Vertical Force Distribution between Lower Limbs in Different Lunge Techniques

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10 authors, including:

Paulo Marchetti
California State University, Northridge

Vincent F Martinez
California State University, Northridge

Farzad Jalilvand
U.S Ski and Snowboard

Shahan Awakimian
California State University, Northridge

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Vertical Force Distribution between Lower Limbs in Different Lunge Techniques

[1]Paulo H. Marchetti, [1]Vincent Martinez, [1]Farzad Jalilvand, [1]Shahan Awakimian, [1]Leran Lhanie, [1]Marisa Pikkel, [1]Priscyla N. Marchetti, [2]Roberto A. Magalhaes, [3]Josinaldo J. da Silva, [3]Willy A. Gomes

[1]*Department of Kinesiology, California State University, Northridge, CA, USA;*
[2]*Department of Physical Education, Mogi Guacu University, MG, Brazil;*
[3]*Department of Physical Education, Nove de Julho University, SP, Brazil.*
dr.pmarchetti@gmail.com

ABSTRACT

The lunge exercise is considered a bilateral and multi-joint exercise; in this way, each lower limb presents different force distributions in different techniques and body positions. The purpose of this study was to measure the vertical force distribution between lower limbs in different lunge exercises. Thirty-two young, resistance-trained (male=27, 27±6 years, 174.6±9.6 cm, 79.1±14.2 kg; female=7, 24±4 years, 165.2±2.6 cm, 67.1±13.5 kg) performed 3 different lunge techniques on the floor [traditional (TL), partial (PL), and long (LL)] and two on the step [Rear-Foot-Elevated Lunge (RFEL) and RFEL at 50% (RFEL50)] in two static positions (upper and lower) in a randomized, counterbalanced fashion. For the assessment of the vertical force, two portable force plates were positioned under the anterior and posterior lower limb for all lunge techniques. Factorial ANOVA was used to test differences between exercises (TL, PL, LL, RFEL, and RFEL50), limbs and moments. An alpha of 5% was used. In conclusion, lunge techniques as the TL, PL, and LL presented differences in force between legs and positions, however similarities between techniques, and might be applied for different sports under unilateral conditions. Lunges with step (RFEL or RFEL50) presented high asymmetry between lower limbs and emphasis on the anterior leg.

Keywords: resistance training; exercise; strength; force; force plate.

1 Introduction

Appropriate exercise selection is a fundamental part of a resistance training program, and the understanding of the mechanical demands of each exercise is vital to impose adequate stress on the neuromuscular system. The lunge is a bilateral, multi-joint exercise, and can be characterized by having one leg positioned forward (anterior position) with knee bent and foot on the floor, and the other leg (posterior leg) positioned behind. This exercise can impact the muscle activation of hip and knee extensors in both legs [1-3], which in turn can indirectly improve the quality of life in a non-athletic population, sports performance in athletic populations [4-7], and rehabilitation [8, 9]. There are several variations of the lunge exercise such as bilateral/on the floor (In-line, Traditional, Partial lunge, Long lunge or Split squat), focusing on one leg (Bulgarian lunge), using a step (Step-up), with leg/torso movements (Forward step lunge, Walking lunge, Reverse lunge, Lateral lunge), and associated with jump tasks (Jump lunge)[6, 10-15],

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however, research comparing different techniques is scarce. Additionally, to the best of the authors' knowledge, no study has verified the force distribution between legs with different lunge techniques (on the floor or using a step) or with different body positions (upper and lower). This knowledge is fundamental to define the best technique to achieve different objectives, participants, and rehabilitation programs. Therefore, the purpose of this study was to measure the vertical force distribution between lower limbs in different lunge exercises. The rationale for this study is based on the assumption that different lunge techniques present different force distribution for each lower limb, and different body positions affect the force distribution in the same technique. The main hypotheses of present the study were: (1) the force distribution would be similar in the high position, except with the rear-foot-elevated lunge; (2) the lower body position would increase the load on the anterior limb when compared to the upper position.

2 Methods

2.1 Subjects

Thirty-two young, healthy, resistance-trained (n=27, male subjects: age: 27±6 years, height: 174.6±9.6 cm, total body mass: 79.1±14.2 kg; n=7, female subjects age: 24±4 years, height: 165.2±2.6 cm, total body mass: 67.1±13.5 kg) with more than 1 year of resistance training and lunge experience (at least 3 times a week) volunteered to participate. Subjects had no previous lower back injuries, surgery on their lower extremities, and no history of injury with residual symptoms (pain, "giving-away" sensations) in their lower limbs within the last year. The study was approved by the University research ethics committee and all subjects read and signed an informed consent document (#3.299.995).

2.2 Protocol

Subjects attended one session in the laboratory. They reported to have refrained from performing any lower body exercise other than activities of daily living for at least 24 hours prior to testing. All anthropometric measurements (height, weight, and lower limb length) were measured. All subjects were asked to identify their preferred leg for kicking a ball, which was considered their dominant leg, and the dominant leg was always used as the anterior lower limb in all lunge techniques [16]. Tests were randomized and counterbalanced across subjects and lunge techniques. All subjects were instructed and familiarized in all lunge techniques supporting their bodyweight, and no additional load was imposed for all techniques. The hands were positioned over the hips and facing forward for all lunge techniques. Subjects received standard instructions regarding each technique, they were monitored and corrected when necessary, and verbal encouragement was provided. Three trials were allowed per technique and position to avoid neuromuscular fatigue. All subjects performed two static (isometric) body positions (~3-sec) for each lunge technique: 1). The upper position (UP) was defined by the knee in full extension with both legs (anterior and posterior leg), and 2). The lower position (LP) was defined by the knee in maximal flexion with both legs (anterior and posterior leg). A rest period of 3-min was provided between techniques. For the assessment of the force distribution with each lower limb, two portable force plates (EMG system Brasil, São José dos Campos, Brazil) were positioned under the anterior and posterior lower limb in all lunge techniques and positions. A sampling rate of 100 Hz using commercially designed software (EMG system Brasil, São José dos Campos, Brazil) was used to determine the vertical ground reaction force (vGRF) data. The digitized vGRF data were low-pass filtered at 10Hz using a fourth-order Butterworth filter with a zero lag. Then, the average force was defined for all lunge techniques and positions. All subjects were asked to wear the same shoes during the session and to maintain their normal dietary intake. Subjects also received verbal encouragement during all trials, and all measurements were performed between 2 PM and 4 PM, and measured by the same researcher.

2.3 Lunge Techniques

a). Traditional lunge (TL): Traditional lunge was performed with lower limbs in a stride stance. For all lunges except the lateral side lunge, feet were hip-width apart and pointing forward, torso remained erect, and chest kept out and up, and head and neck straight forward. For the UP with all lunges, all participants were instructed to keep a full knee extension with both legs. For the LP with all lunges, all participants were positioned at 90º of knee flexion. The anterior knee was aligned directly above the foot and was placed flat with both ball and heel in contact with the ground surface. The posterior knee was positioned at 90º of knee flexion, and foot was dorsiflexed with the ball of the foot on the ground surface, toes extended and heel off the ground (Figure Ia).

b). Partial lunge (PL): Partial lunge was performed similarly to the traditional lunge except the lower limbs were positioned at 50% of the traditional lunge distance (Figure Ib).

c). Long lunge (LL): Long lunge was performed with lower limbs in a stride stance. For the low position, all participants were positioned at 90º of knee flexion only for the anterior leg. The anterior knee was aligned directly above the foot and was placed flat with both ball and heel in contact with the ground surface. The posterior knee was maintained at full knee extension, and foot was dorsiflexed with the ball of the foot on the ground surface, toes extended and heel off the ground (Figure Ic).

d). Rear-Foot-Elevated Lunge (RFEL): RFEL was performed with lower limbs in a stride stance. For the RFE technique, the posterior limb was positioned at knee height, RFE. The posterior knee was positioned on a step at knee height, the contact between foot and step was on the metatarsophalangeal joint (Figure Id).

e). Rear-Foot-Elevated Lunge at 50% (RFEL50): RFEL50 was performed with lower limbs in a stride stance. For the RFE technique, the posterior limb was positioned at 50% of the knee height, with all other characteristics similar to the RFEL [15] (Figure Ie).

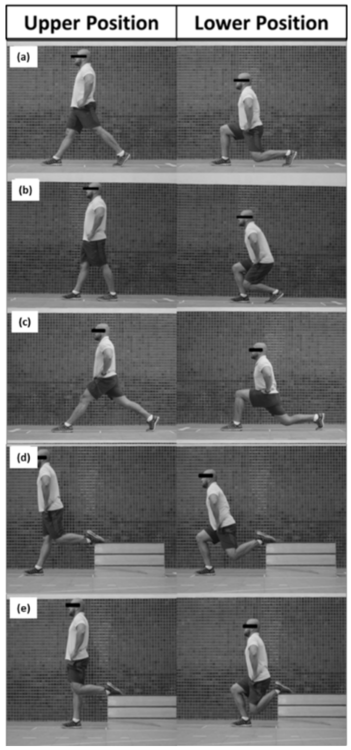

Figure I. Lunge techniques in both positions (Upper and Lower): (a) Traditional lunge, (b) Partial lunge, (c) Long lunge, (d) Rear-Foot-Elevated Lunge, and (e) Rear-Foot-Elevated Lunge at 50%.

2.4 Statistical Analysis

The normality and homogeneity of variances were confirmed by the Shapiro-Wilk and Levene's tests, respectively. The mean, standard deviation (SD), delta percentage (Δ%), and 95% confidence intervals (95%CI) were calculated. Factorial ANOVA (3x2x2) was used to test differences between exercises (TL, PL, and LL), limbs (anterior and posterior) and moments (upper and lower positions). Factorial ANOVA (2x2x2) was used to test differences between exercises (RFEL and RFEL50), limbs (anterior and posterior) and moments (upper and lower positions). Post-hoc comparisons were performed with the Bonferroni test. Furthermore, the magnitudes of the difference were examined using the standardized difference based on Cohen's d units using effect sizes (d) (14). The *d* results were qualitatively interpreted using the following thresholds: <0.35 - trivial; 0.35-0.8 - small; 0.8-1.5 - moderate; >1.5 - large for recreationally trained [17]. An alpha of 5% was used to determine statistical significance.

3 Results

Comparison between lunge exercises: There were significant main effects for exercises (*p*=.03) and limbs (*p*<.001). There was significant interaction between limbs and moments (*p*<.001). There were significantly differences for TL: $UP_{anterior}$ x $UP_{posterior}$ (*p*=.001, *d*=0.66 (small), Δ%=12.7, and 95%CI=[1.16, 9.20]), $LP_{anterior}$ x $LP_{posterior}$ (*p*<.001, *d*=3.13 (large), Δ%=46.9, and 95%CI=[18.18, 28.38]), $UP_{anterior}$ x $LP_{anterior}$ (*p*<.001, *d*=1.05 (moderate), Δ%=17.9, and 95%CI=[10.84, 17.91]), $UP_{posterior}$ x $LP_{posterior}$ (*p*<.001, *d*=1.59 (large), Δ%=25.8, and 95%CI=[-10.91, -4.33]). There were significantly differences for PL: $UP_{anterior}$ x $UP_{posterior}$ (*p*=.031, *d*=1.19 (moderate), Δ%=28.5, and 95%CI=[0.47, 24.46]), $LP_{anterior}$ x $LP_{posterior}$ (*p*<.001, *d*=2.18 (large), Δ%=40.5, and 95%CI=[11.35, 24.89]). There were significantly differences for LL: $UP_{anterior}$ x $UP_{posterior}$ (*p*=.001, *d*=0.84

(moderate), Δ%=14.8, and 95%CI=[2.32, 9.81]), $LP_{anterior}$ x $LP_{posterior}$ (*p*<.001, *d*=2.09 (large), Δ%=38.7, and 95%CI=[9.59, 27.09]), $UP_{anterior}$ x $LP_{anterior}$ (*p*<.001, *d*=0.76 (small), Δ%=13.8, and 95%CI=[-11.28, -1.84]), $UP_{posterior}$ x $LP_{posterior}$ (*p*=.01, *d*=0.75 (small), Δ%=16.5, and 95%CI=[0.66, 10.77]).

Comparison between lunge exercises with step: There were significant main effects for exercises (*p*=.023), limbs (*p*<.001), and moments (*p*=.016). There was significant interaction between limbs and moments (*p*<.001). There were significantly differences for RFEL: $UP_{anterior}$ x $UP_{posterior}$ (*p*<.001, *d*=7.17 (large), Δ%=79.6, and 95%CI=[53.05, 71.95]), $LP_{anterior}$ x $LP_{posterior}$ (*p*<.001, *d*=5.33 (large), Δ%=75.4, and 95%CI=[37.22, 53.96]), $UP_{anterior}$ x $LP_{anterior}$ (*p*<.001, *d*=0.80 (moderate), Δ%=13.3, and 95%CI=[5.92, 12.64]), $UP_{posterior}$ x $LP_{posterior}$ (*p*<.001, *d*=4.62 (large), Δ%=51.2, and 95%CI=[-10.91, -4.33]). There were significantly differences for RFEL50: $UP_{anterior}$ x $UP_{posterior}$ (*p*<.001, *d*=6.95 (large), Δ%=91.1, and 95%CI=[55.62, 74.19]), $LP_{anterior}$ x $LP_{posterior}$ (*p*<.001, *d*=5.19 (large), Δ%=75.4, and 95%CI=[38.12, 55.06]), $UP_{anterior}$ x $LP_{anterior}$ (*p*<.001, *d*=0.77 (small), Δ%=13.3, and 95%CI=[5.59, 13.40]), $UP_{posterior}$ x $LP_{posterior}$ (*p*<.001, *d*=2.20 (large), Δ%=57.9, and 95%CI=[-11.40, -6.22]). Table 1 shows the mean and standard deviation of the force distribution for each lower limb for all techniques and positions (upper and lower position).

Table 1. Mean ± standard deviation of the force distribution for each lower limb for all techniques and positions (upper and lower position).

Technique	Anterior Limb		Posterior Limb	
	UP	LP	UP	LP
TL, kgf	40.7±7.4$^{*\#}$	49.6±9.4^{+}	35.5±8.4$^{\$}$	26.3±4.8
PL, kgf	44.4±11.6$^{*\#}$	48.4±11.2^{+}	32.0±8.9$^{\$}$	28.8±5.9
LL, kgf	40.8±6.9$^{*\#}$	47.4±10.1^{+}	34.8±7.6$^{\$}$	29.1±7.5
RFEL, kgf	69.7±12.6$^{*\#}$	60.5±11.5^{+}	7.3±2.8$^{\$}$	14.8±5.1
RFEL50, kgf	71.3±12.9$^{*\#}$	61.8±11.7^{+}	6.1±2.8$^{\$}$	15.2±4.9

Notes. Traditional lunge (TL), Partial lunge (PL), Long lunge (LL), Rear-Foot-Elevated Lunge (RFEL), Rear-Foot-Elevated Lunge at 50% (RFEL50), Upper Position (UP), and Lower Position (LP). *significant between $UP_{anterior}$ x $UP_{posterior}$, *p*<0.05; $^{+}$significant between $LP_{anterior}$ x $LP_{posterior}$, *p*<0.05; $^{\#}$significant between $UP_{anterior}$ x $LP_{anterior}$, *p*<0.05; $^{\$}$significant between $UP_{posterior}$ x $LP_{posterior}$, *p*<0.05.

4 Discussion

A multi-joint task to strengthen the knee and hip extensors are more complex for the neuromuscular system as two joints work in concert to achieve a task [18]. In general, the lunge exercise presents important neuromechanical characteristics such as positioning of the legs and techniques [1]; consequently, each leg should be analyzed separately. To the best of authors' knowledge, no study has verified the force distribution in different lunge techniques and body positions. The purpose of this study was to measure the vertical force distribution between lower limbs in different lunge exercises. The rationale for this study is based on the assumption that different lunge techniques present different force distribution for each lower limb, and different body positions affect the force distribution in the same technique. The main findings were that all techniques presented some level of stress in both legs, characterizing them as bilateral exercises. The force distribution, during UP, was not similar between legs in all lunge techniques due to the full extension of the knee joint and balance. The force distribution between TL, PL, and LL (12.7%, 28%, and 14.8%, respectively) was different between lower limbs, with the anterior limb presenting the greatest vertical forces. The PL presented a high value in the anterior limb with a high difference between limbs (28%). Interestingly, in the LP, the lunges (TL, PL, and LL) showed an increase in force for the anterior limb and a reduction in force of the posterior limb. This means that, during different positions (UP or LP), the force distribution might not be considered similar in both legs, and consequently, the stress coming from an external force might not be considered equally distributed. Additionally, PL showed the highest values of force in the anterior limb in both positions (UP and LP) analyzed, proving to be an interesting technique to increase the stress imposed on this leg.

Regarding the lunge techniques that use the step as support, the force distribution between lower limbs for RFEL and RFEL50 (79.6% and 91.1%, respectively) was different between lower limbs for both positions (UP and LP), with the anterior limb presenting the greatest vertical forces. Curiously, in the LP, both lunges techniques (RFEL and RFEL50) showed a decrease in force for the anterior limb and an increase in force of the posterior limb. This means that RFEL and RFEL50 presented a distinct force pattern when compared with other lunge techniques. In these techniques, the force distribution during the UP was considerably lower for the posterior leg (~6-15kgf) when compared to the anterior leg (~60-71kgf). Probably, part of this difference between positions might be related to balance, where even with stable surfaces, it is necessary to control the center of gravity during anterior-posterior exercises. The erect body acts as an inverted pendulum and thus during static postures, there is always movement of the center of gravity (or pressure) around the base of support [19]. A reduced mediolateral base of support may demand higher neuromuscular activity and force to support the body in the frontal plane [1, 20]. Besides, based on the posterior lower limb's height (RFEL or RFEL50), the amount of force distribution changed between positions (UP and LP). For RFEL50, the difference between a UP and LP for the posterior leg was about 51.2%; and for RFEL was about 57.9%. In this way, this knowledge is important to help define the best lunge technique to prioritize one of the two legs (anterior or posterior), even with a bilateral exercise.

Different lunge techniques can affect the force distribution for each lower limb. The LP presents greater differences in force distribution when compared to the UP. The force distribution might help coaches to choose the best variation for each session of strength training. Traditional, partial, and long lunge exercises may be used in a wide range of sports under unilateral conditions (i.e. tennis, squash, rugby, American football, etc.) or as the rear-foot-elevated lunges when the unilateral transfer of forces is required (i.e. change of direction, throwing, kicking, and striking). Different lunge techniques change the force distribution for each lower limb. The force data presented highlights a few salient points regarding the exercise selection. Since all the lunge variations exhibited a force distribution in both limbs in any given condition, there will be a certain degree of fatigue in both limbs during a bilateral exercise within a given set and repetition range prescribed by the practitioner. Depending on the training goal (i.e. strength), a pragmatic approach could be to allow additional rest such as a modified cluster set(s) when changing limbs, which may allow the non-dominant limb to recover for subsequent repetitions without fatigue. This data also indicates that if the coach decides to create a true isolative condition in the lower limbs, changing the orientation of the non-dominant limb such as keeping it off the ground may be warranted.

From a reconditioning or late-stage rehabilitation standpoint, understanding the force distribution between the limbs may aid the sports medicine staff to modify ranges of motion as a form of progression with injured athletes when prescribing bilateral exercises. Furthermore, since the non-dominant limb experiences forces, the sports medicine staff can also assign the injured limb as non-dominant during the different lunge variations to safely progress to more load-bearing conditions.

This study has limitations that must be considered when interpreting the current results. This study analyzed only the vertical ground reaction forces, therefore; the frictional forces in the antero-posterior direction were disregarded. This study analyzed only isometric positions; dynamic movements add momentum in the system and the main aim of this study was to measure only vertical forces in each lower limb. The findings of this study are specific to young resistance-trained subjects and therefore cannot necessarily be generalized to other populations including adolescents, athletes, and the elderly.

5 Conclusion

In conclusion, lunge techniques as the traditional, partial, and long lunge presented differences in force between legs and positions, however similarities between techniques, and might be applied for different sports under unilateral conditions. Lunges with step (RFEL or RFEL50) presented high asymmetry between lower limbs and emphasis on the anterior leg. The results of the current study allow coaches to make informed decisions when selecting lunge techniques for strength training sessions and rehabilitation programs and can help to adjust training programs to meet the needs of each participant.

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