Gait & Posture 39 (2014) 404–409

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Exercise intensity progression for exercises performed on unstable and stable platforms based on ankle muscle activation

Sebastien Borreani [a], Joaquin Calatayud [a], Julio Martin [b], Juan Carlos Colado [a,*], Victor Tella [a], David Behm [c]

[a] Laboratory of Physical Activity and Health, Research Group in Sport and Health, Department of Physical Education and Sports, University of Valencia, Valencia, Spain
[b] University Institute of Science in Physical Activity and Sports, Catholic University of Valencia, Valencia, Spain
[c] School of Human Kinetics and Recreation, Memorial University of Newfoundland, St. John's, Newfoundland, Canada

ARTICLE INFO

Article history:
Received 10 June 2013
Received in revised form 7 August 2013
Accepted 10 August 2013

Keywords:
Balance training
Sensorimotor training
EMG
Proprioception

ABSTRACT

Ankle sprains are a common sports injury. The literature focuses on the application of neuromuscular training for the improvement of balance, injury prevention and rehabilitation. However, there is a dearth of knowledge about the appropriate prescription of exercises using unstable platforms and surfaces. The purpose of this study was to devise an ankle rehabilitation or training program with exercise progression based on the extent of muscle activation, employing platforms with different levels of stability and additional resistance. A descriptive study of electromyography (EMG) during ankle exercises was performed with a convenience sample of healthy subjects. Forty-four subjects completed 12 exercises performed in a random order. Exercises were performed unipedally or bipedally with or without elastic tubing as resistance on various unstable (uncontrolled multiaxial and uniaxial movement) and stable surfaces. Surface EMG from the tibialis anterior (TA), peroneus longus (PL) and soleus (SOL) were collected to quantify the amount of muscle activity. Significant differences were found between exercise conditions for PL ($p < .001$), TA ($p = .011$), and SOL ($p < .001$). The greatest EMG activity for all muscles occurred with an upright unipedal stance on a soft stability surface with resistance. The least EMG activity for the TA and SOL were in a seated position and for the PL in an erect bipedal position without resistance. Based on the level of ankle muscle activation, exercises for the ankle should progress from bilateral exercises on exercise balls (lowest intensity), to a unipedal position on a soft surface in combination with elastic tubing (highest intensity) in order to achieve progressively greater ankle muscle activation.

1. Introduction

The ankle is the second most commonly injured area of the body during sport practice and is thus in frequent need of physical therapy assessment and rehabilitation [1]. Considering all types of ankle injuries, sprains are the most common injury [1–3] (incidence rate of 85% of all ankle injuries are acute lateral sprains) [4]. It is common that ankle injuries involve long-term alterations in postural control [5,6], as well as ankle proprioceptive and neuromuscular functions [7]. Deficits in balance lead to an elevated risk for ankle injuries [6,8]. Reviews have corroborated that a key to the reduction of recurrent ankle sprains occur when the individuals perform a neuromuscular training program, and thus restoring postural control has been suggested as an important component to reducing injury recurrence [7]. Postural control restoration may be the key to the recurrent ankle sprains reduction [9]. Some authors [9,10] recommend balance training for the prevention and rehabilitation of ankle sprains. Balance training is a common rehabilitation tool for ankle injury and a safe first step in rehabilitation if progressed appropriately [11]. The utilization of unstable surfaces and platforms has shown effectiveness for increasing the sensorimotor control of soft tissues that stabilize the knee and ankle joints [12,13].

In addition to its use as a rehabilitation tool, instability or balance training can be an important prehabilitation or preventive training tool for the general healthy population. The Canadian Society for Exercise Physiology states that, “Individuals who are involved with rehabilitation, health-related fitness pursuits or cannot access or are less interested in the training stresses associated with ground based free weightlifts, can also receive

* Corresponding author at: Department of Physical Education and Sports, University of Valencia, C/ Gascó Oliag 3, 46010 Valencia, Spain.
Tel.: +34 667507636.
E-mail address: juan.colado@uv.es (J.C. Colado).

0966-6362/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gaitpost.2013.08.006

beneficial resistance training adaptations with instability devices and exercises to achieve functional health benefits" [14]. Furthermore, the American College of Sports Medicine position stand [15] recommends that an increase in the level of difficulty of balance training progression exercises can be achieved by progressively reducing the base of support, performing dynamic movements that disturb the center of gravity, stressing postural muscles or reduce the sensory inputs. In the same vein, Muehlbauer et al. [16] recommends the combination of sensory and postural manipulations in all phases of balance training. Behm et al. [17] stated that a progressive decrease in the amount of stability support during resistance training may be recommended with rehabilitation. Whereas there are many articles reporting upon the positive training effects of instability resistance training, there are far fewer articles establishing appropriate intensity progressions using these exercises. For example, Anderson and Behm [18] demonstrated higher soleus activation with squats performed on unstable versus stable surfaces but did not provide recommendations on progression of exercises. Many interventions applying neuromuscular training have been published [2,19,20] despite the lack of scientific evidence of the appropriate frequency, duration, intensity [10,15,21] and optimal progression methods [16,21]. Appropriate neuromuscular adaptations from training are sought during prehabilitation and rehabilitation, which involves prescribing exercises that activate a range of muscle fibers and challenge the sensorimotor system.

It is unknown if additional resistance applied to postural stability exercises performed on stable platforms would increase exercise intensity by promoting higher ankle muscle activation. Thus, the aim of this study was to investigate the amount of muscle activity in a series of balance exercises with differing levels of stability and additional resistance to establish a progression based on the amount of muscle activation. It was hypothesized that activities placing subjects at greater risk of instability with higher resistance would elicit the greatest muscle activation.

2. Methods

2.1. Subjects

Young university students (24 men and 20 women) participated voluntarily in this study. Subject characteristics, separated by sex, are presented in Table 1. Subjects included in the research had a minimum of 1 year of experience with resistance training. Exclusion criteria included musculoskeletal pain, neuromuscular disorders, joint or bone disease, previous ankle sprains and tendon, fascia or ligament inflammation. All subjects signed an informed consent form before starting the protocol, and the institution's review boards approved the study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

2.2. Procedures

Each subject took part in 2 sessions: familiarization and data collection. The familiarization session occurred 48–72 h before the data collection. Several restrictions were imposed on the volunteers: no food 3–4 h before and no stimulants or intense physical activity 12 h before the experimentation.

Familiarization. In the first session, the subjects were familiarized with the testing activities that would be performed on the day of data collection. Subjects practiced the exercises typically 1–3 times each until the subject felt confident and the researcher was satisfied that proper form was achieved. Moreover, height, body mass, and body fat percentage using bioelectric impedance (Tanita model BF-350, Arlington Heights, Illinois, USA) were obtained according to the protocols used in previous studies [22].

Data collection. The protocol started with the preparation of the subjects' skin and followed by electrode placement, maximal isometric voluntary contraction (MIVC) collection and exercise performance.

Hair was removed from the skin surface overlying the muscles of interest. The skin was then cleaned by rubbing with cotton wool dipped in alcohol for the subsequent placement of the electrodes on the peroneus longus (PL), tibialis anterior (TA) and soleus (SOL) [23,24]. Pre-gelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Olstykke, DNK) were placed with an inter-electrode distance of 2 cm on the following muscle groups:

- PL: 3 fingerbreadths below the fibular head directed toward the lateral aspect of the fibula [24].
- TA: placed parallel to and just lateral to the medial shaft of the tibia (shin), at approximately one-quarter to one-third the distance between the knee and the ankle [23].
- SOL: placed parallel to the muscle fibers on the inferior and lateral aspects of the leg, clearly below the belly of the gastrocnemius [23].

These muscles were chosen for investigation as they help control anteroposterior and lateral movement of the ankles.

The reference electrode for each muscle was placed perpendicular to the axis of the other 2 active electrodes, at 10 cm from the midpoint of the 2 active electrodes, according to the manufacturer's specifications. The assessment of muscle activity was performed on the dominant leg with the subjects barefoot in all exercises.

MIVC. A 5 s MIVC was performed for each involved joint to estimate the maximal electromyographic (EMG) amplitude for each muscle (PL, TA, SOL). For normalization of the EMG activity the MIVC were performed according to the techniques described by Kendall et al. [25].

Equipment. The different exercises were performed on stable (Thera-Band® Exercise Station, Hadamar, Germany) or unstable (Exercise Ball, Rocker Board and Soft Stability Trainer: Thera-Band®, Hadamar, Germany) surfaces with or without external resistance (Elastic tubing, Thera-Band®, Hadamar, Germany). The exercise station was a stable platform, the Rocker Board was unstable in the anteroposterior direction and the Exercise Ball and Soft Stability Trainer were unstable in a multi-axial direction. Furthermore, men used green exercise tubing and women used red exercise tubing, based on pilot studies to ensure the given position for each exercise could be maintained for 20 s. A Cross Line Auto Laser Level was fixated with a tripod (Black & Decker LZR6TP, New Britain, CT, USA) and used as visual feedback for subjects in connection to requested hip and knee joint positioning during exercises.

2.3. Exercise performance

Each subject completed the 12 exercises in a random order that was assigned to subjects employing Matlab software (Version 7.0, Mathworks Inc, Natick, MA, USA). Each exercise was performed for

Table 1
Subject characteristics (means ± standard deviations).

Sex	N	Age (yrs)	Weight (kg)	Body fat (%)	Height (cm)
Male	24	22.63 ± 2.4	72.1 ± 7.6	8.7 ± 3.0	176.5 ± 5.4
Female	20	23.6 ± 3.1	58.8 ± 6.3	21.9 ± 5.4	163.7 ± 5.6
All	44	23.1 ± 2.8	66.1 ± 9.7	14.7 ± 7.9	170.7 ± 8.4

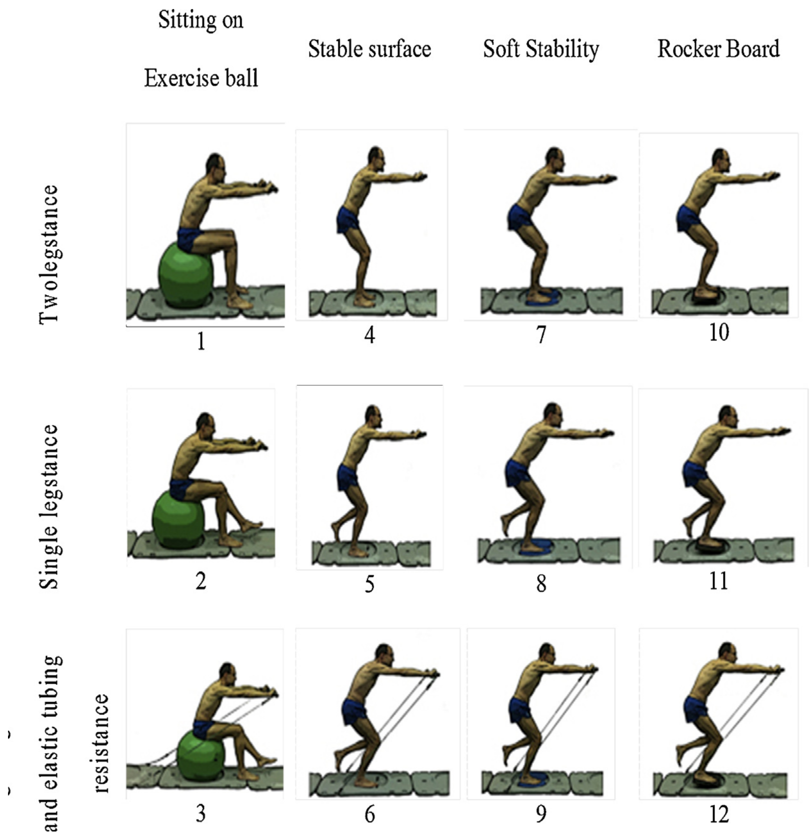

Fig. 1. The 12 exercises performed.

a duration of 20 s with a 2 min rest interval between exercises. Except for the Exercise Ball activities, all exercises were completed with 140° knee flexion (180° represents the straight knee position with the femur and tibia bones aligned) and 60° hip flexion (0° represents an erect posture with the femur extended). Exercise Ball activities were completed in a seated posture with 90° knee flexion and 20° hip flexion. Moreover, all exercises were completed with the arms parallel to the ground while maintaining a static position. All exercises are shown in Fig. 1. For the sake of brevity, each exercise was assigned a number designation as illustrated in Fig. 1. Exercises were performed in 3 separate positions (two leg stance, single leg stance and single leg stance with exercise tubing). Each exercise position was assumed on the 4 different platforms to alter the amount of stability for a total of 12 exercises.

In all exercises, subjects held a bar (445 grams) at a biacromial (shoulder) width and height. The shoulder width position was selected to reflect the shoulder position conventionally used in many other resistance exercises. The purpose of the bar was to ensure standardization of the exercises with and without elastic resistance as the elastic resistance exercise necessitated a bar to secure the elastic bands. To ensure consistent elastic tubing tension, the distance between standing and seated position was measured for each subject, hooking the elastic tubing to a steel chain with this distance.

2.4. Data analysis

Surface EMG amplitude in the time domain was quantified by using the root-mean-square (RMS) and processed as a moving average over 100 ms. The mean amplitudes of the RMS EMG signal were selected for every trial (exercises and MIVCs). Surface EMG signals of the exercises were analyzed by using the middle 16 s of the 20 s exercises. The EMG data obtained from each exercise were normalized to the RMS EMG value obtained from the MVIC recording for each one of the muscles investigated. MIVC EMG signals were analyzed by using the 3 middle seconds of the 5 s isometric contraction. All signals were bandpass filtered using a 20–400-Hz cutoff frequency and a fourth-order Butterworth filter employing a 14-bit analog–digital (AD) converter. All signals were acquired at a sampling frequency of 1 kHz, amplified and converted from analog to digital. All records of myoelectrical activity (in microvolts) were stored on a hard drive for later analysis. To acquire the surface EMG signals produced during the exercises, an ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used. All surface EMG signal analyses were performed using Matlab (Version 7.0, Mathworks Inc, Natick, MA, USA).

2.5. Statistical analysis

The SPSS statistical software package (Version 17.0, SPSS Inc, Chicago, IL, USA) was used to analyze all data. Normality of the data distribution was tested using the Shapiro–Wilk's test. Statistical comparisons for each individual muscle between the 12 exercises were performed by using a one way repeated measures analysis of variance (ANOVA). Post hoc analysis with Bonferroni correction was used in the case of significant interaction effects. Significance was accepted when $p < .05$. Results are reported as means ± SE values.

3. Results

All data were normally distributed. Significant differences were found between exercise conditions for PL ($p < .001$), TA ($p = .011$), and soleus ($p < .001$) (Figs. 2–4).

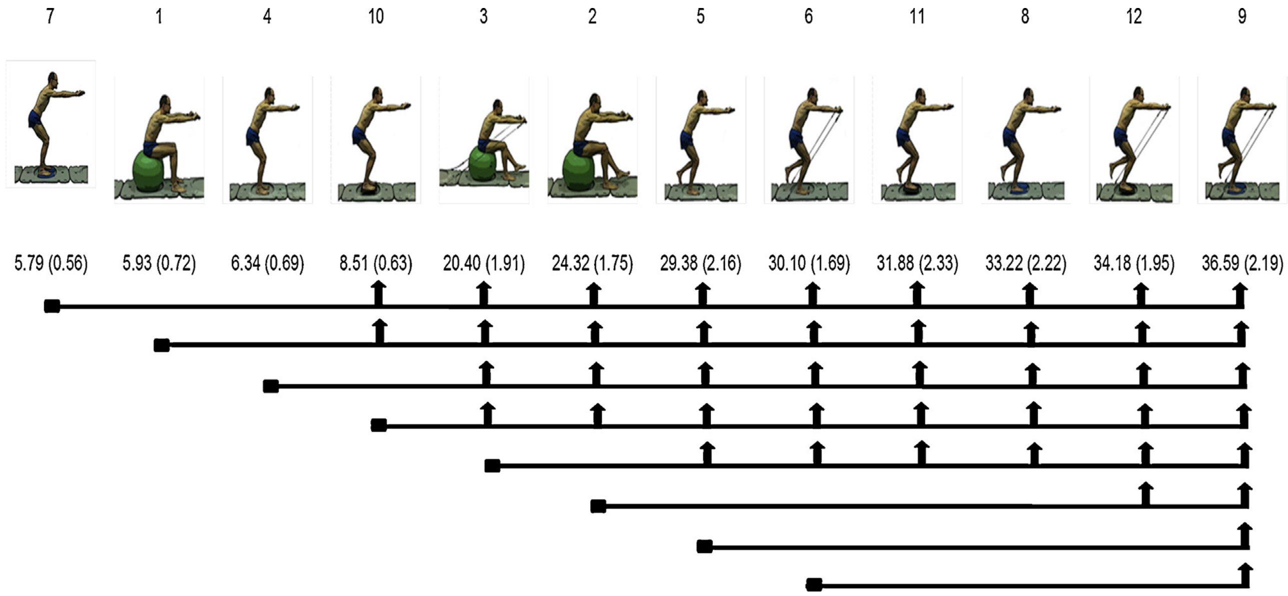

Fig. 2. PL EMG comparisons between conditions. Data expressed as mean percentage of the maximum isometric activation ($n = 44$). SEM values are in parentheses. Data correspond to the RMS of the PL. Arrows indicate significant differences ($p < .05$) between the exercise condition identified by a square and exercises corresponding to the arrows. PL: peroneus longus.

There was a great similarity in the response of each muscle to the 12 exercise conditions. Figs. 2–4 illustrate that exercises #9 and #5 were uniformly ranked (SOL, TA, PL) with the greatest activation and 6th highest activation for each muscle respectively. When examining the muscle activation rankings of the exercises as quartiles (e.g. 1–3, 4–6, 7–9, 10–12), it is observed that the same 3 exercises (#9, #12, #8) provide the greatest activation (first quartile: 1–3) for both the PL and SOL with 2 of those 3 exercises (#9, #8) ranked first and second for the TA. In the second quartile ranking (4–6), exercises #11 and #5 were common for all muscles. The third (#2, #3, #10) and fourth (#1, #4, #7) quartiles had the same exercises for all muscles.

In general, bilateral exercises induced the lowest activation followed by unipedal stance exercises with the highest activation with the unipedal stance exercises with elastic tubing.

4. Discussion

In accordance with the hypothesis, the greatest ankle muscle activation was achieved with exercises involving a unipedal stance. Unipedal exercises #5, #6, #8, #9, #11, #12 rank as the top six exercises for ankle muscle activation for all recorded muscles (PL, TA and SOL). The findings indicate that narrowing the base of support produces greater activation in order to stabilize the body. These findings concur with Amiridis et al. [26] who reported higher TA activation during the one leg stance position in comparison with a bipedal stance position.

Whether the instability is derived from a unipedal stance or unstable platforms, the literature tends to report greater ankle muscle activation with unstable supportive environments [11,14]. For example, Ferreira et al. [27] reported greater TA, tibialis posterior, PL, and lateral gastrocnemius EMG activity on unstable versus stable surfaces, as well as higher EMG activity with closed vs. open eyes. Wahl and Behm [28] also found that unstable platforms induced greater SOL activation in comparison to stable conditions. Anderson and Behm [18] reported higher SOL activation when squats were performed on unstable rather than stable surfaces. One of the few studies that did not show increased activation when comparing similar exercises on unstable and stable surfaces was by Laudner et al. [29] who did not find

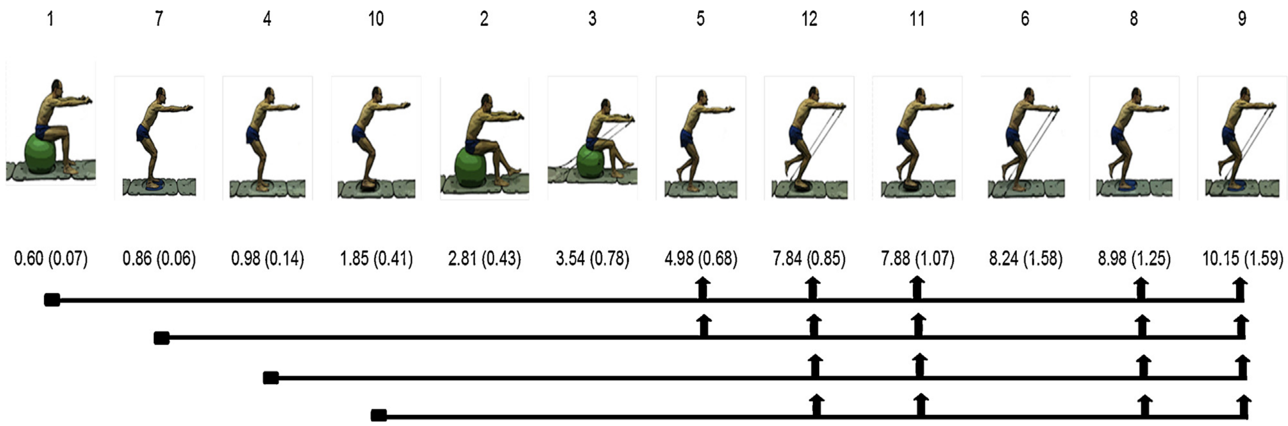

Fig. 3. TA EMG comparisons between conditions. Data expressed as mean percentage of the maximum isometric activation ($n = 44$). SEM values are in parentheses. Data correspond to the RMS of the TA. Arrows indicate significant differences ($p < .05$) between the exercise condition identified by a square and exercises corresponding to the arrows. TA: tibialis anterior.

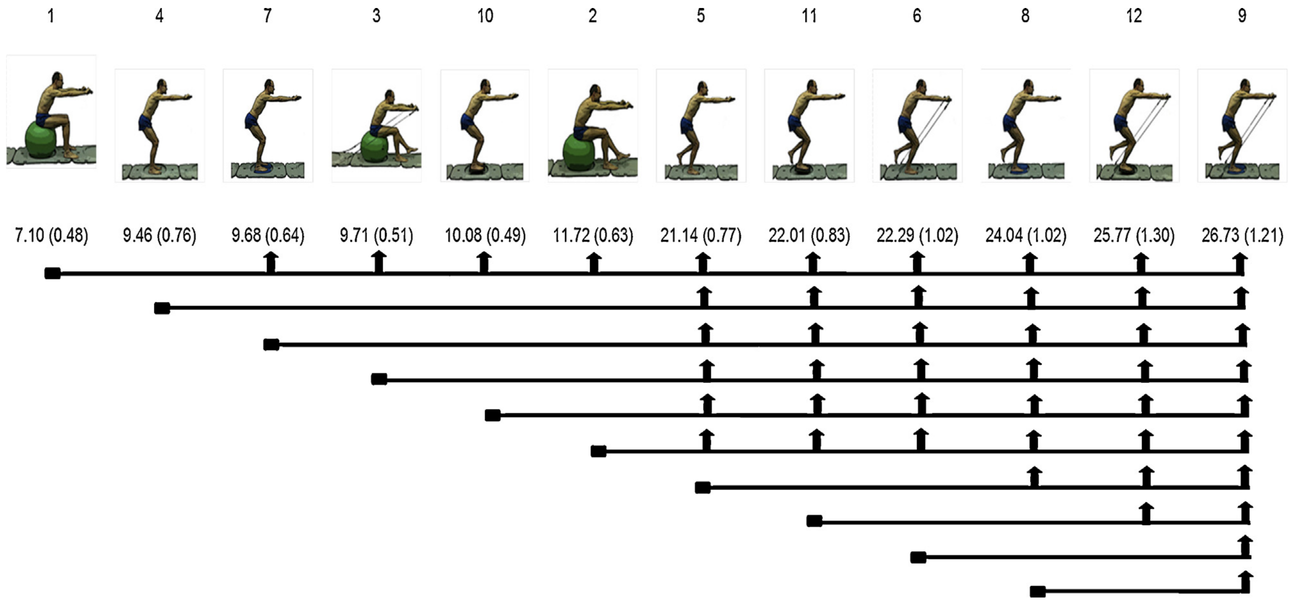

Fig. 4. SOL EMG comparisons between conditions. Data expressed as mean percentage of the maximum isometric activation ($n = 44$). SEM values are in parentheses. Data correspond to the RMS of the soleus. Arrows indicate significant differences ($p < .05$) between the exercise condition identified by a square and exercises corresponding to the arrows. SOL: soleus.

significant differences in the activation of PL, TA and gastrocnemius medialis when comparing both sides of the BOSU™ ball. However both sides of the BOSU™ ball should be considered as an unstable surface with the differences residing in the degree of instability. Hence the general findings of the present study are in agreement with the literature reporting effects of change in surface stability on muscle activation and function at the ankle.

Specifically, the present study found that a multiaxial platform (Soft Stability) did not provoke significantly greater ankle muscle activation than a uniaxial platform (Rocker Board) when the same conditions were used (with or without elastic tubing). These findings are consistent with the training study of Eisen et al. [30], who reported no significant differences in the improvement in a Star Excursion Balance Test when training with a uniaxial (Rocker Board) versus a multiaxial platform (Dynadisc). Hence, the level of instability or amount of difficulty provided by either platform (uniaxial versus multiaxial) were sufficient to elicit similar ankle muscle activation in university students with at least 1 year of resistance training experience. Similar to the aforementioned Laudner et al. [29] study findings, the difference in the levels or amount of stability between the Soft Stability and Rocker Board platforms must have been too small to elicit a significant difference in the amount of ankle muscle activity in the current study.

There are few studies that attempt to establish an optimal progression of stable and unstable exercises for ankle neuromuscular training. Recently, Muehlbauer et al. [16] evaluated different surfaces and conditions using center of pressure displacement to establish a balance exercise progression. The authors found that changing the support conditions and the sensory information increased the displacement. An exercise progression was established: easy exercises (bipedal and step position with open or closed eyes), intermediate exercises (tandem and unipedal position with eyes open on firm surface or foam) and hard exercises (tandem and unipedal position with closed eyes). Although different methods were used, these results are in accordance with our results, where the unipedal position generated the greatest muscle activation and bipedal position generated the lowest muscle activation for all the muscles evaluated, except for the soleus with exercise #10. Moreover, Muehlbauer et al. [16] found greater displacements in the center of pressure on a foam surface with eyes open than on stable surface with eyes open and in the present study, a similar material (Soft Stability) caused the greatest activation. Thus similar to a number of other authors who have found no significant differences under various destabilizing conditions [28,29], the extent of instability must be substantial in order to challenge equilibrium and provoke greater compensatory limb activation to maintain balance.

The present results indicate that elastic tubing with a unipedal stance did not generate significantly higher PL or TA activation than unresisted unipedal stances on a Rocker Board or Soft Stability platform. While the three unipedal stances with resistance exercises consistently ranked in the top 5 exercises for PL, TA and SOL activation, unipedal stances performed on stable surfaces without resistance provided significantly less activation for the TA and PL. SOL activation was significantly less with unresisted unipedal stances performed on stable surfaces, Rocker Boards and Soft Stability compared to elastic resistance unipedal stances on Soft Stability. Presumably, the implementation of bilateral elastic resistance provided a balanced resistance, which did not consistently create greater instability or disruptive torques to promote greater PL and TA activation compared to unstable unipedal stances. The resisted unipedal exercises can therefore be considered useful in clinical practice as the increased SOL activation can aid in promoting a greater recruitment of muscle fibers (type I to type IIb) in order to rehabilitate neuromuscular deficits following an injury. For PL and TA rehabilitation, resisted unipedal and unresisted unipedal exercises performed on unstable surfaces (Rocker Board and Soft Stability) can provide similar training environments.

This study presents a series of ankle exercises with a progression in exercise difficulty based on the amount of muscle activity. This progression was established in a cohort of young healthy individuals and practitioners should be conservative when applying these exercises to previously injured or sedentary populations. The progressions are intended to be used over a prolonged training program and not instituted into a single session with untrained or detrained groups.

5. Conclusion

As intensity is a factor in prescribing exercise progressions, the results of the present study would suggest that changes to an ankle stability exercise program based on muscle activation could start with a seated bipedal exercise, progressing to a standing bipedal position. Further progressions would involve increasing the difficulty by reducing the base of support to a unipedal stance. In this position either a uniaxial or multiaxial instability platform could be incorporated, as there was no significant difference in ankle activation in this population. Furthermore, the addition of elastic resistance to a multiaxial instability platform can provide even greater levels of SOL muscle activation.

Ethical approval statement

Statement of Institutional Review Board approval of the study protocol: Comissió d'Ética en Investigació Experimental (H1340632215316).

Acknowledgment

The authors wish to thank the participants for their contribution to this study.

References

[1] Fong DT, Hong Y, Chan LK, Yung PS, Chan KM. A systematic review on ankle injury and ankle sprain in sports. Sports Med 2007;37:73–94.
[2] Eils E, Rosenbaum D. A multi-station proprioceptive exercise program in patients with ankle instability. Med Sci Sports Exerc 2001;33:1991–8.
[3] Fernandez WG, Yard EE, Comstock RD. Epidemiology of lower extremity injuries among U.S. high school athletes. Acad Emerg Med 2007;14:641–5.
[4] Janssen KW, Van Mechelen W, Verhagen E. Ankles back in randomized controlled trial (ABrCt): braces versus neuromuscular exercises for the secondary prevention of ankle sprains. Design of a randomized controlled trial. BMC Musculoskelet Disord 2011;12:210.
[5] Arnold BL, De la Motte S, Linens S, Ross SE. Ankle instability is associated with balance impairments: a meta-analysis. Med Sci Sports Exerc 2009;41:1048–62.
[6] Mackeon PO, Hertel J. Systematic review of postural control and lateral ankle instability. Part 1. Can deficits be detected with instrumented testing? J Athl Train 2008;43:293–304.
[7] Zech A, Hübscher M, Vogt L, Banzer W, Hänsel F, Pfeifer K. Neuromuscular training for rehabilitation of sports injuries: a systematic review. Med Sci Sports Exerc 2009;41:1831–41.
[8] McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. Clin J Sport Med 2000;10:239–44.
[9] Wikstrom EA, Naik S, Lodha N, Cauraugh JH. Balance capabilities after lateral ankle trauma and intervention: a meta-analysis. Med Sci Sports Exerc 2009;41:1287–95.
[10] Taube W, Gruber M, Gollhofer A. Spinal and supraspinal adaptations associated with balance training and their functional relevance. Acta Physiol 2008;193:101–16.
[11] Behm DG, Colado JC. The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. Int J Sports Phys Ther 2012;7:226–41.
[12] Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. Knee Surg Sports Traumatol Arthrosc 1996;4:19–21.
[13] Carter JM, Beam WC, McMahan SG, Barr ML, Brown LE. The effects of stability ball training on spinal stability in sedentary individuals. J Strength Cond Res 2006;20:429–35.
[14] Behm DG, Drinkwater EJ, Willardson JM, Cowley PM. Canadian Society for Exercise Physiology position stand: the use of instability to train the core in athletic and non-athletic conditioning. Appl Physiol Nutr Metab 2010;35:11–4.
[15] American College of Sports Medicine. American College of Sports Medicine position stand. Exercise and physical activity for older adults. Med Sci Sports Exerc 2009;41:1510–30.
[16] Muehlbauer T, Roth R, Bopp M, Granacher U. An exercise sequence for progression in balance training. J Strength Cond Res 2012;26:568–74.
[17] Behm DG, Willardson JM, Cowley PM. The role of instability rehabilitative resistance training for the core musculature. Strength Cond J 2011;33:72–81.
[18] Anderson K, Behm DG. Trunk muscle activity increases with unstable squat movements. Can J Appl Physiol 2005;30:33–45.
[19] O'Driscoll J, Kevin F, Delahunt E. Effect of a 6-week dynamic neuromuscular training programme on ankle joint function: a case report. Sports Med Arthrosc Rehabil Ther Technol 2011;3:13.
[20] Paterno MV, Myer GD, Ford KR, Hewett TE. Neuromuscular training improves single-limb stability in young female athletes. J Orthop Sports Phys Ther 2004;31:305–16.
[21] American College of Sports Medicine. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc 2011;43:1334–59.
[22] Pantoja PD, Alberton CL, Pilla C, Vendrusculo AP, Kruel LFM. Effect of resistive exercise on muscle damage in water and on land. J Strength Cond Res 2009;23:1051–4.
[23] Cram JR, Kasman GS, Holtz J. Introduction to surface electromyography. Gaithersburg: Aspen Publishers; 1998.
[24] Delagi E, Perotto A. Anatomic guide for the electromyographer. Springfield, IL: Charles C. Thomas; 1981.
[25] Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. Muscles: testing and function with posture and pain. 5th ed. Baltimore: Lippincott Williams & Wilkins; 2005.
[26] Amiridis IG, Hatzitaki V, Arabatzi F. Age-induced modifications of static postural control in humans. Neurosci Lett 2003;350:137–40.
[27] Ferreira LA, Pereira WM, Rossi LP, Kerpers II, de Paula Jr AR, Oliveira CS. Analysis of electromyographic activity of ankle muscles on stable and unstable surfaces with eyes open and closed. J Bodyw Mov Ther 2011;15:496–501.
[28] Wahl MJ, Behm DG. Not all instability training devices enhance muscle activation in highly resistance-trained individuals. J Strength Cond Res 2008;22:1360–70.
[29] Laudner KG, Koschnitzky MM. Ankle muscle activation when using the both sides utilized (BOSU) balance trainer. J Strength Cond Res 2010;24:218–22.
[30] Eisen TC, Danoff JV, Leone JE, Millar TA. The effects of multiaxial and uniaxial unstable surface balance training in college athletes. J Strength Cond Res 2010;24:1740–5.