



Full length article

Instability training, assessing the impact of level of difficulty on balance: A randomized clinical trial

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ARTICLE INFO

Keywords:

Instability
Postural control
Balance

ABSTRACT

Background: Most human movements are executed while in a state of postural instability. For this reason, instability training is a highly-specific method that is intended to improve balance and postural control. This research aimed to determine the effect of instability training on the balance of individuals with similar baseline abilities, who initiated training within different stability conditions.

Research question: Does the level of difficulty with which instability training is performed determine improvements in balance?

Method: A two-arm randomized trial was undertaken, for which 22 and 21 participants were included in the experimental and control groups, respectively. The experimental group performed balance training on unstable surfaces and the control group implemented the same training on stable ground. The primary outcome was the Y-Balance Test (YBT); the Emery test, Functional Reach test, and platform measures were the secondary outcomes. Confidence intervals were set at 95% and Cohen's *f* statistic was used to estimate effect size.

Results: Dynamic balance, as measured by the YBT, showed significant *Time* improvements in both groups for right ($p < 0.001$, $f = 0.53$) and left ($p = 0.005$, $f = 0.33$) limbs. Similar results were found in the Emery test and Functional Reach test. No statistical *Group* and *Time*Group* interactions were found. None of the proposals modified the center of pressure excursions.

Significance: Instability training is a safe and effective approach to enhance balance. However, the findings deduced that the level of difficulty (instability) with which participants with similar abilities initiate the training is not a determining factor in the balance improvements achieved. It follows that instability training may be either used as an alternative or as an additional method to train for balance on a stable ground.

1. Introduction

Balance and postural control are fundamental to the maintenance of a static position, body segment movements and displacement of the entire body. For this reason, balance exercises are commonly incorporated into training programs with diverse orientations, such as to enhance performance in sports [1], prevent falls, rehabilitate, or maintain and promote musculoskeletal health [2,3].

Considering the wide range of applications, the level of difficulty of the training program must be adapted to the target population. Applying external disturbances, dynamic movements or reducing sensory inputs are some of the options to increase difficulty [4]. In addition, reduction of the size and stability of the base of support

additionally increases difficulty through an approach known as instability training [5].

Instability training is a highly-specific approach which relies in providing disruptive torque to the body, contributing to instability challenges [6]. To keep the center of gravity within the base of support, instability training requires accurate response strategies, adequate muscular conditioning and a high degree of postural control [7,8]. The approach has important applications as most basic human movements occur in a situation of postural instability.

The effects of instability training have been researched extensively [5]. Overall, programs are recommended to be progressive in difficulty, by reducing stability to enhance neuromuscular demands [9,10]. However, the literature evaluating the optimal methods in terms of

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<https://doi.org/10.1016/j.gaitpost.2019.02.029>

Received 24 September 2018; Received in revised form 18 February 2019; Accepted 25 February 2019

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intensity, frequency and duration of exercises is scarce [11]. Based on the activation sequences of the ankle and core musculature, emerging literature has recommended that training may progress from seated to bipedal standing exercises, and subsequently increase difficulty with greater instabilities and resistance work [10–12]. However, the advisable degree of instability with which an individual with certain balancing abilities should initiate to train to achieve the greatest improvements in balance is yet to be resolved. Therefore, the aim of the current study was to assess the effects of instability training on balance, when performed by individuals with similar balancing abilities who initiated training with different degrees of instability. It was hypothesized that the level of difficulty used in training would be a decisive factor in the improvements achieved.

2. Method

2.1. Design and ethics

A randomized clinical trial was performed with two arms: the experimental group underwent instability training on diverse unstable surfaces, and the control group underwent the same intervention on stable ground. The study was prospectively registered (NCT03443050). The trial was designed according to the Declaration of Helsinki, revised in Hong Kong, and was approved by the Ethics Committee of the University of Valencia (H1515057880965). Informed consent was obtained from all participants and data were anonymized from the origin with numerical code.

2.2. Participants and sample size

The sample criteria included university students aged 18–30 years. Individuals with muscle skeletal injury in the preceding 6 months and athletes from any field were excluded, in addition to those with known balance disorders, such as vertigo and central or vestibular disorder.

Sample size estimations were based on the arbitrary assumption that the experimental group would obtain an evolution superior to 10% against the control group in the primary outcome, the Y-Balance Test. Assuming a sample loss of 15%, if the true difference between the means of the groups were at least 10%, a sample size of $n = 44$ participants would be adequate to reject the null hypothesis with statistical power of 80% with a confidence interval of 95%.

2.3. Randomization and masking

Randomization was carried out by an external assessor, based on the output of a random number generator program (Matlab®). The interventions were supervised by two qualified physiotherapists experienced in sport training. The supervisors were not blinded to the interventions but they were blinded to the outcomes. Blinding of participants was not assured because it was necessary to inform participants about the interventions before obtaining their consent.

Table 1

Domains and operational components of balance covered by the tests.

Domains in Systems Framework for Postural Control (Horak, 2005)	1. Biomechanical constraints			2. Orientation in space	3. Movement strategies		4. Control of dynamics	5. Sensory strategies	6. Cognitive processing
	1. Static stability	2. Underlying motor systems	3. Functional stability limits	4. Verticality	5. Reactive postural control	6. Anticipatory postural control	7. Dynamic stability	8. Sensory integration	9. Cognitive influences
Components of balance (Sibley, 2015)									
Balance measures									
Y Balance	✓	✓	✓			✓			
Romberg	✓	✓						✓	
Emery	✓	✓	✓		✓	✓	✓	✓	
Functional Reach		✓	✓			✓			

2.4. Interventions

As suggested in previous research, there are two possible components in instability training: progressive challenges to balance and the addition of load and resistance [6]. While combining these components is a widely accepted approach, the former approach with no external loads was used within the current study. Under this criteria, both groups performed the same intervention program. The level of difficulty underpinned the difference between the interventions: the control group trained on stable ground, while the experimental group initiate the training with higher level of difficulty, i.e. on unstable surfaces.

The intervention was designed in accordance with recommendations for instability training [5,6,9,13,14], where the base of support was reduced with mono-pedal exercises that also included dynamic movements and additional proprioceptive work with tandem and braiding exercise (detailed in Appendix A). The number of exercises and dosage were a pragmatic decision based on previous works [5,6,9,13,14], clinical experience and available resources. The program consisted of nine sessions that were performed across three weeks in alternate weekdays [13]. The 40–45 minute sessions initiated with a 10-min warm-up phase including five exercises, three which involved global body mobilization and breathing control and then ankle circumduction. A 25- to 30-min work-phase was then completed which included eight balance exercises (Appendix A). A progressive increase of the degree of instability was proposed for the experimental group. The objective was twofold: adhere to previous recommendations for instability training [6,9] and prevent injuries. Specifically, foam Airex® Balance-Pads and -Beams were used in the first three sessions; inflatable balance discs and BOSU balls were incorporated in sessions four through nine as tolerated by participants. Finally, 7- to 10-min of global stretching and relaxation was performed to conclude the session.

2.5. Balance outcomes

Balance tests are usually categorized to measure dynamic, static and overall balance. In addition, the Systems Framework for Postural Control described by Horak [15] suggested six major components required for the maintenance of postural control. The domains have multiple constructs. For this reason, Sibley et al. [16] translated the former domains into nine operational definitions of balance components: functional stability limits, underlying motor systems, static stability, verticality, reactive postural control, anticipatory postural control, dynamic stability, sensory integration and cognitive influences. According to Table 1, all the operational components of balance except verticality and cognitive influences were assessed with the following outcomes.

2.5.1. Primary balance outcome

The Y Balance Test (YBT), which is commonly used to assess dynamic balance, was developed to refine the Star Excursion Balance Test. The test required participants to balance themselves on one leg whilst

simultaneously reaching as far as possible with the contralateral leg in three separate directions. To do so, a three-lined grid was constructed with adhesive tape and a goniometer. The two posterior lines extended from the center of the grid and were positioned 135° from the anterior line with 45° between the two posterior lines. In accordance with Plisky et al. [17], the directional sequence was: anterior, posteromedial, and then, posterolateral. Firstly, the participants were allowed to practice to familiarize themselves with the steps. The test then began with bearing the weight on the right foot. The participants had to complete three successful reaches in the first direction, allowing 15 s of rest. Reach distances were recorded to the nearest 5 mm. The process was then repeated in the same direction but bearing the weight on the left foot. The sequence was repeated alternating right and left foot at posteromedial and the posterolateral reach. All trials were conducted barefooted, with the hands placed on the hips and stance foot movement was minimized. The YBT score was calculated by summing the maximal reach for each direction and leg and normalizing the results to limb length. Limb length was measured in supine position, from the anterior-superior iliac spine to the center of the medial malleolus [18]. The following formula was used:

$$\text{YBT} = (\text{maximum anterior reach distance} + \text{maximum posteromedial reach distance} + \text{maximum posterolateral reach distance}) / (\text{leg length} \times 3) \times 100 (\%)$$

2.5.2. Secondary balance outcomes

Static balance and center of pressure excursions in upright position was evaluated with the Romberg test [19]. The test was performed using a T-Plate® platform. The test relies on the basis that maintaining balance while standing in the stationary position depends on the correct functioning of sensory pathways, sensorimotor integration centers and motor pathways. The participants were asked to stand erect, with the eyes open and hands by the sides. The test was repeated with closed eyes. The excursion of the center of pressure was then estimated in terms of the sway area (mm²) and velocity (m/s) after 1 min of test.

The single-leg Emery timed balance test was specifically designed to assess the balancing abilities of young people and adolescents [20]. In this work, we conducted the eyes-closed dynamic test. The participants were asked to stand barefooted on an Airex® Balance-Pad with slight knee flexion of the weight-bearing limb and 45° degree flexion of the non-weight-bearing limb, keeping their hands on their hips. The timer was stopped when a participant lost their balance owing to one of the following situations: removal of hand from the hip; opening of the eyes; the non-weight-bearing limb touching the floor, the pad, or the weight-bearing limb; or the pad or the foot of the non-weight-bearing limb moving from the initial test position. The longest duration of three attempts was recorded for each leg, allowing 15 s of rest between trials.

The final test used was a Functional Reach Test. As a clinical measure of balance, this test was selected to provide a reasonable clinical approximation of the margin of stability [21]. The participants were instructed to stand close to, but not touching, a wall where a meter was placed to measure reaching distances. The arm was positioned with 90° of shoulder flexion and held with a closed fist. The starting position measurement was taken on the third meta-carpal head. The participants were then instructed to reach as far as possible without taking a step, and the location of the third metacarpal head was subsequently recorded. Height is a confounding factor influencing results, so a modified version calculated the ratio of functional reach distance and body height to yield more accurate results for the test. We used the mean of two attempts for further analysis.

2.6. Data synthesis

Data was analyzed with the IBM SPSS software version 24.0 licensed by the University of Valencia. Descriptive statistics were used to extract

demographical data. Data was presented as means and standard deviations.

Possible baseline differences were assessed with Shapiro-Wilk test. An analysis of variance based on a mixed linear model was used to assess *Time*, *Group* and *Time*Group* interactions. Post-hoc tests were planned in case of *Time*Group* significant results.

Effect sizes, determined using *f* statistic, were established according to the limits recommended by Cohen with small ($f < 0.24$), moderate ($0.24 < f < 0.39$) and large effect size ($f > 0.4$) [22]. All tests were conducted with the confidence interval set at 95%.

2.7. Results

Fifty-one potential participants were assessed for eligibility. Forty-eight agreed to participate and were randomized into two equal groups. Forty-three completed the study: The experimental group was formed of 22 participants (13 females and 9 males), aged 22.7 (3.5) years, with a mean body mass index (BMI) of 22.9 (4.5) kg/m². The control group consisted of 11 females and 10 males ($n = 21$), aged 22.0 (2.9) years and with a BMI of 22.1 (3.1) kg/m². Compliance was greater than 97% in both groups. After baseline assessment, three participants did not start the training for personal reasons: one in the experimental group dropped out for personal reasons, while the schedule of the training did not allow a further two control group participants to attend. One participant could not complete intervention due to sprain while practicing sport, while one participant was excluded from data synthesis for attending less than half of the sessions. None of the participants reported injury derived from the training. There were no between-group baseline differences in any of the demographic outcomes. A flow chart is presented in Fig. 1.

2.8. Effects on balance

No baseline differences were identified in the balance measures (confidence interval, 95%). Dynamic balance as measured with the YBT and Emery balance test and stability in terms of the Functional Reach test showed significant *Time* improvements after the interventions in both groups. The first two tests presented different effect size in the right and left leg, which ranged from moderate to high (Table 2). However, *Group* and *Time*Group* interaction differences were not observed.

Conversely, platform measures suggested that neither group presented significant changes in center of pressure excursions after the interventions. Balance outcome data is presented in Table 2.

2.9. Discussion

This research assessed the effects of instability training on the balance of university students who initiated training from different level of difficulty. The assumption that all participants presented with similar balancing abilities at baseline was confirmed through measurements of the proposed outcomes. Under this condition, the participants were able to train with different degrees of instability; however, the results showed that higher difficulty in exercise did not translate into greater improvements. Therefore, the main finding was that training with a higher degree of instability does not necessarily determine greater improvements in balance.

In a recent review, Behm et al. [5] included 15 randomized trials that evaluated young adults who performed instability training. However, only three of them are comparable with this research, since evaluated balance of young untrained participants [23–25]. The findings suggested that training on stable ground may correspond with enhanced static balance, whereas instability training may further improve dynamic balance. However, the results were not significant. The conclusions suggesting inconclusive results were consistent with our findings [5], as this trial verified that greater effects on balance cannot

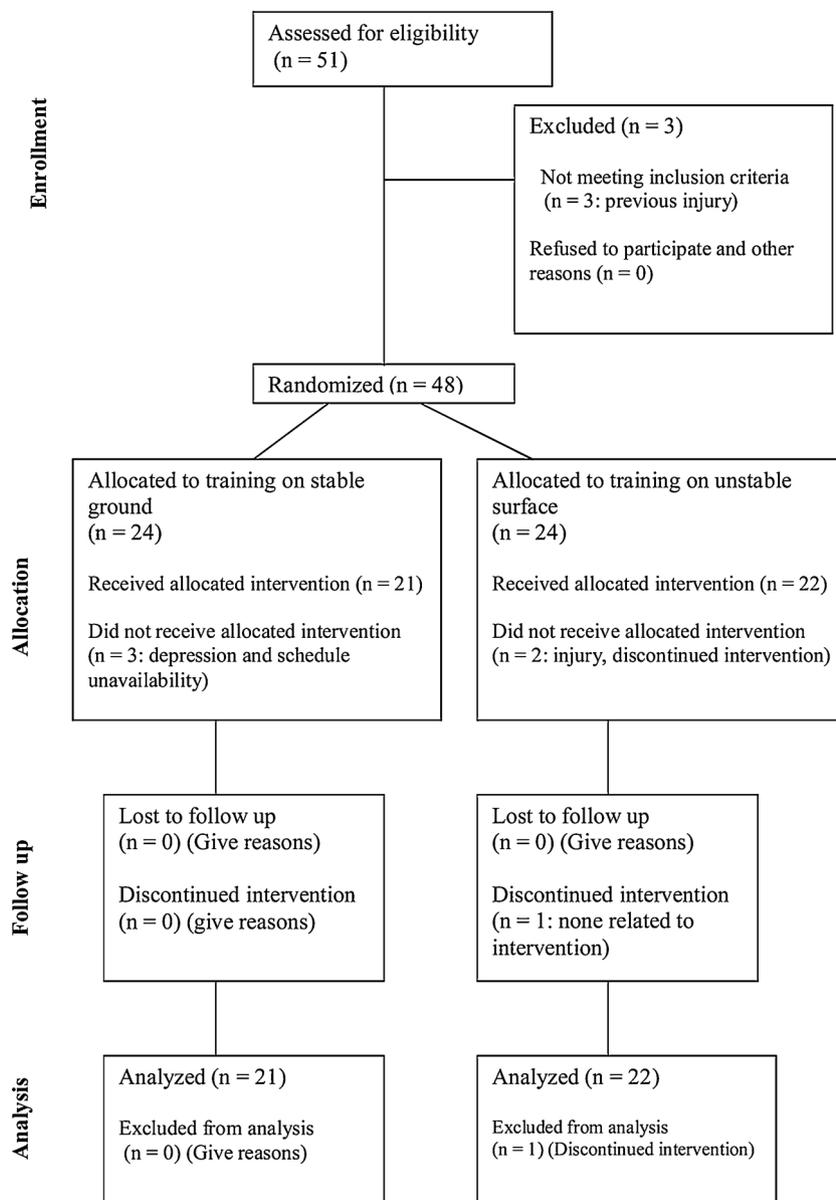


Fig. 1. Participants flow chart based on CONSORT guidelines.

be attributed to the degree of instability included in the training of the target population.

The results of this research indicated that participants did not present significant modifications in the center of pressure excursions regardless of the training methodology, and it was unaffected by whether the eyes were closed or open during the tests. We speculate that the planned training dose might not have been enough to improve this outcome evaluated via the Romberg test. Indeed, the dose is highly variable in previous reports (doses between 7 and 30 sessions spanning between 2 and 10 weeks) [5]. However, no previous study has comprehensively evaluated the time required to improve static balance using unstable surfaces. Kibele et al. [24] did not find improvements in these terms either, whereas Gauchard et al. [26] already suggested that static balance seemed to take longer to enhance than dynamic balance.

It is known that the level of difficulty of balance training can be increased by reducing stability [9,11,12]. Overall, a greater degree of instability is more likely to have an increased impact on the mechanisms underlying postural control, with more pronounced neuromuscular adaptations and muscle activation demands, which may lead to balance improvements. The high specificity of the approach would be

beneficial for every action requiring high degree of postural control owing to situations of instability, such as in sports practice or even basic activities such as gait. Indeed, previous research found positive effects owing to instability training targeting different populations and goals [5,7,24,27,28], however, we can state in a qualitative way that when the studies appraised the effects of training on unstable versus stable surfaces on balance, significant differences were either found in isolated cases or the results presented a small effect [5].

Though, it is important to emphasize that significant improvement in time, high compliance, and no occurrence of adverse effects suggests that this instability training is a feasible and safe way to improve balance. Based on our results, we recommend this instability training, but also suggest that incorporation of unstable surfaces in balance training may be either applied as an alternative or as an additional method to train on a stable ground without risk of different outcomes. Importantly, it is important to notice that there are additional factors that are decisive in the effects achieved and paramount in any training design. For instance, the type of exercise (i.e. chest press, squats), type of unstable device, frequency, intensity, loads, work and rest intervals [27], while the optimal methods in terms of progression remain

Table 2
Effects of training on stable vs unstable surface on balance.

Outcomes	n	M (SD) Pre	M (SD) Post	Δ (SD)	P-value (f) Time	P-value (f) Group	P-value (f) Time*Group
YBT right (%)					< 0.001 (0.53)	0.827 (0.00)	0.792 (0.00)
Stable	21	88.7 (10.7)	93.4 (8.2)	4.7 (9.5)			
Unstable	22	88.2 (8.1)	92.0 (8.4)	3.2 (8.2)			
YBT left (%)					0.005 (0.33)	0.504 (0.02)	0.267 (0.06)
Stable	21	91.1 (10.3)	93.7 (8.5)	2.6 (9.4)			
Unstable	22	88.1 (7.2)	92.6 (8.7)	4.5 (7.9)			
Emery test right (s)					0.002 (0.39)	0.614 (0.01)	0.970 (0.00)
Stable	21	5.1 (3.0)	8.8 (8.3)	3.7 (6.2)			
Unstable	22	4.6 (2.3)	7.9 (5.5)	3.3 (4.2)			
Emery test left (s)					< 0.001 (0.60)	0.219 (0.07)	0.113 (0.12)
Stable	21	4.6 (2.5)	8.1 (5.5)	3.5 (4.3)			
Unstable	22	4.5 (2.4)	10.6 (8.0)	6.1 (5.9)			
ROE sway (mm ²)					0.123 (0.11)	0.637 (0.01)	0.747 (0.01)
Stable	21	26.5 (22.7)	38.7 (47.1)	12.2 (36.9)			
Unstable	22	34.5 (34.2)	39.7 (42.4)	5.2 (38.4)			
ROE velocity (m/s)					0.181 (0.08)	0.239 (0.07)	0.368 (0.04)
Stable	21	1.6 (0.3)	1.6 (0.4)	0.0 (0.4)			
Unstable	22	1.7 (0.4)	1.8 (0.7)	0.1 (0.6)			
RCE sway (mm ²)					0.239 (0.07)	0.399 (0.04)	0.968 (0.00)
Stable	21	32.2 (28.3)	40.6 (38.0)	8.4 (33.5)			
Unstable	22	39.7 (27.4)	48.8 (50.4)	9.1 (40.5)			
RCE velocity (m/s)					0.638 (0.01)	0.051 (0.18)	0.737 (0.00)
Stable	21	1.9 (0.5)	1.9 (0.4)	0.0 (0.4)			
Unstable	22	2.4 (0.8)	2.4 (1.4)	0.0 (1.1)			
FRM (score)					< 0.001 (0.88)	0.153 (0.09)	0.999 (0.00)
Stable	21	22.0 (2.6)	22.4 (2.3)	0.4 (2.4)			
Unstable	22	21.0 (2.9)	23.8 (3.2)	2.8 (3.0)			

Note. M = mean, SD = standard deviation, YBT = Y Balance Test, ROE = Romberg Open Eyes, RCE = Romberg Closed Eyes, FRM = Functional Reach Modified. YBT = [(maximum anterior reach distance + maximum posteromedial reach. distance + maximum posterolateral reach distance) / (leg length × 3)] * 100. FRM = [Maximum frontal reach distance (cm) / height (cm)] * 100.

understudied [11,12].

Among the strengths, this research comprehensively and primarily evaluated various balance components of healthy young adults. A practical implication is that performing nine sessions of instability training would be sufficient to significantly improve dynamic balance and the margins of stability, but not the static maintenance of the upright posture. The clinical importance is suggesting that the degree of instability with which the performance of the exercises of a balance training begins, may not be decisive in the improvements.

It is necessary to recognize some limitations. The programmed number of sessions were enough to enhance balance, but as highlighted in this section, literature has been highly variable in terms of dosage. Future research is necessary to elucidate the dose-response rate to improve static balance, but also whether higher or even lower number of sessions could impact the between-group differences. Reliable conclusions have been drawn on healthy untrained university students, but these cannot be extended to consider the effects in relation to injury recovery, such as knee or ankle sprains, where to apply progressive instabilities has shown to be an effective method to train proprioception [29]. All of the operational components of balance, except verticality and cognitive influences, were assessed [16], so there is still scope for further research. Although literature exists, consistency in research targeting middle-aged and old adults is required [5].

In conclusion, the results provided scientific support to training on unstable surfaces as an effective and safe approach to enhance balance. However, it is necessary to be aware that the degree of instability with which participants with similar overall balancing abilities when training was initiated was not a determining factor in the improvements achieved, at least in terms of balance. Therefore, instability training may be either used as an alternative or as an additional method to train balance on a stable ground.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest statement

The authors certify that they have no affiliations with any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.gaitpost.2019.02.029>.

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