
European Journal of Sport Science
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tejs20

# Comparison of EMG activity during stable and unstable push-up protocols

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Published online: 02 Nov 2011.

*European Journal of Sport Science*, January 2013; 13(1): 42–48



ORIGINAL ARTICLE

# Comparison of EMG activity during stable and unstable push-up protocols

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**Abstract**

This experiment examined muscle activation measured using electromyography (EMG) during a standardized push-up performed on stable and unstable surfaces. Fifteen highly trained participants performed four push-ups: standard (hands and feet on the floor), either the hands or feet on an unstable surface (single instability), and with both hands and feet on unstable surfaces (dual instability). Unstable surfaces were created using a stability ball and an extreme balance board. EMG activity was recorded from three core stabilizers (erector spinae, rectus abdominus and internal obliques), one prime mover (triceps), and one lower body stabilizer (soleus). The EMG time series were smoothed using a 10-point moving average and root mean squares (RMS) were calculated for the entire time series. The results showed that push-ups performed with dual instability had significantly greater EMG activation compared to single instability or the stable push-up. In addition, as instability increased, there was a greater amount of muscle activation for the core stabilizers, prime movers and lower body stabilizers. The findings are consistent with the position that unstable surfaces in conjunction with standard exercises can be used to increase activation of core trunk stabilizers. This may in turn provide increased trunk strength and greater resistance to injury.

**Keywords:** *Instability, muscle activation, core, stabilizing muscles*

## Introduction

Researchers and trainers that promote training on unstable platforms claim that utilizing equipment such as a stability ball, wobble board or BOSU Balance Trainer provide a greater stress of the overall musculature (Anderson & Behm, 2005; Behm & Anderson, 2006; de Oliveira, Carvalho, & de Brum, 2008; Marshall & Murphy, 2005; Steckey, 2004; Vera-Garcia, Grenier, & McGill, 2000). It has been hypothesized that performing exercise on an unstable surface stresses the synergistic and stabilizing muscles around a joint system for any given movement, providing a more specific and functional form of training. The use of unstable surfaces in exercise programs has the goal of increasing motor unit recruitment without increasing mechanical load. The use of unstable surfaces to train core strength has been ingrained in popular training practices, and has led to the introduction of new sport specific training paradigms. However, despite the popularity of this type of training, very little research has been done to confirm the efficacy of instability training and its ability to increase recruitment of the trunk stabilizing musculature and neuromuscular adaptations for improved segmental or movement coordination patterns.

Several studies have examined EMG responses of core stabilizing muscles during the execution of various exercises on stable and unstable surfaces, with two recent reviews by Behm and colleagues (Anderson & Behm, 2005; Behm & Anderson, 2006). Clark, Holt, and Sinyard (2003) examined the muscular response to a variety of abdominal exercises, finding the greatest increase in EMG activity of the abdominal muscles during a crunch or roll out performed on a stability ball, as compared to exercises performed on stable surfaces. Similarly, Vera-Garcia

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ISSN 1746-1391 print/ISSN 1536-7290 online 
http://dx.doi.org/10.1080/17461391.2011.577240

et al. (2000) demonstrated increased EMG activity in the abdominal muscles when performing unstable crunches as compared to crunches performed on a stable surface. More recently, Anderson and Behm (2003) and Behm, Leonard, Young, Bonsey and Mackinnon (2003) demonstrated increased core and trunk stabilizer muscle recruitment in unstable conditions for both the squat and shoulder press activities. Similarly, Marshall and Murphy (2005) reported increased deltoid and abdominal muscle activation during upper body instability provided by a stability ball during a moderately loaded bench press.

Examining muscular activation during a bench press, Norwood, Anderson, Gaetz and Twist (2007) introduced the terms single instability to denote either destabilization of the shoulders (upper body instability) or the feet (lower body instability), and dual instability where both the shoulders and feet are on unstable surfaces. With the prescription of instability during a bench press, Norwood et al. (2007) demonstrated an increase in total muscle activation of the stabilizing musculature as one moved from stable, to upper, lower and then dual instability conditions.

To date, research on the push-up has focused on power output (Baumgartner, Oh, Chung, & Hales, 2002) and muscle activation of the primary movers (Barnett, Kippers, & Turner, 1995; Lachance & Hortobagyi, 1994); limited data described core stabilization during the push-up movement. The current study was designed to examine core and stabilizing muscle activation patterns during a push-up performed in each of stable, upper body, lower body and dual instability conditions. By using stable, single and dual instability conditions the purpose of this study was to examine differences in EMG muscle activation of the trunk stabilizers (TSs), lower body stabilizers (LBSs) and prime movers (PMs) during the performance of a standardized push-up. It is hypothesized that EMG activity will significantly increase over each of the TSs, LBSs and PMs as the push-up difficulty progresses from stable to single and dual instability.

## Methods

Subjects performed a push-up under four different conditions: hands and feet on the floor (stable condition); hands on an extreme balance board and feet on the floor (single instability – upper); hands on the floor and feet on a stability ball (single instability – lower), and hands on an extreme balance board with feet on a stability ball (dual instability). Muscle activation was quantified using surface electromyography (EMG).

### *Subjects*

Subjects included 10 male and five female elite conditioning coaches and/or personal trainers with an average of 8.4 years experience (see Table I).

### *Instrumentation*

Surface EMG recording locations were measured for five muscle groups (Basmajian & Deluca, 1985; Behm, Anderson, & Curnew 2002; Cram, Kasman, & Holtz 1998): triceps (medial head at the midline), rectus abdominus (muscle belly lateral to the umbilicus), internal obliques (2.5 cm medial to the anterior superior iliac spine), erector spinae (2 cm lateral to L5-S1), and soleus (mid-point between medial malleolus and medial condyle of the tibia). Each EMG location was shaved, cleansed with alcohol, and then abraded. Recording electrodes were positioned parallel to the orientation of the fibres being measured with inter-electrode distances of approximately 2.5 cm.

Surface EMG activity was recorded using Grass Model 10A amplifiers (Grass Technologies, West Warwick, RI) with a digital interface. Electrical activity was recorded using 11 silver–silver chloride disposable electrodes (BIOPAC Systems, Inc., Goleta, CA) applied to the skin's surface (10 EMG electrodes and a ground). Electrode impedances were maintained below 5 kω. Filter settings were 10 Hz for the low filter and 1000 Hz for the high filter. The recording epoch was five seconds at a sample rate of 2000 Hz. All data were digitized using a National Instruments AT-MIO-16F-5 A-D card and stored on a CD. The data were smoothed using a 10-point moving average and root mean square (RMS) values

Table I. Subject characteristics

| Gender | Age (years) | Height (cm) | Weight (kg) | Coaching experience (years) | Training experience (years) |
|---|---|---|---|---|---|
| F | 24 | 167.6 | 56.8 | 3 | 18.0 |
| F | 38 | 172.7 | 58.2 | 4 | 15.0 |
| F | 23 | 174.0 | 64.1 | 3 | 10.0 |
| F | 29 | 165.0 | 67.0 | 8 | 16.0 |
| F | 38 | 172.7 | 62.7 | 15 | 12.0 |
| M | 31 | 169.0 | 68.0 | 3 | 10.0 |
| M | 33 | 177.8 | 95.5 | 5 | 5.0 |
| M | 27 | 175.3 | 75.0 | 5 | 14.0 |
| M | 40 | 182.9 | 90.9 | 20 | 20.0 |
| M | 21 | 180.3 | 83.2 | 3 | 2.0 |
| M | 37 | 177.8 | 88.6 | 12 | 20.0 |
| M | 27 | 185.4 | 85.9 | 7 | 10.0 |
| M | 25 | 184.2 | 102.3 | 6 | 10.0 |
| M | 23 | 193.0 | 109.0 | 6 | 6.0 |
| M | 24 | 193.0 | 88.6 | 2 | 6.0 |
| Mean | 29.3 | 178.1 | 79.7 | 7.1 | 10.4 |
| Standard deviation | 6.4 | 8.5 | 16.5 | 5.1 | 5.9 |

were calculated for time-series using a Microsoft EXCEL spreadsheet.

*Procedures*

Each subject performed one repetition for each test condition. A metronome was used to count down trial initiation and for timing the eccentric and concentric portions of the exercise. Subjects started the push-up from a position where the elbows were fully extended, with the thumbs placed directly below shoulder with hands at shoulder's width. The body, in a straight plane from feet to shoulders, was then lowered until the elbows broke 90 degrees of flexion and then pressed back to full elbow extension on a 2-1-2 count. With the metronome set to beep each second, there was a three second countdown to the initiation of the trial. The timing sequence during the movement involved two seconds for the eccentric phase, a one second hold, and two seconds for the "up" concentric phase returning to the start position. EMG recording was initiated at the end of a three second countdown and continued over the full five seconds required to complete the exercise. Subjects were asked to repeat trials when there was a miscommunication, electrical artefact, or when the subject could not maintain their balance long enough to complete the entire exercise. A timed two minute interval was placed between the four push-up exercises, while a minimum time interval between repeated trials of the same exercise was 30 seconds.

Overall, four push-up exercises were performed using a stability ball and extreme balance board. The push-up exercises progressed from stable to unstable conditions. Each subject completed all exercise trials in the same order. Prior to each exercise a brief description of the exercise was given by an assistant, and then sufficient time was allotted for the participant to practice one repetition of the specific exercise. The push-up exercise sequence was as follows:

(1) *Stable push-up.* Both the feet and hands were on the floor. Subjects placed their hands directly beneath their shoulders and placed their feet, with legs extended, roughly the same width away from mid-line as their hand were placed. Starting with the arms in the fully extended position and using the metronome countdown, subjects lowered themselves until the elbows reached a 90° angle at two seconds. Keeping their body rigid, straight and extended, subjects held the push-up movement for a pause and then slowly fully extended the arms for the final 2 s metronome count. This stable exercise was utilized as the baseline or control EMG recording.

(2) *Lower body instability with stability ball (SB).* With hands on the floor the subject put both feet on top of the SB. Using the same procedure as the stable push-up the subject set their hands into the proper position and then placed their toes on top of the SB. It was important in this experiment that the subject had their feet directly in the middle of the stability ball and roughly the same width apart as their hands. With an assistant providing initial stability prior to the metronome count, emphasis was placed on the participant's body not being over-extended or arched. Ideally, a straight rigid posture was emphasized before push-up initiation. Once the metronome count began, no external stability from the assistants was provided. Each subject then followed the same procedure as the stable push-up protocol, trying to maintain a 2-1-2 movement tempo while keeping the body stabilized.

(3) *Upper body instability with the extreme balance board (EBB)*. With the hands on the EBB and the feet on the floor, the subject followed the same push-up protocol as described for the stable push-up. Care was taken to ensure that the palms of the hands were placed directly on top of the EBB surface and directly beneath the shoulders. During the push-up, the sides of the EBB were aloud to touch the floor but only briefly. When EBB floor contact duration exceeded 0.5 s, the trial was considered a failure and the exercise was repeated.

(4) *Dual instability with the stability ball and the EEB*. With the hands on the EBB and the toes on the stability ball, the subject followed the same push-up protocol as exercise two and three combined.

*Statistical analysis*

Statistical analyses for all RMS EMG used a repeated measures analysis of variance (general linear model ANOVA SPSS v. 13.0) to test overall differences between exercise conditions for each muscle. When Mauchley's test of sphericity was significant, Huynh–Feldt adjustment for violations of sphericity were utilized and degrees of freedom were adjusted based on the value of epsilon. Linear effects for each muscle across exercise conditions were analysed to determine the presence of significant trends in the data.

In addition, paired equal variance *t*-tests with a Bonferroni correction for multiple contrasts were performed for muscles with significant repeated measures ANOVA results. For the statistically significant *t*-tests, effect sizes were computed using the method proposed by Cohen (1988): $d =$ the mean difference divided by the pooled standard deviation. Technically, the pooled standard deviation is a weighted standard deviation computed by multiplying the individual group standard deviations by the proportion of subjects each group contributes to the total sample, and then summing these two products. Effect sizes of 0.2 represent “small effects”, 0.5 “medium effects”, and 0.8 “large effects”. Only statistically significant two-tailed *t*-tests with $P < 0.01$ are reported. Finally, intra-class correlations were performed for the experimental conditions within muscle using a two way mixed model. Rejection of the null hypothesis indicated reliability and *P*-values were considered significant when below 0.05.

To demonstrate the relative increase in muscle activation in each muscle, a RMS per cent change ((mean RMS unstable exercise/mean RMS stable exercise) $\times$ 100) score for each muscle was calculated.

## Results

The means and standard deviations for RMS EMG for each muscle and exercise condition are presented in Table II. A total of 21 post-hoc contrasts were performed. Contrasts not performed included those where the unstable surface was distant from the muscle investigated (e.g. the single instability – lower limb condition was not included for triceps contrasts).

### *Triceps brachii*

A repeated measures ANOVA revealed a significant difference for RMS EMG activity of the triceps over three conditions: stable, single instability – upper, and dual instability [$F(1, 1.09) = 48.40$, $P < 0.01$]. A significant linear effect was also observed [$F(1, 3) = 46.83$, $P < 0.01$] indicating that RMS values increased with increasing instability. Three paired post-hoc contrasts were performed for this muscle: the stable condition versus single instability – upper, the stable condition versus dual instability, and single instability – upper versus dual instability. Significant Bonferroni corrected paired contrasts were observed for the stable condition versus single instability – upper [$t(14) = -7.21$; $P < 0.01$; $d = 2.48$, very large effect] and single instability – upper versus dual instability [$t(13) = -7.35$; $P < 0.01$; $d = 2.16$, very large effect]. The intra-class correlation for triceps brachii was $R = 0.44$ [$F(13, 26) = 3.33$, $P < 0.01$].

### *Soleus*

A repeated measures ANOVA revealed a significant difference for RMS EMG activity of the soleus over three conditions: stable, single instability – lower, and dual instability [$F(1, 2) = 11.15$, $P < 0.01$]. A significant linear effect was also observed [$F(1, 3) = 15.85$, $P < 0.01$]. Three paired post-hoc contrasts were performed for this muscle. A significant Bonferroni corrected paired contrast was observed for the stable condition versus dual instability [$t(14) = -3.98$; $P < 0.01$; $d = 0.8$, large effect]. The intra-class correlation for soleus was $R = 0.79$ [$F(14, 28) = 12.10$, $P < 0.01$].

### *Rectus abdominus*

A repeated measures ANOVA revealed a significant difference for RMS EMG activity of the rectus abdominus over four conditions: stable, single instability – upper, single instability – lower, and dual instability [$F(1, 1.28) = 13.51$, $P < 0.01$]. A significant linear effect was also observed [$F(1, 3) = 15.01$, $P < 0.01$] indicating that RMS values increased with greater instability. Five paired post-hoc contrasts were performed for this muscle. Significant Bonferroni corrected paired contrasts were observed for the stable condition versus single instability – lower [$t(14) = -4.19$; $P < 0.01$; $d = 1.39$, ]very large effect] and single instability – upper versus single instability – lower [$t(13) = 4.09$; $P < 0.01$; $d = 1.24$, very large effect]. The intra-class correlation for rectus abdominus was $R = 0.54$ [$F(13, 39) = 5.72$, $P < 0.01$].

### *Erector spinae*

A repeated measures ANOVA revealed a significant difference for RMS EMG activity from the erector spinae over four conditions: stable, single instability – upper, single instability – lower, and dual instability [$F(1, 1.88) = 9.52$, $P < 0.01$]. A significant linear effect was also observed [$F(1, 3) = 34.25$, $P < 0.01$] indicating that RMS values increased with increasing instability. Five paired post-hoc contrasts were performed for this muscle. Significant Bonferroni corrected paired contrasts were observed for the stable condition versus

Table II. Mean (standard deviation) for RMS values by muscle and base of support

| Base of support | Triceps brachii | Soleus | Rectus abdominus | Erector spinae | Internal obliques |
|---|---|---|---|---|---|
| Stable | 57.48 (23.51) | 9.03 (15.97) | 27.37 (16.77) | 11.80 (5.94) | 38.56 (23.64) |
| Single-lower | 86.93 (43.99) | 16.78 (22.58) | 70.25 (52.72) | 23.63 (21.14) | 98.00 (62.47) |
| Single-upper | 63.51 (29.08) | 16.12 (17.38) | 29.90 (23.00) | 11.62 (5.00) | 46.16 (26.74) |
| Dual | 162.14 (61.03) | 29.23 (34.73) | 100.29 (88.14) | 31.79 (16.78) | 151.10 (79.54) |

dual instability [$t(14) = -5.52$; $P<0.01$; $d=1.76$, very large effect] and single instability – upper versus dual instability [$t(13) = -5.07$; $P<0.01$; $d=1.82$, very large effect]. The intra-class correlation for erector spinae was $R=0.37$ [$F(13, 39) = 3.30$, $P<0.01$].

*Internal oblique*

A repeated measures ANOVA revealed a significant difference for RMS EMG activity from the internal oblique over four conditions: stable, single instability – upper, single instability – lower, and dual instability [$F(1, 1.53) = 27.36$, $P<0.01$]. A significant linear effect was also observed [$F(1, 3) = 33.75$, $P<0.01$]. Five paired post-hoc contrasts were performed for this muscle. Significant Bonferroni corrected paired contrasts were observed for the stable condition versus single instability – lower [$t(14) = -4.67$; $P<0.01$; $d=1.38$, very large effect], stable condition versus dual instability [$t(14) = -6.37$; $P<0.01$; $d=2.18$, very large effect], single instability – upper versus dual instability [$t(13) = -5.57$; $P<0.01$; $d=1.94$, very large effect], and single instability – lower versus dual instability [$t(14) = -3.88$; $P<0.01$; $d=0.75$, medium effect]. The intra-class correlation for internal oblique was $R=0.53$ [$F(13, 39) = 3.30$, $P<0.01$].

*Per cent change*

Per cent change is presented for each of upper-body instability, lower-body instability and dual instability experimental conditions in Figure 1. As can be seen, the patterns of increased muscle activation were similar across all muscle groups, moving from stable, to upper-body, lower-body and dual instability conditions.

## Discussion

Several authors have attempted to classify common exercise protocols for training and rehabilitation according to the level of electrical activation of the musculature through the use of EMG (Anders, Bretschneider, Bernsdorf, Erler, & Schneider, 2004; de Oliveira et al., 2008). The use of unstable training surfaces has been found to increase the level of muscle activation and the patterns of stabilizing muscle co-activation stressing the neural coordination of movement (Vera-Garcia et al., 2000). However, research to date has typically destabilized one limb segment by placing the shoulders on the stability ball during a bench press, placing shoulders or lower back on a stability ball during trunk exercises, standing on an unstable surface during a squat exercise, or placing the hands on an unstable surface during a push-up. The present study examined both stable and unstable push-ups, while investigating destabilization of the upper body, lower body, and both. The results of the present study support the hypothesis that EMG muscle activation significantly increases in response to increased levels of instability, and provides evidence for training progressions built on varying the destabilization of the upper-body, lower-body, or both.

A significant linear effect across stability condition was observed for each muscle, indicating that RMS values increased with increasing instability. The greatest mean muscle activation of the three stability conditions was found when performing dual instability push-ups. These results are similar to those of Norwood et al. (2007) who introduced differential limb segment destabilization and dual instability during the bench press. These authors reported significant increases in EMG activity with increasing levels of instability, moving from stable to single to dual instability conditions. This supports the present results that suggest performing the push-up in a progressively unstable environment may prove to be an effective means to increase activation of the core stabilizing musculature. However, all muscles do not respond in the same way when adding surface instability (Anders et al., 2004; de Oliveira et al., 2008; Norwood et al., 2007), and their response may be linked to their role as either local or global stabilizers, or global mobilizers (Comerford & Mottram, 2000; Gibbons & Comerford, 2001; Mottram & Comerford, 1998).

Muscles of the core have been described by function since the late 1960s as local stabilizers, global stabilizers or global mobilizers (Gibbons & Comerford, 2001). Local stabilizers function under low load to increase muscle stiffness to create segmental control, producing a continuous force with little or no shortening or resultant range of motion such as the transverses abdominus or multifidus (Gibbons & Comerford, 2001). Global stabilizers such as the internal obliques and erector spinae are hypothesized to function through phasic contractions

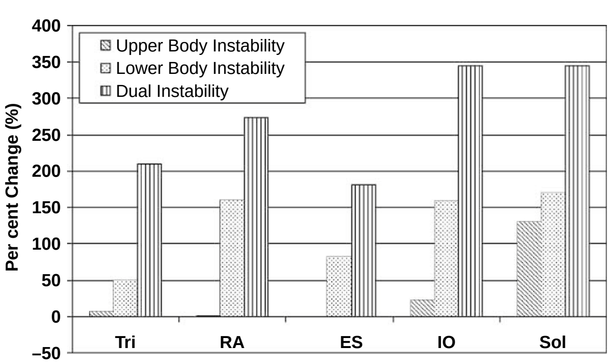


Figure 1. The per cent change scores for each muscle in each experimental condition.

to control range of motion and deceleration through eccentric contractions (Gibbons & Comerford, 2001). The global mobilizer muscles such as the rectus abdominus are used to generate concentric force and torque to create movement across large ranges of motion and are recruited for stabilizing functions only under high load, high speed movements (Gibbons & Comerford, 2001). Accordingly, during the push-up under the various stabilities the erector spinae and the internal obliques would function as global stabilizers, while the rectus abdominus would function as a global mobilizer, and their patterns of activation may be linked to their role.

The internal obliques act as global stabilizers during each phase of the push-up movement, resisting movement through the core (Comerford & Mottram, 2000).The erector spinae functions as both a local and global stabilizer during the push-up by increasing muscle stiffness during segmental movement to create spinal stability locally, while keeping the back straight and rigid to enable the prime movers to generate the forces required for the movement (Comerford & Mottram, 2000). Working in tandem as global stabilizers, muscle activity significantly increased when the limb segments were destabilized.

The rectus abdominus acts as a global mobilizer generating torque that facilitates prime mover activity (Comerford & Mottram, 2000). One possible function of the rectus abdominus would be to decelerate movement under the higher stress load during the eccentric phases of the unstable push-ups, and in particular, when the feet were elevated during lower body and dual instability. During a stable push-up the rectus abdominus would have a reduced role and lower activation levels as its contraction would not be required to facilitate the power generation of the prime movers. However, with the addition of instabilities (single and dual), the rectus abdominus may move from a low load to high load stress situation (Mottram & Comerford, 1998), forcing the erector spinae and internal obliques to produce force to control the movement, while the rectus abdominus takes on a torque-producing role to facilitate power generation during the concentric phase of movement. This phenomenon can be supported by the pattern of increased muscle activation as seen in the present results. In the dual instability condition the global stabilizers are producing large forces to stabilize the core to allow global mobilizers to create power, permitting the prime movers to generate just enough force to complete the movement. The neural coordination required to control such muscle activity may be a primary adaptation that may lead to increased functional capacities of persons trained in this method, and hence its proposed use in rehabilitation settings (Anders et al., 2004; de Oliveira et al., 2008; Norwood et al., 2007; Vera-Garcia et al., 2000).

Increased muscle activity in local stabilizers has also been reported by Lear and Gross (1998) who observed greater muscle activation in the stabilizing muscles of the scapulae when a push-up with foot elevation was compared to a regular push-up. In the present study, lifting the feet and placing them on an unstable surface increased the prime mover activity, but also engaged the global stabilizers, with large increases in internal oblique activity. The large increase in rectus abdominus and erector spinae activity counters the gravitational forces that try to place the lower back into a lordotic position, particularly when decelerating the body during the eccentric phase of movement. In the present study with highly trained individuals, dual instability posed an increased challenge, and in some, unfused tetanus (shakiness) was observed. With elevated feet, and unstable surfaces, it can be hypothesized that the erector spinae and internal obliques are unable to generate enough force for trunk stabilization or to completely control the eccentric movement of the push-up. This lack of trunk stabilization from the global stabilizers may in turn affect the performance of the global mobilizers and the coordinated muscle activity for the concentric phase of movement. Cholewicki and McGill (1996) hypothesized motor control deficits related to recruitment in stability systems when the rectus abdominus is put into a stability-producing role rather than a torque-producing role. This would occur to compensate for stability dysfunction in the local and global stabilizers. These trunk muscle adaptations to dual instability could result in poor segmental control and instability (Lear & Gross, 1998) with poor coordination between the prime movers and trunk stabilizers, resulting in increased instability and potentially explaining the ”shakiness” observed in the movement pattern during dual instability push-ups (Cholewicki & McGill, 1996; Gibbons & Comerford, 2001).

In summary, the present study demonstrated a linear increase in trunk musculature activation as instability progresses to a point where both the upper and lower body are placed on unstable surfaces. Exercise progressions may utilize stable, single and dual instability as training variables in order to increase core muscle activity, and gain an enhanced training effect in slow twitch muscle fibres (Lehman, MacMillan, MacIntyre, Chivers, & Fluter, 2006). The use of unstable surfaces in conjunction with commonly performed exercises can be used to increase core muscle activation (Anderson & Behm, 2003, 2005; Behm et al., 2003; Clark et al., 2003; Comerford & Mottram, 2000; Vera-Garcia et al., 2000).

Dual instability is not recommended early in training or for those who are deconditioned. Under these circumstances motor control deficits (Cholewicki & McGill, 1996) could result in improper movement patterns that might not be beneficial. For an athlete or person in a rehabilitation environment, stability training goals should be to improve overall movement patterns through neuromuscular adaptations. The proper use and application of unstable surface adaptations in agonist, antagonist, synergist and stabilizer muscles may lead to increased neural coordination of movement and increased muscle activation (Rutherford & Jones, 1986) resulting in strength gains (Behm et al., 2002).

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