Original Research

Analysis of Heel Raise Exercise with Three Foot Positions

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ABSTRACT

Int J Exerc Sci 4(1) : 13-21, 2011. Prior research revealed activation differences between the medial (MG) and lateral (LG) gastrocnemius when performing heel raise exercise with neutral (N), internally-rotated (IR) and externally-rotated (ER) foot positions. Studying underlying biomechanics may help explain activation differences. The purpose was to compare ankle (AN), knee (KN), and hip (HI) contributions (initial joint angles) to attaining each initial foot position, ankle flexion-extension range of motion, ankle mechanical energy expenditure, repetition time, and percent cycle concentric-eccentric transition between N, IR, and ER foot positions. Twenty healthy subjects (11 male, 9 female) with resistance training experience performed twelve repetitions of free-weight (135% body mass) heel raise exercise using N, IR and ER foot positions in a counterbalanced order. Forefeet were elevated .05m onto separate forceplates. Electromagnetic sensors secured along dominant lower limb recorded kinematic data. Dependent variables were averaged across five selected repetitions. No significant differences existed for repetition time (P=.209), percent cycle concentric-eccentric transition (P=.668), ankle mechanical energy expenditure (P=.590), and ankle flexion-extension range of motion (P=.129) between foot positions. Post hoc comparison of a significant joint by foot position interaction (P<.001) demonstrated IR>N>ER for the initial HI and KN angles, whereas for AN, ER>IR and N. Between joints: AN<KN and HI for N and AN<KN<HI for IR. Although it was expected the IR/ER/N positions would induce large start AN angle changes, our results reveal the greatest changes at the HI followed by the KN. Small AN differences may be explained by beginning dorsiflexed (close-packed position). Further research is needed to explain the MG and LG activation differences previously reported.

KEY WORDS: Plantar flexion, motion analysis, strength training, ankle range of motion

INTRODUCTION

Ankle plantar flexion exercise has been incorporated as part of rehabilitation programs and (11) an exercise to promote hypertrophy of the gastrocnemius or to increase power and strength of the plantar flexors (4, 5). Various populations are interested in the benefits from training the gastrocnemius and soleus such as body builders for implementing symmetry in the lower extremities (15), sprinters (2), and jumpers for improving performance (3), older adults for maintaining function and performance of daily activities (4), and individuals recovering from Achilles tendinopathy (8, 14).

The medial (MG) and lateral gastrocnemius (LG) and soleus are known collectively as the triceps surae and work together to aide human locomotion (12). The triceps surae muscles are responsible for plantar flexion of the foot (1) and acting against the forces of gravity in day to day life (18). The MG and LG attach proximally to the posterior aspect of the medial and lateral femoral condyle and attach distally to the calcaneal tuberosity by way of the Achilles tendon (11). The soleus attaches proximally attachment to the posterior surface of the fibula head and distally to calcaneal tuberosity by way of the Achilles tendon (11). Due to the biarticular nature of the MG and LG, the gastrocnemius can produce greater leverage than the soleus which is monoarticlar in nature (12). Due to the biarticular nature of the gastrocnemius, the contribution of ankle plantar flexion is dependent upon both the knee and ankle joints, whereas the soleus may be targeted independent of knee position. Therefore in order to better promote gastrocnemius and soleus function, one might incorporate knee flexion and extension variations of the heel raise exercises into a strength training program (15).

Evidence has also suggested functional differences exist among the MG and LG heads, by demonstrating differences in force-producing abilities among the MG and LG depending on ankle and knee joint position (7). Typically, those involved in some form of strength training are observed executing the heel raise in three different foot positions, forward or a neutral stance, inward or an internally rotated stance, and outward or an externally rotated stance. The variance in foot position is thought to maximize the activation of both the MG and LG during the exercise bout.

A recent study (13) demonstrated muscle activation differences using electromyography among the MG and LG while performing a standing heel raise exercise in three different foot positions, neutral, internally rotated, and externally rotated. The externally rotated foot position demonstrated significantly greater muscle activation of the MG (approximately 10%), whereas the internally rotated foot position initiated statistically greater LG (approximately 13%) muscle activation (13).

While electromyography is a good measurement tool to use for the assessment of muscle activation it does not provide information concerning muscle forces nor the resulting kinematics or kinetics. Plausible explanations for the differences between the three stance positions reported by Riemann et al (13) could be differences in plantar flexion-dorsiflexion range of motion and/or mechanical energy expenditure. While Riemann et al (13) demonstrated muscle activation differences between the three foot positions, the contributions of the ankle, knee and hip joints to achieve the internally rotated and externally rotated stances were not determined. Therefore the purpose of this investigation was to compare ankle, knee and hip contributions to achieving the starting stance positions, ankle flexion-extension range of motion and ankle extension mechanical energy expenditure between heel raise exercise with neutral, internally rotated, and externally rotated stances.

METHODS

Subjects

The study involved twenty healthy subjects (11 male, 9 female; 22.7 ± 3.13 yrs; 1.73 ± .104 m; 74.9 ± 15.1 kg) who participated in resistance training at least three times a week and 30 minutes per exercise bout. Their participation was voluntary and no incentives were provided. All subjects were without prior injury history preventing proper execution of a freestanding heel raise exercise or any other conditions that might confound the performance of this exercise in all three foot positions. Prior to participation each subject was given a verbal summary of the study's purpose and a demonstration of the standing heel raise exercise. Following the summary and demonstration they were given time to read, review, and sign an Institutional Review Board approved consent form.

Protocol

A repeated measures counterbalanced design was used to examine the kinetic and kinematic differences, across three foot positions, while performing a standing heel raise. Participants completed all testing procedures within a single thirty minute session. Participants completed a standardized warm-up prior to data collection that consisted of having each subject practice the standing heel raise, in all three foot positions, while holding a 16kg Olympic weight lifting bar. 35% of their mass was calculated and sufficient weight was added to the weight lifting bar so that the total weight (bar plus additional plates) equaled 35% body mass (within 1.14kg). Electromagnetic sensors (Motion Monitor, IST, Inc) were secured onto their dominant foot, shank, thigh, sacrum, and non dominant foot and recorded kinematic data. Subjects performed one set of 12 repetitions in each of the three foot positions (neutral, internal rotation, and external rotation), using a counterbalanced order. All repetitions began with subjects' acquiring a comfortable hip-width stance with their forefeet elevated .05m onto separate force plates while holding the loaded weight lifting bar. The neutral stance involved having the subjects assume a foot position where their feet pointed anterior, their natural everyday stance. While engaging in an internally rotated and externally rotated foot position, participants were asked to rotate their legs as far as they could, while maintaining a safe and effective execution of the exercise. While engaging in all three foot positions, subjects were instructed to maintain full extension at the knee. The 12 repetitions in each foot position were self-initiated and data was collected within a 30 second time frame after initiation. We instructed participants to perform each repetition on an “up one thousand down one thousand” cadence, however verbal cues were not given during the trials. Following completion of each set the subject unloaded barbell on the squat rack and a one minute rest interval was provided between sets.

Data Collection and Reduction

An extended range electromagnetic tracking system (Motion Monitor, IST, Inc, Chicago, IL) collected three-dimensional kinematic data (100Hz). Following the completion of the warm-up trials, sensors were attached to the subject’s sacrum (specifically over the second sacral process), dominant foot, shank and thigh using double sided tape. During subject setup, the ankle, and knee joint centers were calculated by taking midpoints between contralateral points at each respective joint using an additional electromagnetic sensor attached to a customized calibrated stylus. The hip joint center was established using a series of five points along a circumduction cycle for each hip to estimate the apex of femoral motion (9). Subject’s mass and height were also recorded, using the forceplates and an additional electromagnetic sensor respectively, for anthropometric calculations required for locating each segment’s center of mass using the Dempster parameters as reported by Winter (17). Ground reaction force data under the forefeet of both limbs were collected (100Hz) using two nonconducting force plates (BP400600NC 2000 Advanced Mechanical Technology, Inc., Watertown, MA) synchronized with the electromagnetic system.

Three dimensional ankle, knee and hip joint angles and ankle plantar flexion-extension net joint moments were calculated using the Motion Monitor software. These data were exported as text files further processed using MatLab (The Mathworks, Inc., Natick, MA) based scripts. First, all data were low-pass filtered with a zero-phase lag Butterworth filter (10Hz cutoff). The beginning and end of a trial were operationally defined as when vertical TBCM velocity exceeded -.15m/s and .15m/s, respectively. Five of the 12 trials under each condition were selected for analysis using a graphic user interface display of the vertical TBCM trajectory and ankle extension/flexion patterns. Criteria for selection included achievement of similar ranges of motion and repetition time across the five trials within each set of 12 repetitions. Attempts were made to choose the five trials that were most similar.

For the selected trials, at repetition initiation, ankle adduction/abduction (adduction positive), knee and hip rotation (IR positive) were set to determine the extent to which each joint contributed to achieving the three stance positions. Ankle flexion-extension range of motion was computed as the difference between ankle flexion at repetition initiation and peak extension. The ankle net joint extensor moments were normalized to body mass and ankle flexion-extension velocity was computed as the derivative of ankle flexion-extension displacement. Net ankle joint extensor power was then calculated as the product of angular velocity (radians) and the body mass normalized net ankle joint moment. Eccentric and concentric work was calculated as the integrated magnitude of the absolute net joint power curve, with the sum of concentric and eccentric work representing mechanical energy expenditure. Finally, to examine differences in performance between the three stance positions, repetition time and percent cycle concentric-eccentric transition were also determined for each trial selected.

Table 1. Descriptive statistics (Means ± standard deviation, 95% confidence intervals) for repetition time, percent cycle concentric-eccentric transition (PC Transition), ankle flexion-extension range of motion (AN FL-EX ROM) and mechanical energy expenditure (MEE).

	Neutral		Internal Rotation		External Rotation	
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI
Repetition Time (s)	1.78 ± 0.36	1.61, 1.94	1.69 ± 0.31	1.54, 1.84	1.71 ± 0.35	1.54, 1.87
PC Transition (%)	45.4 ± 3.6	43.8, 47.1	46.3 ± 5.2	43.6, 48.7	45.6 ± 4.7	43.4, 47.8
AN FL-EX ROM (°)	57.3 ± 9.8	52.9, 61.6	57.9 ± 10.9	53.1, 62.8	55.9 ± 11.1	51.0, 60.8
MEE (J/kg)	1.40 ± 0.27	1.28, 1.53	1.42 ± 0.25	1.30, 1.54	1.43 ± 0.26	1.31, 1.55

Statistical Analysis

Each dependent variable (ankle, knee and hip angles at repetition initiation, ankle flexion-extension range of motion, ankle mechanical energy expenditure, repetition time and percent cycle concentric-eccentric transition), was averaged across the five trials within each stance condition and used for statistical analysis. Separate one factor repeated measures analysis of variance (RMANOVA) were used to compare ankle flexion-extension range of motion, mechanical energy expenditure, repetition time and percent cycle concentric-eccentric transition, between the three stance conditions. A two factor RMANOVA (stance by joint) was used for statistical comparison of the ankle, knee and hip angles at repetition initiation. Simple main effect post hoc analyses were conducted to examine significant stance and joint effects with Bonferroni adjusted P values used to identify significant differences. The alpha level for all statistical analysis was set at 0.05.

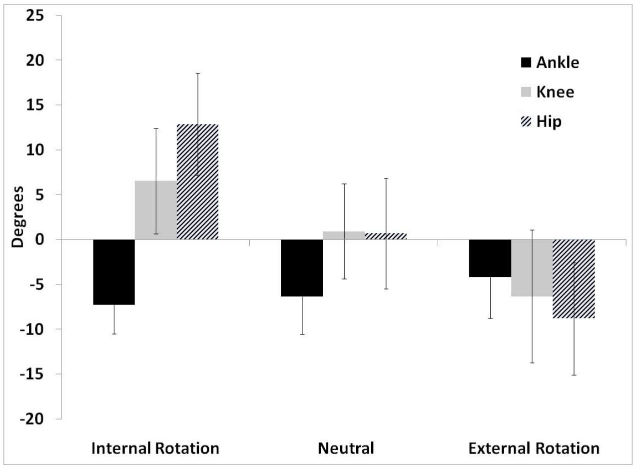

Figure 1. Graphical display (means, standard deviations) of the stance by joint interaction. Negative values indicate ankle abduction, knee and hip external rotation.

RESULTS

Descriptive statistics for repetition time, percent cycle concentric-eccentric transition, ankle flexion-extension range of motion and mechanical energy expenditure are provided in Table 1. No statistically significant differences were revealed for repetition time ($F_{2,38}=1.63$, $P=.209$, $\eta^2_p=,079$), percent cycle concentric-eccentric transition ($F_{2,38}=0.41$, $P=.668$, $\eta^2_p=,021$) or ankle mechanical energy expenditure ($F_{2,38}=.535$, $P=.590$, $\eta^2_p=,027$). Ankle flexion-extension range of motion ($F_{2,38}=2.15$, $P=.129$, $\eta^2_p=,093$) was not significantly different between conditions. Finally, a significant stance by joint interaction (Figure 1) was revealed for ankle, knee and hip starting angle ($F_{2,38}=104.1$ $P<.001$, $\eta^2_p=,846$). Results of the post hoc comparisons are summarized in Tables 2 and 3.

DISCUSSION

The current findings suggest that performing a freestanding heel raise exercise using the internally rotated, externally rotated, and neutral foot positions induce the greatest start angle changes at the hip, followed by the knee, followed by the ankle. No statistically significant differences were found for the dependent variables: ankle flexion-extension range of motion, ankle mechanical energy expenditure, and repetition time of percent cycle concentric-eccentric transition. The lack in statistical significance among the dependent variables eliminates them as rival explanations for the MG and LG muscle activation differences found in the Riemann et al(13) study. Alternatively because the current study used a different sample of participants, there is a chance that our participants may not have produced similar electromyographical findings as the Riemann et al (13) study. Clearly there is a need for replication of both the electromyographical analysis used by Riemann et al (13) as well as the kinematic and kinetic methods used in the current investigation.

Table 2. Results of the post hoc comparisons (p values, effect sizes) between stances within each joint

	Neutral v. Internal Rotation		Neutral v. External Rotation		Internal Rotation v. External Rotation	
	P value	Effect size	*P* value	Effect size	*P* value	Effect size
Ankle	0.04	0.03	<.001	-0.49	<.001	-0.78
Knee	<.001	-1.01	<.001	1.13	<.001	1.92
Hip	<.001	-2.05	<.001	1.53	<.001	3.62

Table 3. Results of the post hoc comparisons (p values, effect sizes) between joints within stances

	Ankle v. Knee		Ankle v. Hip		Knee v. Hip	
	P value	Effect size	*P* value	Effect size	*P* value	Effect size
Neutral	<.001	-1.52	0.01	-1.33	1	0.04
Internal Rotation	<.001	-2.92	<.001	-4.35	0.03	-1.09
External Rotation	0.84	0.35	0.12	0.74	1	0.36

Although the ankle position changed significantly between the three foot positions, the differences were small, with the largest difference between the externally rotated and internally rotated foot positions (3.1°±2.7°). At the initiation of each repetition recorded, subjects elevated their forefeet .05m onto two separate force plates. In doing so, the subject's ankle was initially placed in approximately 20-25° dorsiflexion. The close-packed position of the talocrural joint is full dorsiflexion (10). As defined by Hertling (6), the close-packed position of a synovial joint is the point in its range of motion where: the joint's surfaces are maximally congruent, its capsule and ligaments are maximally taut and elongated, and its surfaces are compressed maximally (6). The minimal mobility permitted in the close-packed position may help explain why the ankle demonstrated relatively small changes in start angles between the three foot positions. Also noteworthy was the ankle position across all three foot positions at repetition initiation. Regardless of foot position, the ankle demonstrated an abducted position. This can be explained by the orientation of the talocrural axis in the closed-pack position (16). Thus it would appear that the ankle does not contribute to achievement of the internally rotated and externally rotated foot positions nor would it contribute to changing the line of action of the MG and LG.

In contrast to minimal differences in starting ankle position between the three foot positions, the knee and hip joints demonstrated large differences. While there were no significant differences between the ankle, knee and hip joints for the externally rotated condition, the hip joint exhibited a significantly greater internal rotation than the knee for the internally rotated condition. These results suggest that acquiring the internally rotated foot position is achieved primarily by hip rotation, followed by knee rotation. While attaining the externally rotated foot position is accomplished equally by the ankle, knee, and hip joints.

It is important to note that only repetition initiation start angles were quantified and compared statistically. Qualitatively observing the recorded kinematic data revealed the ankle to increasingly adduct, across all three foot positions, as the foot plantar flexes during the concentric phase. The ankle joint returned to an abducted position during the eccentric phase. Likewise, the knee and hip exhibited rotational changes during the concentric and eccentric phases. The changes in the ankle position are likely a function of the triplanar orientation of the talocrural joint previously discussed. In turn, with the foot fixed to the ground, as the ankle rotated, the knee and hip demonstrated obligatory rotation. Future research, considering the ankle, knee and hip joint angles throughout the entire range of motion, might help better explain the MG and LG muscle activation differences previously reported.

No significant differences existed for repetition time and % cycle concentric-eccentric transition. Hence, the time it took to perform one repetition and the cadence (up one-thousand, down one-thousand) remained the same across internally rotated, neutral, and externally rotated foot positions. From a temporal perspective the repetition time and % cycle concentric-eccentric transition were identical across all three foot positions; thereby, eliminating them as rival explanations for the EMG results. Likewise, ankle flexion-extension range of motion showed no statistical significance between internally rotated, neutral, and externally rotated foot positions. Additionally, no significant differences existed for ankle extension mechanical energy expenditure. Therefore, the absolute sum of the angular concentric and eccentric work did not change between foot positions. Conclusively, the absence in statistical significance, discounts the previously mentioned variables as credible explanations for the EMG results.

It is also important to note several factors regarding the generalizability of our study design. First, the heel raise exercise was performed free standing. In doing so, participants relied heavily on their ability to balance in order to perform the required exercise. Due to between subject variability, with respect to varying levels of balance and ankle proprioception, performing the exercise using a different mode of external resistance, such as a machine, could very well produce different results. Secondly, in order to limit confounding effects different shoes might have on ankle motion, participants performed the exercise unshod. The extent to which shoes may influence the kinematic and kinetic results attained is unknown. Thirdly, 35% of the subject's body mass was used as the additional load, under which the freestanding heel raise exercise was performed. An increase or decrease in load could very well alter segment mechanics and produce different results. Finally, our inclusion criteria only required that subjects have resistance training experience without specifically inquiring about heel raise exercise experience. Based on our experience with persons who routinely participate in resistance training, we feel confident that the majority of our participants had prior heel raise experience. Thus although there is a chance that a few of our participants may not have had prior heel raise experience, it is important to note that sufficient practice time was given prior to data collection to allow the participants to become proficient in performing heel raise exercise in all three foot positions.

In conclusion no significant differences between the three foot positions were found in temporal events, ankle flexion-extension range of motion, or ankle extension mechanical energy expenditure thereby eliminating these variables as plausible explanations for MG and LG activation differences previously reported. The start joint angles of the ankle, knee, and hip were measured at repetition initiation but not throughout the concentric and eccentric phases. Studying segment rotations of the lower extremities, during performance of the standing heel raise, may help explain the MG and LG activation differences between internally rotated, neutral, and externally rotated foot positions.

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