

## Effects of slackline training on core endurance and dynamic balance Efectos del entrenamiento en slackline sobre la resistencia del core y el equilibrio dinámico

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**Abstract.** Slackline challenges balance by walking on a tensioned strap, where the trunk muscles help to maintain or regain balance. This study aimed to compare a cohort of individuals who regularly practiced slackline and physically inactive individuals on core endurance (CE) and dynamic balance (DB) and to determine whether CE is associated with years of slackline practice. Nine individuals (7 men) who practiced slackline regularly (SG; age= 24.5±3.6 years) and nine physically inactive individuals (7 men) (CG; age= 23.2±3.3 years) were compared. CE was assessed with the McGill battery (trunk flexor, extensor, and side-bridge test) and the plank test. DB was measured with the modified star excursion balance test in stable and unstable conditions. The SG maintained a 36.2% and 45% longer time in left lateral bridge ( $p=.049$ ) and plank ( $p=.031$ ), respectively, compared to the CG. The distance achieved in the stable DB test was similar between groups, but in unstable condition was 37.8% greater ( $p=.016$ ) in SG in both legs and 46.6% greater in the non-dominant leg ( $p=.039$ ) compared to CG. The SG showed a correlation between years of slackline practice and flexor ( $r=.674$ ;  $p=.046$ ), right lateral ( $r=.765$ ;  $p=.016$ ) and left ( $r=.730$ ;  $p=.026$ ) trunk endurance. In conclusion, those who practice slackline maintain a longer time in the plank and left lateral bridge test and achieve a higher reach distance in unstable DB compared to physically inactive individuals who do not practice slackline.

**Key words:** trunk, postural control, modified Star Excursion Balance Test, unstable surfaces.

**Resumen.** El slackline desafía el equilibrio al caminar sobre una cinta en tensión, donde los músculos del tronco ayudan a mantener o recuperar el equilibrio. El objetivo de este estudio fue comparar individuos que practicaban slackline e individuos inactivos físicamente (IF) en resistencia del core (RC) y equilibrio dinámico (ED), y conocer si la RC se asocia a los años de práctica de slackline. Nueve individuos (7 hombres) que practicaban slackline regularmente (GS; edad= 24.5±3.6 años) y nueve individuos IF (7 hombres) (GC; edad= 23.2±3.3 años) fueron comparados. La RC se evaluó con la batería de McGill (prueba de flexores y extensores de tronco y puente lateral) y la prueba de la plancha. El ED se midió con la prueba de excursión de la estrella modificada en condiciones estables e inestables. El GS mantuvo un tiempo 36.2% y 45% mayor en puente lateral izquierdo ( $p=.049$ ) y plancha ( $p=.031$ ) respectivamente comparado con el GC. La distancia alcanzada en la prueba de ED estable fue similar entre grupos, pero en condición inestable fue 37.8% mayor ( $p=.016$ ) en GS en ambas piernas y 46.6% mayor en la pierna no dominante ( $p=.039$ ) comparado al GC. El GS mostró una correlación entre años de práctica de slackline y resistencia flexora ( $r=.674$ ;  $p=.046$ ), lateral derecha ( $r=.765$ ;  $p=.016$ ) e izquierda ( $r=.730$ ;  $p=.026$ ) de tronco. En conclusión, quienes practican slackline mantienen un tiempo mayor la prueba de la plancha y puente lateral izquierdo y logran un mayor alcance en ED inestable comparados con individuos IF que no lo practican.

**Palabras claves:** tronco, control postural, prueba de la estrella modificada, superficies inestables.

### Introduction

It is generally stated that the core muscles acts as the anatomical base of the movement (Kibler et al., 2006). Core muscles surround the center of gravity in the lumbopelvic region, and its action is vital to keep the center of gravity stable within the support base (Akuthota & Nadler, 2004). It is considered that the core is the center of the kinetic chains, transferring forces and acting as a bridge between the upper and lower

extremities, which provides proximal stability for distal mobility (Kibler et al., 2006). The function of the core muscles is usually assessed in terms of strength (Estrázulas et al., 2020; Rodriguez-Perea et al., 2019), stability (Barbado et al., 2016; Bastida Castillo et al., 2017) and/or endurance (Juan-Recio et al., 2018). Trunk endurance is a crucial component in core training (Faries & Greenwood, 2007), since it helps maintain an efficient trunk position, and is of great importance in both, health and sports performance. Core endurance has been evaluated by measuring the time that a given position can be maintained (McGill et al., 1999; Strand et al., 2014). Furthermore, a decreased endurance has been related to the onset of low back pain (Abdelraouf &

Abdel-Aziem, 2016; Biering-Sorensen, 1984; Lindsay & Horton, 2006), and it has been shown that fatigue of these muscles could negatively affect spinal stability and postural control in athletes (Davidson et al., 2004; Granata & Gottipati, 2008; Van Dieën et al., 2012). Thus, core endurance seems to play a fundamental role in health and sports performance (Imai & Kaneoka, 2016; Tong, Wu, Nie, et al., 2014)

Core endurance training has been associated with improvements in balance (Suri et al., 2011), and core muscle fatigue has been associated with impaired balance and functional tasks (Helbostad et al., 2010). In this sense, a relationship between core endurance and balance has been described in young (Barati et al., 2013) and old individuals (Suri et al., 2009). Recently, it has been described that the greater the instability of the surface, the greater the activation of the core muscles to recover the postural balance (Calatayud et al., 2015). Postural balance describes the dynamics of the body trying not to fall; therefore, it is crucial for daily life activities and sports (Ringhof & Stein, 2018), and is especially relevant in activities that involve constant disturbances or changes in position.

The slackline is an emerging sport activity, considered a motivating and challenging exercise that aims to improve balance (Donath et al., 2017). The slackline consists of maintaining balance on a strap tensioned between two anchor points and can be considered an attractive and demanding alternative compared to traditional balance training (Paoletti & Mahadevan, 2012). It allows a high variability of movement with a small and unstable base of support that produces medio-lateral disturbances to the body, continually challenging balance (Keller et al., 2012). Supervised training in slackline has been shown to improve postural control and jumping performance in female basketball players (Santos et al., 2016), sensorimotor control (Jäger et al., 2017), acceleration and agility in young players (Fernández-Rio et al., 2019), lower limb muscle activity (Donath et al., 2016), and also improve static and dynamic balance (Donath et al., 2017). However, it is not known if this type of balance training induces changes in the core endurance performance.

Slackline training not only involves the well-known ankle and hip strategies to regain balance, but also introduces multi-joint strategies to accomplish the task of walking on the strap, controlling and slowing trunk swings and coordinating hip and arm movement to regain balance (Mildren et al., 2018; Serrien et al., 2017). When comparing beginners to slackline trained

individuals, trained slackliners show a more precise control of the acceleration of the center of mass, projecting it close to the center of the foot and allowing better balance control over time (Stein & Mombaur, 2019). These adaptations of the slackline practice may be translated into a greater ability to keep the center of gravity stable within the base of support through the maintained action of the core muscles in those who practice slackline when compared to physically inactive individuals without experience in this type of training. However, this has not yet been investigated. The aims of this study were (I) to compare the core muscle endurance and dynamic balance between individuals who practice slackline and physically inactive healthy individuals, and (II) to determine the relationship between core endurance performance and years of practice of slackline. It was hypothesized that (I) systematic training on the slackline would produce an increase in core endurance performance and dynamic balance on unstable surfaces, and (II) there was a correlation between years of practice of slackline and core endurance performance.

## **Methods**

### ***Design and Procedures***

This was a cross-sectional descriptive study. On one occasion only, participants from both groups were invited to the laboratory for data collection. First, the anthropometric measurements were made at participant arrival. The core endurance performance was evaluated first (McGill et al., 1999), followed by the modified Star Excursion Balance Test in the anterior, posteromedial and posterolateral direction (Plisky et al., 2006) in stable and unstable conditions with the dominant and non-dominant lower limbs. The subjects were always evaluated by the same researcher, while another researcher was in charge of registering the data.

### ***Participants***

Eighteen healthy volunteers (14 men and 4 women) participated in this study. Nine individuals (7 males and 2 females) with slackline (SG) training experience (age =  $24.5 \pm 3.6$  years, body mass =  $67.5 \pm 12.5$  kg, height =  $168.6 \pm 7.4$  cm, slackline experience =  $5.5 \pm 2.2$  years) were matched according to gender and physical characteristics with nine healthy (7 males and 2 females), but physically inactive individuals according to the criteria of the world health organization (WHO, 2020) and, with no slackline experience, which were used as

the control group (CG) (age =  $23.2 \pm 3.3$  years, body mass =  $67.5 \pm 12.3$  kg, height =  $170.6 \pm 7.3$  cm). The SG participants were recruited from different slackline clubs, considering a minimum of two years of training experience and a training frequency of three times per week. The CG was recruited from the university community. All participants were right-dominant, which was assessed by asking the subject to kick a ball strongly, and also by observing with which limb they would push themselves first when asking to perform a vertical jump. Participants were excluded if they had injuries or surgeries to the lower extremities or trunk in the last six months, any type of musculoskeletal or neurological injury affecting their mobility or balance, or those with vestibular or balance problems. For the CG, those who performed some type of physical training three or more times a week were excluded. This study was approved by the Institutional Ethics Committee and was carried out in accordance with the Declaration of Helsinki. All participants were informed of the risks and benefits of this research and voluntarily signed an informed consent form.

### *Measures*

#### *Core endurance*

The McGill's battery test (Figure 1) was used to measure trunk muscle endurance. This battery is composed of four tests or positions: trunk flexors, trunk extensors, and left and right lateral bridges, from which the maximal time of maintaining the position is measured in seconds, using a stopwatch (McGill et al., 1999). In the flexor's endurance test, the subject sat on a table with the back supported on a stable surface that allowed the trunk to be inclined at  $60^\circ$ . The participants flexed their hips and knees by  $90^\circ$ , crossed their arms on their chests with their hands touching the opposite shoulder, and attached their feet to the table with straps. An investigator started the test by moving the support surface 10 cm backwards, instructing the participants to maintain the static position for as long as possible. The test was verbally stopped when the investigator observed that the back moved forward or backward from  $60^\circ$  or when the participant rounded the spine. An researcher recorded the time with a stopwatch as shown in previous study (Evans et al., 2007). For the extensor endurance or Biering-Sorensen test, the subjects were placed in a prone position with the anterior superior iliac spines at the edge of the table and the trunk outside the table. The hips, knees and ankles were fixed to the treatment table with straps. At the beginning,

the participants supported their hands on a chair in front of them on the edge of the table, until they were told to cross their arms on the chest and keep the horizontal position with the trunk for as long as possible. The time was measured in seconds, and the test was stopped when the participant's trunk moved below or above the horizontal. This test has previously been shown to be reliable (Latimer et al., 1999). In the side-bridge test, the subjects lay on the side to be evaluated, with the legs extended, and one foot supported in front of the other. They were asked to raise their hips from the ground using only their feet and forearm for support, the uninjured arm crossing the chest with the hand resting on the opposite shoulder. The test was stopped when the researcher visually determined that the line of the trunk and lower extremities was not maintained. This test was performed bilaterally, that is, for the right and left sides as shown in previous study (Evans et al., 2007). In addition, to measure the flexor muscles endurance, the prone plank test was used as in previous study (Tong, Wu, & Nie, 2014). The participants were asked to raise the pelvis from a prone position and maintain this bridged position over the forearms and toes as long as possible. When the pelvic alignment could not be maintained, despite the investigator's verbal prompts, the test was terminated. This test has previously been shown to be valid and reliable (Bohannon et al., 2018; Schellenberg et al., 2007; Tong, Wu, & Nie, 2014).

The participants were allowed to perform a familiarization practice, to confirm positions. After one minute of rest, the measurements were taken for all tests. The time in seconds that each participant was able to maintain the position was measured using a stopwatch. The same researcher was in charge of giving the beginning and end of the test and visually determined when the test should be stopped, verbally indicating the participant to stop. Another researcher was in charge of measuring the time using a stopwatch.

#### *Dynamic balance*

The modified star excursion balance test (mSEBT) has been used as a reliable screening tool to evaluate dynamic balance through maximum reach distance in three directions: anterior, posteromedial, and posterolateral (Gribble et al., 2012; Hertel et al., 2000). Participants stood on one leg position with their bare feet on the floor (i.e., stable condition), and each participant was asked to slide a cone with the free lower limb in all three directions, while maintaining the other

limb stable in the center. This was done with the dominant lower limb followed by the non-dominant one (Figure 1). Each participant was taught how to perform the test using verbal instructions and demonstration. Six familiarization attempts were given, and then the test began with three attempts with a one-minute rest between trials (Hertel et al., 2000). The attempt was cancelled and repeated if the participant was not able to maintain the unipodal position, or if the heel of the supporting leg did not maintain contact with the ground or if the weight was placed on the reaching leg. Then the same procedure was repeated but using a Bosu board (Bosu balance trainer PRO, USA), of 18 centimeters of height, as an unstable surface where the subject stood with the supporting limb (i.e., unstable condition). For both conditions, the maximum range distance was measured in centimeters (Gribble et al., 2012). In addition, this value was normalized to the length of the participant's lower limb, measured supine from the anterior superior iliac spine to the most distal part of the medial malleolus, and then multiplied by 100 (Gribble & Hertel, 2003). For the analysis, the greatest reach distance of each direction was summed, and we used the accumulated normalized value for the dominant limb (mSEBTD), the non-dominant limb (mSEBTND) and the total reach distance of both limbs (mSEBTT) on stable surface, and then the same was calculated for the unstable surface.

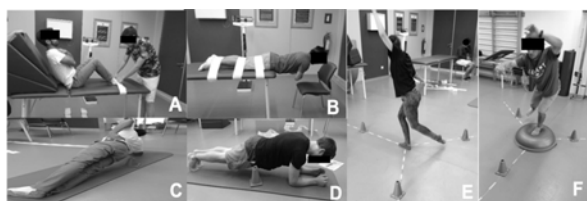


Figure 1. Core endurance and dynamic balance test. A): Flexor endurance test, B): Extensor endurance test, C): Side-bridge test; D): Plank test; E): Stable modified Star Excursion Balance Test; F): Unstable modified Star Excursion Balance Test

### Statistical Analysis

All data are presented in means and standard deviation. Data normality was verified using the Shapiro-Wilk test and the homogeneity of variances (Levene test) were confirmed ( $p > .05$ ). Once the normal distribution was confirmed, both groups were compared using the unpaired Student's *t* test (two tailed) and the effect size (ES) using Cohen's *d*. The criteria for interpreting the magnitude of the ES were as follows: trivial ( $< 0.20$ ), small ( $0.2-0.59$ ), moderate ( $0.60-1.19$ ), large ( $1.20-2.00$ ) and very large ( $> 2.00$ ). For the cases where significant differences were observed, we proceeded to look for a correlation using Pearson's correlation coefficient between the years of practice of the slackline and that variable. The criteria for

interpreting the magnitude of the *r* values were: trivial ( $0.00-0.09$ ), small ( $0.10-0.29$ ), moderate ( $0.30-0.49$ ), large ( $0.50-0.69$ ), very large ( $0.70-0.89$ ), nearly perfect ( $0.90-0.99$ ), and perfect ( $1.00$ ) (Hopkins et al., 2009). The statistical analyses were performed using the JASP software (version 0.9.1.0, <http://www.jasp-stats.org>). The statistical significance was set at  $p < .05$ .

## Results

The performance time in the left side-bridge in the SG was 36.2% longer ( $p = .049$ ) compared to the CG (Table 1). In the plank test the SG maintained the position for a time 45.5% longer ( $p = .026$ ) compared to the CG (Figure 2). No differences were observed in the flexor endurance test ( $p = .127$ ), extensor endurance test ( $p = .358$ ), and right side-bridge ( $p = .194$ ) between SG and CG, despite the fact that the SG had a performance 14.2%, 33.0% and 25.8% higher than the CG respectively.

Table 1  
Core endurance between Slackline Group and Control Group

Core endurance test	SG (mean $\pm$ SD)	CG (mean $\pm$ SD)	p-value	ES	95% CI for Cohen's <i>d</i> lower upper	
Flexor endurance test	103.93 $\pm$ 58.25	69.62 $\pm$ 26.47	.127	-0.758	-1.707	0.212
Extensor endurance test	117.09 $\pm$ 46.68	100.37 $\pm$ 25.12	.358	-0.446	-1.375	0.497
Left side-bridge test	70.29 $\pm$ 31.64	44.81 $\pm$ 17.17	.049	-1.000	-1.973	-0.001
Right side-bridge test	71.61 $\pm$ 35.18	53.11 $\pm$ 21.03	.194	-0.638	-1.578	0.320
Plank test	78.59 $\pm$ 40.65	42.70 $\pm$ 16.66	.026	-1.152	-2.142	-0.132

Note: SD=standard deviation, ES: effect size, CI: confidence interval.

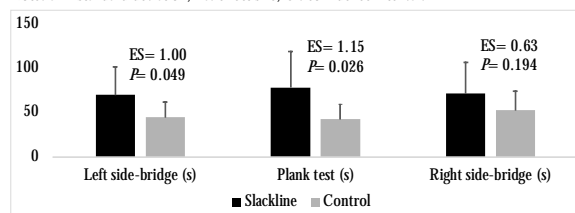


Figure 2. Core endurance between the Slackline Group and Control Group. A) Left side-bridge test, B) Plank test and C) Right side-bridge test. (\*) significant difference

There is a correlation between the years of practice of slackline and the left side-bridge test ( $r = .730$ ;  $p = .026$ ) (Figure 3 A), with the plank test ( $r = .674$ ,  $p = .046$ ) (Figure 3 B) and with the right side-bridge test ( $r = .765$ ,  $p = .016$ ) (Figure 3 C).

There were no differences in the stable dynamic balance between the groups when comparing dominant and non-dominant lower limbs, or in the total balance (Table 2).

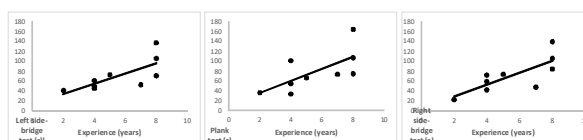


Figure 3. Correlation between core muscle endurance and years of slackline practice. A) Left side-bridge test, B) Plank test and C) Right side-bridge test

For unstable dynamic balance, SG showed a 37.80% ( $91.05 \pm 24.46$ ,  $p = .016$ ,  $ES = 1.268$ ,  $95\% CI -2.273 -$

Table 2  
Dynamic balance in stable and unstable conditions between Slackline Group and Control Group

mSEBT (%LL)	Extremity	SG (mean ± SD)	CG (mean ± SD)	p-value	ES	95% CI for Cohen's d lower upper	
Both legs	Stable	111.98 ± 10.02	102.83 ± 10.45	.076	0.893	-1.855	0.092
	Unstable	91.05 ± 24.46	56.63 ± 29.57	.016	1.268	-2.273	-0.230
Dominant leg	Stable	111.80 ± 8.85	101.55 ± 11.56	.050	0.995	-1.967	0.003
	Unstable	97.13 ± 17.45	69.47 ± 39.83	.074	0.899	-1.861	0.087
Non-dominant leg	Stable	112.17 ± 11.93	104.11 ± 9.60	.134	0.743	-1.691	0.225
	Unstable	84.97 ± 35.76	43.79 ± 41.90	.039	0.157	-2.035	-0.050

Note. mSEBT= modified Star Excursion Balance Test. %LL: percentage of leg length. SD=standard deviation, ES: effect size, CI: confidence interval.

0.230) higher total balance of both legs compared to CG (56.63 ± 29.57) and a 46.57% higher non-dominant total balance (84.97 ± 35.76;  $p = .039$ ; ES= 1.057; 95% CI -2.035 -0.050) compared to CG (43.79 ± 41.90).

## Discussion

The aims of this study were (I) to compare core muscle endurance and dynamic balance between individuals who practice slackline (SG) and a control group (CG), and (II) to determine the relationship between core endurance and years of practice in slackline. The main findings of this study were that the practice of slackline could produce a greater endurance performance of the flexors and left lateral muscles on the trunk compared to physically inactive individuals. Furthermore, there is a relationship between years of slackline practice and the endurance performance of the flexors and left and right lateral muscles of the trunk. The practice of this discipline may improve the core endurance, so we could consider the slackline as a useful tool when the objective is to develop this ability.

It is known that training in unstable conditions increases the requirements of postural control in order to stabilize the spine and the whole body (Vera-Garcia et al., 2000). Vera-Garcia et al. (2007) showed that activation of the core muscles is necessary to stabilize the spine in response to sudden disturbances and imbalances. In this study the SG showed a greater flexor (45.5%;  $p = .026$ ) and left lateral (36.2%;  $p = .049$ ) trunk endurance performance than the CG. This difference could be explained because the function of the core is to provide proximal stability for distal mobility, so when the demands of balance increase, subjects try to avoid falling from the strap by counteracting the lateral oscillations by moving the extremities and trunk, minimizing the displacement of the center of mass within the support base (Mildren et al., 2018; Reeves et al., 2006; Stein & Mombaur, 2019). Thus, increasing muscle recruitment of the trunk and may avoid falling. We did not observe differences on the right side endurance time between the groups. The right side corresponds to the dominant side of all subjects.

This lack of differences could be explained by the fact that this side of the trunk may be more active due to the greater use of the right extremity in most activities of daily living or sports. Thus, both groups could have an optimal muscular performance with an increased mechanical efficiency which is reflected in this absence of differences. On the other hand, the non-dominant side has different activation thresholds (Adam et al., 1998), therefore, this instability stimulus may have been more important during muscular endurance. The fact of having observed a high correlation between the years of practice of slackline and the endurance of the left trunk ( $r = .730$ ;  $p = .026$ ), flexors ( $r = .674$ ,  $p = .046$ ) and right ( $r = .765$ ,  $p = .016$ ), might be interpreted as the practice of slackline could be an efficient training tool to increase the core endurance.

There were no differences between SG and CG in the stable dynamic balance, but we found that the unstable dynamic balance performance was greater in SG. The absence of differences in the stable dynamic balance (Table 2) could be explained due to the specificity of the training, which in the case of the slackline, produces a constant challenge of the balance on an unstable surface (Giboin et al., 2015; Kümmel et al., 2016). Giboin, Gruber & Kramer (2018) and Ringhof et al. (2018) have reported improvements in the balance after slackline training, but these improvements were specific to the task being trained and not to the overall balance performance. It seems that slackline training produces specific balance adaptations, which may be related to the content of the training (Donath et al., 2017). Giboin et al. (2019) showed that although twelve sessions of slackline training produce neuroplastic changes at the brain and spinal level in response to destabilization, these changes were not transferred to balance in conditions other than slackline, such as the mSEBT in stable condition. It is essential to consider that this test is a screening tool for risk of injury of the lower extremities, in which it has been reported a total distance of reach less than 94% of the length of the extremity as a risk factor of injury, in this study both groups are conformed by young and healthy subjects, which overcome this cut point (Plisky et al., 2006).

On the other hand, the differences observed in the dynamic balance in unstable condition (Table 2) may be because we used a bosu board as unstable surface, which simulates the medio-lateral instability produced by the slackline strap, observing a better performance in SG in comparison to the CG. When subjects learning to walk on the strap, the balance strategies change from

gross adjustments dominated by the hip, to the use of the upper extremities and the slowing down and control of the trunk oscillations to recover the balance (Mildren et al., 2018; Serrien et al., 2017). It is possible that the slackline could transfer these improvements in the postural control, optimizing the ability to recover the balance before major disturbances of the balance or exercises of high instability. These results are in agreement with Donath et al. (2017), suggesting that slackline training should be part of multimodal balance training and not be used as a single training option when the objective is to improve body balance as a general and non-specific skill.

It is important to note some limitations of this study; among them is the descriptive design of this study, which does not allow us to determine causality. In addition, the fact of having used only field tests for core endurance performance may not allow us to observe the differences in all endurance tests. Concerning to the flexor and extensor endurance test, Tse, McManus & Masters (2010) reported that a trunk position error of the only 5° could alter the reliability of the test, which would translate into a measurement error. We propose to use a test battery, including isometric planks or bridges, to evaluate the core endurance, and to look for new functional alternatives for measuring the group of flexors and extensors to be used in future studies. In addition, it is important to consider that the use of an unstable surface in the mSEBT is a modification to the original test, in which the pressure on the bosu board was not controlled but was verified that the height of the bosu board remained constant for all subjects in the study, this may have affected the results of this investigation. On the other hand, comparing subjects who fulfill the physical activity recommendations proposed by the WHO with subjects who do not fulfill them may not correspond to the ideal comparison, so we propose to carry out new research comparing slackline with other sports disciplines. Finally, the sample size presented is probably not representative of the population, so the results should be analyzed with caution. However, a strength of this research is to have considered subjects with at least two years of slackline training since most of the research regarding slackline considers interventions of a maximum of three months and, within its limitations, considers the short time of training of its participants. In addition, to our knowledge, this is the only study that investigates the core endurance and balance on subjects with a slackline experience.

## Conclusion

In conclusion, our results show that individuals that practice slackline have greater flexor and lateral endurance of the left core muscles, as well as greater dynamic balance performance in unstable conditions compared to physically inactive individuals. Thus, we could consider the slackline as a motivating and useful tool when it is required to train these qualities.

## Acknowledgments

This paper will be part of Waleska Reyes-Ferrada Doctoral Thesis performed in the Biomedicine Doctorate Program of the University of Granada, Spain. We would like to thank all the participants who selflessly participated in the study.

## Funding

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

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