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Agonist and Stabilizer Muscle Activity during a Push Up on Unstable Surfaces

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AGONIST AND STABILIZER MUSCLE ACTIVITY DURING A PUSH UP ON UNSTABLE SURFACES

by

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ABSTRACT

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A recent trend among fitness professionals is to have clients perform resistance exercises on unstable equipment. Anecdotally, this is done with the intent that stabilizing and agonist muscles are more active while doing certain exercises on unstable surfaces. However, there are limited data as to whether or not this is the case and no studies have investigated muscle activity while doing the same exercise on surfaces that offer different levels of stability. Therefore, the purpose of this study is to measure electromyography (EMG) during push up exercise performed on unstable surfaces as well as on the ground. Surface EMG was measured at 6 muscles (Pectoralis Major, Anterior Deltoid, Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, External Oblique) while participants performed push ups on 3 different surfaces: ground, stability ball, suspension trainer. A repeated measures analysis of variance (ANOVA) was used to compare average and root mean square (RMS) EMG across three repetitions between surface conditions for each muscle. A Sidak planned main effects multiple comparison was used to compare differences between conditions. For each muscle, average EMG and RMS EMG was influenced by surface the push ups were performed on ($p<.05$). The suspension training system showing increased muscle activity in four of the measured muscles (Tricep

Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique); the ball showing increased EMG in the Pectoralis Major; and the ground showing increased EMG for the Anterior Deltoid. Doing push ups on unstable surfaces results in an increased muscle activity of stabilizing muscles. Furthermore, the type and level of stability of the surface influences muscle activity.

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CHAPTER 1

INTRODUCTION

There are many options available to provide an overload to a muscle. Recently, it has become common to perform strength training exercises on unstable surfaces. For example, fitness facilities provide stability balls, 'both sides up' (BOSU) balls, inflatable discs and other unstable surfaces that a client would stand on while doing some type of exercise. Anecdotally, it is thought that by performing exercise on an unstable surface that the exercise becomes more demanding and therefore the exercise is more efficient at providing an overload response to targeted muscles as well as ancillary stabilizing muscles (e.g., abdominal muscles).

There may be some evidence that this hypothesis is reasonable. For example, it has been shown that there is more activity of the Medial Deltoid while performing a bench press using free weights vs. a Smith machine (McCaw, 1994; Schick, 2010). Also, it has been reported that the Gastrocnemius, Biceps Femoris, Vastus Medialis were more active while performing a squat using free weights vs. a Smith machine as well(Schwanbeck, 2009). This makes sense because a machine is designed to isolate recruitment of agonist muscle(s) whereas there are greater degrees of freedom during free weights. The greater degrees of freedom means that stabilizing muscles must be recruited in order for the exercise to be completed successfully.

Strength gains are attributed to both increases in muscles cross-sectional area and improvements in neuromuscular coordination (Baechle, 2000). Behm (1995) reported that neural adaptations play the most important role in strength gains in the early stages of a resistance training and has hypothesized that using free weights create instability which an increase in the body's neuromuscular response. The result would be a greater neuromuscular coordination compared to using machine based exercise which controls the degrees of freedom. This line of thought has been extended to increasing the instability of an exercise.

Unstable surface training (UST) in a push up on a stability ball has been shown to increase muscle activity of the abdominal muscles and other synergist muscles (Beach, 2008; Freeman, 2006; Lehman, 2006; Mori, 2004). Although it is not clear if increase muscle activity will yield greater strength training results, it does make sense that there is a link between a greater stimulus (i.e., greater activity) and training response. It is also understandable, therefore, that new equipment is being made available to increase instability with the idea that this will lead to greater performance gains. For example, another UST device that is the TRX suspension training (FitnessAnywhere.com San Francisco, CA). Suspension training systems appear to increase instability more than stability ball training and could possibly increase muscular activity of stabilizing muscles (e.g., Rectus Abdominus) during an exercise such as a push up. This may not be the case since the challenge of performing a push up on an unstable surface (stability ball or suspension training system) could reduce the number of total repetitions that can be performed compared to the number that can be completed on a stable surface (i.e., ground). Therefore, the purpose of this study is to determine if the level of instability of a surface influences muscle activity of key agonist and key stabilizing muscles during a push up exercise. The surfaces of interest were the stability ball, suspension trainer, and ground.

Null Hypothesis

There is no difference in Electromyography (EMG) when doing a push up on the ground, a stability ball, or a suspension training system at the Pectoral Major, Anterior Deltoid, Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique muscles.

Research Hypothesis

There are significant differences in EMG when doing a push up on the ground, a stability ball, and a suspension training system at the Pectoral Major, Anterior Deltoid, Tricep Brachii, Latissumus Dorsi, Rectus Abdominus, and External Oblique muscles.

Definitions

Stable surface- A firm/rigid surface on which exercises can be performed, for example, the floor or bench.

Unstable suface- A labile/moving surface in which exercises can be performed. Some examples include stability balls, BOSU balls, medicine balls, balance boards.

BOSU ball- stands for "both side up" ball. It is a half of a stability ball connected to a ridged platform (Aronovitch, 2008)

Stabilizer muscles- The muscles of the body that act to stabilize one joint so a desired movement can be performed in another joint.

Rate coding- The rate at which motor units are recruited. (Baechle, 2000)

TRX Suspension Training- A unstable surface training product that creates instability by balancing on straps with handles that are anchored over head, much like gymnast rings. (Quelch, 2009)

Smith Machine- A barbell that is fixed within guided steel rails that only allows for vertical movement.

Average EMG- Average Rectified Value- The mean amplitude of the absolute value of EMG activity within a defined window.

Root Mean Square (RMS) EMG- The square root of the mean of all the acquired values of EMG activity within a given widow of data

Limitations

- Experience was not controlled and that could have influenced muscle activity since novel tasks tend to have more activity.
- All subjects were male and it is not known if the results are applicable to females.
- All subjects had at least one year of resistance and were strong enough to perform pushups on the unstable surfaces. Subjects were excluded if they could not complete the protocol.

CHAPTER 2

LITERATURE REVIEW

Stability has become an important factor when designing an exercise program. During the 1980's health clubs and exercise facilities became very interested in fixed range of motion equipment. This equipment was designed with safety in mind. Making exercise safer, simpler, and more user-friendly became the priority. But one of the criticisms with this equipment was that it eliminated using potential stabilizing muscles by having the user sit or stand in a fixed position while doing the exercise. When in a fixed position, like when an exerciser is using a machine that follows a specific range of motion, many muscle groups that normally stabilize the body are not needed and therefore not exercised. So the exerciser does not perform the movement in the way when performed in a free, gravity based, and unrestricted manner. With the use of free-weights, there is an added risk of losing stability when the body's center of gravity moves away from or outside the base of support. Normally stabilizer muscles contract to compensate for such imbalances and maintain stability. McCaw and Friday (1994) tested 5 healthy male subjects who performed at 60% and 80% of their one repetition max (1RM) on a bench with free weights and on a machine bench press with fixed guided range of motion. They found that doing a bench press using free weights yielded more EMG than doing the bench press on the bench press machine; and that muscle activity significantly increased when the participants used free weights compared to the machine weights, especially at lower intensities. This suggests that having a non-restricted range of motion will allow for more muscle activity in those muscles used for stability. Similarly, Schick and colleagues (2010) found that the anterior deltoid muscle's EMG was significantly greater when executing a bench press with free weights when compared to the Smith machine. This further suggests that a fixed range of motion is inferior to training with free weights because a free weights force the body to stress and coordinate more stabilizer, and synergist muscle groups. This is also seen in the lower body with squats. In a study by Schwanbeck and colleagues (2009) they compared six healthy, trained male subjects in a electromyographic assessment of the lower leg muscles when performing squats with a free weight barbell and on the Smith machine. They found that the free weights had a 43% higher EMG than the Smith machine. The free weights trial when compared to the Smith machine had significantly higher percentages of EMG in the gastrocnemius (34%), biceps femoris (26%), and vastus medialis (49%.) Sale (Sale, 1988) concluded that more muscular activity would lead to more neural muscular rate coding and increased strength in the untrained muscle. Therefore if stability is decreased, there are increased gains in muscle activity. The question arises, would performing exercises on unstable surfaces (stability balls, wobble boards, bosu ball, inflatable discs, etc.) give a greater stimulus and increase the benefit of the exercise?

Unstable Surfaces

The literature on UST, such as exercise balls and suspension training, is mixed. Vera-Garcia, Grenier, and McGill (2000) studying eight healthy male subjects, showed that using EMG of the abdominal muscles while performing abdominal curls on a stability ball produce a higher percentage of the subject's maximal voluntary contraction (MVC) in Rectus Abdominus and External Oblique muscles compared with the same exercise done on the floor. When the subjects performed the standard curl up exercise on the ground, their Rectus Abdominus and External Oblique muscles contracted at 20% and

5% of their MVC; but when they performed the exercise on a stability ball, their Rectus Abdominus and External Oblique muscular activity increased to approximately 55% and 20%, respectively. They postulated that the observed increase in muscle activity is most likely due to the increased requirement of spine stability and whole body stability to reduce the threat of losing balance and falling. Therefore the increase in muscle activity could be in efforts to stay in balance. Using a stability ball to do sit ups change both the level of muscle activity and the way that they are used to stabilize not only the spine, but the whole body as well. With this high demand on the motor control system, muscles can be stimulated much more; which would be advantageous for certain stages of rehabilitation treatment programs or to maximize neural strength gains.

Using EMG, Cosio-Lima and associates (2003) studied 15 female subjects who trained for 5 weeks on the stability ball and compared the results to another 15 females who trained on the floor. They found that in torso balance and trunk muscles there were greater changes in the 15 women that trained using a stability ball than the 15 women that trained on floor. Cosio-Lima showed the group that trained with UST had significantly higher mean changes muscle activity (170.80 mVs. in trunk flexors and 83.07 mVs. in trunk extensors) than the control group (-55.73 mVs. in trunk flexors and -30.87 mVs. in trunk extensors.) The subjects in the UST group also displayed significant increase in single leg balance tests on both the dominant and non-dominant leg. Not only do we see an increase in EMG from pretest to posttest, but they found an improvement in a performance measure of static balance

Behm colleagues (2002), used EMG to evaluate muscle activity in 8 male subjects examined leg extensions on and off the stability ball. They found that when the subjects performed leg extensions, while agonist and antagonist muscles were measured, there was a decrease in the activity of the prime movers, but an increase in the antagonistic muscles. “Unstable [condition testing the] quadriceps and PF (plantar flexors) activation averaged 44.3 and 2.9% less than activation under stable conditions. Unstable antagonist/agonist ratios were 40.2 and 30.7% greater than the stable ratios in the LE (leg extensors) and PF (plantar flexors) protocols, respectively.” With a decrease in force output in the prime movers, there was a substantial increase in muscle activity in the antagonist muscles. The problem is this could decrease the primary training stimulus of an exercise if the agonist muscles can produce less force on an unstable surface. This is an intriguing finding since there has been an increase in antagonist muscles when stability is threatened, but there was an observed decrease in the action potential of the prime movers.

Using ten healthy male subjects Anderson and Behm (2004) examined the difference in EMG between performing a dumbbell bench press at 75 percent of their one repetition maximum on a stable surface and an unstable surface (a stability ball.) They found no significant difference in EMG between conditions during the concentric, eccentric, or isometric phase of the contractions at 75 percent. The interesting finding was when the MVC was tested on both surfaces. They had the subjects perform a MVC on the bench and the ball with their arms completely abducted and their elbows at 90 degrees and had the participants but push as hard as they could on handgrips that were connected to a force transducer that was firmly secured to the ground below the lifting platform. They found that although the EMG of the prime movers during a maximal isometric chest press, done on a stable versus unstable surface, was not significantly different. The resulting strength performance of the prime movers was reduced 60% when performed on an unstable surface compared with doing the maximal isometric contractions on a bench. During the isometric chest press there were no significant differences between unstable and stable conditions in the EMG of the Pectoralis Major, Anterior Deltoid, Tricep Brachii, Latissimus Dorsi, and Rectus Abdominus muscles. They found that there was no significant difference between EMG activity of the abdominal muscles or prime movement muscles involved in a chest press. But even with no significant difference in the muscular activity, there was a significant, 60% decrease in the amount of force produced in mean maximal isometric contraction. They theorize that doing the exercise on an unstable surface reduces the ability of the muscle to produce maximal force due to maintaining stability.

Koshida and colleagues (2008) conducted a follow up study to the Anderson and Behm study. A similar decrease in the isometric contraction of the chest press was observed in 20 competitive Judo fighters. He theorized that experienced Judo fighters would not see the decrease in force output that the average healthy man experienced in study presented above (Anderson, 2004). The Judo fighters in Koshida's study experienced a 6% decrease in force output on the stability ball compared to a standard workout bench at 50% of their 1RM. So even though UST will increase muscular activity of the stabilizer, synergist, and antagonist muscles, they observe a significant decrease in the prime movers. So if the goal of doing a bench press is to increase muscular strength of the chest muscles, UST would not be as beneficial as the traditional bench press.

Anderson and Behm's (2004) study and Koshida and colleagues (2008) research have differing results. Anderson and Behm's study showed an average decrease in force output of 59.6% when 10 healthy college age males did chest presses at 75% of their 1RM. Koshida et.al's study measured a 5.9% average decrease in force output with 20 male collegiate judo athletes when they were tested at 50% of their 1RM. These studies were conducted in different laboratories and had two major differences in their methodology; they used different populations and different exercise intensities. Anderson and Behm used average college males while Koshida et.al's study used collegiate athletes. Anderson and Behm used 75% intensity of 1RM while Koshida et.al used an intensity of 50% of 1RM. Koshida et.al hypothesized that the athletes would experience less of a decrease in force output as compared to the Anderson and Behm's study. The question arises as to whether it was because he used collegiate athletes as compared to the average males or because they were tested with less intensity.

Stanforth and associates (1998) found that when 15 female subjects trained for 10 weeks with the stability ball saw differences from a group (n=20) that did traditional floor exercises in the double leg lowering (DLL) test. But the stability ball trained group did not perform significantly better in a trunk flexor or back extension muscular endurance test compared to the traditionally trained group. An increase in the DLL test for the UST group demonstrates a more favorable muscular balance between pelvic stabilizing muscles and the hip flexor muscle group.

Although Stanforth's study did not show significant improvement in muscular endurance, a study by Carter and colleagues (2006) showed an increase in isometric muscular endurance. In Carter's study, 20 subjects were divided into a control group (traditional training) or a stability ball training group. After ten weeks of training twice a week, the stability ball training group did significantly better on a static back endurance test (Figure 1) and a static side bridge (Figure 2), which indicates that the stability ball participants benefited from the extra instability created by the stability ball more so than the traditional exercises in isometric contractions of the abdominal and back musculature. This increased instability could have caused an increase in muscle activity and translated into the UST group performing significantly better than the traditional training group on isometric muscular endurance tests.

Figure 1. Back endurance test used in Carter's Research (2006)

Figure 2. Side bridge test used in Carter's research. (2006)

Kibele and Behm (2009) found different results when they measured isotonic movements. They pre and post-tested 40 participants (20 UST, 20 traditional) who trained for seven weeks, twice a week. They tested them on basic performance measures such as running, hopping, jumping, and balance. Specifically, they were evaluated with 20-m sprint, 20-m right and left leg hops, shuttle run, standing long jump, static and dynamic balance tests, an abdominal muscle endurance test, and a leg extensor strength test. They found that all participants showed significant improvement from pre to post test except for the 20 meter sprint, but the only improvement shown after seven weeks of stability training above and beyond what was achieved with traditional training is sit-up endurance and 20 meter jumping speed on the dominant leg. So the increased stress put on the abdominals pelvis and low back allowed the participants in the UST group to perform better on a sit up endurance test. As for the increase in the hopping on the dominant leg test, the researchers concluded that the stress of UST training would be greater on the dominant leg since the dominant leg does not maintain equilibrium nearly as much as the non-dominant leg. The researchers also suggest that it is plausible that seven weeks, twice a week, may not be enough of a training stimulus to see a difference between stability training and traditional training.

Hamlyn, Behm, and Young (2007) further studied stability ball exercises like the stability ball superman and stability ball side bridges (Figure 2), and compared it to the more conventional means of training like weighted squats and dead lifts to see if a body weight exercise used on a stable surface (a stability ball) could yield the same amount of muscle activity. They investigated how movements, such as unstable calisthenics, compared with movements performed with free weights. EMG in sixteen physically active subjects (8 men and 8 women) was compared among trunk muscles in the back squat, working at 80% of 1RM and the dead lift working at 80% of 1RM with body weight squats and dead lifts, using unstable calisthenics, and static isometric exercises. They found that 80% 1RM back squat and the dead lift had significantly higher muscle activity than all other conditions. This indicates that performing UST non-weight bearing calisthenics cannot illicit high enough stimulus to compare with traditional multi-joint free weight exercises.

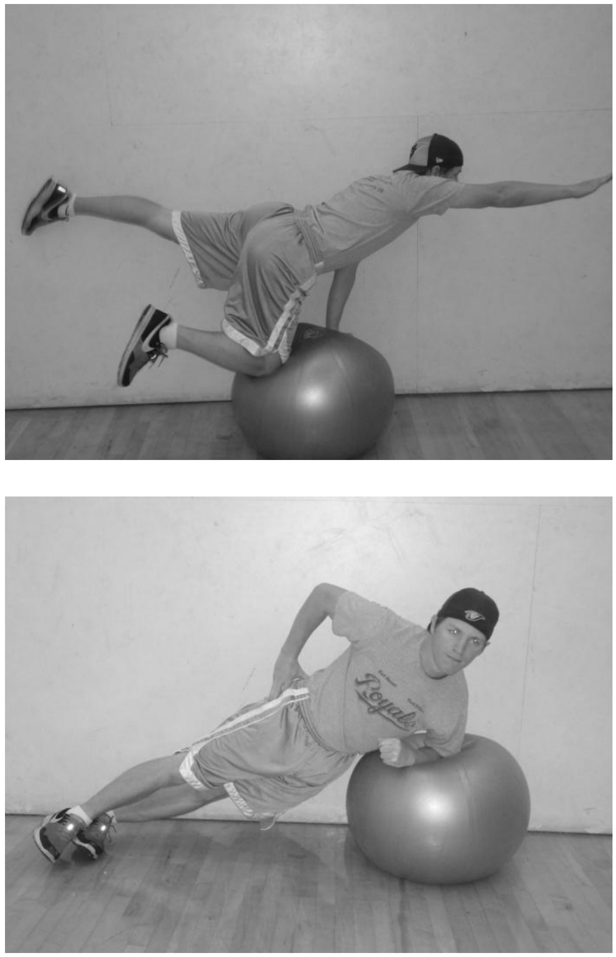

Figure 3. Exercises used in Hamlyn's Study. Above: stability ball superman. Below: stability ball side bride (Hamlyn, 2007).

Nuzzo and colleagues (2008) compared muscle activity of the back extensor muscles across squats performed at 50, 70, 90, and 100%; dead lifts performed at 50, 70, 90, and 100%; and three body weight back exercises performed on the ball (Quadruped, pelvic thrust, and back extension.) The back extensor muscles (Longissumus and Multifidus) showed higher muscular activity in the weighted dead lifts and squats than the body weight exercise done on the ball. Nuzzo and associates showed that a body weight exercise performed on the ball will not yield the same amount of muscle activity that is displayed from the squats and dead lifts. They explained "It appears that stability ball exercises may not provide a sufficient stimulus for increasing muscular strength and hypertrophy; consequently, the role of stability ball exercises in strength and conditioning programs is questioned." According to the authors squats and dead lifts are recommended for increasing strength and hypertrophy of the back extensor musculature and utilizing UST will not help nearly as much with these goals.

Stability Balls and Bench Press

Recently, in many health clubs, exercise programs are designed with the use of the stability ball instead of the standard workout bench. Instead of performing exercises like the chest press, overhead press, seated curls, or chest flies on a standard workout bench, exercisers and strength coaches are incorporating the stability ball in their workout routines. The belief is that the added instability provided by the ball will stimulate muscles more than normal to compensate for added instability and will in turn, increase strength.

Lehman and colleagues (2005) studied 7 well-trained male subjects and also compared the EMG of the prime movers of the bench press and found that there was no significant difference between the muscle activity of these muscles when the exercise was done on a standard exercise bench or a stability ball.

Marshall and Murphy (2006) expanded on McCaw's (1994) study which displayed that the shoulder musculature was more activated in a chest press utilizing free weights instead of a machine. Since the instability of free weights caused an increase in shoulder musculature activity, Marshall and Murphy wanted to see if further threatening stability with doing a bench press on a stability ball will further increase shoulder activity. They tested 14 subjects with at least 6 months of resistance training experience. The study reported an increase in muscle activity for the Rectus Abdominus, Transverses Abdominus/Internal Obliques, and the Anterior Deltoid when the participants were on an unstable surface compared to a stable surface. This illustrates that stabilizing muscles of the shoulder joint are stressed more when stability is threatened.

Norwood and associates (2007) further tested Marshall and Murphy's finding of increased abdominal activation in unstable conditions by adding instability at the legs. They tested 15 strength coaches who were well versed in unstable training on the chest press on a stable condition (a), upper extremity instability condition (b), lower extremity instability condition(c), and a dual instability condition(d) (Figure 4); and they measured EGM activity of the Latissimus Dorsi, Rectus Abdominus, Internal Obliques, Erector Spinae, Bicep Femoris, and Soleus. The results show significant increases in EMG with increasing instability. Specifically, the dual instability bench press resulted in the greatest mean muscle activation of the 3 instability conditions, with single instability conditions being significantly greater than the stable condition. This pattern of results is consistent with the position that performing the bench press in a progressively unstable environment may be an effective method to increase activation of the core stabilizing musculature, while the upper- and lower-body stabilizers can be activated differentially depending on the mode of instability. This also supports the notion that the more stability is threatened, more muscle activation is reported.

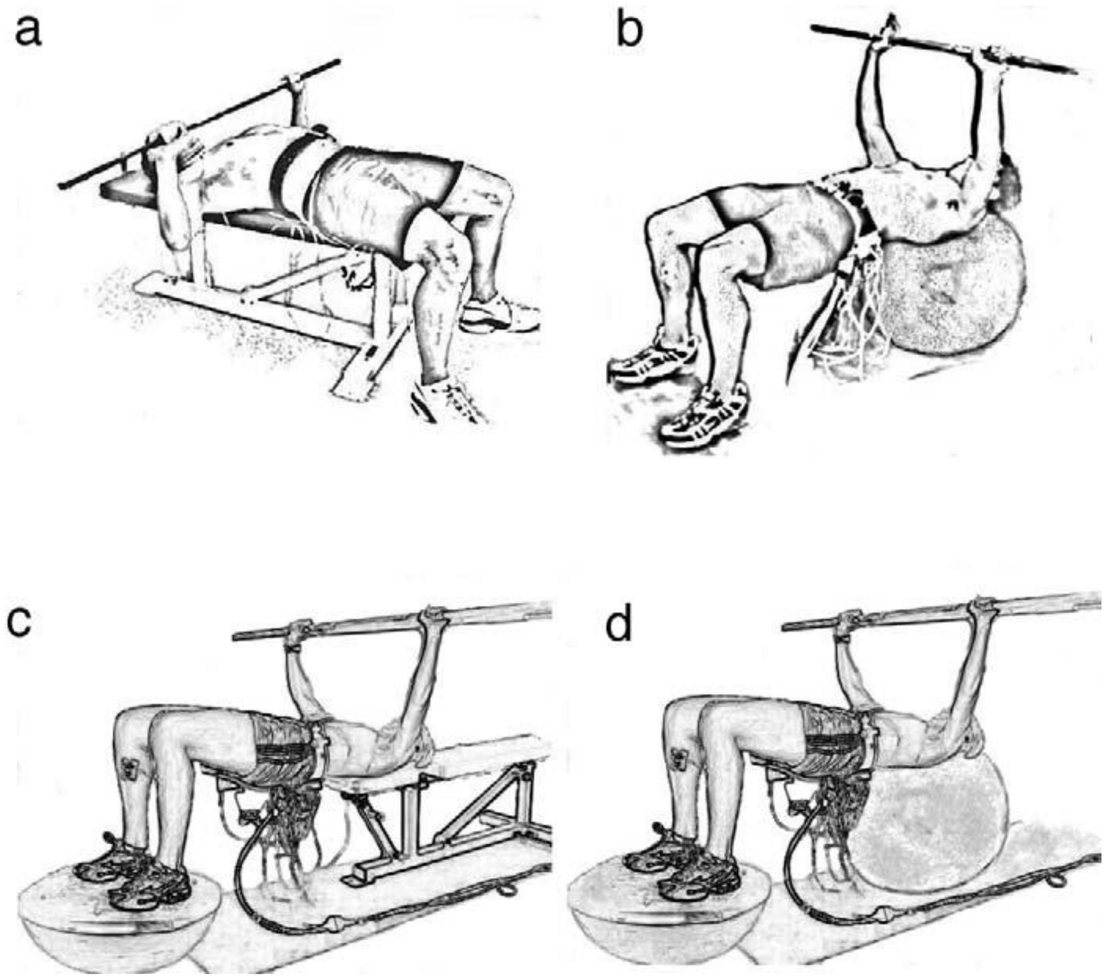

Figure 4. Norwood's conditions for an unstable bench press. A. Stable condition. B. Upper extremity unstable condition. C. Lower extremity unstable condition. D. Dual unstable condition.(Norwood, 2007)

Stability and Push ups

As indicated in the aforementioned studies, performing a chest press on a stability ball did not show an increase in EMG of the prime movers as previously shown in the curl up exercise (Marshall & Murphy, 2006; Vera-Garcia, 2000). This could be explained by examining the form of a chest press on a standard bench. A bench press has five (5) parts of the body being supported by the bench (head, shoulders, low back/gluteals, and each foot). By removing two of these five points of contact (head and low back/gluteals) and challenging only one (shoulders) of the three remaining points of contact (shoulders and two feet,) which is what happens when someone performs a chest press on a ball, is perhaps not challenging enough to stimulate the muscles to increase EMG. But if we consider changing the mode of exercise to a push up, different results may be found. A push up has less points of contact and is a closed chained exercise rather an open chain exercise with five points of contact, like the bench press.

Lehman, Hoda, and Oliver (2005) compared muscle activity when performing a prone bridge on the ground and on the stability ball. A prone bridge is an abdominal exercise where the exerciser assumes a prone position on the floor and, when instructed, establishes a prone plank position with elbows placed beneath the shoulders and upper arms, perpendicular to the floor. In this position the feet are on the floor and the forearms are on the ground or on the stability ball depending upon the condition. They found that doing a prone bridge on the ball significantly increased the muscle activity in the Rectus Abdominus compared with performing it on the ground. The increase in muscle activity that was not seen in the stabilizer muscles in his previous research study with the supine bench press task, was seen in the in the prone push up isometric hold.

Lehman and associates (2006) further showed that doing a push up with the hands on the stability ball yielded higher EMG in the Tricep Brachii and Rectus Abdominus when compared with doing it with the hands on a stable surface, although there was no significant difference of EMG in the Pectoralis Major or the External Oblique between conditions. No difference was seen when the feet were on the ball or the stable surface. It cannot be concluded that adding an unstable surface will increase muscle activity. The findings in this study display that the unstable surface needs to be under the stability ball to increase muscle activity of stabilizing muscles. It seems that there is an unknown threshold for intensity to illicit such an increase.

Mori (2004) examined 11 men and compared abdominal muscle activity in seven difference exercises performed using a stability ball. The exercises were a leg lift with ball pressed between the flexed legs; a leg lift with ball pressed between the extended legs; a push up with the ball supporting the legs; a push up with the ball supporting the hands; a sit up on the ball; a back bridge with the ball supporting the legs; and the a back bridge with the ball supporting the shoulders. Push ups with hands on the ball was significantly greater than all of the other exercises in the upper and lower Rectus Abdominus and the External Oblique recorded significantly greater muscle activity than five of the six exercises. Although Mori did deem that push ups with the hands on the ball and feet on the ground could be considered too dangerous in comparison to the other exercises.

The only study that has been done that tests suspension training and the push up is an experiment done by Beach and colleagues (Beach, 2008). They found a significant difference between EMG of the abdominal muscles (Rectus Abdominus, External Oblique, and Internal Oblique) and the Latissimus Dorsi when performing a standard push up compared to a suspended push up. Suspension training does appear to have similar effects on muscle activity of the abdominal muscles. Although the suspended push ups in this study were done on two independent chains instead of the TRX suspension training system and he did not test prime movers in this study. Also, Beach found that doing a suspension training push up puts more tension on the lower back and they could potentially contribute to low back pain.

CHAPTER 3

METHODS

Participants

Subjects (n=22 males, age: 27±5 yo; height: 178±6.8 cm; mass: 79.8±7.1 kg) were healthy and had at least one year of strength training experience. All subjects completed all conditions and gave their written informed consent. The study was approved by the Institutional Review Board.

Instrumentation

Muscle activity was measured using an 8-channel telemetry EMG system (TeleMyo 2400 G2 Telemetry System, Noraxon USA Inc. Scottsdale, AZ). Duel electrodes (Part 242, Noraxon USA Inc. Scottsdale, AZ) were placed in line with the muscle fibers on the surface of the skin following Noraxon guidelines (Shewman, 2007) for lead placement. Elbow flexion/extension was measured using an electrogoniometer (2D Goniometer, Noraxon USA Inc. Scottsdale, AZ). Subjects performed all push ups at a cadence of a metronome (Mobile Metronome, Gabriel Simoes, Salvador, BA) so subject was alternating between the "up" and "down" position at every beat at a rate of 40 bpm. Subjects then performed push ups on the ground, a stability ball (65 cm Pro Stability Ball, Perform Better, Cranston, RI) and a suspension training system (TRX Suspension Trainer, Fitness Anywhere LLC. San Francisco, CA). Subjects had a 5 minute passive recovery that was measured with a Gra Lab Timer (Model 254 60 minute timer, Centerville, OH)

Procedures

Subjects completed two sessions: 1) Orientation and 2) Test. All test sessions were done between 24 hours and 7 days after the orientation session. The orientation session was used to explain all procedures to the subject as well as to provide instruction to subjects on how to perform a push up on each surface. All push ups were done at a rate of 1 push up every three seconds with the metronome set to give a beat on the up and down points of the push up.

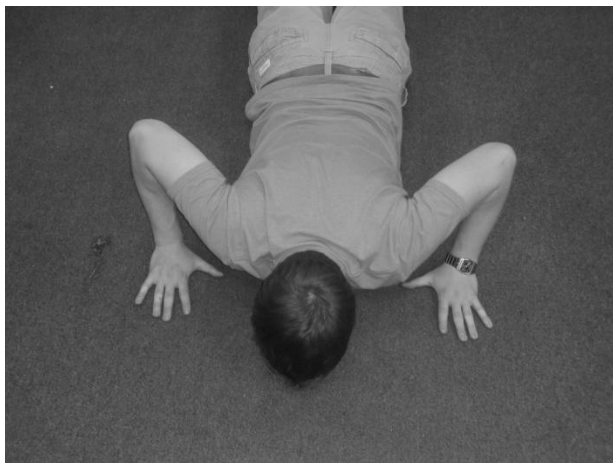

Figure 5. Hand position for push ups. Hands were placed so bottom of the palm parallel to the shoulder at a thumb's distance from the shoulder.

The instructions for doing the push up included the following: On the ground surface, subjects were told to do the push up with the bottom of their palms parallel to their shoulders and at a thumbs distance away from the shoulders (Figure 5). They were also instructed to keep their feet together and their spine in a neutral position. On the stability ball, subjects were provided instructions to complete a series of exercises leading up to doing a push up in the horizontal position. All push up progressions were done with the hands on the ball at the same hand placement used for on the ground. The first progression was having the subject stand next to the wall with the ball raised to eye level between the subject and the wall (Figure 6 A). The second progression was with the ball on the floor and the wall (Figure 6 B). The third progression was with the ball on the floor with no assistance from the wall (Figure 6 C). The forth progression was with the ball on the ground and the feet on a bench that was the height of a compressed ball yet the ball was supported by the bench (Figure 6 D). The last progression was with the ball on the ground with the feet on a bench that was the height of a compressed ball with the ball far enough away from the bench so the bench could not add any stabilizing support (Figure 6 E). After they could comfortably complete each progression at the required cadence, they moved on to the next progression.

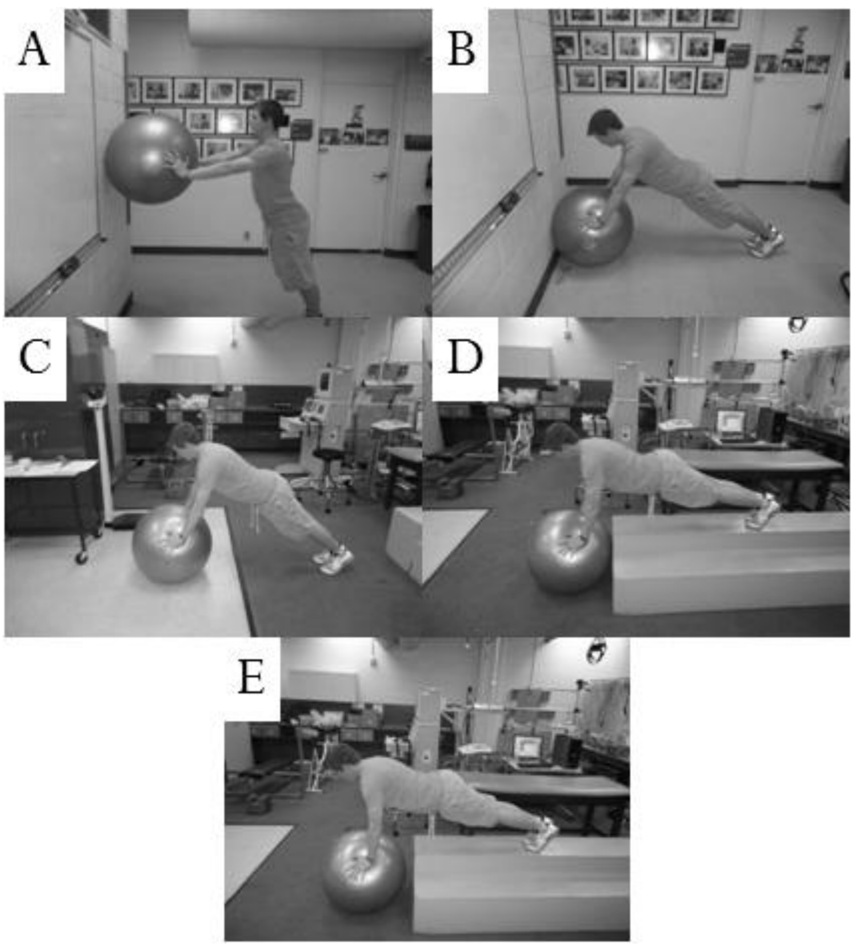

Figure. 6: Progressions of instruction for performing a push up on the stability ball

Instructions for performing a push up on the suspension training system were analogous to what was done on the stability ball. Specifically, the first progression had subjects complete a push up while standing almost completely upright, placing much of their weight on their lower extremities, thus making the exercise easier (Figure 7 A). Once they were comfortable doing a push up at that angle, they stepped back putting more and more weight on their upper body and increasing the resistance of the push up (Figure 7 B & C) until they were doing the push up with the suspension training systems completely perpendicular to the ground and their feet on the ground (Figure 7 D). The final progression was with the suspension training system's handles lowered to the height of the bench, and the feet on the bench (Figure 7 E).

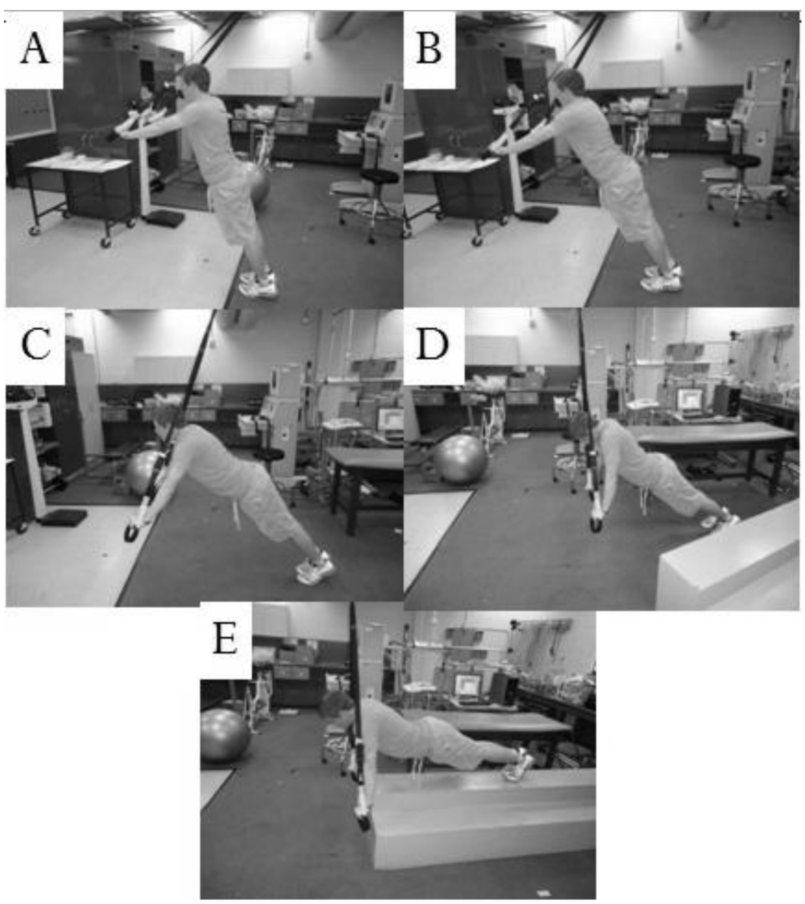

Figure 7: Suspension Progressions

Test Session

On the day of data collection, subjects were instrumented to record EMG of the Pectoralis Major, Anterior Deltoid, Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique of the right side. Lead placement was done following Noraxon guidelines. Specifically, for the Pectoralis Major, a pair of leads were placed in line with the muscle fibers 6 cm below the Mid Clavical. For the Anterior Deltoid, a pair of leads were placed in line with the muscle fibers on the anterior aspect of the arm approximately 4 cm below the Clavicle. For the Tricep Brachii, a pair of leads were placed in line with the muscle fibers 1/3 of the distance from the Acromion to the Olecranon Process. For the Latissimus Dorsi, a pair of leads were placed in line with the muscle fibers approximately 4 cm below the inferior tip of the Scapula, half the distance between the spine and the lateral edge of the torso on an oblique angle of 25 degrees. For the Rectus Abdominus, a pair of electrodes were placed parallel to the muscle fiber direction, approximately 2 cm lateral to the Umbilicus. For the External Oblique, a pair of electrodes were placed lateral to the Rectus Abdominus, directly above the Anterior Superior Illiac Spine (ASIS), half way between the crest and the ribs at a slightly oblique angle, parallel to muscle fiber direction. A ground lead was also placed on the on the Acromion. All sites were shaved of any hair, abraded and cleaned before lead placement. Finally, the electrogoniometer was placed across the elbow in order to measure flexion/extension.

All data were recorded 4.5 seconds before the start of each condition (i.e., ground, stability, suspension) and continued until the completion of 5 push ups. Condition order was randomized and subjects were required to wait at least 5 minutes between conditions.

Data Reduction

Custom laboratory software (MatLab R2009a, Natick, MA) was used to calculate the Average EMG and the root mean square (RMS) EMG between the second to fourth repetitions of each condition. The start of the second and end of the fourth repetition were identified by determining the point of maximum flexion (Figure 8).

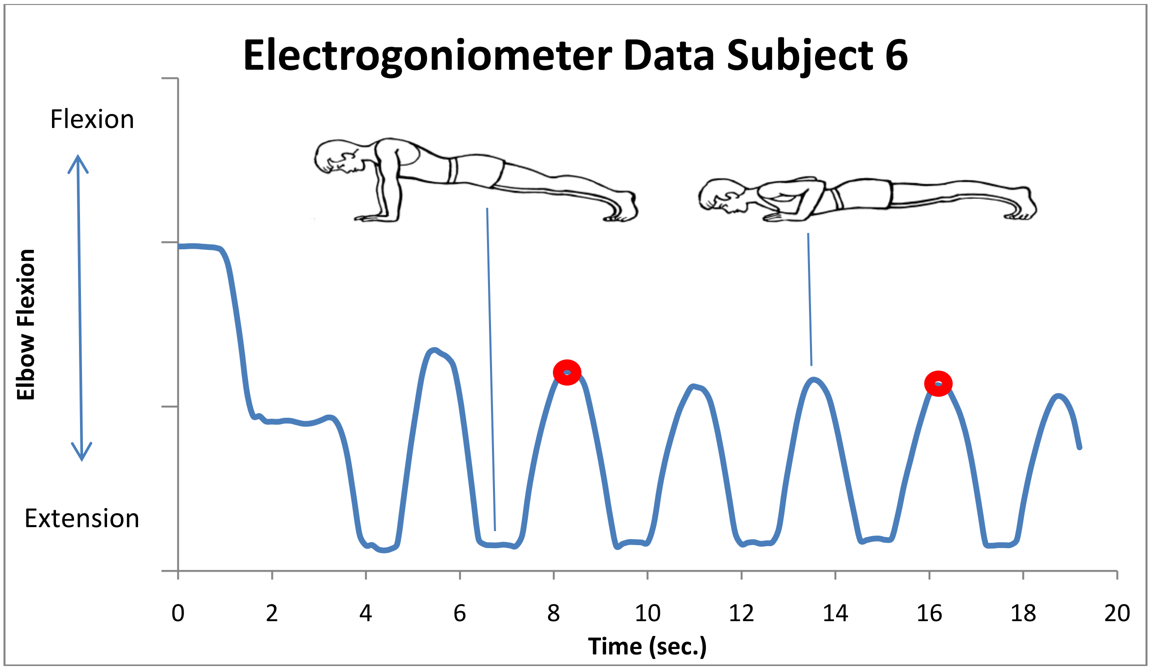

Figure 8 Data Reduction Example. The red dots are at the start point and end point for the reduced data.

Extracted EMG data were processed by removing any DC bias and full-wave rectifying the data. Average EMG was calculated by taking the average of the rectified data between the extracted data set. RMS EMG was calculated using the following formula:

$$RMS = \sqrt{\frac{{x_1}^2 + {x_2}^2 + {x_3}^2 + \cdots + {x_n}^2}{n}}$$

Statistical Analysis

The dependent variables were average EMG and RMS EMG for each muscle (Pectoralis Major, Anterior Deltoid, Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, External Oblique.) The independent variable was surface (ground, stability, suspension). All statistical analyses were conducted with SPSS 18 (Chicago, IL.) Sphericity was tested with Mauchly's test of sphericity. If the assumption of sphericity was violated ($p < .05$,) data were analyzed with an adjustment to the degrees of freedom. The Huynh-Feldt correction to the epsilon was used to adjust the degrees of freedom. A repeated measures analysis of variance (ANOVA) with Sidak planned main effects multiple comparisons were used to demine if there is a statistical difference in the dependent variables between the different surfaces (ground, stability ball, suspension training system) for each muscle. Twelve separate analyses were ran for each muscle (6) with average EMG and RMS EMG. The alpha level was set at $\alpha < .05$.

CHAPTER 4

RESULTS

Data from two subjects were excluded from the analysis due to instrument noise. All results are based upon 20 subjects (age: 27.3 ±5.2 yo; height: 178.56 ±6.9 cm; mass: 80.6± 6.6 kg). All statistical results as well as mean difference between conditions are presented in Table 1 and 2.

Table 1 F ratios, p-values, percent changes from ground condition for root mean square (RMS) EMG during push ups

	Main Effects		Ground vs. Ball		Ground vs. Suspension		Ball vs. Suspension	
	F	Sig	Percent Change	Sig	Percent Change	Sig	Percent Change	Sig
RMS Pec Maj	7.065	0.002	-24.6	0.005	-0.01	0.999	23.8	0.026
RMS Ant Delt	4.081	0.025	17.9	0.047	16.1	0.068	7.4	0.993
RMS Tri Brach +	45.305	<0.001	-34.9	<0.001	-56.3	<0.001	-21.5	0.002
RMS Lat Dors +	19.968	<0.001	-18.0	0.117	-69.3	<0.001	-51.1	0.007
RMS Rect Ab +	17.422	<0.001	-204.2	<0.001	-333.4	<0.001	129.7	0.124
RMS Ex Ob +	27.898	<0.001	-116.7	<0.001	-165.1	<0.001	-48.4	0.010

+ = The assumption of Sphericity was violated and the Huynh-Feldt correction factor was used.

Table 2 F ratios, p-values, percent changes from ground condition for average EMG during push ups.

	Main Effects		Ground vs. Ball		Ground vs. Suspension		Ball vs. Suspension	
20 FILTER AVE	F	Sig	Percent Change	Sig	Percent Change	Sig	Percent Change	Sig
Ave Pec Maj	10.168	<0.001	-26.2	0.004	-0.07	0.784	33.5	0.001
Ave Ant Delt	10.646	<0.001	23.6	0.008	29.1	0.001	0.05	0.810
Ave Tri Brach +	27.271	<0.001	-31.9	<0.001	-56.5	<0.001	-24.7	0.006
Ave Lat Dors +	11.855	<0.001	-12.0	0.365	-48.2	<0.001	-36.2	0.030
Ave Rect Ab +	16.817	<0.001	-186.9	<0.001	-331.2	0.001	-144.8	0.083
Ave Ex Ob +	29.412	<0.001	-103.1	<0.001	-158.8	<0.001	-54.0	0.009

+ = The assumption of Sphericity was violated and the Huynh-Feldt correction factor was used.
Table 2

Average EMG and RMS EMG of the Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique failed Mauchley’s test for sphericity and the degrees of freedom were adjusted with Huyn-Feldt correction. Average EMG and RMS EMG for all muscles were influenced by surface (i.e., ground, stability ball, suspension training system) (Table 1 & 2, $p < .05$).

Using planned comparisons, it was determined that average EMG and RMS EMG of the Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique were higher during suspension training system vs. ground (Table 1 & 2, $p \leq .001$). Likewise, the Average EMG and RMS EMG for these muscles were higher on the stability ball vs. ground, $p \leq .001$.

Average EMG and RMS EMG of the Pectoralis Major was higher when push ups were performed on the stability ball compared to both the ground and the suspension training system (Table 1 & 2, $p < .05$). Average EMG and RMS EMG of the Anterior Deltoid was higher when push ups were performed on the ground vs. stability ball and the suspension training system (Table 1 & 2, $p < .05$).

CHAPTER 5

DISSCUSION

The main observation made from this study was that there was greater muscle activity of a prime mover (Tricep Brachii) and stabilizer muscles (Latissimus Dorsi, Rectus Abdominus, and External Oblique) when performing push ups on unstable surfaces relative to on the ground. Furthermore, there seems to be a relationship between how unstable a surface is and muscle activity since it was observed that muscle activity was greater for the Tricep Brachii, Latissimus Dorsi, and External Oblique muscles during push ups using the suspension training system compared to the stability ball. As instability increased, from the ground being the most stable and the suspension trainer the least stable, muscle activity in stabilizer muscles and some prime movers tended to increase as well. The figure below (figure 9) depicts the EMG data as normalized to the ground condition at 100%. This was done for illustration purpose only.

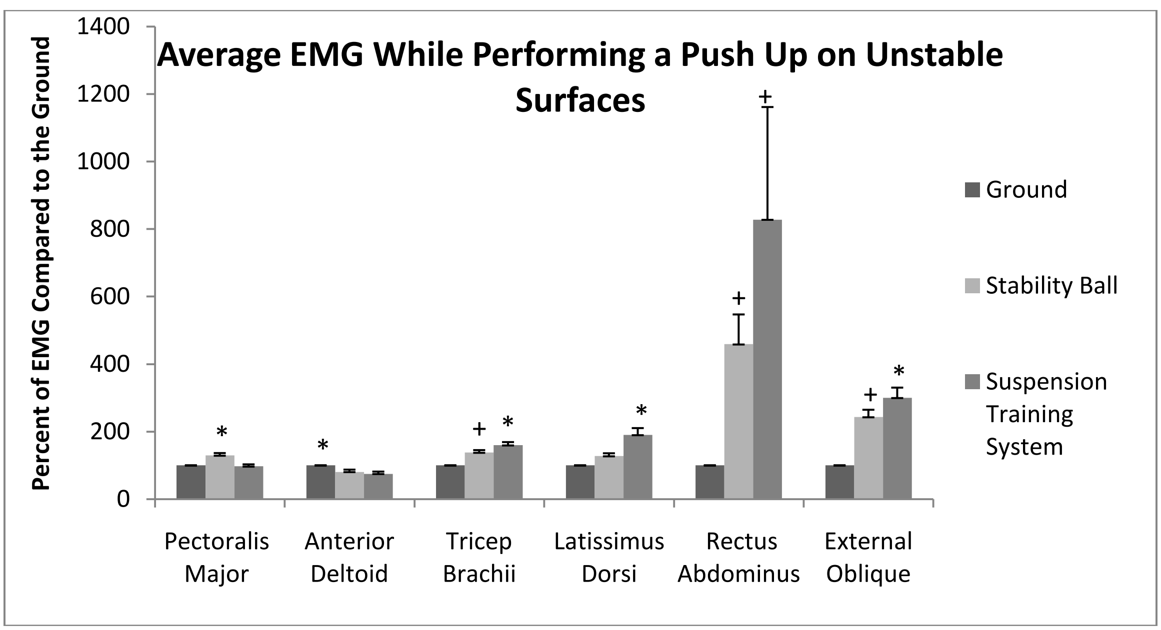

Figure 9: Means and Standard Error for Average EMG While Performing a Push Up on Unstable Surfaces. + = more EMG activity ($p < .05$) than ground, * = more EMG activity ($p < .05$) than all other conditions.

There are no published data comparing EMG during push ups using the three surfaces used in this study. However, Beach (2008) compared EMG of the Erector Spinae, Rectus Abdominus, Internal Obliques External Obliques, and Latissimus Dorsi during push ups on the ground and on a suspended handle system (similar to the suspension training system used in the present study). The observation of greater EMG of the Latissimus Dorsi, Rectus Abdominus, and External Oblique muscles observed in the present study are in agreement with the observations made by Beach (2008). Although the suspension training system used in the present study is a little different from suspended push up system used by Beach (2008), the differences in the equipment are minor. Lehman (2006) also reported an increase of muscle activity of at the Tricep Brachii, Rectus Abdominus, and External Oblique while doing push ups on a stability ball compared to the ground. That observation is consistent with the findings in the current study. Furthermore, Norwood (2007) reported increased muscle activity of the Latissimus Dorsi, Erector Spinae, Internal Oblique, Soleus, and Biceps Femoris as stability is threatened while subjects performed a bench press exercise on surfaces with different stability.   Taken together, there is agreement in the literature that muscle activity increases in agonist and synergist muscles when exercises are performed on unstable surfaces.

In the present study, there was greater muscle activity of the Pectoralis Major when performing the push ups on the stability ball compared to both the ground and the suspension training system. This observation is not consistent with the past research conducted by Lehman (2006). In that study, there was no difference in activity of the

Pectoralis Major during the push up between the ground and the stability ball. It is not clear why there is a difference in results between studies. It may be that the subjects in Lehman and colleagues (2006) completed the exercise at a lower intensity than the push ups used in the present experiment. Specifically, in that study, the participants performed the push up with their hands on the stability ball and feet on the ground. In the present study, participants performed a push up with their hands on the stability ball and their feet raised to height of the compressed ball. The change in height of the feet (relative to the ground) during the push up influences how much body weight support is placed on the hands. It may be that the difference in results between studies is related to the intensity of the push up. Another explanation for the differences between studies is related to hand position during the push up. It may be that the participants of the present study performed the push up using a wider grip (hands placed a thumbs distance from the shoulder) than the grip (shoulder width apart) that was used in study conducted by Lehman and colleagues (2006). With a wider grip there could have been more internal rotation of the Humerus causing more activity at that muscle. Future research is needed to better understand the influence of body position and push up technique on how surface stability influences muscle activity.

In the present study, both average and RMS EMG were analyzed for each muscle. The statistical results were identical regardless of which parameter was used. Nevertheless, it was considered that noise was present in the signal. Therefore, data were filtered post-hoc using a fourth order zero lag Butterworth low pass filter (cut off frequency = 350 Hz) with average and RMS EMG calculated from the smoothed data.

Using those data in the statistical analysis resulted in the same outcome as when raw data were used. Therefore, the analyses using the raw data were retained and interpreted.

It was considered that fatigue could influence the outcome of the study. However, subjects were given at least 5 minutes rest between conditions and they all appeared rested and ready before the next condition and the rest time in this study was an ample amount of time and was considerably more than the similarly designed protocols (Beach, 2008; Freeman, 2006; Lehman, 2006; Mori, 2004). Furthermore, condition order was counterbalanced to control for order effects.

It is not clear what influence experience with doing push ups on unstable surfaces influences muscle activity. It would seem that more experience with an unstable surface over the other could have made the subject more proficient with one unstable surface over another. Since stability balls are more commonly seen in fitness facilities compared to suspension training systems, the subjects might have been more proficient at a stability ball push up compared to suspended push ups because of more exposure. As proficiency increases, there may be a reduced reliance on stabilizing muscles. Future research is needed to determine if experience is a confounding factor.

Muscle activity for the Anterior Deltoid was greater when performing push ups on the ground compared to either unstable surface. This was unexpected, especially since Marshall and Murphy (2006) reported an increase in Anterior Deltoid activity when performing a bench press on the stability ball compared to a standard bench. It may be that the reason the Anterior Deltoid had greater muscle activity during push ups on the ground vs. the unstable surfaces is related to humeral flexion in the sagittal plane since activity at the Anterior Deltoid is dependent on how much flexion there is at the

Humerus.   A hypothesis to the increase muscle activity at the Anterior Deltoid is the form used in the push up on the ground was fixed with the ground where Humerus flexion was at the same angle. Due to the nature of the unstable surface, the subjects could have moved into a push up that had less Humoral flexion and therefore less EMG activity at the site of the Anterior Deltoid.

The new finding of the present experiment is that muscle activity was influenced by the type and/or level of unstable surface. For example, when the hands are placed on the ball to do a push up, the hands do move due to the unstable nature of the ball, but the movements of the hands are concurrent to one another since they are both placed on the same surface. When using the suspension training system to do push ups, the hands move independent of one another. Therefore, the mechanism of providing instability seems to influence muscle activity.

An increase in muscle activity of key stabilizing muscles as surface stability is threatened is generally consistent between studies (Freeman, 2006; Lehman, 2005; Lehman, 2006; Marshall, 2006; Mori, 2004; Norwood, 2007; Vera-Garcia, 2000). Although an increase in muscle activity does not necessarily mean there is an increase in force production, it does make sense that the task of a push up on an unstable surface is harder than performing the same task on the ground. Interestingly, some studies have reported that training on an unstable surface leads to a decrease in maximal force production (Anderson, 2004). However, since subjects in this study performed a set of 5 push ups on each surface, they were not operating at maximal muscle force.

Recommendations for Further Research

In this study, there is a clear difference in muscle activity between the unstable surfaces during 1 set of 5 push ups. There was more muscle activity in four out of the six muscles tested while performing push ups using a suspension training system than when using the ball. A longitudinal training study is now needed to clarify if the increased muscle activity leads to greater strength gains. At this point, it is unclear that suspension training would be superior to stability ball training for achieving strength gains. Experience could be an issue and the most beneficial training stimulus very well could be the one the user has the least amount of experience with.

Practical Application

The use of unstable surfaces is becoming more popular with the increase of different products on the market. It is important to quantify the differences seen between them. The results of the study demonstrate the difference in neuromuscular response to performing a push up on an unstable surface and these results cannot infer a potential training effect of unstable surfaces. This study shows the acute effects of using unstable surfaces like stability balls and suspension training systems during a push up are an increase in muscle activity in response to increase instability, especially in the Tricep Brachii and stabilizing muscles. A training study needs to be designed to examine long term differences between using different unstable surfaces to provide effective use of unstable surface training. This study also contributes to the body of evidence that unstable surface training can increase activity of the trunk musculature. This provides anecdotal evidence that stability balls and unstable surface training systems enhance abdominal muscle activity.

Training on a stability ball has been shown to increase balance and muscular endurance (Carter, 2006; Cosio-Lima, 2003; Kibele 2009; Stanforth, 1998). The acute difference between unstable surface training and traditional training is the higher muscle activity that was demonstrated in this study and others (Lehman, 2005; Lehman, 2006; Marshall, 2006; Norwood, 2007; Vera-Garcia, 2000). There could be a link between this increased muscle activity and the performance increases seen in the training studies that used stability ball. Since it was observed that the suspension training system recorded higher average and RMS muscle activity than the stability ball, it could be hypothesized that the suspension training system could be more beneficial in increasing core stability, balance, and muscular endurance. This could be empirically tested with a training study.

Conclusion

Unstable surface training can increase muscle activity in lieu of increasing mechanical load. The suspension training system increases muscle activity of some prime movers and stabilizer muscles more than the stability ball during a push up because of the added instability the suspension training system. Although, the stability ball may increase muscle activity more at the Pectoralis Major if a wide grip push up is performed because of the increased adduction of the Humerus. Even though there is an increase in muscle activity, the increased difficulty of using an unstable surface to perform push ups could reduce the amount of work done because fewer repetitions may be performed because of the threat to stability. This should be considered when prescribing unstable surfaces in workouts.

APPENDIX 1

INFORMED CONSENT

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

INFORMED CONSENT

Department of Kinesiology

TITLE OF STUDY: Muscle activity of a pushup between unstable surfaces.

INVESTIGATOR(S): Lawrence A Golding, PhD and Anthony Dyrek

CONTACT PHONE NUMBER: (702) 895-2069

Purpose of the Study
You are invited to participate in a research study. The purpose of this study is to compare muscle activity during a push up exercise between the different commonly used support systems: 1) the floor, 2) a stability ball, and a 3) suspension training system.

Participants
You are being asked to volunteer for the study because you are a healthy male between the age of 18 and 45, with at least one year of strength training and can perform a push up exercise.

Procedures
If you have never used a stability ball or a suspension training apparatus you will be asked to come in for two days (orientation day and a test day); however, you will only need to come in test day if you are familiar with this equipment.

Orientation day consists of getting you comfortable with doing a pushup on the ground, the stability ball, and the suspension training apparatus. You will be taught how to do a pushup with correct form so you will be ready for the test which will be at least 24 hours after the orientation day.

When you are comfortable doing the push up, we will ask you to come back for the test day and place some stickers (about the size of a quarter) on your skin to measure how active your muscles are (there will be wires connecting the stickers to a computer). In order to do this, we will need to shave hair from the places where we will put the stickers (electrodes). We will use two stickers for each muscle that we measure which will be your chest muscles (pectroalis major), arm/shoulder muscles (anterior deltoid, tricep) and back/trunk muscles (latissimus dorsi, rectus abdominus, external/internal obliques).

Once we have the instrument to measure muscle activity set up, you will be asked to do three (3) sets of five (5) push ups on each of the three (3) surfaces in random order: 1) the floor, 2) a stability ball, and a 3) suspension training system.

Benefits of Participation
You will have learned how to properly execute a new method of strength and core training. The subject may not have any direct benefits by participating in the study. This will be useful in terms of developing strength, balance, proprioception, and other variables needed to develop athletic potential.

Participant Initials _____

Risks of Participation

There are risks involved in most human research studies. There is only minimal risk of mild discomfort or apprehension during the exercise due to possibly being unfamiliar with performing a push up exercise on an unstable surface; however, we will give you time and instruction so you become comfortable with the exercise. There is also a possibility of some mild muscle soreness.

Cost /Compensation

There will not be financial cost to you to participate in this study and you will not be compensated for your time. The orientation day will take 30 minutes. The test day will take about 1-2 hours.

Contact Information

If you have any questions or concerns about the study, you may contact Dr. Golding or Anthony Dyrek at **702-895-2069.** For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact **the UNLV Office for the Protection of Research Subjects at 702-895-2794.**

Voluntary Participation

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your relations with the university. You are encouraged to ask questions about this study at the beginning or any time during the research study.

Confidentiality

All information gathered in this study will be kept completely confidential. No reference will be made in written or oral materials that could link you to this study. All records will be stored in a locked facility at UNLV for 3 years after completion of the study. After the storage time the identifiable information gathered will be shredded.

Participant Consent:

I have read the above information and agree to participate in this study. I am at least 18 years of age. A copy of this form has been given to me.

______________________________ ____________

Signature of Participant Date

____

Participant Name (Please Print)

Participant Note: Please do not sign this document if the Approval Stamp is missing or is expired.

Participant Initials _____

APPENDIX 2

Data Reduction Program

```
% EMG Data Reduction for Thesis
%
%
%
%
%clean up workspace and command window
clc
clear
close gcf



%-------------------------------------------------------
startwithsubj   = 1;
startwithcond   = 1;
%---------------------------------------------------------

%assign opening wariables
directory       ='c:\Thesis';

outputfile      = ['thesisoutsm.txt'];
```

```
singlefileoutputname = ['_extractedsm.txt']; %added 3/21 to
indicated smoothed data
endbaseline     = 1000; %the number of rows used to
calculate baseline elgon
columns         = 9;
rows            = inf;
headers         = 10;
numberofsubj    = 22;
numberofcond    = 3;
movingwindow    = 100;
fs              = 1500;  %sample rate
fc              = 350; %Cut off freq  added 3/21
counter         = 1;
precision       = 4;
alldata         = [];

%set up columns of EMG data
elgoncol    = 8;
timecol     = 1;
pecmajcol   = 2;
antdeltcol  = 3;
lattricol   = 4;
latdorcol   = 5;
```

```
rectabcol   = 6;

exobcol     = 7;

search      = 200;

    for s=startwithsubj:numberofsubj+startwithsubj-1

       for c=startwithcond:numberofcond+startwithcond-1


        % clear variables

        datasm= [];

        data= [];



        file = ['s' int2str(s) 'c' int2str(c) '.txt'];


        %open a file

        data=

my_fopen(directory,file,columns,rows,headers);




%===========================================================

        %smooth data - 3/23/2011

        %skip the first (time) and last two (elgon + ?)

columns
```

```
        datasm(:,1) = data(:,1);

        datasm(:,8:9) = data(:,8:9);

        for i = 2:7


            %smooth a column of data

            datasm(:,i) = my_filt(data(:,i), fc, fs, 1);


        end


        %recreate data column with smoothed data

        data = datasm;



%===========================================================


        %assign variables

        elgon= data(:,elgoncol);

        time = data(:,timecol);



%===========================================================

        %            Extract data
```

```
%==========================================================

        %plot elgon data
        plot(time, elgon)
        ylabel('elgon data')
        xlabel('time (s)')
        hold on

        %identify baseline angle
        baseline = mean(elgon(1:endbaseline));

        %create a data set to plot straight lin
        plotbaseline = baseline*ones(1,length(time));

        %plot baseline on graph
        plot(time, plotbaseline, 'k');
        plot(time(1:endbaseline), elgon(1:endbaseline),
'r');

        %click to the right of the 2nd peak
        fprintf(1, '\nClick at the 2nd peak.')
        [peak2, begin] = findpeak(elgon, search, fs);
```

```
        plot(time(begin), elgon(begin), 'ro')

        %find the end of the 4th rep
        fprintf(1, '\nClick at the 5th peak.')
        [peak2, end4th] = findpeak(elgon, search, fs);
        plot(time(end4th), elgon(end4th), 'ro')
        pause(.5)

        %extract emg data between the two data points
        data = data(begin:end4th, :);

        %clean up variables not needed
        clear tempbegin tempend elgon time plotbaseline
begin2 end4;

        %save data per condition
        subjectfile = ['s' int2str(s) 'c' int2str(c)
singlefileoutputname];
        my_save(directory, subjectfile, data, precision);


%=====================================================
        %assign variables
```

```
elgon = data(:,elgoncol);

time = data(:,timecol);

pecmaj = data(:,pecmajcol);

antdelt = data(:,antdeltcol);

lattri = data(:,lattricol);

latdor = data(:,latdorcol);

rectab = data(:,rectabcol);

exob   = data(:,exobcol);


%plot extracted data

close(gcf)

subplot(7,1,1)

plot(time, pecmaj)

ylabel('Pec Maj')

subplot(7,1,2)

plot(time, antdelt)

ylabel('Ant Delt')

subplot(7,1,3)

plot(time, lattri)

ylabel('Lat Tri')

subplot(7,1,4)

plot(time, latdor)

ylabel('Lat Dor')
```

```
subplot(7,1,5)
plot(time, rectab)
ylabel('Rect Abs')
subplot(7,1,6)
plot(time, exob)
ylabel('Ex Obl')
subplot(7,1,7)
plot(time, elgon)
ylabel('Elbow Angle')

pause
close(gcf)


%====================================================
%            EMG data processing

%====================================================

%rectify data
pecmaj = abs (pecmaj);
antdelt = abs (antdelt);
lattri = abs (lattri);
```

```
latdor = abs (latdor);

rectab = abs (rectab);

exob   = abs (exob);


%calculate mean

avepecmaj = mean (pecmaj);

aveantdelt = mean (antdelt);

avelattri = mean (lattri);

avelatdor = mean (latdor);

averectab = mean (rectab);

aveexob = mean (exob);


%calculate RMS

rmspecmaj = sqrt (mean (pecmaj.^2));

rmsantdelt = sqrt (mean (antdelt.^2));

rmslattri = sqrt (mean (lattri.^2));

rmslatdor = sqrt (mean (latdor.^2));

rmsrectab = sqrt (mean (rectab.^2));

rmsexob = sqrt (mean (exob.^2));


%compile data

counter = counter + 1;
```

```
        alldata(counter, :) = [s c avepecmaj aveantdelt
avelattri avelatdor averectab aveexob rmspecmaj rmsantdelt
rmslattri rmslatdor rmsrectab rmsexob (end4th-begin)/fs];


    end
    end

    %save data
    my_save(directory, outputfile, alldata, precision);

    %done
```

APPENDIX 3

Manuscript Submission

ABSTRACT

A recent trend among fitness professionals is to have clients perform resistance exercises on unstable equipment. Anecdotally, this is done with the intent that stabilizing and agonist muscles are more active while doing certain exercises on unstable surfaces. However, there are limited data as to whether or not this is the case and no studies have investigated muscle activity while doing the same exercise on surfaces that offer different levels of stability. Therefore, the purpose of this study is to measure electromyography (EMG) during push up exercise performed on unstable surfaces as well as on the ground. Surface EMG was measured at 6 muscles (Pectoralis Major, Anterior Deltoid, Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, External Oblique) while participants performed push ups on 3 different surfaces: ground, stability ball, suspension trainer. A repeated measures analysis of variance (ANOVA) was used to compare average and root mean square (RMS) EMG across three repetitions between surface conditions for each muscle. A Sidak planned main effects multiple comparison was used to compare differences between conditions. For each muscle, average EMG and RMS EMG was influenced by surface the push ups were performed on. The suspension training system showing increased muscle activity in four of the measured muscles (Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique); the ball showing increased EMG in the Pectoralis Major; and the ground showing increased EMG for the Anterior Deltoid. Doing push ups on unstable surfaces results in an increased muscle activity of

stabilizing muscles. Furthermore, the type and level of stability of the surface influences muscle activity. Keywords: Electromyography, Stability ball, Suspension training system.

INTRODUCTION

There are many options available to provide an overload to a muscle. Recently, it has become common to perform strength training exercises on unstable surfaces. For example, fitness facilities provide stability balls, 'both sides up' (BOSU) balls, inflatable discs and other unstable surfaces that a client would stand on while doing some type of exercise. Anecdotally, it is thought that by performing exercise on an unstable surface that the exercise becomes more demanding and therefore the exercise is more efficient at providing an overload response to targeted muscles as well as ancillary stabilizing muscles (e.g., abdominal muscles).

There may be some evidence that this hypothesis is reasonable. For example, it has been shown that there is more activity of the Medial Deltoid while performing a bench press (McCaw, 1994; Schick, 2010) and the Gastrocnemius, Biceps Femoris, Vastus Medialis while performing a squat, using free weights vs. a Smith machine (Schwanbeck, 2009). This makes sense because a machine is designed to isolate recruitment of agonist muscle(s) whereas there are greater degrees of freedom during free weights. The greater degrees of freedom means that stabilizing muscles must be recruited in order for the exercise to be completed successfully.

Strength gains are attributed to both increases in muscles cross-sectional area and improvements in neuromuscular coordination (Baechle, 2000). Behm (1995) reported that neural adaptations play the most important role in strength gains in the early stages of a resistance training and has hypothesized that using free weights create instability which an increase in the body's neuromuscular response. The result would be a greater neuromuscular coordination compared to using machine based exercise which controls the degrees of freedom. This line of thought has been extended to increasing the instability of an exercise.

Unstable surface training (UST) in a push up on a stability ball has been shown to increase muscle activity of the abdominal muscles and other synergist muscles (Beach, 2008; Freeman, 2006; Lehman, 2006; Mori, 2004). Although it is not clear if increase muscle activity will yield greater strength training results, it does make sense that there is a link between a greater stimulus (i.e., greater activity) and training response. It is also understandable, therefore, that new equipment is being made available to increase instability with the idea that this will lead to greater performance gains. For example, another UST device that is the TRX suspension training (FitnessAnywhere.com San Francisco, CA). Suspension training systems appear to increase instability more than stability ball training and could possibly increase muscular activity of stabilizing muscles (e.g., Rectus Abdominus) during an exercise such as a push up. This may not be the case since the challenge of performing a push up on an unstable surface (stability ball or suspension training system) could reduce the number of total repetitions that can be performed compared to the number that can be completed on a stable surface (i.e., ground). Therefore, the purpose of this study is to determine if the level of instability of a surface influences muscle activity of key agonist and key stabilizing muscles during a push up exercise. The surfaces of interest were the stability ball, suspension trainer, and ground.

METHODS

Participants

Subjects (n=22 males, age: 27±5 yo; height: 178±6.8 cm; mass: 79.8±7.1 kg) were healthy and had at least one year of strength training experience. All subjects completed all conditions and gave their written informed consent. The study was approved by the Institutional Review Board.

Instrumentation

Muscle activity was measured using an 8-channel telemetry EMG system (TeleMyo 2400 G2 Telemetry System, Noraxon USA Inc. Scottsdale, AZ). Duel electrodes (Part 242, Noraxon USA Inc. Scottsdale, AZ) were placed in line with the muscle fibers on the surface of the skin following Noraxon guidelines (Shewman, 2007) for lead placement. Elbow flexion/extension was measured using an electrogoniometer (2D Goniometer, Noraxon USA Inc. Scottsdale, AZ). Subjects performed all push ups at a cadence of a metronome (Mobile Metronome, Gabriel Simoes, Salvador, BA) so subject was alternating between the "up" and "down" position at every beat at a rate of 40 bpm. Subjects then performed push ups on the ground, a stability ball (65 cm Pro Stability Ball, Perform Better, Cranston, RI) and a suspension training system (TRX Suspension Trainer, Fitness Anywhere LLC. San Francisco, CA). Subjects had a 5 minute passive recovery that was measured with a Gra Lab Timer (Model 254 60 minute timer, Centerville, OH)

Procedures

Subjects completed two sessions: 1) Orientation and 2) Test. All test sessions were done between 24 hours and 7 days after the orientation session. The orientation session was used to explain all procedures to the subject as well as to provide instruction to subjects on how to perform a push up on each surface. All push ups were done at a rate of 1 push up every three seconds with the metronome set to give a beat on the up and down points of the push up.

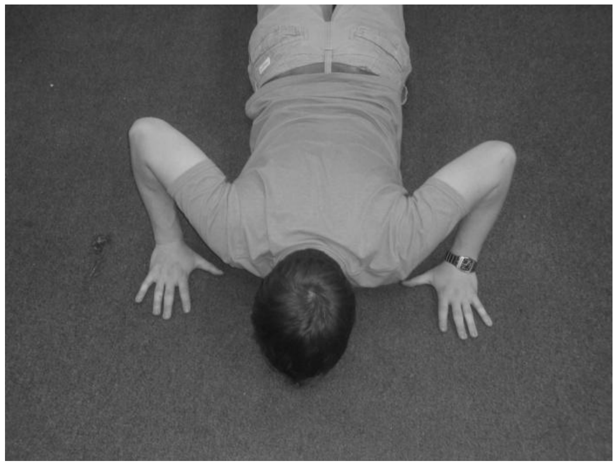

Figure 5. Hand position for push ups. Hands were placed so bottom of the palm parallel to the shoulder at a thumb’s distance from the shoulder.

The instructions for doing the push up included the following: On the ground surface, subjects were told to do the push up with the bottom of their palms parallel to their shoulders and at a thumbs distance away from the shoulders (Figure 5). They were also instructed to keep their feet together and their spine in a neutral position. On the stability ball, subjects were provided instructions to complete a series of exercises leading up to doing a push up in the horizontal position. All push up progressions were done with the hands on the ball at the same hand placement used for on the ground. The first progression was having the subject stand next to the wall with the ball raised to eye level between the subject and the wall (Figure 6 A). The second progression was with the ball on the floor and the wall (Figure 6 B). The third progression was with the ball on the floor with no assistance from the wall (Figure 6 C). The forth progression was with the ball on the ground and the feet on a bench that was the height of a compressed ball yet the ball was supported by the bench (Figure 6 D). The last progression was with the ball on the ground with the feet on a bench that was the height of a compressed ball with the ball far enough away from the bench so the bench could not add any stabilizing support (Figure 6 E). After they could comfortably complete each progression at the required cadence, they moved on to the next progression.

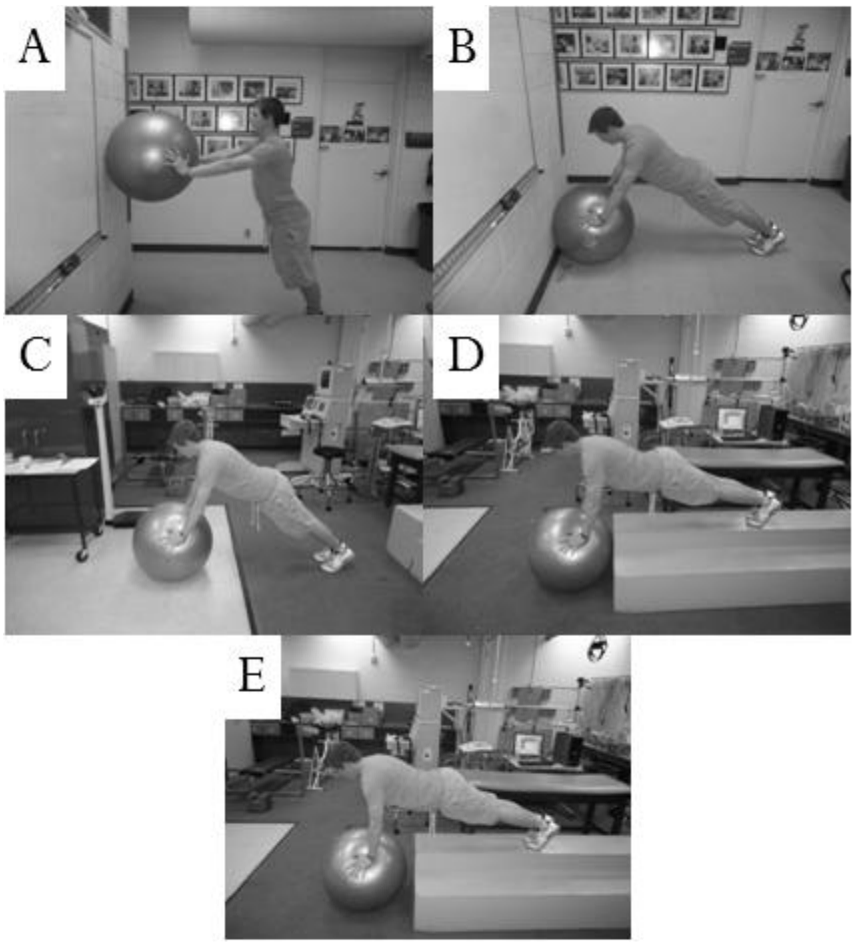

Figure. 6: Progressions of instruction for performing a push up on the stability ball

Instructions for performing a push up on the suspension training system were analogous to what was done on the stability ball. Specifically, the first progression had subjects complete a push up while standing almost completely upright, placing much of their weight on their lower extremities, thus making the exercise easier (Figure 7 A).

Once they were comfortable doing a push up at that angle, they stepped back putting more and more weight on their upper body and increasing the resistance of the push up (Figure 7 B & C) until they were doing the push up with the suspension training systems completely perpendicular to the ground and their feet on the ground (Figure 7 D). The final progression was with the suspension training system's handles lowered to the height of the bench, and the feet on the bench (Figure 7 E).

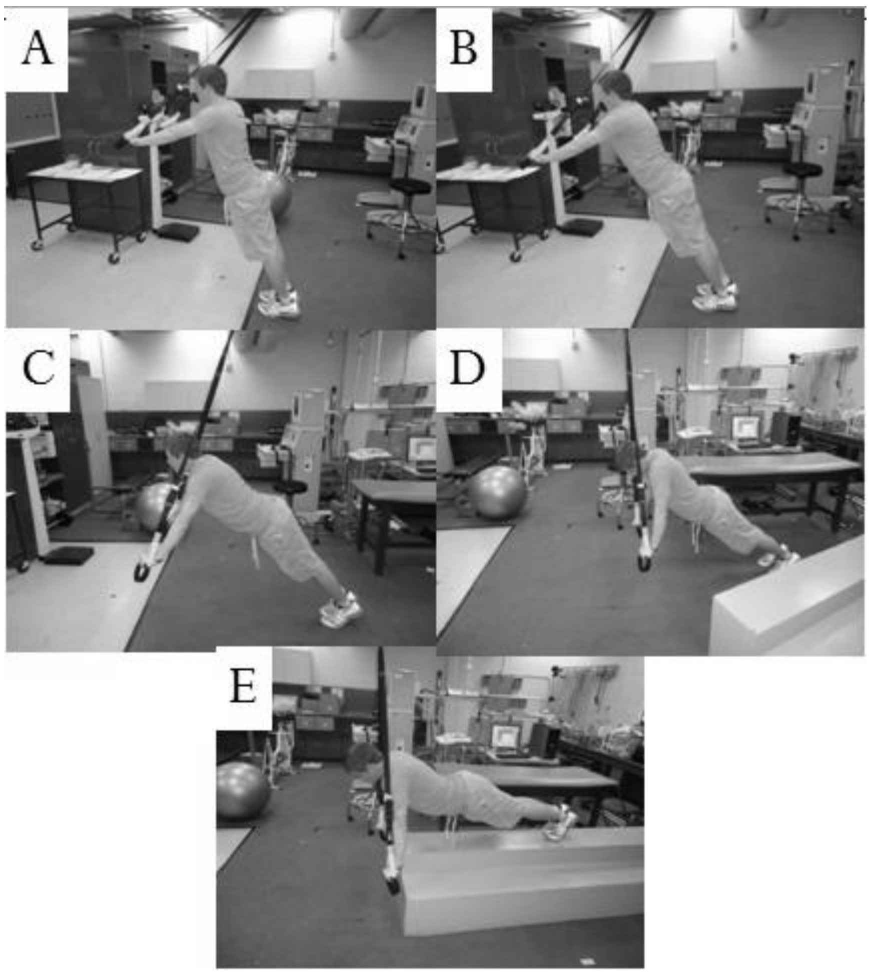

Figure 7: Suspension Progressions

Test Session

On the day of data collection, subjects were instrumented to record EMG of the Pectoralis Major, Anterior Deltoid, Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique of the right side. Lead placement was done following Noraxon guidelines. Specifically, for the Pectoralis Major, a pair of leads were placed in line with the muscle fibers 6 cm below the Mid Clavical. For the Anterior Deltoid, a pair of leads were placed in line with the muscle fibers on the anterior aspect of the arm approximately 4 cm below the Clavicle. For the Tricep Brachii, a pair of leads were placed in line with the muscle fibers 1/3 of the distance from the Acromion to the Olecranon Process. For the Latissimus Dorsi, a pair of leads were placed in line with the muscle fibers approximately 4 cm below the inferior tip of the Scapula, half the distance between the spine and the lateral edge of the torso on an oblique angle of 25 degrees. For the Rectus Abdominus, a pair of electrodes were placed parallel to the muscle fiber direction, approximately 2 cm lateral to the Umbilicus. For the External Oblique, a pair of electrodes were placed lateral to the Rectus Abdominus, directly above the Anterior Superior Illiac Spine (ASIS), half way between the crest and the ribs at a slightly oblique angle, parallel to muscle fiber direction. A ground lead was also placed on the on the Acromion. All sites were shaved of any hair, abraded and cleaned before lead placement. Finally, the electrogoniometer was placed across the elbow in order to measure flexion/extension.

All data were recorded 4.5 seconds before the start of each condition (i.e., ground, stability, suspension) and continued until the completion of 5 push ups. Condition order was randomized and subjects were required to wait at least 5 minutes between conditions.

Data Reduction

Custom laboratory software (MatLab R2009a, Natick, MA) was used to calculate the Average EMG and the root mean square (RMS) EMG between the second to fourth repetitions of each condition. The start of the second and end of the fourth repetition were identified by determining the point of maximum flexion (Figure 8).

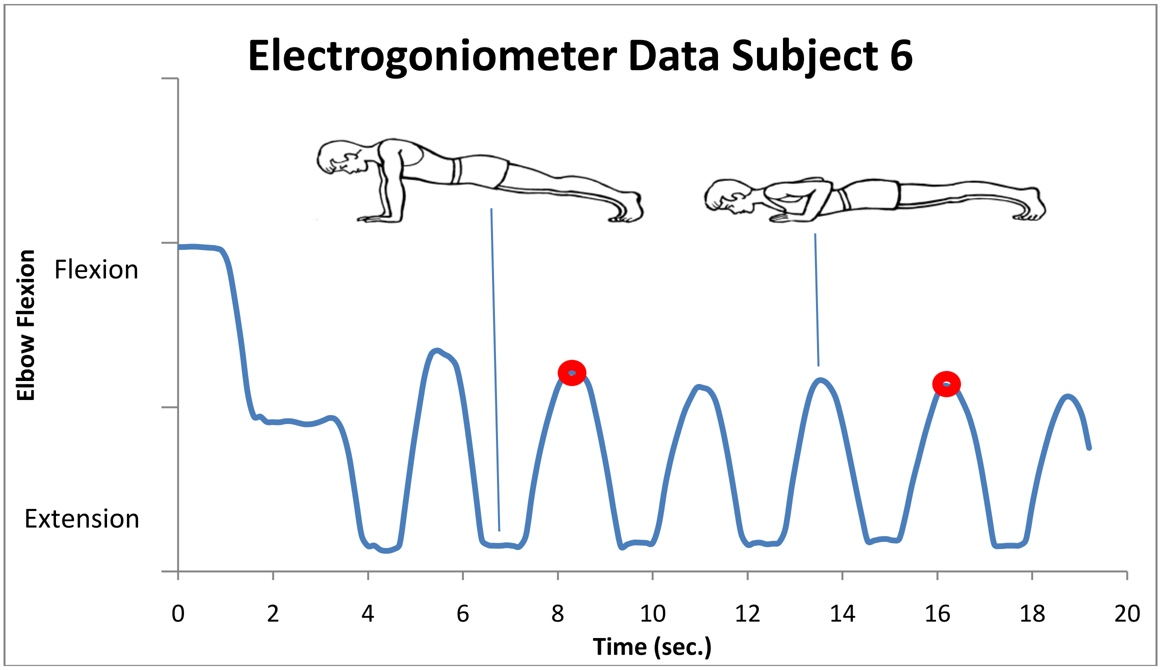

Figure 8 Data Reduction Example. The red dots are at the start point and end point for the reduced data.

Extracted EMG data were processed by removing any DC bias and full-wave rectifying the data. Average EMG was calculated by taking the average of the rectified data between the extracted data set. RMS EMG was calculated using the following formula:

$$RMS = \sqrt{\frac{{x_1}^2 + {x_2}^2 + {x_3}^2 + \cdots + {x_n}^2}{n}}$$

Statistical Analysis

The dependent variables were average EMG and RMS EMG for each muscle (name all the muscles). The independent variable was surface (ground, stability, suspension). All statistical analyses were conducted with SPSS 18 (Chicago, IL.) Sphericity was tested with Mauchly's test of sphericity. If the assumption of sphericity was violated (p <.05,) data were analyzed with an adjustment to the degrees of freedom. The Huynh-Feldt correction to the epsilon was used to adjust the degrees of freedom. A repeated measures analysis of variance (ANOVA) with Sidak planned main effects multiple comparisons were used to demine if there is a statistical difference in the dependent variables between the different surfaces (ground, stability ball, suspension training system) for each muscle. Twelve separate analyses were ran for each muscle (6) with average EMG and RMS EMG. The alpha level was set at α <.05.

RESULTS

Data from two subjects were excluded from the analysis due to instrument noise. All results are based upon 20 subjects (age: 27.3 ±5.2 yo; height: 178.56 ±6.9 cm; mass: 80.6± 6.6 kg). All statistical results as well as mean difference between conditions are presented in Table 1 and 2.

Table 1 F ratios, p-values, mean differences for root mean square EMG during push ups

	Main Effects		Ground vs. Ball		Ground vs. Suspension		Ball vs. Suspension	
	F	Sig	Mean Diff	Sig	Mean Diff	Sig	Mean Diff	Sig
RMS Pec Maj	7.065	0.002	-71.119	0.005	-2.326	0.999	68.793	0.026
RMS Ant Delt	4.081	0.025	77.194	0.047	69.522	0.068	31.875	0.993
RMS Lat Tri +	45.305	<0.001	-122.282	<0.001	197.614	<0.001	-75.332	0.002
RMS Lat Dors +	19.968	<0.001	-6.702	0.117	-25.750	<0.001	-19.048	0.007
RMS Rect Ab +	17.422	<0.001	-88.412	<0.001	144.687	<0.001	-56.275	0.124
RMS Ex Ob +	27.898	<0.001	-74.174	<0.001	105.019	<0.001	30.845	0.010

+ = The assumption of Sphericity was violated and the Huynh-Feldt correction factor was used.

Table 2 F ratios, p-values, mean differences for average EMG during push ups.

20 FILTER AVE	Main Effects F	Main Effects Sig	Ground vs. Ball Mean Diff	Ground vs. Ball Sig	Ground vs. Suspension Mean Diff	Ground vs. Suspension Sig	Ball vs. Suspension Mean Diff	Ball vs. Suspension Sig
Ave Pec Maj	10.168	<0.001	-52.164	0.004	16.653	0.784	66.514	0.001
Ave Ant Delt	10.646	<0.001	71.586	0.008	88.072	0.001	16.486	0.810
Ave Lat Tri +	27.271	<0.001	-72.787	<0.001	129.144	<0.001	-56.357	0.006
Ave Lat Dors +	11.855	<0.001	-3.550	0.365	-14.012	<0.001	-10.461	0.030
Ave Rect Ab +	16.817	<0.001	-61.067	<0.001	108.288	0.001	-47.221	0.083
Ave Ex Ob +	29.412	<0.001	-50.988	<0.001	-77.179	<0.001	-26.191	0.009

+ = The assumption of Sphericity was violated and the Huynh-Feldt correction factor was used.
Table 2

Average EMG and RMS EMG of the Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique failed Mauchley's test for sphericity and the degrees of freedom were adjusted with Huyn-Feldt correction. Average EMG and RMS EMG for all muscles were influenced by surface (i.e., ground, stability ball, suspension training system) (Table 1 & 2, $p < .05$).

Using planned comparisons, it was determined that average EMG and RMS EMG of the Tricep Brachii, Latissimus Dorsi, Rectus Abdominus, and External Oblique were higher during suspension training system vs. ground (Table 1 & 2, $p \leq .001$). Likewise, the Average EMG and RMS EMG for these muscles were higher on the stability ball vs. ground, $p \leq .001$.

Average EMG and RMS EMG of the Pectoralis Major was higher when push ups were performed on the stability ball compared to both the ground and the suspension training system (Table 1 & 2, $p < .05$). Average EMG and RMS EMG of the Anterior Deltoid was higher when push ups were performed on the ground vs. stability ball and the suspension training system (Table 1 & 2, $p < .05$).

DISSCUSION

The main observation made from this study was that there was greater muscle activity of the some prime movers (Tricep Brachii) and stabilizer muscles (Latissimus Dorsi, Rectus Abdominus, and External Oblique) when performing push ups on unstable surfaces relative to on the ground. Furthermore, there seems to be a relationship between how unstable a surface is and muscle activity since it was observed that muscle activity was greater for the Tricep Brachii, Latissimus Dorsi, and External Oblique muscles during push ups using the suspension training system compared to the stability ball. As instability increased, from the ground being the most stable and the suspension trainer the least stable, muscle activity in stabilizer muscles and some prime movers tended to increase as well.

There are no published data comparing EMG during push ups using the three surfaces used in this study. However, Beach (2008) compared EMG of the Erector Spinae, Rectus Abdominus, Internal Obliques External Obliques, and Latissimus Dorsi during push ups on the ground and on a suspended handle system (similar to the suspension training system used in the present study). The observation of greater EMG of the Latissimus Dorsi, Rectus Abdominus, and External Oblique muscles observed in the present study are in agreement with the observations made by Beach (2008). Although the suspension training system used in the present study is a little different from suspended push up system used by Beach (2008), the differences in the equipment are minor. Lehman (2006) also reported an increase of muscle activity of at the Tricep Brachii, Rectus Abdominus, and External Oblique while doing push ups on a stability ball compared to the ground. That observation is consistent with the findings in the current study. Furthermore, Norwood (2007) reported increased muscle activity of the

Latissimus Dorsi, Erector Spinae, Internal Oblique, Soleus, and Biceps Femoris as stability is threatened while subjects performed a bench press exercise on surfaces with different stability. Taken together, there is agreement in the literature that muscle activity increases in agonist and synergist muscles when exercises are performed on unstable surfaces.

In the present study, there was greater muscle activity of the Pectoralis Major when performing the push ups on the stability ball compared to both the ground and the suspension training system. This observation is not consistent with the past research conducted by Lehman (2006). In that study, there was no difference in activity of the Pectoralis Major during the push up between the ground and the stability ball. It is not clear why there is a difference in results between studies. It may be that the subjects in Lehman and colleagues (2006) completed the exercise at a lower intensity than the push ups used in the present experiment. Specifically, in that study, the participants performed the push up with their hands on the stability ball and feet on the ground. In the present study, participants performed a push up with their hands on the stability ball and their feet raised to height of the compressed ball. The change in height of the feet (relative to the ground) during the push up influences how much body weight support is placed on the hands. It may be that the difference in results between studies is related to the intensity of the push up. Another explanation for the differences between studies is related to hand position during the push up. It may be that the participants of the present study performed the push up using a wider grip (hands placed a thumbs distance from the should) than the grip (shoulder width apart) that was used in study conducted by Lehman and colleagues (2006). With a wider grip there could have been more internal rotation of the Humerus causing more activity at that muscle. Future research is needed to better understand the influence of body position and push up technique on how surface stability influences muscle activity.

In the present study, both average and RMS EMG were analyzed for each muscle. The statistical results were identical regardless of which parameter was used. Nevertheless, it was considered that noise was present in the signal. Therefore, data were filtered post-hoc using a fourth order zero lag Butterworth low pass filter (cut off frequency = 350 Hz) with average and RMS EMG calculated from the smoothed data. Using those data in the statistical analysis resulted in the same outcome as when raw data were used. Therefore, the analyses using the raw data were retained and interpreted.

It was considered that fatigue could influence the outcome of the study. However, subjects were given at least 5 minutes rest between conditions and they all appeared rested and ready before the next condition and the rest time in this study was an ample amount of time and was considerably more than the similarly designed protocols (Beach, 2008; Freeman, 2006; Lehman, 2006; Mori, 2004). Furthermore, condition order was counterbalanced to control for order effects.

It is not clear what influence experience with doing push ups on unstable surfaces influences muscle activity. It would seem that more experience with an unstable surface over the other could have made the subject more proficient with one unstable surface over another. Since stability balls are more commonly seen in fitness facilities compared to suspension training systems, the subjects might have been more proficient at a stability ball push up compared to suspended push ups because of more exposure. As proficiency increases, there may be a reduced reliance on stabilizing muscles. Future research is needed to determine if experience is a confounding factor.

Muscle activity for the Anterior Deltoid was greater when performing push ups on the ground compared to either unstable surface. This was unexpected, especially since Marshall and Murphy (2006) reported an increase in Anterior Deltoid activity when performing a bench press on the stability ball compared to a standard bench. It may be that the reason the Anterior Deltoid had greater muscle activity during push ups on the ground vs. the unstable surfaces is related to humeral flexion in the sagittal plane since activity at the Anterior Deltoid is dependent on how much flexion there is at the Humerus. A hypothesis to the increase muscle activity at the Anterior Deltoid is the form used in the push up on the ground was fixed with the ground where Humerus flexion was at the same angle. Due to the nature of the unstable surface, the subjects could have moved into a push up that had less Humoral flexion and therefore less EMG activity at the site of the Anterior Deltoid.

The new finding of the present experiment is that muscle activity was influenced by the type and/or level of unstable surface. For example, when the hands are placed on the ball to do a push up, the hands do move due to the unstable nature of the ball, but the movements of the hands are concurrent to one another since they are both placed on the same surface. When using the suspension training system to do push ups, the hands move independent of one another. Therefore, the mechanism of providing instability seems to influence muscle activity.

An increase in muscle activity of key stabilizing muscles as surface stability is threatened is generally consistent between studies (Freeman, 2006; Lehman, 2005;

Lehman, 2006; Marshall, 2006; Mori, 2004; Norwood, 2007; Vera-Garcia, 2000). Although an increase in muscle activity does not necessarily mean there is an increase in force production, it does make sense that the task of a push up on an unstable surface is harder than performing the same task on the ground. Interestingly, some studies have reported that training on an unstable surface leads to a decrease in maximal force production (Anderson, 2004). However, since subjects in this study performed a set of 5 push ups on each surface, they were not operating at maximal muscle force.

Recommendations for Further Research

In this study, there is a clear difference in muscle activity between the unstable surfaces during 1 set of 5 push ups. There was more muscle activity in four out of the six muscles tested while performing push ups using a suspension training system than when using the ball. A longitudinal training study is now needed to clarify if the increased muscle activity leads to greater strength gains. At this point, it is unclear that suspension training would be superior to stability ball training for achieving strength gains. Experience could be an issue and the most beneficial training stimulus very well could be the one the user has the least amount of experience with.

PRACTICAL APPLICATION

The use of unstable surfaces is becoming more popular with the increase of different products on the market. It is important to quantify the differences seen between them. The results of the study demonstrate the difference in neuromuscular response to performing a push up on an unstable surface and these results cannot infer a potential training effect of unstable surfaces. This study shows the acute effects of using unstable surfaces like stability balls and suspension training systems during a push up are an increase in muscle activity in response to increase instability, especially in the Tricep Brachii and stabilizing muscles. A training study needs to be designed to examine long term differences between using different unstable surfaces to provide effective use of unstable surface training. This study also contributes to the body of evidence that unstable surface training can increase activity of the trunk musculature. This provides anecdotal evidence that stability balls and unstable surface training systems enhance abdominal muscle activity.

Training on a stability ball has been shown to increase balance and muscular endurance (Carter, 2006; Cosio-Lima, 2003; Kibele 2009; Stanforth, 1998). The acute difference between unstable surface training and traditional training is the higher muscle activity that was demonstrated in this study and others (Lehman, 2005; Lehman, 2006; Marshall, 2006; Norwood, 2007; Vera-Garcia, 2000). There could be a link between this increased muscle activity and the performance increases seen in the training studies that used stability ball. Since it was observed that the suspension training system recorded higher average and RMS muscle activity than the stability ball, it could be hypothesized that the suspension training system could be more beneficial in increasing core stability, balance, and muscular endurance. This could be empirically tested with a training study.

Conclusion

Unstable surface training can increase muscle activity in lieu of increasing mechanical load. The suspension training system increases muscle activity of some prime movers and stabilizer muscles more than the stability ball during a push up because of the added instability the suspension training system. Although, the stability ball may increase muscle activity more at the Pectoralis Major if a wide grip push up is performed because of the increased adduction of the Humerus. Even though there is an increase in muscle activity, the increased difficulty of using an unstable surface to perform push ups could reduce the amount of work done because fewer repetitions are performed because of the threat to stability. This should be considered when prescribing unstable surfaces in workouts.

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