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Heel Lifts and the Stance Phase of Gait in Subjects With Limited Ankle Dorsiflexion

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Context: Heel lifts are often prescribed as part of the treatment program for patients with overuse injuries associated with limited ankle dorsiflexion. However, little is known about how joint kinematics and temporal variables are affected by heel lifts.

Objective: To determine the effects of heel lifts on selected lower extremity kinematic and temporal variables during the stance phase of gait in subjects with limited ankle dorsiflexion.

Design: Two-way, fully repeated-measures design. The 2 factors were side (right or left) and walking condition (shoes alone, 6-mm heel lifts in shoes, 9-mm heel lifts in shoes).

Setting: University biomechanics laboratory.

Patients or Other Participants: Twenty-six volunteers (21 females, 5 males) with no more than 5° of ankle joint dorsiflexion.

Intervention(s): Subjects were tested in shoes alone and in shoes with 6-mm and 9-mm heel lifts.

Main Outcome Measure(s): We used the Qualisys Motion Analysis System to measure ankle dorsiflexion excursion, maximal knee extension, and time to heel off during the stance phase of gait under the 3 walking conditions.

Results: On the right side, ankle dorsiflexion excursion increased significantly with the 6-mm and 9-mm heel lifts compared with shoes alone ($P < .05$). On the left side, ankle dorsiflexion increased significantly with the 9-mm heels lifts over shoes alone and with the 9-mm heel lifts compared with the 6-mm heel lifts ($P < .05$). Time to heel off increased significantly for walking with the 9-mm heel lifts compared with shoes alone ($P < .05$). No differences were noted for maximal knee extension ($P > .05$).

Conclusions: Clinicians may consider prescribing heel lifts for patients with limited dorsiflexion range of motion if increasing ankle dorsiflexion excursion and time to heel off during the stance phase of gait may be beneficial.

Key Words: gait analysis, time to heel off, ankle dorsiflexion, knee extension

The ankle joint dorsiflexes 4° to 10° beyond neutral during the stance phase of ambulation,[1–4] with maximal dorsiflexion occurring just before heel off.[1] Normal dorsiflexion range of motion (ROM) at the ankle joint during midstance allows the tibia to advance anteriorly relative to the foot while maintaining heel contact with the ground.[3] Clinicians theorize that limited ankle joint dorsiflexion ROM predisposes individuals to lower extremity overuse injuries due to the association of limited dorsiflexion with these overuse injuries.[5–10] Clinicians may include placement of heel lifts in a patient's shoes as part of a comprehensive treatment program for patients with overuse injuries associated with limited dorsiflexion. Heel lifts are used in an attempt to alter lower extremity joint kinematics and temporal variables during weight-bearing activities to reduce stress on affected tissues. However, little is known about how joint kinematics and temporal variables are affected by heel lifts.

Limited passive ankle dorsiflexion ROM may decrease ankle dorsiflexion excursion, decrease time to heel off, and/or change the maximal amount of knee extension before heel off during gait.[11–15] Heel lifts theoretically increase ankle dorsiflexion excursion, increase time to heel off, and/or either increase or decrease the maximal amount of knee extension before heel off when ankle dorsiflexion is limited.[11,15] Increasing ankle dorsiflexion excursion and time to heel off reduces the time of weight bearing solely on the forefoot,[12–14] which may ease stress to tissues involved in some patients' conditions. Increasing ankle dorsiflexion excursion may also reduce compensatory dorsiflexion at the subtalar and midtarsal joints related to restricted dorsiflexion at the talocrural joint.[11] No data are readily available regarding the effectiveness of heel lifts in altering ankle and knee joint angles or time to heel off when ankle dorsiflexion is limited. Knowledge of gait factors affected by heel lifts may assist clinicians in identifying which patients may benefit most from this intervention. Our purpose for this study was to ascertain the effects of heel lifts on ankle dorsiflexion excursion, maximal knee extension, and time to heel off during the stance phase of gait in subjects with limited dorsiflexion. We hypothesized that heel lifts would increase ankle dorsiflexion excursion and time to heel off and change maximal knee extension.

Table 1. Subject Characteristics

Characteristic	Mean ± SD	Minimum	Maximum
Age (y)	25.23 ± 5.89	21.00	52.00
Mass (kg)	65.49 ± 9.18	48.10	81.20
Height (cm)	169.16 ± 8.38	156.21	186.69
Leg length (cm)			
Right	88.63 ± 5.65	78.00	99.00
Left	88.73 ± 5.70	78.33	99.50
Passive ankle dorsiflexion (°)			
Right	1.90 ± 1.53	−1.00	4.67
Left	0.59 ± 1.71	−4.00	3.33
Passive knee extension (°)			
Right	−0.36 ± 1.29	−3.33	3.00
Left	−0.28 ± 1.37	−4.00	2.33

METHODS

A 2-way, fully repeated-measures design guided this study. The 2 independent variables were side (right or left) and walking condition (shoes alone, 6-mm heel lifts in shoes, or 9-mm heel lifts in shoes). The 3 dependent variables were ankle dorsiflexion excursion (°), time to heel off (ms), and maximal knee extension (°).

Subjects

We used convenience sampling to enroll 26 subjects (21 females, 5 males) from the metropolitan Atlanta, GA area. Subjects were recruited by posted flyers and by e-mails to individuals known to the investigators. Eligibility criteria for inclusion in the study were (1) no more than 5° of passive ankle dorsiflexion ROM bilaterally; (2) no less than 0° of subtalar joint eversion passive ROM bilaterally; (3) no more than 5° of knee flexion contracture bilaterally; 4) age between 18 and 55 years; (5) no pain while walking with shoes on; (6) no history of neurologic dysfunction or disease, systemic disease affecting the lower extremities or ambulation, macrotrauma involving bone or nerve injury to the lower extremity, or musculoskeletal soft tissue injury to the lower extremity within the past 6 months; (7) owning a pair of athletic shoes; (8) leg length discrepancy less than 2 cm; and (9) ability to perform a one-half squat such that the knees flexed to approximately 90°. Limited passive ankle dorsiflexion ROM with the knee extended 5° or less in a non–weight-bearing position was chosen because it was below the 10° to 20° that has been reported as normal.[16,17] Subject characteristics are summarized in Table 1. Before participating, each subject signed an informed consent form approved by our university's institutional review board, which also approved the study.

Instrumentation

Ankle dorsiflexion excursion, maximal knee extension, and time to heel off during the stance phase of gait were measured using the Qualisys Motion Analysis System (Qualisys, Inc, Gothenburg, Sweden) and custom software. We used the Qualisys Motion Analysis System to establish a 3-dimensional (3-D) coordinate system, track markers, and calculate time to heel off. Three cameras (charge-coupled devices) positioned along one side of a walkway were set at a recording frequency of 100 Hz. Custom software in LabVIEW (National Instruments Corp, Austin, TX) and MATLAB (The MathWorks, Natick, MA) was used to smooth and plot the data and calculate 2-dimensional (2-D) ankle and knee joint angles.

Passive ankle dorsiflexion ROM and knee extension ROM were measured using a goniometer. Leg length was measured with a tape measure.

Procedures

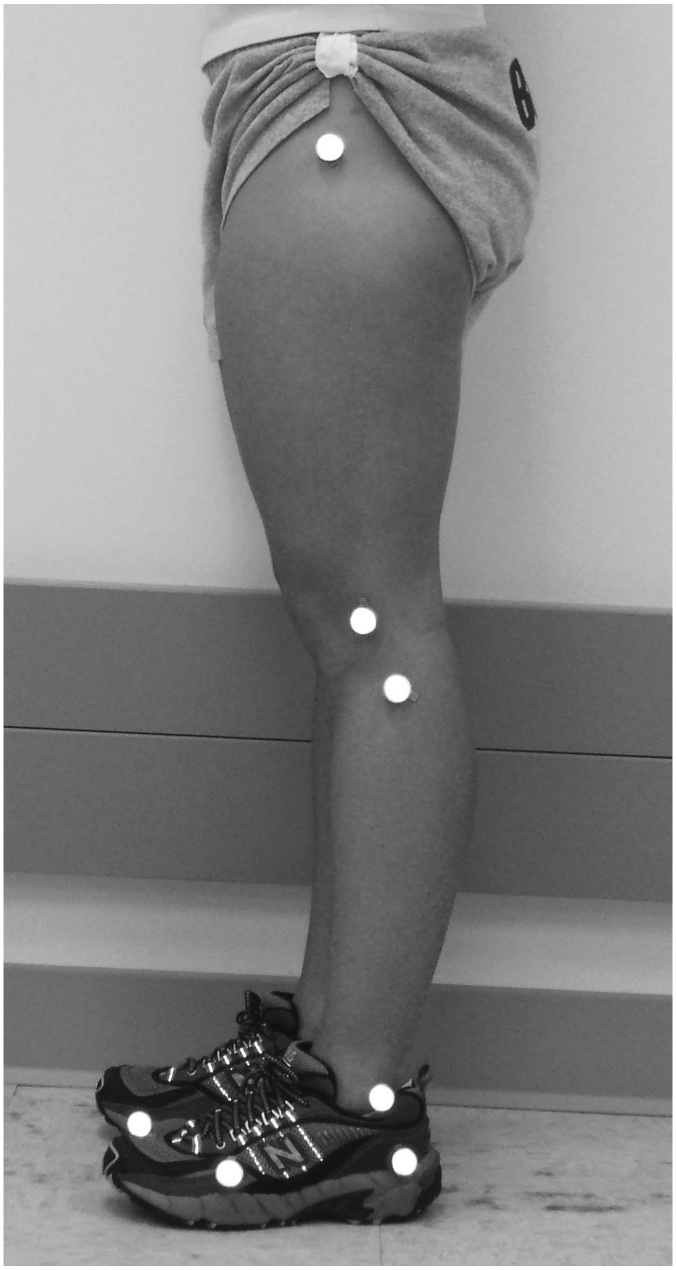
At the start of a data collection session, we calibrated the Qualisys Motion Analysis System with known distances between reflective markers on a wand and L-shaped bar to establish the 3-D coordinate system for 3 cameras. Calibration was accepted if the standard deviation of wand length was less than 2.0 mm and range of wand length was less than 5.0 mm.[18] All walking trials were recorded with the 3 cameras set at a frequency of 100 Hz.

Passive ankle dorsiflexion ROM was measured with the subject lying prone and the knee extended. One of the investigators maintained the subtalar joint in anatomical zero as determined with a goniometer by the angle formed by the midlines of the posterior calf and posterior calcaneus. Another investigator measured ankle dorsiflexion ROM by passively moving the ankle into dorsiflexion; applying force over the plantar aspect of the subject's midfoot and forefoot; and placing the axis of a standard 20.32-cm goniometer over the lateral calcaneus, aligning the stationary arm with the fibular head and aligning the moving arm along the midline of the fifth metatarsal.

Knee extension passive ROM was measured using standard goniometric procedures[17] with the subject positioned supine. A towel roll was placed under the subject's heel to allow the lower extremity to relax into maximal knee extension passive ROM. A second investigator measured passive ankle and knee ROM on every fourth subject to assess interrater reliability.

The subject's weight and height were measured, and each subject was then screened for leg length discrepancy and the ability to perform a partial squat to 90°. The latter request was to ensure that strength of the lower extremity musculature was adequate for ambulation without major gait deviations. Leg length was measured with the subject lying supine on a plinth with the hips and knees extended bilaterally. Using a tape measure, an investigator measured the subject's leg length from the most inferior portion of the anterior superior iliac spine to the most prominent aspect of the ipsilateral lateral malleolus.

We randomly assigned subjects to the order of side tested and then to the sequence of walking conditions. Next, the reflective areas of the subject's shoes were covered with athletic tape. An investigator applied markers to the subject's randomly determined right or left lower extremity over the (1) greater trochanter, (2) lateral femoral epicondyle, (3) fibular head, (4) lateral malleolus, (5) shoe overlying the lateral aspect of the calcaneus, (6) shoe overlying the lateral aspect of the fifth metatarsal head, and (7) shoe overlying the dorsal aspect of the distal end of the great toe (Figure). All marker locations were outlined with a pen to ensure consistent repositioning if any markers were displaced during the walking trials. Based on the predetermined randomization of conditions, the subject ambulated while (1) walking in his or her own athletic shoes, (2) walking with 6-mm heel lifts in his or her shoes, and (3) walking with 9-mm heel lifts in his or her shoes. The subject was asked to walk across an elevated walkway at a self-selected speed until he or she reported feeling comfortable and



Marker placement for ankle and knee joint angles measurements during gait.

appeared comfortable to the investigators. The subject then walked the length of the walkway until 8 trials per side for all walking conditions were recorded. After 8 trials were recorded, we removed the subject's shoes and inserted or removed heel lifts based on the randomly determined subsequent condition. Before recording each condition, the subject repeated warm-up walking trials.

The marker paths were then tracked in PCReflex software (version 1.2b; Qualisys) and any missing data in the marker paths of 30 frames or less were interpolated by the software. Graphic representations of the raw data for all markers' paths and any interpolated data were inspected carefully for artifacts and improper interpolation of data. Heel strike was defined as the first frame in which the lateral calcaneus marker ceased to move forward. Heel off was defined as the first frame in which the lateral calcaneus marker began to move upward. Toe off was defined as the first frame in which the great toe marker began to move forward at the end of the stance phase of gait.

Time to heel off (in milliseconds) was calculated by subtracting the frame number at heel strike from the frame number at heel off. The Qualisys tracking software generates the timing data based on a known recording frequency of 100 Hz; therefore, the time between frames was 10 ms. A second investigator measured time to heel off on every fourth subject to assess interrater reliability. The data were then exported, and custom software in LabVIEW smoothed the marker paths, retaining 97% of the signal energy. Custom software was used to plot YZ-plane (sagittal) marker displacements representing ankle and knee joint angles from the smoothed coordinate data. Another software program (MATLAB) was used to plot sagittal-plane ankle angles and calculate ankle dorsiflexion excursion between foot flat and heel off. Ankle dorsiflexion excursion was calculated by determining the minimal and maximal angles formed by markers placed on the fibular head, on the shoe over the lateral calcaneus, and on the shoe over the fifth metatarsal head between foot flat and heel off (see Figure).

We measured ankle dorsiflexion excursion rather than absolute values of dorsiflexion (at foot flat and heel off) for 2 reasons. First, the angle formed between the markers used for the measurement was expected to change at any one point in stance when heel lifts were inserted into the shoes (due to a change in the orientation of the tibia relative to the shoe, a change in the relationship of the sole of the shoe and the sole of the foot, or both). We expected any changes in the orientation of the tibia relative to the shoe or the relationship of the sole of the shoe and sole of the foot to be consistent during stance within each condition. Second, we expected that ankle dorsiflexion excursion and not the absolute maximum dorsiflexion value would increase.

MATLAB was also used to plot sagittal-plane knee angle data and calculate maximal knee extension between foot flat and heel off about the X axis in the sagittal plane. Maximal knee extension between foot flat and heel off was calculated using the angle formed by the markers placed on the greater trochanter, the lateral femoral epicondyle, and the lateral malleolus (see Figure). The first 4 trials successfully tracked in PCReflex from 10 frames before heel strike through 10 frames after toe off for each subject were used in the data analysis. Intrarater reliability for ankle dorsiflexion excursion, maximal knee extension, and time to heel off during the stance phase of gait was determined by analyzing these 4 trials on every subject.

Statistical Analysis

We analyzed the data using SPSS (version 12.0; SPSS Inc, Chicago, IL) statistical software. Intrarater reliability for passive ankle dorsiflexion ROM, passive knee extension ROM, leg length, ankle dorsiflexion excursion, maximal knee extension, and time to heel off was assessed using type (3,k) intraclass correlation coefficients (ICCs).[19] Interrater reliability was also determined for passive ankle dorsiflexion ROM, passive knee extension ROM, and time to heel off using type (2,k) ICCs.[19]

Normality of distribution and homogeneity of variance for ankle dorsiflexion excursion, maximal knee extension, and time to heel off during the stance phase of gait were assessed with the Shapiro-Wilk and Mauchly tests of sphericity, re-

Table 2. Ankle Dorsiflexion Excursion, Maximal Knee Extension, and Time-to-Heel-Off Values

Variable	Mean ± SD	Minimum	Maximum	ICC (3,k) ± SEM*	ICC (2,k) ± SEM*
Ankle dorsiflexion excursion (°)					
Shoes alone†					
Right	17.95 ± 3.41	10.89	24.22	.95 ± 0.67	
Left	18.80 ± 4.17	10.02	26.11	.96 ± 0.82	
6-mm heel lifts					
Right‡	19.06 ± 3.37	12.68	25.62	.95 ± 0.66	
Left	19.06 ± 4.78	7.60	27.46	.97 ± 0.94	
9-mm heel lifts					
Right§	19.10 ± 3.59	11.87	25.18	.97 ± 0.70	
Left	20.12 ± 4.18	12.25	30.23	.97 ± 0.82	
Maximal knee extension (°)					
Shoes alone†					
Right	173.28 ± 5.26	165.08	184.38	.98 ± 1.03	
Left	174.89 ± 5.85	156.11	187.88	.98 ± 1.15	
6-mm heel lifts‡					
Right	173.37 ± 5.66	164.30	185.46	.98 ± 1.11	
Left	174.82 ± 5.88	156.55	186.73	.98 ± 1.15	
9-mm heel lifts§					
Right	173.25 ± 5.48	165.46	186.09	.98 ± 1.07	
Left	174.77 ± 5.87	156.44	186.30	.98 ± 1.15	
Time to heel off (ms)					
Shoes alone†					
Right	393.37 ± 63.64	225	495	.95 ± 12.48	.98 ± 29.34
Left	405.67 ± 63.36	290	548	.96 ± 12.43	.99 ± 22.44
6-mm heel lifts‡					
Right	406.15 ± 60.21	273	520	.97 ± 11.81	.99 ± 31.03
Left	405.77 ± 66.94	243	528	.97 ± 13.13	.90 ± 19.12
9-mm heel lifts§					
Right	407.31 ± 62.67	250	518	.96 ± 12.29	.98 ± 29.49
Left	422.02 ± 63.91	278	543	.95 ± 12.53	.99 ± 27.61

*ICC indicates intraclass correlation coefficients.
†Shoes alone indicates walking in subject's own shoes.
‡6-mm heel lifts indicates walking in shoes with 6-mm heel lifts.
§9-mm heel lifts indicates walking in shoes with 9-mm heel lifts.

spectively, to determine the validity of using parametric statistical tests. The relationships between walking conditions and side for each of the 3 dependent variables (ankle dorsiflexion excursion, maximal knee extension, and time to heel off) were tested with a 2-way repeated-measures analysis of variance (ANOVA). For significant main effects, we performed post hoc tests using a Bonferroni correction to determine which pairwise comparisons were different. For significant interactions, simple main effects testing was used to determine where significant differences of side by condition occurred. The level of significance for all statistical tests was set at $P < .05$.

RESULTS

Reliability for passive ankle dorsiflexion ROM, passive knee extension ROM, leg length, and time-to-heel-off measurements determined by ICCs ranged from 0.90 to 0.99 for both intrarater and interrater reliability. Intrarater reliability for ankle dorsiflexion excursion and maximal knee extension determined by ICCs ranged from 0.95 to 0.98 (Table 2).

Descriptive statistics for dependent variables for each walking condition during the stance phase of gait are also presented in Table 2. The Shapiro-Wilk test was not significant for any dependent variables except maximal knee extension on the left side for one walking condition. The Mauchly test of sphericity was not significant for any of the 3 dependent variables. Therefore, we used the planned parametric tests.

The 2-way repeated-measures ANOVA showed a significant side-by-walking condition interaction for ankle dorsiflexion excursion ($F_{2,50} = 3.31$, $P = .045$) and a significant main effect for condition ($F_{2,50} = 14.93$, $P < .0001$). No significant main effect was noted for side ($F_{1,25} = 1.34$, $P > .05$). Simple main effects testing of the significant side-by-condition interaction showed no significant differences for ankle dorsiflexion excursion between the right and left sides walking with shoes alone ($F_{1,25} = 2.31$, $P > .05$), walking with 6-mm heel lifts in shoes ($F_{1,25} = 0.00$, $P > .05$), or walking with 9-mm heel lifts in shoes ($F_{1,25} = 2.89$, $P > .05$). On the right side, significant increases were seen in ankle dorsiflexion excursion walking with 6-mm heel lifts in shoes compared with shoes alone ($F_{1,25} = 25.28$, $P < .0001$) and 9-mm heel lifts in shoes compared with shoes alone ($F_{1,25} = 17.79$, $P < .0001$), but no increase was demonstrated for walking with 9-mm heel lifts in shoes compared with 6-mm heel lifts in shoes ($F_{1,25} = 0.03$, $P > .05$). On the left side, significant increases were noted in ankle dorsiflexion excursion walking with 9-mm heel lifts in shoes compared with shoes alone ($F_{1,25}$ = 12.12, P = .002) and walking with 9-mm heel lifts in shoes compared with 6-mm heel lifts in shoes ($F_{1,25}$ = 16.23, $P < .0001$), but no significant increase was seen for walking with 6-mm heel lifts in shoes compared with shoes alone ($F_{1,25}$ = 0.37, $P > .05$).

The 2-way repeated-measures ANOVA showed a significant main effect of walking condition for time to heel off ($F_{2,50}$ = 7.56, P = .001) but no significant effect of side ($F_{1,25}$ = 2.30, $P > .05$) and no significant side-by-condition interaction ($F_{2,50}$ = 2.33, $P > .05$). Post hoc tests using a Bonferroni correction revealed significant increases in time to heel off for walking with 9-mm heel lifts compared with walking in shoes alone (P = .003) but no increases when walking with 9-mm heel lifts compared with walking with 6-mm heel lifts or when walking with 6-mm heel lifts compared with walking in shoes alone ($P > .05$).

Maximal knee extension showed no significant differences for condition-by-side interaction ($F_{2,50}$ = 0.06, $P > .05$), walking condition ($F_{2,50}$ = 0.13, $P > .05$), or side ($F_{1,25}$ = 2.03, $P > .05$) in the 2-way repeated-measures ANOVA.

DISCUSSION

In this sample, heel lifts increased ankle dorsiflexion excursion and time to heel off but did not affect maximal knee extension during the stance phase of gait. Walking with 9-mm heel lifts resulted in the greatest increase in ankle dorsiflexion excursion compared with walking in shoes alone. In contrast to walking in shoes alone, the addition of 9-mm heel lifts resulted in an average increase of 1.23° in ankle dorsiflexion excursion during stance, whereas the 6-mm heel lifts resulted in an average increase of 0.68°. It is possible that heel lifts position the ankle in more plantar flexion at foot flat, which may allow greater ankle dorsiflexion excursion between foot flat and heel off. Our marker system was not likely to generate meaningful absolute values of ankle dorsiflexion at foot flat and heel off due to changes in the orientation of the tibia relative to the shoe or a change in the sole of the foot relative to the sole of the shoe when inserting heel lifts as described in the Methods section. Future researchers should measure absolute dorsiflexion at foot flat and heel off to substantiate the speculation that heel lifts position the ankle joint in a more plantar-flexed position at foot flat during gait.

Although statistically significant, the increases in ankle dorsiflexion excursion and time to heel off during the stance phase of gait between walking conditions were small. The effect sizes[20] for the statistically significant increases in ankle dorsiflexion excursion and time to heel off were 0.22 and 0.20, respectively. These observed effect sizes are between small (0.10) and medium (0.25).[20] Although speculative, the addition of approximately 1° of ankle dorsiflexion excursion across a repetitious activity, such as gait, may represent a clinically significant reduction of stress to structures within the ankle joint and adjacent joints. Limited ankle joint dorsiflexion has been associated with many overuse injuries of the lower extremity, including plantar fasciitis,[7,8,21] Achilles tendinitis,[6,8] shin splints,[5,10] iliotibial band syndrome,[5] and patellofemoral pain syndrome.[22] Stretching exercises to increase ankle dorsiflexion ROM are likely the best long-term treatment approach. However, knowledge regarding the variables of gait affected by heel lifts in individuals with limited dorsiflexion may cue clinicians to the patient populations most likely to benefit from heel lifts (either for treatment of an existing problem or prevention of injury) before stretching exercises or other interventions have effectively increased ankle dorsiflexion ROM.

We chose to insert heel lifts in shoes to simulate the clinical use of heel lifts rather than securing heel lifts to the subject's bare feet. The subjects may have ambulated in an atypical manner due to different sensory input from heel lifts in shoes. Also, athletic shoes have a heel wedge built into the shoe, so heel lifts in shoes may affect gait differently than heel lifts secured to bare feet. Future researchers should focus on the effects of heel lifts on symptoms in specific patient populations with limited ankle dorsiflexion.

The right and left sides exhibited differences between walking conditions for ankle dorsiflexion excursion. When walking in 6-mm heel lifts compared with shoes alone, the right side increased more in ankle dorsiflexion excursion than the left side (1.11° on the right versus 0.26° on the left). Because the subjects, on average, exhibited fewer degrees of ankle dorsiflexion excursion on the right side when walking in shoes alone, the smaller heel lift may have been more likely to produce an increase in ankle dorsiflexion excursion on that side. In contrast, the left side demonstrated a greater increase in ankle dorsiflexion excursion when subjects walked with 9-mm heel lifts versus 6-mm heel lifts than the right side (1.06° on the left versus 0.04° on the right). Because the left side exhibited more ankle dorsiflexion excursion while subjects walked in shoes alone, the left side may have required a higher heel lift to produce an increase in ankle dorsiflexion excursion than the right side.

It is also possible that subjects in our sample pronated more on the left than the right, with more dorsiflexion occurring as a component of pronation at the subtalar and midtarsal joints that contributed to the greater ankle dorsiflexion excursion on the left side. Our measurement techniques controlled subtalar and midtarsal joint pronation during the goniometric measurements of dorsiflexion but not during gait. Therefore, if our subjects pronated more on the left than the right during stance, the result may have been more ankle dorsiflexion excursion on the left side, even though the left ankle exhibited less passive dorsiflexion ROM when measured with a goniometer. Future authors who measure frontal-plane and transverse-plane kinematics, in addition to sagittal-plane kinematics during gait, could determine if asymmetric findings in ankle dorsiflexion excursion relate to asymmetric pronation.

As expected, walking in 9-mm heel lifts resulted in the greatest increase in time to heel off (15.14 milliseconds) compared with walking in shoes alone. Although the mean time to heel off was greater while walking in 6-mm heel lifts versus shoes alone and walking in 9-mm versus 6-mm heel lifts, these increases were not statistically significant. Based on these results, when a clinician suspects that early heel rise is contributing to a patient's overuse injury, 9-mm heel lifts may be a more effective intervention than 6-mm heel lifts. Early heel rise may contribute to a patient's symptoms due to the increased portion of stance spent weight bearing on the forefoot. More time weight bearing on the forefoot may increase stress to structures involved in some patients' conditions, including the plantar fascia, tibialis posterior muscle, and metatarsal heads.

Cornwall and McPoil[13] reported significantly decreased time to heel off in subjects with limited passive ankle dorsiflexion ROM ($<10°$) than in subjects with normal passive ankle dorsiflexion ROM ($>15°$). Because of the expected correlation between ankle dorsiflexion excursion and time to heel off, increasing ankle dorsiflexion excursion would be expected to increase time to heel off during the stance phase of gait. Thus, one would expect that the same heel lift conditions would be significant for both variables. Although the changes in mean values supported this expectation, ankle dorsiflexion excursion significantly increased with walking in 6-mm heel lifts compared with shoes alone on the right side and with walking in 9-mm versus 6-mm heel lifts on the left side, whereas overall, time to heel off did not increase. The correlations between ankle dorsiflexion excursion and time to heel off during the 3 different walking conditions on the right and left sides in this study ranged from $r = 0.53$ to $r = 0.62$. These correlations might have been higher if we had measured time to heel off as a percentage of stance time rather than in milliseconds. Use of a self-selected walking speed may account for some variation between ankle dorsiflexion excursion and time to heel off because faster walking speeds would be expected to increase ankle dorsiflexion excursion[23] but decrease time to heel off measured in milliseconds. Measuring time to heel off as a percentage of stance would mitigate any differences based on the speed of gait. Future authors who examine the degree of correlation between ankle dorsiflexion excursion and time to heel off (measured as a percentage of stance) for both normal subjects and subjects with limited dorsiflexion may shed light on any different effects of 6-mm heel lifts on ankle dorsiflexion excursion versus time to heel off.

No significant change was noted in maximal knee extension during the stance phase of gait between walking conditions. Subotnick[12] theorized that increased extension of the knee due to a short gastrocnemius-soleus muscle complex may allow an individual with a limited amount of dorsiflexion to maintain the heel on the ground longer during the stance phase of gait by allowing continued forward progression of the body over the foot while the heel remains on the ground. Conversely, Clement et al[9] surmised that some patients with decreased gastrocnemius muscle flexibility might compensate by decreasing knee extension to reduce strain on the Achilles tendon during running. Decreased knee extension potentially reduces tension within the gastrocnemius muscle, thereby allowing more dorsiflexion at the ankle joint. Perhaps a heel lift height greater than 9 mm would significantly affect the more proximal knee joint. However, in this sample, the effect of heel lifts appeared to be confined primarily to joints distal to the knee.

Limitations of this study include the placement of markers on the subjects' shoes rather than on the subjects' skin, because movements of the shoe may not precisely represent movements of the foot and ankle. This limitation could account for the differences between right and left sides among walking conditions for ankle dorsiflexion excursion and decrease the overall precision of ankle dorsiflexion excursion and time-to-heel-off measurements. Use of a self-selected walking speed could also have affected the findings in this study, because increased speed of gait would be expected to result in an increase in ankle dorsiflexion excursion but a decrease in time to heel off. Given the small mean differences in ankle dorsiflexion excursion and time to heel off among walking conditions and the error associated with calculating 2-D joint angles based on 3-D data, the significant differences could have resulted from random error in the data. The study of asymptomatic subjects presents additional limitations because the effect of the increases in ankle dorsiflexion excursion and time to heel off while ambulating with heel lifts on the resolution of symptoms in a patient population cannot be determined.

Clinical Relevance

In addition to ascertaining the effect of heel lifts on patients' symptoms related to specific conditions, it is important for clinicians to gain an understanding of the mechanism(s) by which heel lifts have an effect. Gaining an understanding of the mechanism by which a treatment has an effect can lead to additional clinical applications for that treatment. Based on these findings, heel lifts may be a treatment option when clinicians deem that increasing ankle joint excursion or increasing time to heel off might reduce a patient's symptoms during walking, even though heel lifts may not have been previously considered or commonly used for that patient's specific condition.

CONCLUSIONS

Our study demonstrated that heel lifts increase ankle dorsiflexion excursion and time to heel off during ambulation in subjects with passive limited dorsiflexion ROM. The temporary use of heel lifts may be an intervention to consider when clinicians believe increases in ankle dorsiflexion excursion and time to heel off may be beneficial for patients with limited ankle dorsiflexion ROM.

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