 s sampling window upon which the mean RMS score were obtained. The alternating nature of these mountain climber planks (traditional and suspended) allowed for EMG data collection while the right leg was either fully extended (foot on the floor) or flexed (knee brought into chest area). This enabled the creation of 6 s sampling windows of all 3 muscles (RA, EO, RF) as the right hip was being flexed and while it was stable (right foot on the floor). Consequently, derivatives of the traditional (MC) and suspended (TRX MC) mountain climber planks were created for both conditions, flexion (MC flexion, TRX MC flexion) and stable (MC stable, TRX MC stable).

For all exercises, the corresponding (6 s) mean RMS (mV) was expressed as a percent of the RMS values (mV) obtained during MVIC testing. This was needed for the sake of normalizing the data and thus, allowing for comparisons of the RMS scores of the tested muscles across subjects. The RMS was selected over other methods of determining EMG signal amplitude (e.g. integrated EMG) as the RMS is more resistant to movement artifact, signal noise, and temporal changes (Renshaw, Bice, Cassidy, Eldridge, & Powell, 2010).

Statistical Analyses

In order to determine the differences in the relative recruitment of the RA, EO, and RF among the eight exercise conditions (crunches, isometric planks [traditional and suspended], mountain climber planks [traditional and suspended], and suspended plank with a knee tuck) a 3x8 analysis of variance (ANOVA) (muscle x exercise) with repeated measures on the exercise factor was used. For all statistical tests, a significance of $p < 0.05$ was set a priori. For all dependent measures, descriptive statistics (means and standard deviations) were also calculated. In cases where multiple mean comparisons were appropriate, pairwise comparisons with a Bonferroni adjustment were used. All analyses were done with the Statistical Package for the Social Sciences (V21; SPSS Inc., Chicago IL).

CHAPTER 4: RESULTS

This chapter presents the results of data collection based on the procedures described in chapter 3. A repeated measures ANOVA (Table 2) was used to determine if the normalized (%MVIC) RMS values for the RA, EO, and RF were significantly different across the eight exercise conditions. The corresponding mean *(±SD*) %MVIC scores are presented in Table 3 and graphically depicted in Figure 7. As indicated in Table 2, ANOVA revealed a significant main effect for both experimental factors (exercise, muscle) ($p < 0.001$), as well as a significant interaction between these (exercise x muscle) ($p < 0.001$). Because of the significant interaction, pairwise comparisons with a Bonferroni adjustment were run on the dependent measures.

Table 2

Results of Repeated Measures ANOVA (n=11)

Source of Variation	Type III Sum of Squares	df	Mean Square	F	Sig
Exercise	49637.074	1.896	26174.201	21.855	.000
Muscle	65671.526	2	32835.763	25.109	.000
Exercise-Muscle	19741.683	5.759	3428.230	8.845	.000

Table 3

Normalized Electromyographic Values (%MVIC) of the Selected Musculature (RA, EO, RF) Among the Different Exercises (n=11)

Muscle	Abdominal Crunch	Plank	TRX Plank	TRX Knee Tuck	MC Flexion	MC Stable	TRX MC Flexion	TRX MC Stable
RA	54.432 ±28.56830	30.243 ±19.33583	46.836 ±18.46929	58.971 ±27.20219	32.705 ±14.87005	31.215 ±14.48322	53.386 ±21.02280	51.724 ±18.63611
EO	32.710 ±13.90748	45.184 ±16.93826	54.299 ±19.44308	92.544 ±38.08277	58.954 ±28.39561	68.083 ±25.73046	83.543 ±24.10233	94.515 ±29.86893
RF	5.342 ±9.27122	16.620 ±8.07645	18.436 ±7.15967	50.587 ±34.25227	14.856 ±8.31719	34.397 ±11.71938	43.350 ±17.23750	37.733 ±23.11894

Crunch = Traditional Abdominal Crunch
Plank = Traditional Plank
TRX Plank = Plank performed with both feet in the foot cradles of the TRX
TRX Knee Tuck = Plank performed with both feet in the foot cradles of the TRX in which both hips and knees were simultaneously flexed and extended.
MC Flexion= A mountain climber performed in which EMG data was collected as the right leg flexed and extended and the left leg acted as a stabilizer.
MC Stable = A mountain climber performed in which EMG data was collected while the left leg flexed and extended and the right leg acted as a stabilizer.
TRX MC Flexion= A mountain climber performed with both feet in the foot cradles of the TRX in which EMG data was collected while the right leg is flexing and extending.
TRX MC Stable = A mountain climber performed with both feet in the foot cradles of the TRX in which EMG data was collected while the left leg flexed and extended and the right leg acts as a stabilizer.

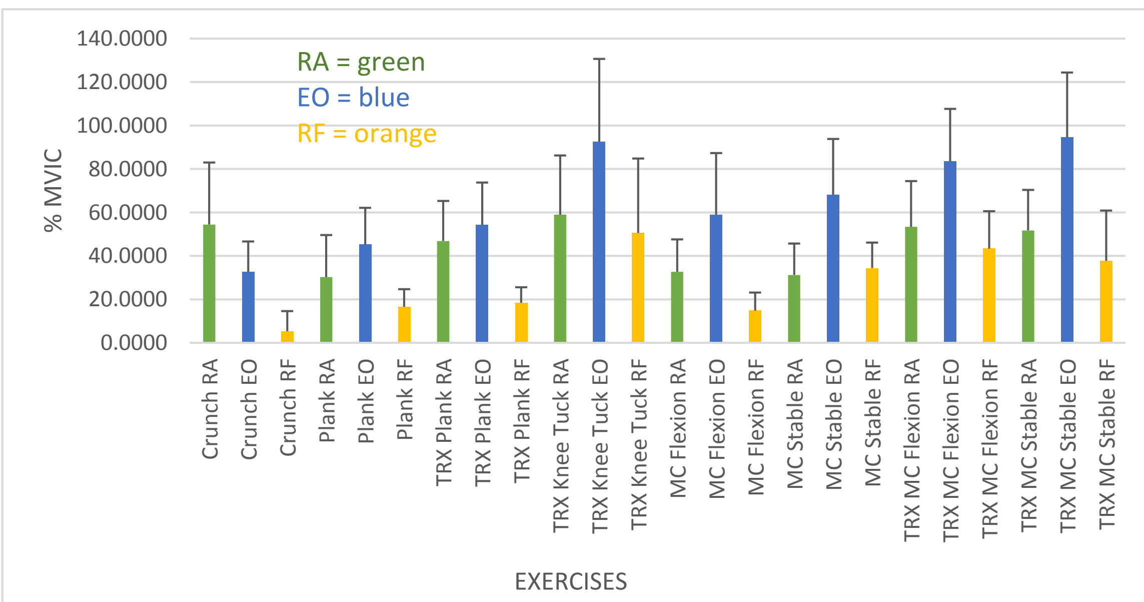

Figure 7. Comparison of the normalized EMG activity (%MVIC) of the RA, EO, and RF across the exercise trials. Refer to the results presented in the following sections for a description of the significant differences.

Interaction Between Exercise and Relative Recruitment

Rectus Abdominis

As depicted in Table 3 and Figure 8, the TRX knee tuck provided the highest %MVIC score for the RA (58.971 ± 27.20219) among the exercise conditions; the plank yielded the lowest value (30.2435 ± 19.33583). Pairwise comparisons revealed that the %MVIC scores for the crunch, TRX knee tuck, TRX MC flexion, and TRX MC stable were all significantly greater than that of MC flexion ($p < 0.05$). In addition, the scores for the TRX knee tuck, TRX MC flexion, and TRX MC stable were all significantly greater than that of the MC stable ($p < 0.05$). No other significant differences were noted.

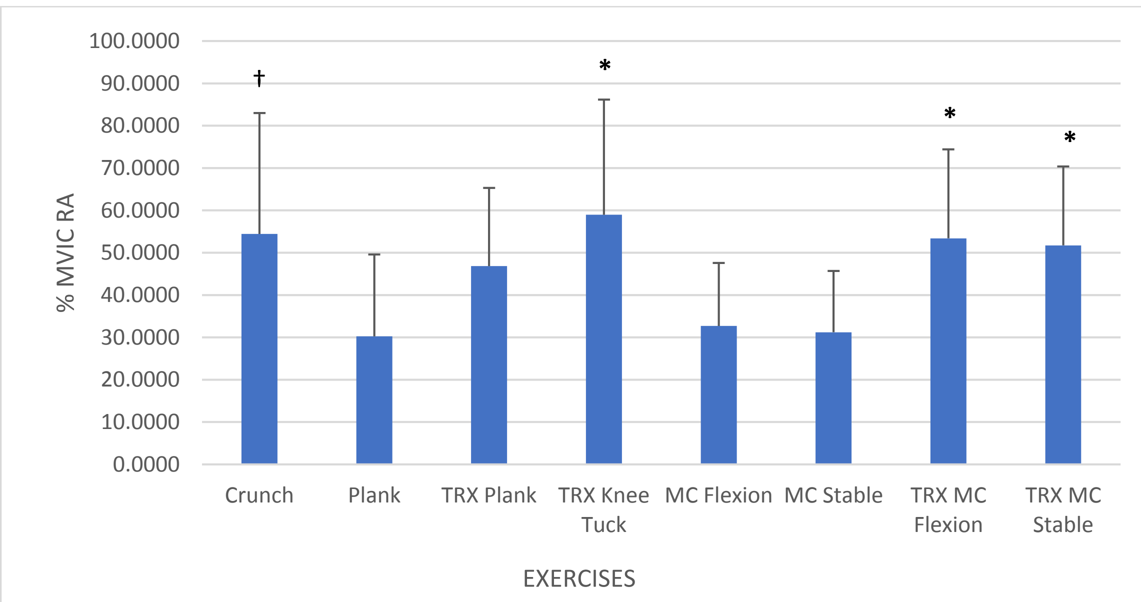

Figure 8. Comparison of the normalized EMG activity (%MVIC) mean RMS scores of the rectus abdominis among the various exercises.
*****TRX knee tuck, TRX MC flexion, and TRX MC stable significantly greater than MC flexion, and MC stable ($p < 0.005$).
†Crunch significantly greater than MC flexion ($p < 0.005$).

External Oblique

As presented in Table 3 and Figure 9, the TRX MC stable elicited the highest %MVIC score for the EO (94.5147 ± 29.86893); the lowest value was produced by the crunch (32.7102 ± 13.90748). Pairwise comparisons revealed that the %MVIC scores for the TRX knee tuck, MC stable, TRX MC flexion, and TRX MC stable were all significantly greater than that of the crunch ($p < 0.05$). The scores for the TRX knee tuck, TRX MC flexion, and TRX MC stable were all significantly greater than the plank ($p < 0.05$). In addition, TRX knee tuck and TRX MC stable were both significantly greater than the MC flexion ($p < 0.05$). Lastly, the TRX MC stable was significantly greater than the TRX plank and MC stable ($p < 0.05$).

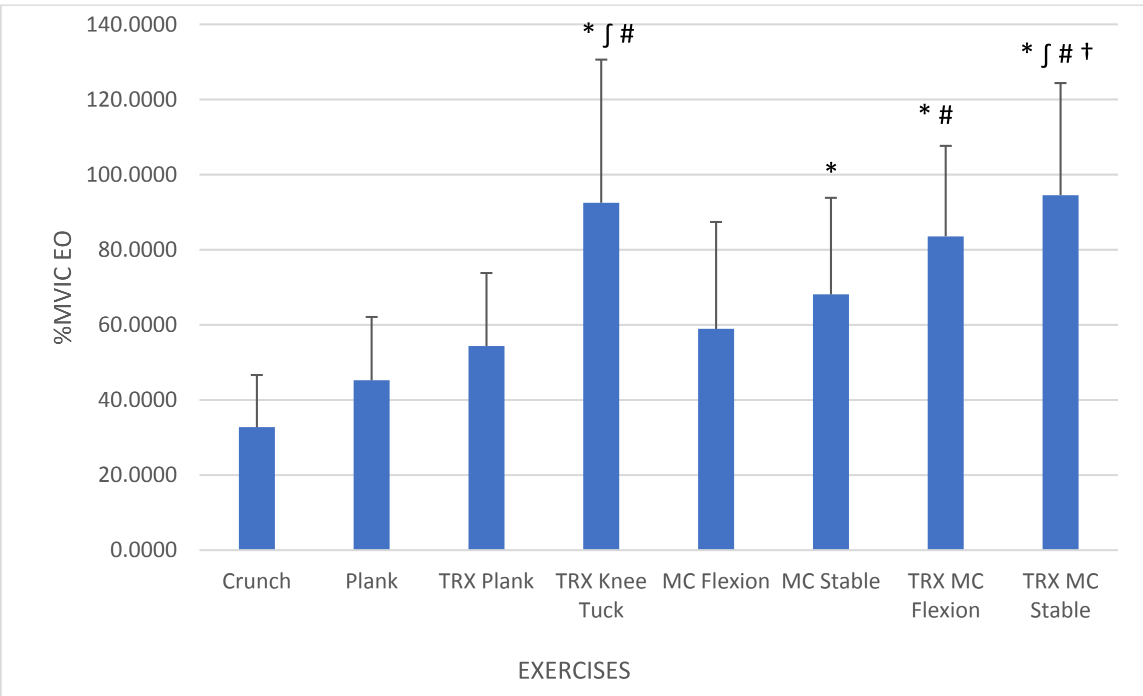

Figure 9. Comparison of the normalized EMG activity (%MVIC) mean RMS scores of the external oblique during the performance of the exercises.

*TRX knee tuck, MC stable, TRX MC flexion, and TRX MC stable significantly greater than crunch .. . . .. ($p < 0.05$).

#TRX knee tuck, TRX MC flexion, and TRX MC stable significantly greater than plank ($p < 0.05$).

∫ TRX knee tuck and TRX MC stable significantly greater than MC flexion ($p<0.05$).

†TRX MC stable significantly greater than TRX plank and MC stable ($p < 0.05$).

<u>Rectus Femoris</u>

As depicted in Table 3 and Figure 10, the TRX knee tuck elicited the highest %MVIC score for the RF (50.5873 ± 34.25227), whereas the crunch elicited the lowest (5.3415 ± 9.27122). Pairwise comparisons revealed that the %MVIC scores for the plank, TRX plank, TRX knee tuck, MC flexion, MC stable, TRX MC flexion, and TRX MC stable were all significantly greater than the crunch. The MC stable and TRX MC flexion were also significantly greater than the plank and MC flexion ($p < 0.05$). Lastly, the TRX MC flexion was significantly greater than the TRX plank ($p < 0.05$).

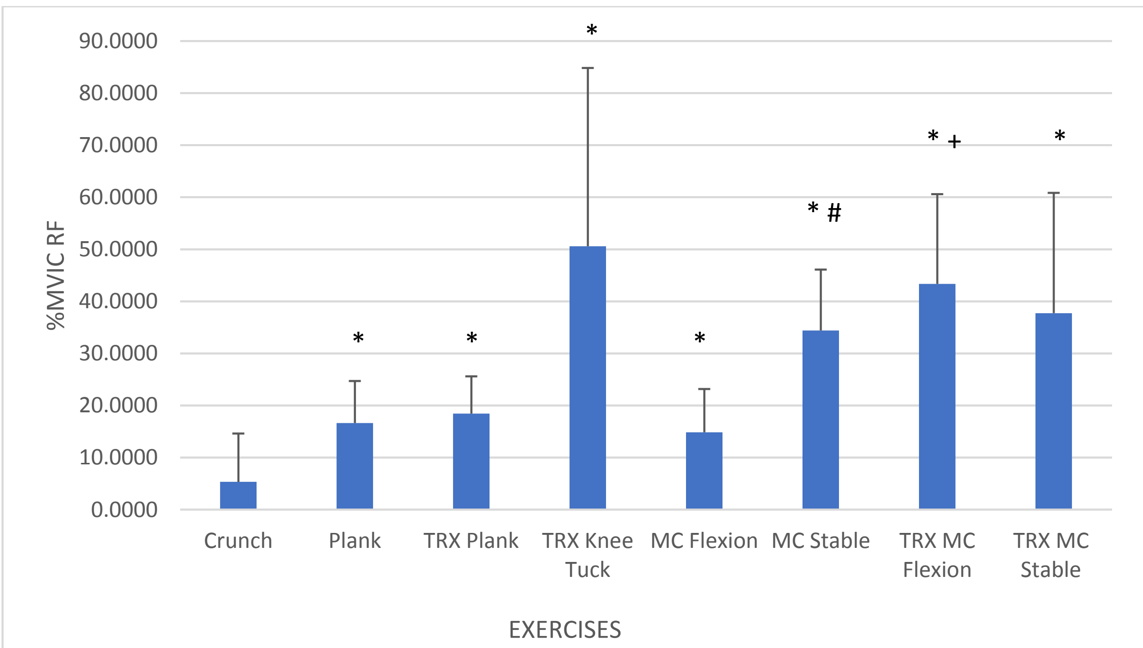

Figure 10. Comparison of the normalized (%MVIC) mean RMS scores of the rectus femoris during the performance of the exercises.
*Plank, TRX plank, TRX knee tuck, MC flexion, MC stable, TRX MC flexion, and TRX MC stable all significantly greater than crunch ($p < 0.05$).
#MC stable and TRX MC flexion significantly greater than plank, and MC flexion ($p < 0.05$).
+TRX MC flexion significantly greater than TRX plank ($p < 0.05$).

Relative Recruitment of the RA, EO, and RF Within the Performed Exercises

Crunch. As illustrated in Figure 7, the %MVIC value for the RA (54.432 ± 28.56830) was significantly greater than both, the EO (32.710 ± 13.90748) and RF (5.3415 ± 9.27122) ($p < 0.05$); the value for the EO was significantly greater than the RF ($p < 0.05$).

Plank. During the performance of the plank (Figure 7), the only significant difference in %MVIC scores was noted between the EO and RF, with the EO eliciting the higher value (45.1836 ± 16.93826) (vs. RF = 16.6202 ± 8.07645) ($p < 0.05$).

TRX plank. As illustrated in Figure 7, the %MVIC scores for the RA (46.8359 ± 18.46929) and EO (54.2990 ± 19.44308) exceeded that of the RF (18.4363 ± 7.15967) ($p < 0.05$). However, there were no significant differences between the RA and EO scores during this exercise.

TRX knee tuck. During the performance of the TRX knee tuck (Figure 7), the %MVIC value of the EO (92.5438 ± 38.08277) was significantly greater than both, the RA (58.9707 ± 27.20219) and RF (50.5873 ± 34.25227) ($p < 0.05$). There were no significant differences between the %MVIC scores of the RA and RF.

MC flexion. As depicted in Figure 7, the %MVIC score of the EO (58.9535 ± 28.39561) was significantly higher than both, the RA (32.7045 ± 14.87005) and RF (14.8559 ± 8.31719) ($p<0.05$). In addition, the RA score was significantly greater than the RF ($p < 0.05$).

MC stable. Similar to the performance of the MC Flexion, during the performance of the MC stable (Figure 7), the %MVIC score of the EO (68.0831 ± 25.73046) was also significantly greater than both, the RA (31.2147 ± 14.48322) and RF (34.3965 ± 11.71938) ($p < 0.05$). There was no significant difference between the RA and RF scores.

TRX MC flexion. The results' pattern presented above was also displayed during the performance of the TRX MC flexion (Figure 7), during which the %MVIC value of the EO (83.5431 ± 24.10233) was again significantly greater than both, the RA (53.3865 ± 21.02280) and RF (43.3502 ± 17.23750) ($p < 0.05$). As during MC stable, no significance was found between the relative recruitment scores of the RA and RF during this exercise.

TRX MC stable. Finally, and similar to the other mountain climbers, during the TRX MC stable the %MVIC score of the EO (94.5147 ± 29.86893) was significantly greater than both, the RA (51.7238 ± 18.63611) and RF (37.7335 ± 23.11894) ($p < 0.05$). There was no significant difference between the RA and RF values.

Muscle Main Effect

As indicated in Table 2, repeated measures ANOVA revealed a main effect for muscle. The latter is illustrated in Figure 11 in which, regardless of the exercise condition, the EO demonstrated a significantly greater ($p < 0.05$) relative recruitment (%MVIC) (66.229 ± 6.120) than the RA (44.939 ± 5.144) and RF (27.665 ± 3.417). The RA % MVIC score was significantly greater than the RF (27.665 ± 3.417) ($p <0.05$).

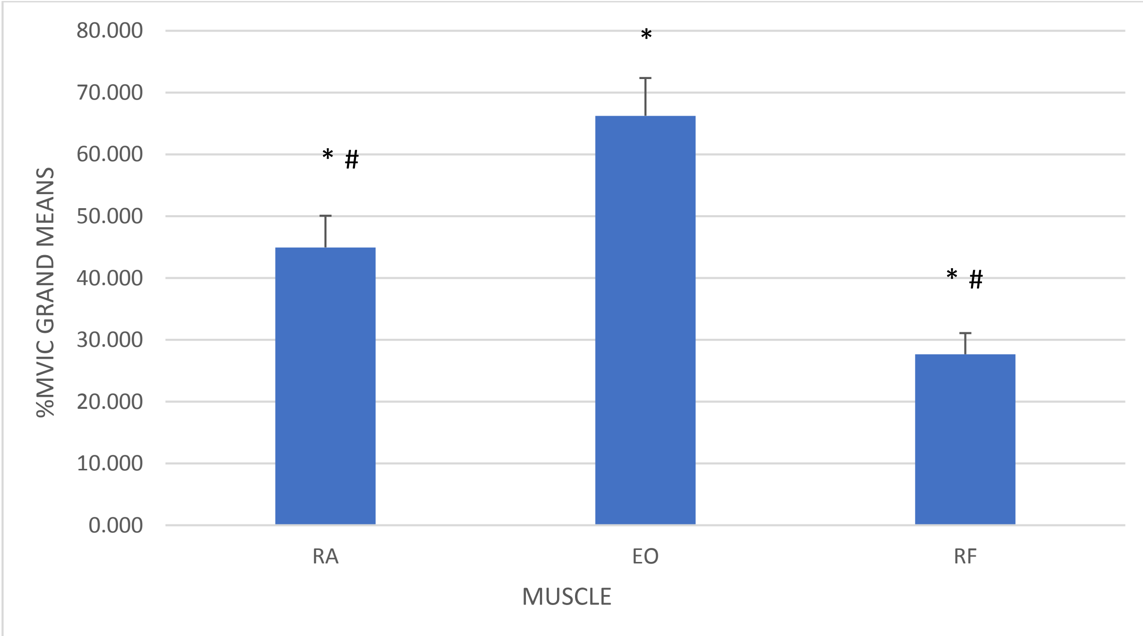

Figure 11. %MVIC Grand Means when collapsing for exercise.
*EO significantly greater than RA and RF ($p < 0.005$).
#RA significantly greater than RF ($p < 0.005$).

<u>Exercise Main Effect</u>

As indicated in Table 2, repeated measures ANOVA also revealed a significant main effect for exercise ($p < 0.001$). This main effect is illustrated in Figure 12 in which, regardless of muscle, the TRX knee tuck provided the highest relative recruitment (%MVIC) (67.367 ± 8.864). This value was significantly greater than the crunch (30.828 ± 3.909), plank (30.682 ± 2.631), TRX plank (39.857 ± 2.448), MC flexion (35.505 ± 4.218), and MC stable (44.565 ± 4.279).

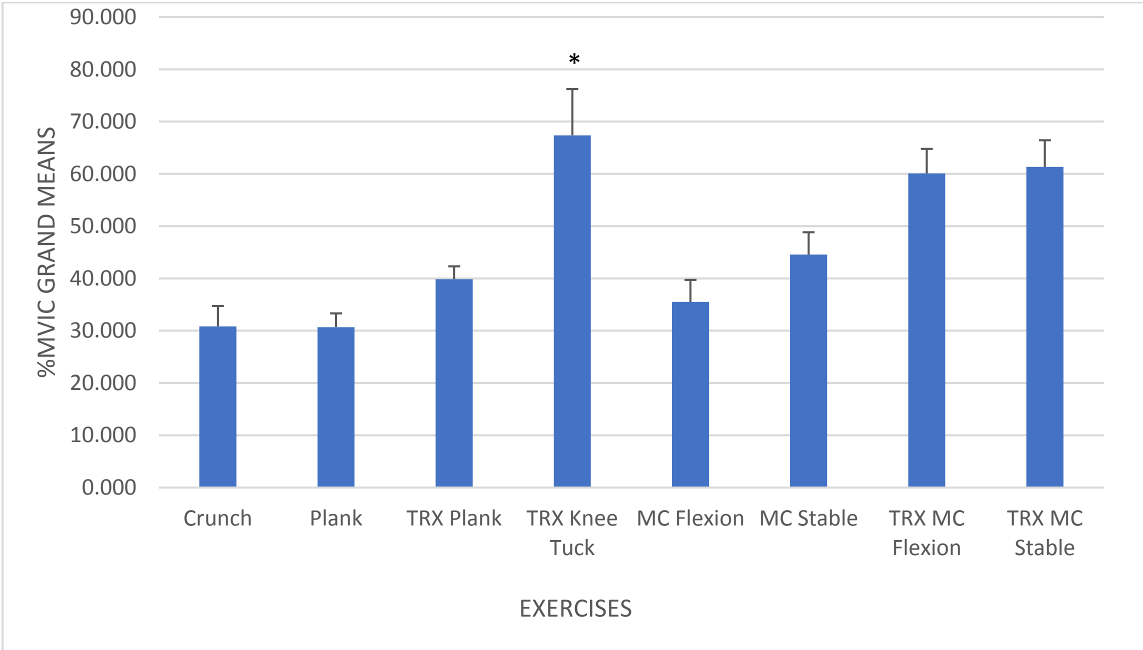

Figure 12. %MVIC Grand Means when collapsing for muscle.
*TRX knee tuck significantly greater than crunch, plank, TRX plank, MC flexion, and MC stable ($p < 0.005$).

CHAPTER 5: CONCLUSION

Discussion

The purpose of this study was to compare the relative recruitment of the RA and EO resulting from the performance of traditional abdominal crunches to that from planks performed with and without the use of a suspension trainer (TRX). Because these muscles (RA, EO) play a role as agonists and stabilizers during the aforementioned exercises we wanted to compare their relative contribution. In addition, we were interested in examining the relative recruitment of the RF among various plank conditions (i.e., traditional and suspended, with and without leg movement). The RF was of particular interest during these plank exercises because of its expected role as a hip stabilizer and antagonist of hip hyperextension.

We hypothesized that the crunch would induce the greatest relative recruitment of the RA and EO when compared to that of the plank and TRX plank. Our rationale was based on the fact that the RA is the main agonist of spinal flexion, which is the resulting motion during the crunch; during this exercise the EO assists the RA in spinal flexion. During the performance of the plank and TRX plank, the RA and EO are acting isometrically as spinal stabilizers (i.e., no dynamic engagement), hence, a lesser relative recruitment was expected from these muscles. As anticipated, the crunch elicited the highest RA relative recruitment (%MVIC) score (vs. plank and TRX plank) (Table 3); however, the differences among these exercises were not significant. Contrary to our hypothesis, the EO exhibited the greatest relative recruitment during the TRX plank, during which the EO is expected to act isometrically. Thus, the apparent instability inherent to the TRX plank requires an isometric stabilizing role by the

EO that exceeds its dynamic role as an assistor to spinal flexion. However, as was the case with the RA, the (%MVIC) scores for EO were not significantly different among the three exercises (crunch, plank, and TRX plank).

Our results agree with the findings of Schoffstall et al. (2010) who found no significant difference in the relative recruitment of the RA and EO between the abdominal crunch and TRX plank. It should be noted that Schoffstall et al. collected EMG data during isometric hold positions for both exercises (crunch, TRX pike) whereas we performed the crunch dynamically. In addition, Schoffstall et al. required subjects to perform the isometric plank while maintaining a pike position. Despite similarity in results, the difference between our methods and theirs makes comparison of the outcomes difficult.

To this author's knowledge, research investigating the dynamic recruitment of abdominal muscles during traditional crunches vs. their isometric recruitment while planking (traditional and suspended) is not existent. Given the novelty of our procedures, equivalent comparisons between our results and the published literature are very difficult. However, it is worth mentioning that Snarr et al. (2013, 2016) have reported %MVIC scores for the RA during dynamic crunches very similar to ours. For example, in the 2013 study the corresponding score for the RA was 52.00 (± 28.7), while that during the latter investigation (2016) was 52.09 (± 19.05). Therefore, in our investigation, the resulting %MVIC score for the RA (54.43 ± 28.57) may be interpreted as correct implementation of established EMG data collection protocols (MVIC procedures, exercise technique).

Regarding the relative recruitment (%MVIC) of the RA and EO during the performance of a traditional plank vs. the TRX plank, past studies (Byrne et al., 2014; Snarr & Esco, 2014) have found the relative recruitment of these muscles during the TRX plank to be significantly greater than during a traditional plank. Our results showed the same trend (i.e., %MVIC TRX plank > %MVIC traditional plank), but no significant difference. This trend was expected give the inherent midsection instability during the suspended (TRX) plank. It should be noted that Byrne et al. did not report the means and standard deviations of their results. However, Snarr and Esco (2014) reported %MVIC scores for the RA and EO during the traditional plank and TRX plank comparable to ours. For example, their %MVIC scores for the RA were 36.1 (± 28.1) and 55.1 (± 45.3) during the performance of the plank and TRX plank, respectively. Our plank %MVIC scores for the RA was very similar (30.24 ± 19.34) but our TRX plank score was lower (46.84 ± 18.47). For the EO, the %MVIC score during the performance of the plank (Snarr & Esco, 2014) was 42.0 (± 21.6), and 63.5 (± 47.1) for the TRX plank. In our investigation, the %MVIC score for the EO during the plank was also similar to that of Snarr and Esco (2014) (45.18 ± 16.94), whereas our %MVIC score for the EO during the TRX plank was lower 54.30 (± 19.44).

A possible explanation for the noted difference in muscle recruitment between Snarr and Esco (2014) TRX plank scores and ours is the participant's experience with the TRX. Snarr and Esco (2014) did not report the participants' previous experience with the TRX nor did they require subjects to become familiar with its use. In our study, eight out of the 11 participants reported regularly performing planks with the TRX. In addition, our subjects participated in a familiarization session before data collection in which planks with the TRX device were practiced. The combination of regular practice and familiarity with the study's protocol may have made our subjects better qualified to handle the midsection instability imposed by the TRX plank; thus, the lower %MVIC scores.

It is worth noting that the crunch produced significantly greater (%MVIC) scores for the RA than MC flexion (i.e., mountain climber plank) (Table 3). This finding conflicts with the study performed by Gottschall et al. (2013), who found greater relative recruitment of the RA during a diagonal mountain climber plank (vs. crunch). This inconsistency may be explained by possible increased spinal flexion (thus, greater RA recruitment as an agonist) during the performance of the diagonal mountain climber plank as the knee is brought to the opposing elbow. In contrast to the mountain climber plank performed in our investigation (MC flexion), the knee was brought directly toward the chest with minimal vertebral flexion. Therefore, during MC flexion the RA acted as a spinal stabilizer as opposed to spinal flexion agonist.

In agreement with Gottschall et al. (2013), the relative recruitment of the EO during the performance of the MC stable was significantly greater than that of the crunch. Because during the crunch spinal flexion occurs in the sagittal place, torso rotation is unlikely, and thus, the expected engagement of the EO would be less. During the MC stable, the on-going instability of the torso in the transverse plane (lateral deviation) prompted by the alternating leg motion may explain the greater EO scores. Thus, it is possible that in situations where there is instability of the spine and pelvis, the EO is recruited as an agonist to prevent lateral deviation and as an assistor to the RA in torso stability.

Additionally, we hypothesized that the TRX knee tuck, TRX MC flexion, and TRX MC stable would result in the greatest relative recruitment of the RA and EO when compared to that resulting from the other exercises. The reason is that during the performance of these suspended exercises, the RA prevents spinal hyperextension while at the same time acting as an agonist of (the minor) spinal flexion resulting the dynamic nature of the exercises. The high activation of the

EO during these exercises may be due to its dual role. The EO acts as an assistor muscle to the RA to prevent spinal hyperextension. It also acts as an agonist to avoid lateral deviation of the spine, since spinal rotation is one of the main actions of the EO.

To this author's knowledge, no research has been performed on the relative recruitment of the abdominals during the performance of a suspended (TRX) plank variation where the lower limbs are engaged dynamically. Our results indicated that the relative recruitment of the RA during the performance of the TRX knee tuck and TRX MC flexion/stable was significantly greater ($p < 0.05$) than that of the traditional mountain climber planks (MC flexion, MC stable) (Table 3). In addition, the %MVIC scores for the RA were greater than those corresponding to the plank and TRX plank; however, the differences were not significant. Lastly, the TRX knee tuck was the only exercise in which the %MVIC score from the RA exceeded that of the crunch (Table 3).

Additionally, the relative recruitment of the EO during the performance of the TRX knee tuck, TRX MC flexion, and TRX MC stable was significantly greater ($p < 0.05$) than that of the crunch and plank. The relative recruitment of the EO during the TRX MC stable was also significantly greater than the TRX plank ($p < 0.05$).

Even though our hypothesis (RA and EO scores during TRX knee tuck, TRX MC flexion, and TRX MC stable > everything else) did not hold true across every exercise condition, it did confirm that instability brought by the suspension trainer (TRX) would produce increased activation of the abdominal muscles. This finding is consistent with previous research (Lehman, Hoda, & Oliver, 2005; Snarr et al., 2014), which found a significantly greater (%MVIC) recruitment of the abdominals with the performance of instability devices compared with traditional methods. The effectiveness of instability in inducing greater recruitment was also noted when the latter was compared between exercises while collapsing for muscle. As illustrated in Figure 12, the TRX knee tuck (67.38 ± 8.86) produced significantly greater recruitment ($p < 0.05$) than the crunch (30.828 ± 3.909), plank (30.68 ± 2.631), TRX plank (39.857 ± 2.448), MC flexion (35.505 ± 4.218), and MC stable (44.565 ± 4.279).

As expected, because the lack of hip flexion during the crunch, this exercise elicited the lowest %MVIC score for the RF among all the exercise conditions ($p < 0.05$). This low activation of the RF during the crunch is consistent with Schoffstall et al. (2010), who compared the crunch to a suspended pike (plank variation) and Snarr et al. (2016), who compared the crunch to a towel pike (plank variation). The higher recruitment of the RF during these plank variations may be explained by the needed engagement of the RF for the sake of offsetting the gravitationally-induced tendency to extend the hip.

It was expected that MC stable would produce higher activation of the RF than MC flexion. Our rationale was based on the fact that prone hip flexion is not done against gravity, making the role of the RF as a hip stabilizer more pronounced during MC stable. The noted %MVIC scores for the RF between MC stable and MC flexion (Table 3, Figure 10) validate our prediction. The above trend was not observed when comparing TRX MC flexion to TRX MC stable. Indeed, the %MVIC score for TRX MC flexion was greater (although not significant) than TRX MC stable. Our explanation for this is as follows. During TRX MC flexion, as the right hip is being flexed, the angle of the strap that extends from the foot cradle becomes more acute ($< 90^0$). As this happens, a retarding force vector oriented inferiorly along the subject's longitudinal axis will add resistance to hip flexion. Thus, a more pronounced engagement from the RF would be needed to induce the required hip flexion during TRC MC flexion.

According to our results, when doing mountain climbers, the engagement of the RF becomes significantly augmented, especially in the phase of the exercise in which the RF is flexing the hip. In our study, the RF acted as a hip flexor during the performance of MC flexion and TRX MC flexion. As expected, the suspended condition (TRX MC flexion) produced a significantly higher %MVIC score (vs. MC flexion) ($p < 0.05$) (Table 3, Figure 10). During TRX MC flexion, the RF is needed to promote hip flexion and antagonize knee flexion and hip hyperextension. The role of antagonist may be explained by the fact that as the feet are in the foot cradles during TRX MC flexion, the cradles will apply an upward force at the ankles that will tend to flex the knees. In addition, gravity will apply a downward force on the subject that will tend to hyperextend the hip. These tendencies to flex the knees and hyperextend the hips will be compensated by the RF, which is both, a knee extensor and a hip flexor. Hence, its heightened recruitment while doing TRC MC flexion was expected. In the MC flexion condition, the lack of suspension diminishes the forces inducing knee flexion and hip hyperextension, along with the degree of RF recruitment needed to compensate these. Lastly, the above-mentioned retarding force effect may have contributed to the higher %MVIC scores during the TRX MC flexion exercise (vs. MC flexion).

The above trend was not observed when comparing MC stable and TRX MC stable (Table 3, Figure 10) in which the RF was expected to play the role of hip stabilizer (while the right leg was extended). Apparently, while the right leg remains extended, the need to offset knee flexion and hip hyperextension while suspended (TRX MC stable) were not as great as originally thought. Thus, the similarity in %MVIC scores for the RF between MC stable (34.40 ± 11.72) and TRX MC stable (37.73 ± 23.12).

Since no study has published results for %MVIC scores for the RF during the performance of the plank and TRX plank, comparison of our results to published evidence is not possible at this time. However, during the performance of the plank, TRX plank, and TRX knee tuck, we found that the %MVIC scores for the RF followed a pattern similar to the %MVIC scores for the RA and EO (Table 3, Figure 10). The plank had the least RF activation (16.62 ± 8.08), followed by the TRX plank (18.44 ± 7.16), and the TRX knee tuck (50.59 ± 34.25). The latter score proved to be the highest for the RF among all exercise conditions. This pattern agrees with Neumann (2010), who reported that when the abdominal muscles are strongly contracted, the RF acts synergistically to help maintain a neutral pelvis, that is, offset the tendency to hyperextend the spine.

In addition, the high recruitment of the RF during the TRX knee tuck may be explained by its role in resisting knee flexion (from the upward force induced by the foot cradles), and its role as agonist of hip flexion as the knees are brought toward the chest. It should be noted that like in the TRX MC flexion, during the TRX knee tuck the RF must work against a retarding force vector that resists hip flexion. Since during the TRX plank there is no hip flexion, the RF only maintains a neutral pelvis (prevent hip hyperextension) and keeps the knees extended. The inclusion of the RF during the regular plank is diminished even more because without suspension, the upward force tending to flex the knees is not as great.

Among the three muscles tested (RA, EO, RF), the EO demonstrated the greatest relative recruitment (%MVIC) across all the plank conditions (traditional and suspended). This was surprising to the authors since it was hypothesized that the relative recruitment of the RF would be greatest during the suspended planks, especially those with lower limb movement. This trend of high activation of the EO may be explained by its role as a spine stabilizer in the sagittal and transvers planes for the sake of preventing spine hypertension and deviation, respectively. This trend agrees with the work by Hildenbrand and Noble (2004) who made the case that exercises with a high degree of difficulty resulting from hip motion or instability result in high activity of the EO and increased activity of the RF, and fail to isolate the abdominal muscles (RA). However, we found that the RA was recruited to a level comparable to the crunch during the TRX knee tuck, TRX MC flexion, and TRX MC stable. These results indicate that the suspended planks with leg movement can provide adequate stress to the abdominal muscles (RA, EO) along with high recruitment of the RF.

Future Investigations

Future investigations may wish to compare the crunch to plank variations while EMG data is collected during the concentric and eccentric phase of the for the sake of a more complete evaluation of such exercise. Also, since this is the first study to examine traditional and suspended plank variations with lower limb movement, future investigations evaluating the relative recruitment of engaged muscles, may wish to perform the mountain climbers (traditional and suspended) at a pace closer to those encountered in real-life settings (e.g., athletic facilities, gyms).

Conclusions

Based on the results obtained and the limitations associated with this investigation, we conclude that:

1. For the sake of inducing recruitment and thus development of the abdominal muscles (RA, EO), the crunch, plank, and TRX plank seem to provide equivalent results.
2. For the sake of inducing the highest recruitment of the RA during planking with lower limb movement, the suspended variations would seem the better choice.
3. For the sake of recruiting, and thus developing the EO, the performance of plank variations that elicit hip instability is preferred. Amongst these variations the suspended versions may be the better choice.
4. When using the mountain climber exercise with the intent of targeting the RF, the suspended version may be the preferred method.
5. For individuals wanting to develop the abdominal musculature, all plank variations (traditional and suspended) seem to be effective.
6. The TRX knee tuck induced the greatest amount overall muscle activity, thus in those with tolerance for this exercise, it may be the most efficient choice for midsection conditioning.

In closing, the comparison of the relative recruitment scores of the RA, EO, and RF during the performance of planks to that of crunches may help establish the prescription parameters (e.g., repetitions, time held) needed to induce equivalent training loads. We felt that these comparisons were needed given the recent surge in the popularity of planks and suspended planks (and associated variations). Significant differences in the relative recruitment of the RA, EO, and RF were observed since these exercises require varying demands of the abdominal musculature, range of motion, and spinal stability (Snarr et al., 2016). It is important for professionals in the fitness and rehabilitation industry (including sport coaches) to make evidence-based decisions regarding the prescription of abdominal strengthening exercises. By establishing relative recruitment patterns among traditional crunches and planks (traditional and suspended), strength coaches, fitness and rehabilitation specialists may be able to better design an abdominal strengthening program that is appropriate for individuals with varying needs and fitness levels.

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APPENDICES

APPENDIX A: SELF-ADMINISTERED PRE-EXERCISE SCREENING QUESTIONNAIRE

Date _______________

Name ____
Last First MI

Address ____
Street Apt #

____
City State Zip Code

Contact ____
Home Phone Cell Phone Email

Date of Birth ______________ Age __________ Gender _____ Ht _________ Wt__________
MM/DD/YYYY

Occupation ____

Emergency Contact ____

Do you exercise regularly? ________ If so, how often? ____________________________

____

Do you regularly perform abdominal crunches and planks? Y / N

If so, how often?____

Do you consider yourself fit? __________ If so, why? ________________________________

APPENDIX B: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ______________________

SIGNATURE OF PARENT ____ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

APPENDIX C: INFORMED CONSENT FORM FOR HUMAN SUBJECTS

California State University, Fresno

Title of Thesis: ELECTROMYOGRAPHICAL COMPARISON OF THE ABDOMINAL CRUNCH TO A PLANK PERFORMED WITH AND WITHOUT A SUSPENSION TRAINER
Principal Investigator: Jacobo Morales, Ph.D. (Professor, Department of Kinesiology)
Co-Investigator: Sarah Pierce (B.S., M.A. in Exercise Science in progress)

The purpose of this study is to compare the relative recruitment of the RA, EO, and RF during the performance of 6 different exercises, the traditional abdominal crunch, a traditional plank, a plank performed with a suspension trainer (TRX), a mountain climber plank (traditional and suspended) and a suspended plank with a knee tuck. The muscles relative recruitment during the above exercises will be established via electromyographic (EMG) analyses. You were selected for possible participation in this study based on your ability to adequately perform the above-mentioned exercises. Your potential inclusion as a participant will also require that your current body fat percentage doesn’t exceed 25% (for women) and 15% (for men). Your percent body fat will be measured using the BOD POD. In addition, your waist circumference will be measured. Your waist circumference cannot exceed 35.5 inches (for men) and 32.5 inches for women. If you opt to participate, you will be required to attend the Human Performance Laboratory (HPL) located in the South Gymnasium, room 139 on two separate occasions.

During the first visit to the HPL, you will give informed consent, be introduced to the various equipment that will be used for data collection and receive instructions regarding the experimental protocol. The investigator will demonstrate the 6 exercises to be performed for this study and you will then be asked to demonstrate proper execution of these. Once the investigator is satisfied with your ability to perform the exercises, your height (m), mass (kg), age (yr), and body fat percentage will also be measured. Next, you will be instructed on how to perform a maximal voluntary isometric contraction (MVIC) of your rectus abdominis (RA), external oblique (EO), and rectus femoris (RF).

The MVIC of your RA will be done by having you assume a supine position on a padded mat with your knees flexed to 90° and your arms crossed over your chest. You will then attempt to perform a maximal-effort sit-up while the investigator provides a matched resistance at the shoulders to prevent you from moving upward. The MVIC for the EO will be accomplished by having you assume a side-lying position with your hips and legs fixated to a table. Next, you will attempt to perform a maximal-effort lateral spinal flexion while the investigator provides a matched resistance at your shoulder. For the RF, you will be asked to extend your right knee as forcefully as possible (sitting position; both legs hanging) while the investigator provides a matched resistance at the right ankle. You will be asked to hold each of three MVIC procedures for 6 seconds. For each muscle, you will be asked to perform two MVIC efforts separated by a self-determined recovery period. All six MVIC efforts will require maximal effort but are unlikely to cause any muscle soreness given their isometric nature. You will be asked to refrain from any strenuous physical activity for at least 24 hours before the experimental session.

During the second (experimental) session EMG data will be collected from the RA, EO and RF during the performance of MVICs, crunches, and planks. The latter will require bipolar electrodes to be placed on your right RA, left EO and right RF. For each muscle, the corresponding ground electrode will be placed on various aspects of anterior (front) midsection. Before electrode placement the respective skin sites will need to be shaved, abraded and cleansed with rubbing alcohol; this may result in some minor and short-lasting irritation.

Before skin preparation and electrode placement, you will be required to perform a standardized warm up presented in a separate handout. Once you perceive that you are ready to start the experimental trial, the skin sites will be prepared and the electrodes will be placed. You will then perform two trials of MVICs for the three muscles in the same manner as in the familiarization session, but this time EMG activity of the three muscles will be recorded. Following MVICs, you will then perform the 6 exercises (referenced above). The order of the exercises to be performed will be randomly selected. The name of the exercises will be written on a small piece of paper and placed in a hat. You will then select the order of the exercises to be performed by pulling a paper out of the hat. Three minutes of rest will be given between each exercise to allow for adequate recovery. The abdominal crunch will be performed for five repetitions at a rate set by a metronome of 4 seconds per repetition (2 seconds concentric, 2 seconds eccentric). The plank and suspended plank (TRX) will each be held for 15 seconds. EMG activity of the RA, EO, and RF will be recorded during the respective time periods.

Any information that the investigators obtain during your participation in this study that could be identified with you will be kept confidential and never be disclosed without your consent. A copy of your data may be requested at any time. By signing this document, you are consenting to allow the results of this study to be made public via submission to scientific journals and presentations at professional conferences. The results of this study are intended to expand the body of scientific knowledge in regards to relative recruitment of the RA, EO, and RF during the performance of the previously mentioned midsection exercises.

Benefits that may come from participation in this study include an improved understanding of RA, EO and RF relative recruitment during the performance of different midsection exercises. This may help you or your coaches better prescribe exercises for a midsection training regimen. In addition, you will be provided with a free body fat % assessment.

Potential risks of participating in this study include muscle ache, muscle soreness, and injury from incorrectly performed abdominal crunches and planks and suspended planks (TRX). Additionally, some limited duration skin irritation from shaving and abrading electrode placement sites is possible.

Whether you consent or decline to participate in this study, your decision will not influence your future relationship with Fresno State. If you opt to volunteer, you may withdraw consent at any time and cease involvement without repercussions. The Committee on the Protection of Human Subjects at Fresno State has given approval of these methods. This committee may be contacted at (559) 278-2985.

If you have any comments or questions you may contact Dr. Jacobo Morales at (559) 278-5168 (jacobom@csufresno.edu) or me, Sarah Pierce, at (209) 658-1564 (saragray28@mail.fresnostate.edu). You will receive a copy of this document for your own records.

BY SIGNING ON THE LINE BELOW YOU ARE PROVIDING YOUR CONSENT TO PARTICIPATE IN THIS STUDY AND UNDERSTAND THE INFORMATION PRESENTED ABOVE.

______________________________ ______________________________

Date Signature

______________________________ ______________________________

Signature of Witness Signature of Investigator

APPENDIX D: STANDARDIZED WARM UP

1) 5-minutes of cycling on a Monark cycle ergometer at a self-determined work-rate
2) 15 trunk twists each way
3) 15 lateral trunk flexions each way
4) 15 alternating hip flexor stretches
5) 5 sitting upper thoracic stretches
6) 6-8 full sit ups
7) one 15 second plank