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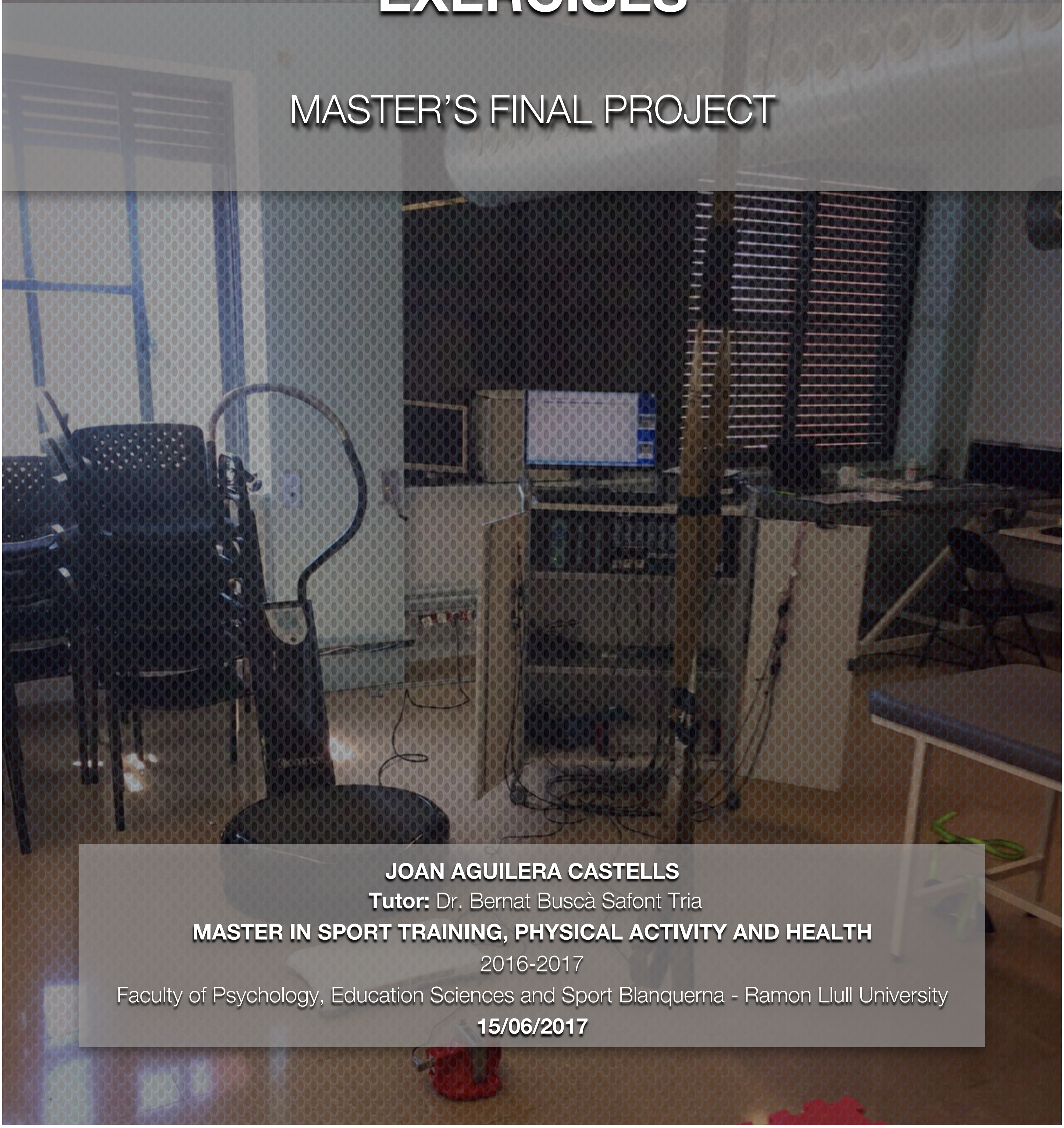
MUSCLE ACTIVITY AND FORCES IN DIFFERENT SUSPENSION LUNGE EXERCISES



MASTER'S FINAL PROJECT

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ABSTRACT

Although there are some researches about lunge exercise and instability conditions (i.e., Bosu, fitball), few researches were found comparing different methods using a suspension device and its load quantification. The purpose of this study was to examine the effect of suspension training and instability surfaces on muscle activity and force production while performing different variations of the lunge exercise. A randomized within-subjects design was used to study the effects of five conditions (traditional, suspension, suspension-Bosu, suspension-Vibro30 or Vibro40) on five different muscles (rectus femoris, biceps femoris, vastus medialis, vastus lateralis and gluteus medius) in physically active male university students (n = 7; age = 25.71± .06 years old). During lunge performance, muscle activation was recorded using surface electromyography (sEMG). Force production was obtained using both Wii Balance Board and a S-Type load cell. Mean peak force and normalized sEMG values were compared across the 5 exercises. Results showed no significant differences in muscle activity between traditional and suspension lunge. However lunges performed with dual instability increased sEMG activity in the analysed muscles in comparison with single instability condition. Furthermore, force output on the strap decrease when instability increase and suspension lunge showed significant differences ($p < .05$) on forward leg exerted force in comparison with traditional lunge. In conclusion, the results obtained in the present study could be useful for select the optimal lunge progression and the load cell seems to be an adequate tool to quantify the load while performing a suspension exercise.

Key words: Suspension training, load cell, instability, electromyography, vibration

Abstract catalan version

Encara que hi ha algunes recerques sobre l'exercici del lunge i les condicions d'inestabilitat (p.e., Bosu, fitball), poques recerques han estat trobades comparant diferents mètodes utilitzant un dispositiu de suspensió i quantificant la seva càrrega. L'objectiu d'aquest estudi vas ser examinar l'efecte de l'entrenament en suspensió i de les superfícies inestables sobre l'activitat muscular i la producció de força fent diferents variacions de l'exercici del lunge. El disseny intra-subjectes aleatoritzar es va utilitzar per estudiar els efectes de les cinc condicions (tradicional, suspensió, suspensió-Bosu, suspensió-Vibro30 o Vibro40) en cinc músculs diferents (recte femoral, bíceps femoral, vast medial, vast lateral i gluti mig) en estudiants universitaris físicament actius (n = 7 homes; edat = 25.71± .06 anys). Quan es feien els lunge, l'activació muscular va ser registrada utilitzant l'electromiografia de superfície (sEMG). La producció de força es va obtenir utilitzant la Wii Balance Board i una cèl·lula de força S-Type. La mitjana dels valors de pic de força i de la sEMG normalitzada es van comparar a través dels 5 exercicis. Els resultats mostren diferències no significatives en l'activitat muscular entre el lunge tradicional i en suspensió. No obstant, lunges fets amb inestabilitat dual incrementaven l'activitat sEMG en els músculs analitzats en comparació amb la inestabilitat senzilla. A més, la producció de força sobre el tirant decreix quan incrementa la inestabilitat i el lunge en suspensió mostra diferències significatives ($p< .05$) en la força exercida per la cama avançada en comparació amb el tradicional. En conclusió, el resultats obtinguts en aquest estudi podrien ser d'utilitat per seleccionar una progressió òptima del lunge i la cèl·lula de força sembla ser una eina adequada per quantificar la càrrega mentre es fa un exercici en suspensió.

Paraules clau: Entrenament en suspensió, cèl·lula de força, inestabilitat, electromiografia, vibració

Abstract spanish version

Aunque hay algunas investigaciones sobre el ejercicio del lunge y las condiciones de inestabilidad (p.e., Bosu, fitball), pocas investigaciones se pueden encontrar comparando diferentes métodos utilizando un dispositivo de suspensión y cuantificando su carga. El objetivo del presente estudio fue examinar el efecto del entrenamiento en suspensión y de las superficies inestables sobre la actividad muscular y la producción de fuerza haciendo diferentes variaciones del ejercicio del lunge. El diseño intra-sujeto aleatorizado se utilizó para estudiar los efectos de las cinco condiciones (tradicional, suspensión, suspensión-Bosu, suspensión-Vibro30 o Vibro40) en cinco músculos distintos (recto femoral, bíceps femoral, vasto medial, vasto lateral y glúteo medio) en estudiantes universitarios físicamente activos ($n = 7$ hombres; edad = 25.71± .06 años). Cuando se hacían los lunge, la activación muscular fue registrada utilizando la electromiografía de superficie (sEMG). La producción de fuerza se obtuvo utilizando la Wii Balance Board y una célula de fuerza S-Type. La media de los valores de pico de fuerza y de la sEMG normalizada se compararon a través de los 5 ejercicios. Los resultados muestran diferencias no significativas en la actividad muscular entre el lunge tradicional y en suspensión. No obstante, lunges realizados con inestabilidad dual incrementaban la actividad sEMG en los músculos analizados en comparación con la inestabilidad sencilla. Además, la producción de fuerza sobre el tirante decrece cuando se incrementa la inestabilidad y el lunge en suspensión muestra diferencias significativas ($p < .05$) en la fuerza ejercida por la pierna adelantada en comparación con el tradicional. En conclusión, los resultados obtenidos en este estudio podrían ser de utilidad para seleccionar una progresión óptima del lunge y la célula de fuerza parece ser una herramienta adecuada para cuantificar la carga mientras se realiza un ejercicio en suspensión.

Palabras clave: Entrenamiento en suspensión, célula de fuerza, inestabilidad, electromiografía, vibración

INTRODUCTION

In strength and conditioning environment, the coaches, athletes and fitness enthusiastic are continuously searching new challenges to increase the demand of training programs and its exercises. In this context, an emerging trend is the utilization of instability devices (i.e., Bosu® Ball, Wobble Board®). Primarily, instability devices are used to increase the load of traditional exercises by providing greater muscular demands as a consequence a superior motor unit recruitment and improved neuromuscular coordination in order to maintain balance (5,45). Some evidences support the idea that the instability training devices elicit a greater activity of some upper body and trunk muscles in comparison with traditional exercises as push-ups (2), planks (19), curl-ups (49) and back extension exercises (16). Also, unstable surfaces are used to strengthen the lower body (13,25). To train the lower body, strength and conditioning programs used several exercises like squat, leg extension or deadlift. Due to the specificity and transfer with the sport abilities, one of the most used exercises is the traditional lunge (36), which is defined as a multijoint, closed kinetic chain and functional exercise (6,20,27,30). Besides, performing traditional lunge remains active the gluteus maximus (Gmax) and medius (Gmed), the vastus medialis (VM), the vastus lateralis (VL), the rectus femoris (RF), the biceps femoris (BF), the semitendinosus, semimembranosus and the gastrocnemius (6,48). Several studies have focused on the surface electromyography signal while performing lunge variations (29,30,46) and other compare lunge with different lower body exercises (18). On the other hand, the effects of using unstable surfaces on muscle activation have been studied while performing lunges. Andersen et al. (1) reported that BF activation was significantly greater in unstable bulgarian squat than in a stable condition. For the other analysed muscles (RF, VM, VL and gastrocnemius), the values of activity were similar in both conditions. In contrast, Youdas et al. (51) found that unstable surface enhanced activation of RF and hamstring during lunge in comparison with stable surface condition. Although, there are poor evidences that the use of unstable surfaces increase the muscular demands during lunge exercise, the interest in increasing the muscular activity through different suspension devices has become very popular.

In suspension training, a suspension device is required to create the instability condition. This method utilize a system of straps with handles on the bottom and attached to a single anchor point (10). This device acts in a pendulum manner by rotating about the singular anchor point. Suspension device uses body weight and force momentum principles to enhanced motor unit recruitment. Likewise, the amount of instability caused by the suspension device and the body weight determine the level of difficulty of the exercise (17,34). The instability caused by the suspension device increase 6% of the maximum voluntary isometric contraction (MVIC) from pectoralis in the push-ups (43), 31,68% MVIC from rectus abdominis in the prone bridge (7) but decrease 8,47% MVIC from latissimus dorsi in the inverted row (44). However, some muscles (i.e. anterior deltoid) decrease activation when the instability augmented with the presence of a pulley in the suspension device (8). On the other hand, lower body suspension exercises had been investigated while performing hamstring curl (21,32,38). Thus, Malliaropoulos et al. (32) found that suspension hamstring curl improve activity for hamstring muscles in comparison with traditional exercises like lunge or dead lift. However, hamstring muscles achieved a greater activity when perform a fitball hamstring curl than in suspension condition. Other studies examined the effects of the suspension on the force production. According to Dawes & Melrose (17), the percentage of body mass resistance on the suspension strap increases when the trunk-leg inclination position is closer to the floor. In the same vein, Gulmez (23) suggested that load on the suspension strap increases while vertical ground reaction forces decreases. These authors investigated inverted row and push-up exercises, respectively. However, the load on the suspension straps while preforming lower body exercises such as squat, lunge or hamstring curl apparently have not been examined. Conversely, the effects of instability on the force production have been examined for lower body exercises. Several studies showed that instability environment led to decrease the force output (4,35). Saeterbakken & Fimland (42) found that a significant greater force production for stable squat than unstable squat. These authors examined four different unstable surfaces and Bosu condition obtained the lowest force output value in comparison with stable squat condition. According to Saeterbakken & Fimland (42) findings, another investigation reported that Bosu and T-Bow® deadlift condition significantly decreased force production respect deadlift on the floor (14). Although literature suggests that unstable surfaces reduce force production, it appears that dual instability could increase the muscle activation. According to Freeman et al. (22), push-ups performed in dual instability conditions achieved a greater muscle activity than both stable and single instability conditions. Likewise, Choi & Kang (12) used a whole-body vibration and a sling strap (a type of a suspension device) to established a dual instability environment. These authors found that trunk muscles significantly enhanced the activity when planks were preformed in sling-vibration condition in comparison with sling without vibration. Nevertheless, Byrne et al. (7) reported that planks performed in a dual suspension instability (arms and feet in suspension) did not differ in the trunk muscle activity while performing a single suspension plank (arms or feet in suspension). Indeed, the dual instability effects are not clear. Moreover, no evidence of dual instability effects in the lower body was found. Although, Marín & Hazell (33) contrasted the effects of two different frequencies in muscle activity during a semi-squat whole-body vibration.

To the best of our knowledge insufficient evidence exists related to muscle activity and force production when performed a suspension lower body exercise. For this reason the aim of this study was to examine the effect of suspension training and instability surfaces on muscle activity and force production during performance of variations of the lunge exercise. It was hypothesized that lunges performed using suspension would result in greater muscle activation than stable lunge and that the highest levels of activation would be observed when lunges were performed in dual instability conditions. Secondly, that force produced on the suspension strap wouldn't significantly differ through conditions. Finally, that suspension lunge condition would elicit a higher load of the body weight on the forward leg than traditional lunge.

METHODS

Experimental Approach to the Problem

A repeated measures design was used to compare the force output and electromyographic activity during five lunges conditions perform on stable and unstable surfaces. Seven participants executed a traditional lunge, suspension lunge, suspension lunge with Bosu and suspension lunge with vibrations platform at two different frequencies (30 and 40 Hz). Traditional lunge was performed lean rear food on a bench and suspension lunge was executed with a TRX Suspension trainer™ device. A S-Type Load Cell was used for measure forces output values from suspension lower limb. Load cell was displayed on the suspension device. Wii Balance Board was utilised for register force production from forward leg on both traditional and suspension lunge. Surface electromyography (sEMG) was used to measure dominant leg muscle activity of 1) RF, 2) BF, 3) Gmed, 4) VM, 5) VL and 6) rectus femoris non-dominant leg (RF_ND).

Subjects

Seven healthy and physically active male university students (mean age = 25.71 ± 3.82 years, height = 1.79 ± 0.06 m, weight = 78.06 ± 1.70 kg, body mass index = 24.35 ± 1.58 kg*m^{-2}) were voluntarily recruited for this study. Participants have been physically active with at least three sessions per week with a minimum duration of 30 minutes. Subjects were excluded if present any injuries and/or pain related from cardiovascular, musculoskeletal and neurological disorders. All participants were asked to come the experimental session having refrained from high intensity physical activity 24h hours before the testing and no food, drinks, or stimulants (i.e., caffeine) to be consumed 3 to 4 hours before the testing. During familiarization session all participants provided written informed consent after having the experimental procedures, exercise protocol, and possible risk associated with participation explained to them. The ethics committee of the Ramon Llull University of Barcelona approved the development of this study, which was conducted according to the latest version of declaration of Helsinki.

Procedures

The study was done in two sessions: 1) Familiarization session and 2) Experimental session. These two sessions was performed at the same time in the morning separated by a week. In the familiarization session, researchers have been collected age, weight, and height of each participant and measured the leg length that was determinate as the distance from the anterior superior iliac spine to the medial malleolus of the tibia (6). Leg dominance was determined by asking participants with which leg they would kick a ball (37). To verify adherence to pre-test instructions participants completed the PAR-Q Test (11). Participants were familiarized with exercises procedures to achievement the proper technique before to data collection.

During experimental session participants were outfitted with the surface electrodes and completed a MVIC test, as describe following. Before MVIC test, participants performed a standardized warm-up that consisted of 5 minutes cycling with a 100 W of cadence maintaining 60 revolutions per minute. After MVIC test protocol, each participant performed 5 consecutive repetitions of lunge exercise under 5 conditions: 1) traditional lunge, 2) suspension lunge, 3) suspension lunge-Bosu, 4) suspension lunge-Vibro30 (whole-body vibration platform at 30 Hz) and 5) suspension lunge-Vibro40 (whole-body vibration platform at 40Hz). Lunges exercises order were randomized between participants using *true random number generator* (24). 90 seconds of rest between exercises was determined to prevent fatigue, pace velocity was standardized with a metronome (application *Pro Metronome* version 3.13.2; EUMLab-Xannin Technology Gmbh., Hangzhou, CHN) set at 70 beats per minute, and the tether of a positional encoder (WSB 16k-200; ASM Inc., Moosinning, DEU) was attached to the hip and used to measure its vertical displacement during all exercises. A trial was discarded and repeated if participants were unable to perform the exercise with the correct technique.

Surface Electromyography Signal

All sEMG values were collected using a BIOPAC MP-150 at a sampling rate of 1.0 kHz. Data was analysed using AcqKnowledge 4.2 software (BIOPAC System, INC., Goleta, CA). The sEMG signals were bandpass filtered at a 20 to 400-Hz frequency, while utilizing a 4th order Butterworth filter. The root mean square (RMS) sEMG signals were recorded throughout each exercise. The mean RMS data was then normalized to the maximal voluntary isometric contraction and reported as % MVIC.

A bipolar sEMG configuration (Biopac EL504 disposable Ag-AgCl) and an inter-electrode distance of 2 cm were used. Surface electrodes were placed on the dominant leg except the RF_ND surface electrodes. Before, affixing the electrodes, the participants skin sites were prepped for application through shaving, exfoliation, and alcohol cleansing in order to reduce impedance from dead surface tissue and oils in accordance with SENIAM (26). Electrode placements for RF, BF, Gmed, VM, VL and RF_ND followed SENIAM recommendations (26). Electrodes for the RF and RF_ND were placed at 50% on the line from the anterior spine iliac superior to the superior part of the patella. BF electrodes were placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia. Gmed electrodes were placed at 50% on the line from the crista iliac to the trochanter. VM electrodes were placed at 80% on the line between the anterior spine iliac superior and the joint space in front of the anterior border of the medial ligament. Electrodes for the VL were placed at 2/3 on the line from the anterior spine iliac superior to the lateral side of the patella. A ground surface electrode was placed directly over the right anterior superior iliac spine.

Force Measurements

Vertical ground reaction forces were measured using the Nintendo Wii Balance Board (WBB; Nintendo, Kyoto, JPN). WBB consists of a rigid platform with four uni-axial vertical force transducers located in the feet at the four corners of the board, one transducer per foot. Each transducer is a load cell consisting of a cantilevered metal bar with a strain gauge that converts wirelessly by electronics in the WBB. Raw data was acquired (sampling rate 40 Hz) using WiiLab software (University of Colorado Boulder, Colorado, USA) for Matlab R2008a (Mathworks Inc, Natick, USA). Calibration of the system was performed according to WiiLab software recommendations. WBB had been shown to have acceptable reliability and validity for assessment vertical force ground and center of pressure (3,39,41). During traditional lunge and suspension lunge performed, participants centred forward foot at a fixed position on WBB.

In order to record the load on the suspension device, S-Type Load Cell (model CZL301C; Phidgets Inc., Alberta, CAN) was displayed between anchor point (2.95 m from the ground) and suspension device straps. The data were collected (sampling rate 200 Hz) using BIOPAC MP-150 (BIOPAC System, INC., Goleta, CA) and its original software (AcqKnowledge 4.2; BIOPAC System, INC., Goleta, CA). Calibration of the system was performed according to the manufacturer’s recommendations in the manual. According to Tiainen et al. (47) and Vivodtzev et al. (50), load cell is a reliable and valid tool to measure muscle strength.

Maximum Voluntary Isometric Contraction (MVIC)

Prior to the exercise trials described below, participants were performed three 5-second MVIC's for each muscle and the trial with the higher sEMG signal was selected in accordance with Jakobsen et al. (28). Participants were instructed to gradually increase muscle contractions force towards maximum over a period of two seconds, sustain the MVIC for three seconds, and slowly release the force again. Three minutes of rest was given between each MVIC, and standardized verbal encouragement was provided to motivate all participants to achieve maximal muscle activation. Positions during the MVIC's were based on Konrad (31) protocol. To obtain the MVIC of the RF, RF_ND, VM and VL, participants performed an isometric 90º single leg knee extension in a seated position against a matched resistance (i.e., resistance forceful enough to elicit an isometric contraction from the participant). To obtain the MVIC of the BF, participants performed an isometric 20-30º single knee flexion in a prone lying position against a matched resistance. Lastly, the MVIC for the Gmed was performed with the participants in a fixed side lying position. An isometric hip abduction was then performed against a matched resistance. Once, all MVIC's were collected the exercise trials were performed.

Exercise Trials

In order to normalized the height and stepped distance in all lunges exercise conditions, the height of both traditional lunge bench and suspension device strap was normalized to 60% of the participants leg length and this length added the height of WBB, Bosu and vibration platform (i.e., total height strap = 60% of participants leg length + Bosu's height). The distance participants stepped in all lunges conditions was normalized to 80% of their leg length, measured as the distance from the anterior superior iliac spine to the medial malleolus of the tibia, in accordance with Boudreau et al. (6). The proper techniques for the exercises are as follows:

- Traditional lunge: Participants were instructed to stand upright with one foot in front and the other behind the body. Participants held their arms on chest and the upper body was maintained in an upright with a lower back natural sway throughout the exercise. Participants lowered the body (eccentric phase) until the forward knee flexed to 90º, and subsequently returned the body to the starting position with a full knee extension of the forward leg (concentric phase). The forward foot was placed at a fixed position with the heel contact on a WBB. The rear foot (instep) was leaned on a horizontal press bench (Salter Fitness SA., Barcelona, ESP). To adjust the height of the rear leg, EVA foam play mat pieces (Sun Ta Toys Sdn. Bhd., Melaka, MYS) were used (Figure 1). The EVA foam play mat pieces were fixed with cinch strap. The contact point between the horizontal press bench and the food was controlled to be identical in all repetitions.
- Suspension lunge: Prior to performing this exercise, a TRX Suspension trainer™ (Fitness Anywhere, San Francisco, CA) was secured in anchor point. Participants were instructed to assume a lunge position with the rear foot placed within the suspension device cradles with a slight plantar flexion (Figure 2). The forward food was placed on a WBB. Then, participant performed the lunge as previously described.

Figure 1. Traditional lunge. The image on the left shows the upper position and the image on the right shows the lower position.

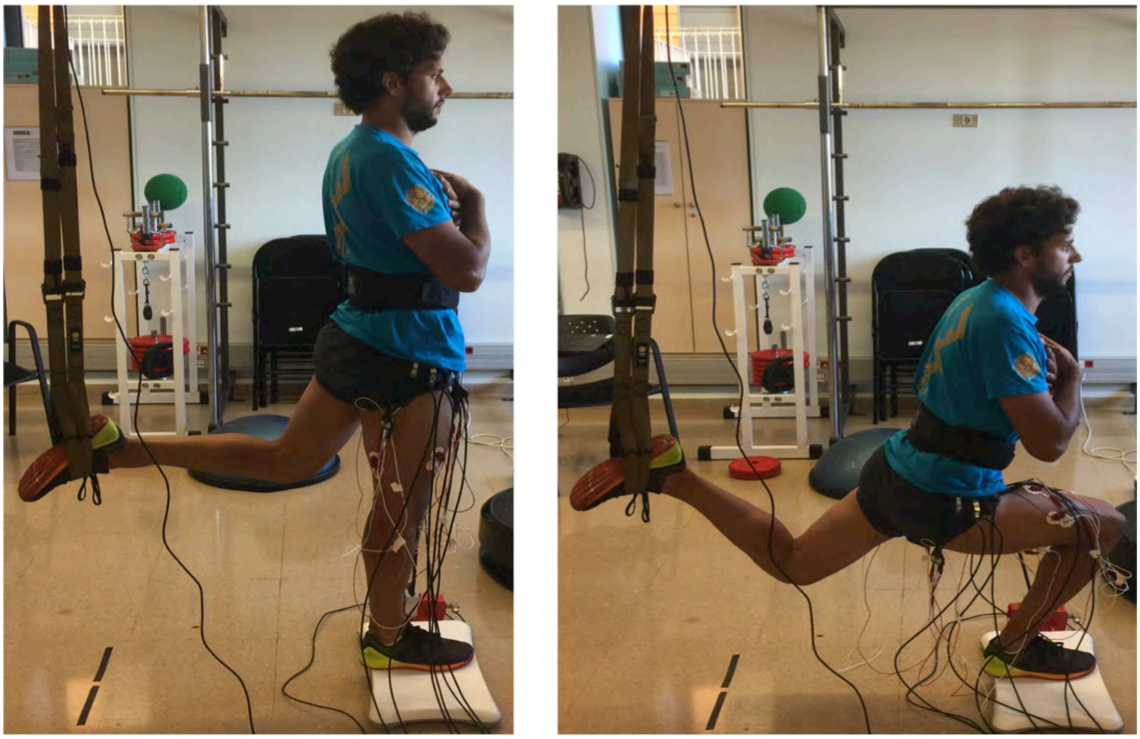

Figure 2. Suspension lunge. The image on the left shows the upper position and the image on the right shows the lower position.

- Suspension lunge-Bosu: To performed this exercise, a Bosu ball (BOSU®., Ashland, OH) was used. Participants were assume the above stated position, but with the forward foot placed upon the Bosu dome side up (Figure 3).
- Suspension lunge-Vibro30: A vibrations platform (Compex® Winplate; DJO UK Ltd., Guildford, GBR) was used to perform this exercise. Participants were instructed to place the forward foot and maintain the heel in contact upon the Compex® Winplate. The vibrations platform setting was: 30 Hz of frequency and 4 mm amplitude (high) (Figure 4). Participants then performed the lunge as previously described.
- Suspension lunge-Vibro40: Participants performed the lunge with a vibrations platform set at 40 Hz of frequency and 4 mm amplitude (high). Participants placed the rear food in the suspension straps using the same techniques as described prior (Figure 4).

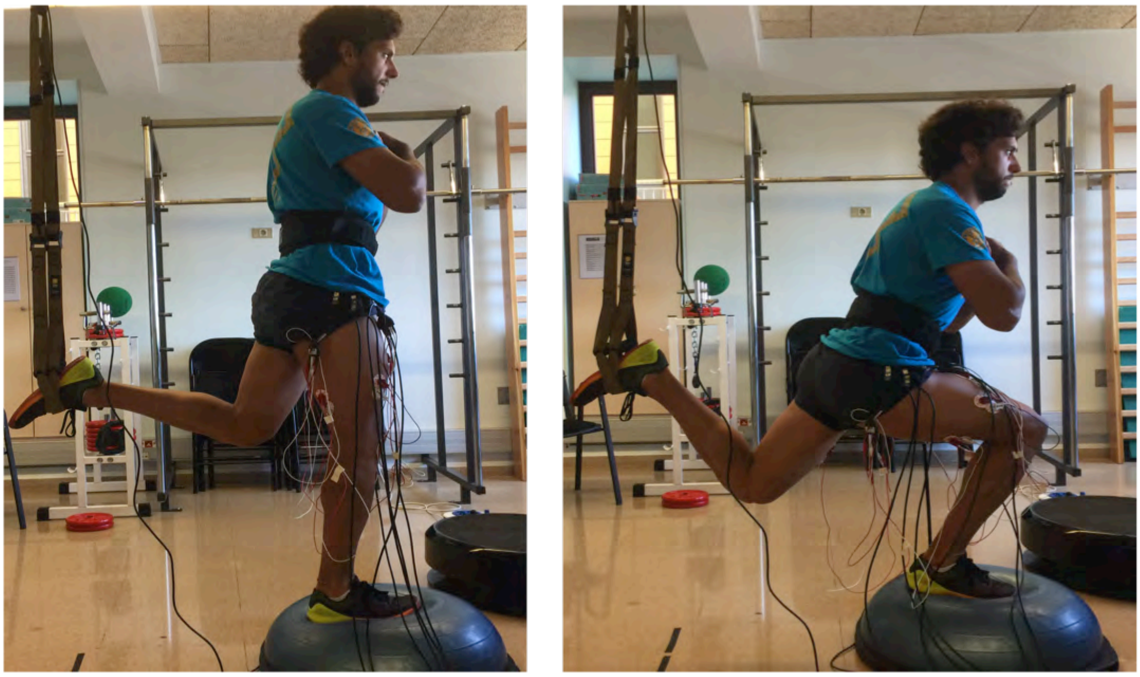

Figure 3. Suspension lunge-Bosu. The image on the left shows the upper position and the image on the right shows the lower position.

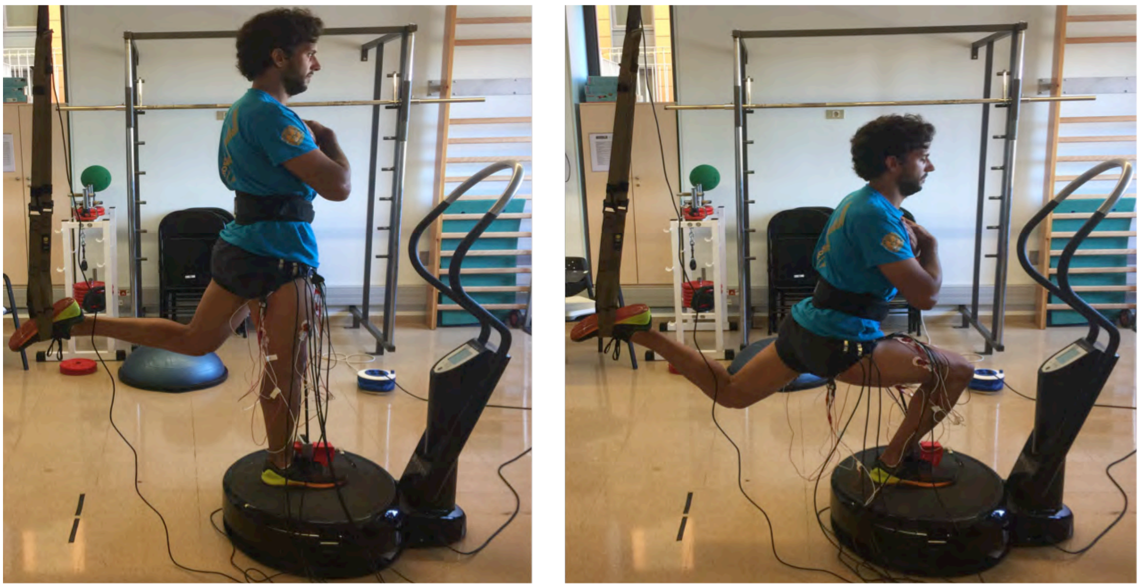

Figure 4. Suspension lunge-Vibro30 and Vibro40. The image on the left shows the upper position and the image on the right shows the lower position.

Data Analysis

All sEMG signal analyses were performed using AcqKnowledge 4.2 (BIOPAC System, INC., Goleta, CA). sEMG signals related to isometric exercises were analysed by using the 3 middle seconds of the 5-second isometric contraction. The sEMG signals of the lunge exercises were analysed by taking the average of the three middle repetitions. The first and fifth repetitions were excluded from data analysis. The sEMG amplitude in the domain was quantified by using RMS. Mean RMS values were selected for every trail and normalized to the maximum EMG (%MVIC). Global mean of all muscles (i.e., RF, BF, Gmed, VM, VL and RF_ND) was also calculated (arithmetic mean) and analysed. To facilitate the comparison of the muscle activation between conditions, activation was categorized into four levels following previous studies: >60%, very high; 41-60%, high; 21-40%, moderate and <21%, low (9,19,38).

The recorder load data from the WBB and the load cell were analysed by using the entire lunge phase (eccentric-concentric repetition). Maximum force values reached in the entire phase were used during the lunge exercises. The first and fifth repetitions were excluded from data analysis. The values obtained from the WBB were classified as loads borne by the WBB force platform and those obtained from load cell as loads borne by suspension straps.

In order to normalize the load, an equation was calculated for each participant based off of load and body weight (load_norm = load / body weight x 100) in accordance with Gulmez (23). The normalized values were expressed as percentage of the total load.

Statistical Analysis

Statistical analysis was accomplished using SPSS (Version 20 for Mac; SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to confirm the data were normally distributed to confirm the use of parametric techniques. The results are reported as mean ± standard deviation. One-way repeated-measures analysis of variance (ANOVA) was employed to examine the effect of exercise condition on mean muscle activation and mean resistance load from the suspension straps. A paired t-test was conducted to compare the mean resistance load from WBB force platform in traditional and suspension lunge conditions. Greenhouse-Greisser correction was used when the assumption of sphericity (Muahcly's test) was violated. Post hoc analysis with Bonferroni correction was used in the case of significant main effects. Effect size are reported as partial eta-squared (η_p^2), with cut-off values of 0.01-0.05, 0.06-0.13, and >0.14 for small, medium, and large effects, respectively (15). Significance was accepted when $p<0,05$.

RESULTS

Exercise condition main effect were identified for mean muscle activation of Gmed [$F_{(4,24)} = 8.199$ $p<0.05$, $\eta_p^2 = 0.57$], VM [$F_{(4,24)} = 3.596$ $p<0.05$, $\eta_p^2 = 0.37$], VL [$F_{(4,24)} = 3.897$ $p<0.05$, $\eta_p^2 = 0.39$] and mean muscle activation of all muscles (Global) [$F_{(1.94,\ 11.66)} = 12.932$ $p<0.05$, $\eta_p^2 = 0.68$]. Pairwise comparisons showed significant differences ($p<0.05$) between suspension lunge and suspension lunge-Vibro40 for VM, and between traditional lunge, suspension lunge, suspension lunge-Vibro30 and suspension lunge-Vibro40 for Global mean. There were no significant main effects observed in mean muscle activation of RF_D [$F_{(1.42, 8.54)}$ = 2.855 p>0.05, η_p^2 = 0.32], BF [$F_{(4, 24)}$ = 0.825 p>0.05, η_p^2 = 0.14] and RF_ND [$F_{(1.31, 7.87)}$ = 2.267 p>0.05, η_p^2 = 0.27]. All muscle activation data are presented in Table 1.

Table 1. Surface electromyography signal of each tested muscle under different conditions. Data are expressed as mean ± SD in the maximum voluntary isometric contraction (%MVIC).

	Traditional Lunge	Suspension Lunge	Suspension Lunge-Bosu	Suspension Lunge-Vibro30	Suspension Lunge-Vibro40
Rectus Femoris_D	26.74±14.15	27.90±15.47	37.52±19.33	28.37±13.67	36.07±22.18
Biceps Femoris	25.79±13.99	20.23±11.28	24.53±11.32	26.23±14.29	25.02±14.70
Gluteus Medius	59.84±21.77	54.99±13.64	76.91±26.09	64.79±18.62	88.90±28.61
Vastus Medialis	52.77±13.41	47.72±13.25§	58.93±10.59	58.51±19.09	62.44±16.63**
Vastus Lateralis	77.82±26.93	64.87±22.60	87.62±48.09	74.83±25.29	94.47±42.17
Rectus Femoris_ND	29.09±14.68	24.63±18.87	20.79±11.72	20.38±10.41	28.75±21.82
Global	46.35±5.24§	40.93±4.38§	51.56±7.11	46.05±6.23§	56.88±6.29* **†

D = Dominant leg; ND = No dominant leg; Global = mean of the 6 muscles
* =Significant differences compared to the Traditional lunge
** =Significant differences compared to the Suspension lunge
† =Significant differences compared to the Suspension lunge-Vibro30
§ =Significant differences compared to the Suspension lunge-Vibro40

Figure 5 shows the percentage of body mass resistance obtained from the suspension straps under exercise condition (suspension lunge, suspension lunge-Bosu, suspension lunge-Vibro30 and suspension lunge-Vibro40). A significant main effect was found for exercise condition [$F_{(3, 18)}$ = 3.806 p<0.05, η_p^2 = 0.38]. Furthermore, there was a significant difference in the forward leg force production for traditional and suspension lunge conditions; $t_{(6)} = -3.084$, $p<0.05$. (Figure 6).

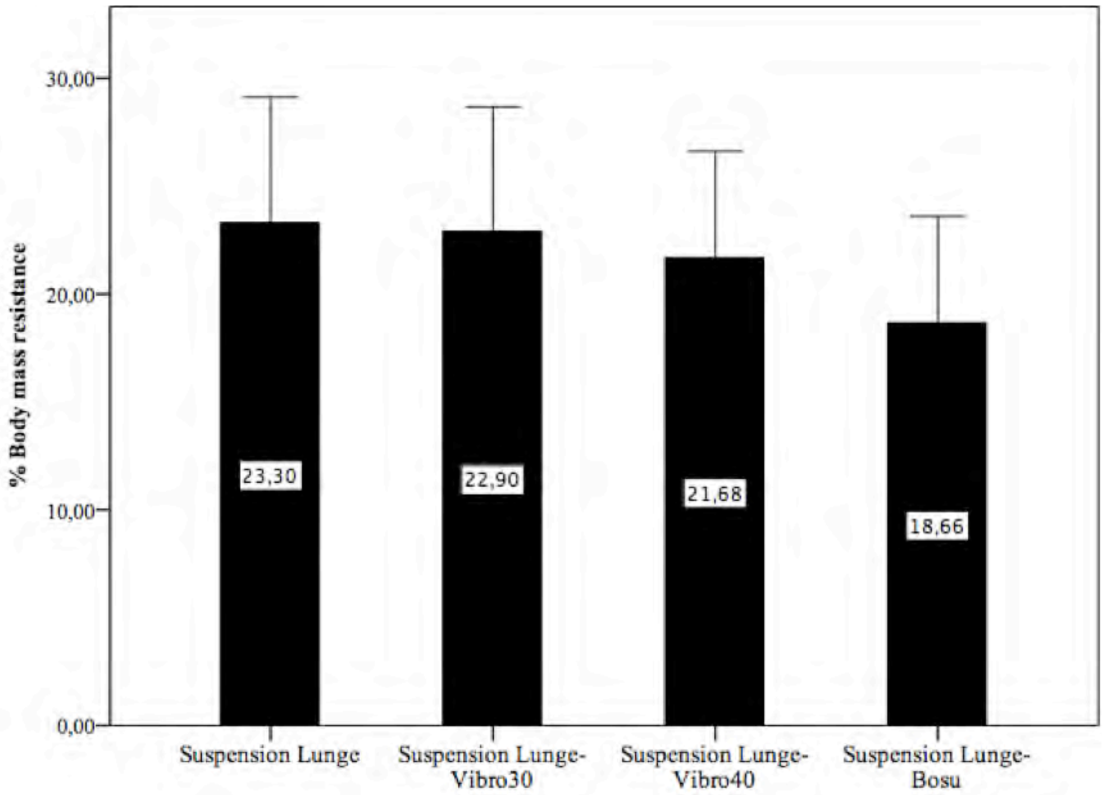

Figure 5. Comparison between suspension lunge conditions related to the percentage of body mass resistance. Each bar represents the mean, and the error bar the SD.

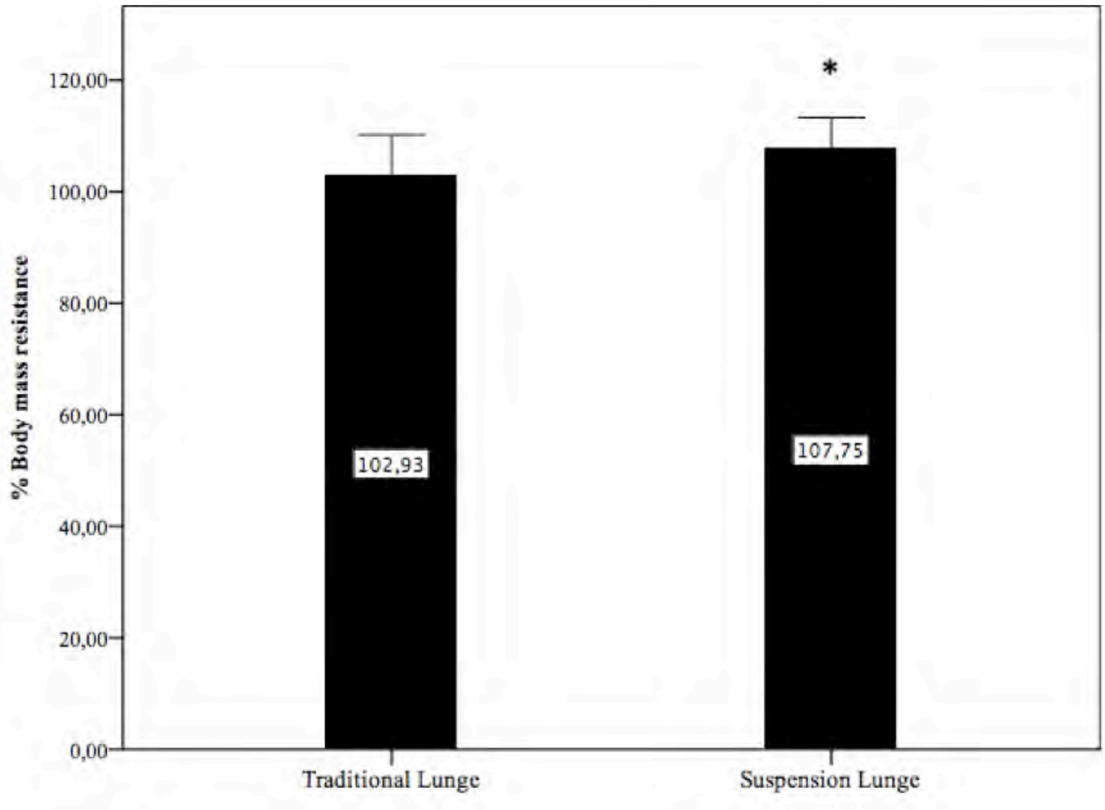

Figure 6. Comparison between forward leg force production and exercise condition. Each bar represents the mean, and the error bar the SD. Data expressed as percentage of body mass resistance. * Significant difference between conditions ($p<0.05$).

DISCUSSION

The first hypothesis of this study was that lunges performed using suspension would result in greater muscle activation than stable lunge and that the highest levels of activation would be observed when lunges were performed in dual instability conditions. The results of this study were partly in accordance with this hypothesis; our findings showed that a higher o similar activation was achieved in traditional lunge (stable condition). However, dual instability conditions enhanced greater muscle activation in comparison with single instability (suspension lunge). This muscle activity difference was significant between suspension lunge-Vibro40 and suspension lunge for the VM. The second hypothesis was that force produced on the suspension strap wouldn't significantly differ through conditions. This hypothesis was supported because force production outcomes showed that loads on the suspension straps differ between suspension lunge-Bosu and the others suspension lunge conditions (single instability, Vibro30 and Vibro40) but no significant differences were found. The thirst hypothesis indicated that suspension lunge condition would elicit a higher load of the body weight on the forward leg than traditional lunge. Our findings are in accordance with this hypothesis, percentage of the body mass resistance significantly increased in the forward leg under suspension lunge condition in comparison with traditional.

RF_D showed a similar muscle activity when performed lunges under stable and unstable conditions. However, instability lunge condition improved RF_D activity in comparison with stable condition. This finding is in accordance with authors who reported no significant differences in muscle activity from RF when performed 6-RM stable and unstable bulgarian squat (1). Moreover, Youdas et al. (51) stated that unstable surface elicited no significantly higher activation of RF than stable surface when performing lunge. In contrast, Saeterbakken & Fimland (42) found greater RF activity during squat performed on the floor in comparison with other instability surfaces conditions. It is suggested that the role of RF as hip flexor and not the knee extensor might explain these differences. Likewise, BF activity was similar in all exercise conditions, despite greater activity was found in traditional lunge. This finding are similar with those of Andersen et al. (1) who found that 6-RM stable bulgarian squat increase BF activation in comparison with unstable bulgarian squat. It seems that single and dual instability lunge conditions did not provoke the appropriate degree of instability to lead to changes in muscle activation and demand a stronger BF co-contraction. Furthermore, unstable conditions can lead to increases in antagonist activity (4). Conversely, our results showed that antagonist activity was lower than agonist activation. On the other hand, we found that lunges performed on dual instability let to higher Gmed activation than traditional and suspension lunge. This fact could be explained by the pelvic stabilizing role of Gmed, which increases its activation to keep dynamic balance when the amount of the instability augmented, however insufficient evidence exists to make a comparison. With regard to VM and VL activity outcomes, we found that no significant differences achieved between traditional and suspension lunge. Andersen et al. (1) suggested that VM and VL activation is similar during stable and unstable bulgarian squat, in accordance with our results. However, suspension lunge-Vibro40 elicited significant greater VM activity in comparison with suspension lunge. This finding are not in accordance with Marín & Hazell (33) who reported a significant greater activity for VM when performed semi-squat on vibration platform with an unstable surface at 30 Hz than the others exercise conditions at 50 Hz. It appears that whole-body vibration increase muscle activity due to control and muscle tuning mechanisms (40). Thus, we could speculate that suspension lunge-Vibro40 provokes the highest degree of instability to increase the stabilizing role of VM during knee extension and enhanced the dynamic stabilization. On the other hand, VL showed the highest activity in all exercise conditions. This finding is consistent with the work by Ebben et al. (18) who reported that closed kinetic chain exercise like lunge or squat attained higher level of activation (94.3% MVIC) in comparison with other lower body resistance training exercise. These results suggested that for VL, a more instability condition may provide a greater activation as more stable conditions. Besides, the highest activity was probably due to the extensor knee role of the VL and its superior motor recruitment and greater neuromuscular coordination under instability conditions. In regard of dual instability, there is a lack of research available investigating muscle activation of lower limb during suspension lunge-Bosu and suspension lunge-Vibro exercises. However, some evidence sustain a significant higher trunk muscle activity when prone and supine bridge were performed in sling (a type of suspension training system used in sling therapy) with vibration than sling without vibration (12). In the same vein, the present study showed in favour of suspension lunge-Vibro40 to elicit a significant increase in the muscle activity for global (mean of the 6 analysed muscles) in comparison with traditional, suspension and Vibro30 lunge conditions. In contrast, other study showed that dual instability suspension plank (arms and feet in suspension straps) in comparison with single instability (arms in suspension straps) was not a factor that provokes a difference on abdominal muscle activity (7). This finding suggested that dual instability with whole-body vibration achieved an appropriate degree of instability, which would lead to increased the muscle tuning mechanisms and the muscle contraction (12,33). However, suspension lunge-Bosu showed a similar muscle activity and greater in comparison with suspension lunge Vibro40 and suspension lunge-Vibro30, respectively. We could speculated that suspension lunge-Bosu would demands a similar recruitment patterns as whole-body vibration required to keep the dynamic stabilization through the forward leg muscle. In addition, suspension lunge-Vibro conditions showed that activation tend to increase linearly with frequency in all muscles except for BF, this result is in line with the study of Pollock et al. (40) that examined the muscle activity for lower body using whole body vibrations at different amplitudes and frequencies.

The results of this study showed that loads on the suspension straps did not significantly differ between exercise conditions (suspension lunge, suspension lunge-Bosu, suspension lunge-Vibro30 and Vibro40). However, the percentage of body mass resistance supported by the suspension strap tends to improvement when the amount of instability decreases. This finding is in accordance with Behm et al. (4) who proposed a hierarchy of force outputs with decreasing force output with increasing instability. These evidence supports the fact that the load exerted by the rear leg on the suspension strap could be influenced by the surface which leans forward leg when perform lunge exercise. It seems that single instability allows for more stability due to the forward leg leans on the floor (stable surface), in contrast, suspension lunge-Bosu condition provokes the highest amount of instability, and therefore the load exerted on the suspension strap is lower due to the characteristics from the side up Bosu platform in comparison with the regular surface of the vibration platform. Likewise, our finding is comparable with Saeterbakken & Fimland (42) who reported the lowest force output when performed squat on Bosu in comparison with different stable and unstable conditions. Finally, the load on the WBB significantly increases when performed suspension lunge in comparison with traditional lunge. This finding may be due to the suspension device provokes greater degree of instability than traditional lunge, because the rear leg is lean on a suspension strap and therefore the forward leg is the only that exert force on the ground for reduce the instability effects. Hence, the percentage of body mass resistance is projected in the forward leg when perform a suspension lunge, however, traditional lunge provides stable conditions on both rear leg and forward leg, this fact suggested that body mass resistance is more balance in traditional lunge. Unfortunately, insufficient evidence exists to make a comparison.

There were some limitations associated with this study. Firstly, the sample size was small, an increasing the number subjects may have helped to bring the numbers closers to statistical significance. Another limitation of our data was the lack of quantification about the amount of instability produced by the device. However, for future studies may be interested the assessment of the perturbation related to the destabilizing material with an accelerometer. Finally, another limitation may be the knee flexion angle was not controlled. However, the displacement during each lunge repetition was measured with a linear encoder. In addition, examine muscle activity and force output when performs suspension lunges resistance training could be interested for compare recruitment patterns between lower body suspension and traditional resistance training exercise.

In conclusion, the results of our study demonstrate that suspension lunge exercise provides no additional benefit in comparison with traditional lunge in order to enhanced lower body muscle activity. Performing lunge at dual instability increases exercise muscle activity in comparison with single instability. However, dual instability tends to decreases the load on the suspension strap when the amount of instability increases. Furthermore, suspension lunge forward leg force production improves in order to maintain the stability in front the instability generated by the suspension device, in comparison with its traditional counterparts.

PRACTICAL APPLICATIONS

Coaches, athletes and fitness enthusiasts can use the present information to select the optimal lunge (traditional, suspension, suspension-Bosu, suspension-Vibro30 and 40) exercise and to establish a lunge progression based on the report extend of muscle activation. From the results obtained in the present study, suspension lunge-Vibro40 and suspension lunge-Bosu seems to be more indicated for increase the activation of all muscle (except for BF and RF_ND). Furthermore, the assessment of the load on suspension strap during lunge may be useful for strength and conditioning coaches in order to evaluated and individualized the athletes force output related to instability adaptations. Likewise, the present study suggests that greater vertical ground reaction force is related to suspension lunge condition and could be to lead to neuromuscular adaptations for improves lower body sports skills. Finally, authors encourage to performed lunge exercises at 70 bpm pace velocity due to this frequency may be reproduce the specific sports demands.

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