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original research

Ankle Dorsiflexion Among Healthy Men With Different Qualities of Lower Extremity Movement

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Context: Lower extremity movement patterns have been implicated as a risk factor for various knee disorders. Ankle-dorsiflexion (DF) range of motion (ROM) has previously been associated with a faulty movement pattern among healthy female participants.

Objective: To determine the association between ankle DF ROM and the quality of lower extremity movement during the lateral step-down test among healthy male participants.

Design: Cross-sectional study.

Setting: Training facility of the Israel Defense Forces.

Patients or Other Participants: Fifty-five healthy male Israeli military recruits (age = 19.7 ± 1.1 years, height = 175.4 ± 6.4 cm, mass = 72.0 ± 7.6 kg).

Intervention(s): Dorsiflexion ROM was measured in weight-bearing and non–weight-bearing conditions using a fluid-filled inclinometer and a universal goniometer, respectively. Lower extremity movement pattern was assessed visually using the lateral step-down test and classified categorically as good or moderate. All measurements were performed bilaterally.

Main Outcome Measure(s): Weight-bearing and non–weight-bearing DF ROM were more limited among participants with moderate quality of movement than in those with good quality of movement on the dominant side ($P = .01$ and $P = .02$ for weight-bearing and non–weight-bearing DF, respectively). Non–weight-bearing DF demonstrated a trend toward a decreased range among participants with moderate compared with participants with good quality of movement on the nondominant side ($P = .03$ [adjusted $P = .025$]). Weight-bearing DF was not different between participants with good and moderate movement patterns on the nondominant side ($P = .10$). Weight-bearing and non–weight-bearing ankle DF ROM correlated significantly with the quality of movement on both sides ($P < .01$ and $P < .05$ on the dominant and nondominant side, respectively).

Conclusions: Ankle DF ROM was associated with quality of movement among healthy male participants. The association seemed weaker in males than in females.

Key Words: anterior cruciate ligament, hip, knee, lateral step-down test, patellofemoral pain syndrome

Key Points

- Healthy males with a moderate quality of movement on the lateral step-down test exhibited less ankle-dorsiflexion range of motion than those with a good quality of movement.
- When a lower quality of movement is present in males, clinicians should consider interventions to increase ankle dorsiflexion.

An altered lower extremity movement pattern, consisting of excessive femoral adduction and internal rotation leading to excessive knee valgus alignment, has been implicated as a risk factor for patellofemoral pain syndrome (PFPS) and noncontact anterior cruciate ligament injuries.[1–3] Various factors have been suggested to contribute to an altered movement pattern, including decreased strength of the ipsilateral hip musculature,[4,5] increased subtalar joint pronation,[6,7] and altered motor control.[8] Assessment of movement pattern and the factors associated with it is therefore commonly performed in the evaluation of patients with PFPS, as well as in screening for the risk of knee injury.[9–11]

Another possible contributor to an altered movement pattern is the available ipsilateral ankle-dorsiflexion (DF) range of motion (ROM). Decreased ankle DF ROM can limit the forward progression of the tibia over the talus during activities that require simultaneous knee flexion and ankle DF (eg, squatting, stair descent). A possible compensation for the limited motion of the tibia could be subtalar pronation, which may shift the tibia and the knee medially into greater valgus alignment.[6,12–14] Some evidence already exists for the association between ankle DF and the lower extremity movement pattern. Decreased DF has been previously associated with increased knee valgus during a drop-land maneuver,[14] a squat,[15] and a step-down maneuver[16] among healthy participants.

One limitation of the current literature regarding this topic is the inclusion of only female participants in many of the studies evaluating lower extremity movement patterns and the associated factors.[4,6,14,16–18] This is likely because of sex differences in kinematics, kinetics, and muscle-activation patterns during various functional activities.[8,19,20] Women have been shown to perform activities such as cutting, jumping, and landing with greater knee valgus alignment and greater knee extension than men.[19,20] These differences are hypothesized to account for the greater incidence of noncontact anterior cruciate ligament tears and PFPS among women.[1,2,21,22] Accordingly, authors[14,16] of the 2 studies that have previously linked decreased ankle DF with a faulty movement pattern included only female participants as well. A third study of a mixed population demonstrated only a statistical trend for the association between ankle DF and a faulty movement pattern.[15] It is therefore unclear whether the association between ankle DF and lower extremity movement pattern is similar for both sexes.

Paradoxically, another limitation of the current literature is the use of sophisticated 3-D motion-analysis systems in many of the studies evaluating lower extremity movement patterns.[2,4,14,17,18] Although this type of analysis certainly contributes to a high level of precision and reliability, clinicians and coaches typically do not have the access, time, or skill to operate such systems. Instead, visual observation is often relied on to assess movement patterns in the clinic or on the field. It is unknown, however, to what extent any movement deviations identified during 3-D motion analyses correlate with movement deviations identified visually. Consequently, the findings from 3-D motion analyses studies may be difficult to apply in the clinical setting or on the field. We therefore decided to assess whether ankle DF ROM is related to the quality of lower extremity movement as assessed visually among healthy male participants.

The lateral step-down (LSD) test is frequently used to assess movement patterns of the lower extremity.[9,11,23–25] Piva et al[25] suggested a visually based rating system for classifying the quality of movement during the LSD test. The reliability of this rating system has been established previously.[16,25] Our hypothesis was that male participants with a lower quality of movement on the LSD would exhibit less ankle DF ROM.

METHODS

This study was approved by the Institutional Review Board of the Israel Defense Forces. All participants read and signed an informed consent form before beginning the study procedures. Data for this study were collected within the framework of a larger prospective investigation into potential risk factors for various injuries during army basic training.

Participants

We studied 55 males. Their age, height, and body mass were 19.7 ± 1.1 years, 175.4 ± 6.4 cm, and 72.0 ± 7.6 kg, respectively. Participants were military recruits who were thoroughly screened for any musculoskeletal injury or condition before beginning army basic training. Participants were included in the study if they were 18 years or older and without any current complaint of pain in the lower extremities or lumbar spine. Volunteers were excluded from participation if they reported any knee or ankle pain or injury in the 2 years before the study. This information was self-reported and subsequently verified by a research assistant before the study began.

Examiners

Two examiners performed data collection for this investigation. One examiner (A.R.), with 13 years of clinical experience in the physical therapy management of musculoskeletal conditions, performed all DF ROM measurements. The other examiner (Z.K.), with more than 25 years of teaching and clinical experience in the field of kinesiology and neurologic rehabilitation, performed all LSD assessments. These 2 examiners had previously demonstrated a moderate level of interrater reliability when performing the LSD test ($\kappa = 0.59$), and an excellent level of reliability when performing the weight-bearing (WB) and non–weight-bearing (NWB) ankle DF ROM measurements (intraclass correlation coefficient = 0.95 and 0.86 for the WB and NWB measures, respectively).[16] Before collecting data for this study, the 2 examiners met for a 4-hour session to review each of the measurement procedures.

Procedures

First, demographic information including age, height, body mass, and leg dominance was collected. The *dominant leg* was defined as the leg preferred for kicking a ball. Next, each participant's anterior tibia was marked 15 cm distal to the tibial tuberosity in black. This mark was later used to measure WB ankle DF. Each examiner was blinded to the measurements of the other examiner in order to avoid the possible introduction of bias based on the study's hypothesis. Participants moved from 1 data-collection station to the next based on the availability of the examiner at each station (ie, LSD and ankle DF). Therefore, the order of the measurements was neither set nor randomized.

Lateral Step-Down Test. The tibial tuberosity of each participant was marked with a 1-cm blue sticker to facilitate its visualization during the test. The testing procedure was orally explained to each participant and followed by a demonstration. The side tested first was alternated between consecutive participants. Participants performed the test on a 15-cm step (Reebok International, Canton, MA). They placed the tested leg by the edge of the step, with the other leg hanging down off the side of the step. Participants were instructed to keep the trunk straight and hands on the waist and to bend the knee of the tested leg until the contralateral heel touched the floor next to the step. They were asked not to put any weight on the contralateral heel once it reached the floor and to immediately re-extend the knee and return to the starting position. Participants were also asked to try to maintain the knee of the tested leg over the second toe of the ipsilateral foot during the test (a piece of black tape was placed perpendicular along the front of the step from just under the participant's second toe to the floor to facilitate the examiner's assessment; Figure 1). Participants performed 5 practice repetitions followed by 5 consecutive test repetitions. The examiner was positioned 3 m in front of the participant during the test. The test was scored on a 7-point scale (0–6) according to the criteria outlined by Piva et al[25] (Table 1). If any 1 of the movement deviations outlined in Table 1 was detected during any of the 5 test repetitions, the participant was considered to demonstrate this deviation, and the corresponding point value (1 or 2) was assigned. A total score of 0 or 1 was classified as *good* quality of movement (Figure 1), a total score of 2 or 3 was classified as *moderate* quality of movement (Figure 2), and a total score of 4 or more was classified as *poor* quality of movement.[25] Only 3

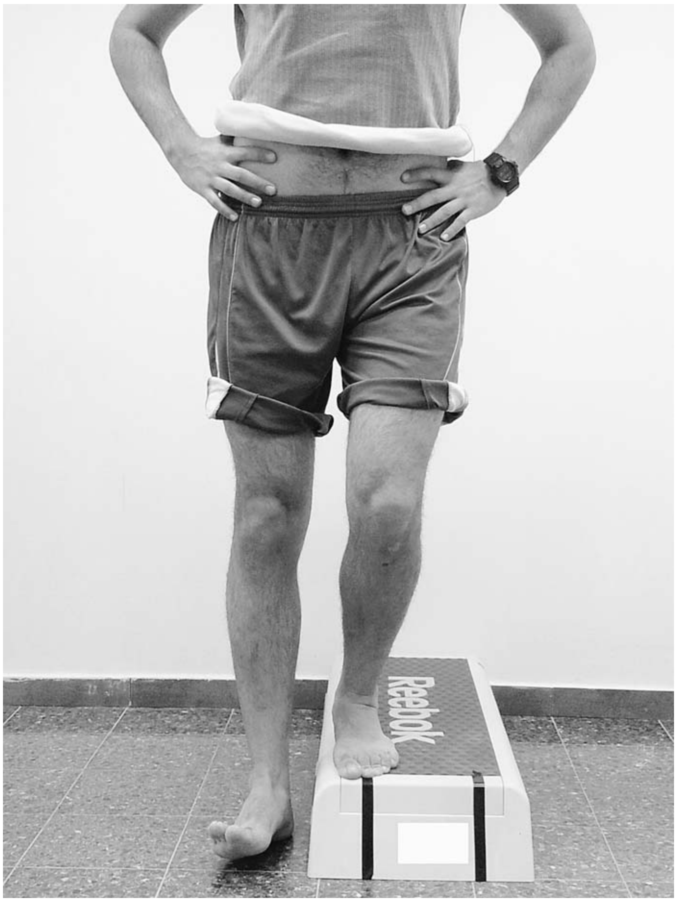

Figure 1. Good-quality movement pattern on the lateral step-down test.

Figure 2. Moderate-quality movement pattern on the lateral step-down test.

participants were classified as having a poor quality of movement (2 on the dominant-side LSD and 1 on the nondominant side), so we did not include their data in the primary statistical analysis.

Ankle DF ROM. Ankle DF was measured in WB and NWB conditions. For both DF measurements, the side tested first, as well as the order of the measurement (WB or NWB), was alternated between consecutive participants. For the WB measurement, a 50-cm-long line was marked on the floor and a continuous 60-cm-long line was marked on a wall where the test was to be performed. The participant placed the tested foot along the floor line so that the line bisected the heel and the second toe was on the line. He was then asked to lunge forward and bring his patella as close as possible to the vertical line drawn on the wall without lifting the heel off the floor. Once maximal DF was reached, the examiner placed an inclinometer (MIE Inclinometer; Nationwide Medical, Inc, Agoura Hills, CA), which was first zeroed on a fixed vertical reference, over the previously marked spot on the anterior tibia. The DF angle was recorded and the participant returned to the starting position. The procedure was repeated 3 times and the average range was recorded.

For the NWB measurement, the participant assumed a prone lying position with the knee bent to 90°. The measurement was taken using a universal goniometer (Baseline Plastic Goniometer; The Therapy Connection Inc, Windham, NH). The examiner manually verified a subtalar neutral position and placed the ankle in full DF. *Dorsiflexion* was measured as the angle between the lateral midline of the lower leg (a line from the head of the fibula to the tip of the lateral malleolus) and the lateral border of the foot (a line along the rearfoot and calcaneus). The average of 3 measurements was recorded.

Table 1. Scoring Criteria for the Lateral Step-Down Test

Criterion	Interpretation	Score
Arm strategy	Removal of a hand from the waist	1
Trunk alignment	Leaning in any direction	1
Pelvis plane	Loss of horizontal plane	1
Knee position	Tibial tuberosity medial to second toe	1
	Tibial tuberosity medial to medial border of foot	2
Steady stance	Participant stepped down on untested limb or the foot wavered from side to side	1

Table 2. Participants' Descriptive Statistics (N = 55)

Variable	Mean ± SD	Range
Age, y	19.7 ± 1.1	18.1–24.6
Height, cm	175.4 ± 6.4	159.0–189.0
Body mass, kg	72.0 ± 7.6	60.3–96.4
Dominant-side weight-bearing dorsiflexion, °	50.9 ± 6.3	35.3–66.0
Nondominant-side weight-bearing dorsiflexion, °	57.3 ± 7.0	40.0–72.0
Dominant-side non–weight-bearing dorsiflexion, °	27.8 ± 6.2	12.3–40.3
Nondominant-side non–weight-bearing dorsiflexion, °	27.9 ± 6.2	10.0–40.7

Statistical Analysis

We conducted separate analyses for the dominant and nondominant sides. Within each side, participants were divided into 2 groups based on their LSD score (good or moderate). Differences in demographic variables, as well as in WB and NWB ankle DF ROM between the groups, were analyzed with an independent *t* test. Because we assessed the dependent variable (ankle DF) in 2 ways (WB and NWB), we used a Bonferroni adjusted *P* value of .025 (.05/2) for analysis. Effect sizes (ESs) for the differences in DF ROM between participants with different qualities of movement on either side were calculated by dividing the difference in the mean scores by their pooled standard deviation. An ES of 0.2 is considered *small*; 0.5, *medium*; and 0.8 or more, *large*.[26] The 3 participants who exhibited poor quality of movement were excluded from this analysis.

As the classification of the quality of movement into good and moderate levels is somewhat arbitrary, we also analyzed the correlation between the raw score of the LSD test (0–6) and the WB and NWB ankle DF ROM with a Spearman rank correlation coefficient (*r*). Correlations were assessed separately for the dominant and nondominant sides. All participants were included in this analysis. The predetermined level of significance (*P* value) for this analysis was set at $< .05$. All statistical analyses were performed using SPSS (version 19; IBM SPSS Inc, Chicago, IL).

RESULTS

We screened 73 participants for eligibility. Ten participants had experienced an ankle sprain and 8 additional participants reported anterior knee pain in the 2 years preceding the study. These participants were therefore excluded. This resulted in 55 participants included in the analysis. Fifty-one (93%) reported the right leg as dominant, whereas 4 reported the left leg as dominant. The main demographic and clinical variables of the entire sample are summarized in Table 2.

Weight-bearing and NWB DF ROM of participants with different qualities of movement on either side (dominant and nondominant) are displayed in Table 3. On the dominant side, 33 participants displayed good quality of movement, and 20 displayed moderate quality of movement. On the nondominant side, 26 participants displayed good movement patterns and 28 displayed moderate patterns ($P = .14$).

On the dominant side, no difference in age or body mass was noted between participants with good versus moderate quality of movement ($P > .05$). Participants with good quality of movement were taller than those with moderate quality of movement (177.0 versus 173.2 cm, $P = .04$). Ankle DF ROM as measured in WB and NWB was greater among participants with good compared with moderate quality of movement ($P = .01$ and $P = .02$ for WB and NWB, respectively). The ESs for the WB and NWB difference on the dominant side were moderate (0.72 and 0.68, respectively).

On the nondominant side, no difference in age, height, or body mass was noted between participants with good versus moderate quality of movement ($P > .05$). Non-WB ankle DF demonstrated a trend toward a decreased range among participants with moderate quality of movement compared with good quality of movement ($P = .03$). The ES for this difference was moderate (0.63). Weight-bearing DF was not different among participants with different qualities of movement on the nondominant side ($P = .10$, ES = 0.45).

The WB and NWB DF ROM values for the 2 participants with poor quality of movement on the dominant-side LSD were 46.5° ± 2.1° and 18.0° ± 1.4°, respectively. The WB and NWB DF ROM values for the participant with poor quality of movement on the nondominant-side LSD were 60.7° and 28.3°, respectively.

The correlation between DF ROM (WB and NWB) and the quality of movement on both sides is presented in Table 4. Both WB and NWB ankle DF ROM correlated significantly with the quality of movement on either side ($P < .05$). The nature of the correlation indicates that a higher score on the LSD test (ie, lower quality of movement) was associated with less ankle DF ROM (Table 4).

DISCUSSION

The association between ankle DF ROM and movement quality among men compares favorably with previous findings among healthy women.[16] Several interesting differences do exist, however. First, whereas 60% of the male participants in our study exhibited a good movement pattern on the dominant-side LSD, only 28% of female participants did so in a previous study.[16] This is in agreement with earlier research[19,20] indicating sex differences in lower extremity kinematics and a possibly more risky movement pattern among females during various functional activities. Another interesting difference is the greater NWB DF ROM among men compared with women (27.8° versus 23.5°).[16] Because these measurements were taken by the same investigator in both studies, it is reasonable to believe that they reflect a true difference. This difference may also help to explain the greater difference in DF ROM among women with different qualities of movement compared with men (ES = 1.1 among women versus 0.68 among men).[16] Ankle DF ROM among the men

Table 3. Ankle-Dorsiflexion Range of Motion and Effect Sizes for the Differences Between Participants With Good and Moderate Lateral Step-Down Test Scores

	Dominant-Side[a]			Nondominant-Side[b]		
	Score, Mean (95% Confidence Interval)			Score, Mean (95% Confidence Interval)		
Weight-Bearing Status in Dorsiflexion	Good	Moderate	Effect Size	Good	Moderate	Effect Size
Weight-bearing	52.7 (50.6, 54.8)	48.3 (45.6, 51.0)	0.72	58.8 (56.1, 61.5)	55.7 (53.1, 58.3)	0.45
Non–weight-bearing	29.6 (27.6, 31.6)	25.7 (23.1, 28.3)	0.68	29.9 (27.5, 32.2)	26.1 (23.8, 28.4)	0.63

[a] Weight-bearing and non–weight-bearing dorsiflexion was greater in the good than in the moderate group ($P = .01$ and $P = .02$, respectively).
[b] A trend toward greater non–weight-bearing dorsiflexion was seen in the good than in the moderate group ($P = .03$).

in this study may not have been limited enough to explain differences in the quality of movement compared with the women in the previous study.[16] Similarly, the correlation between the raw score for the dominant-side LSD and the WB and NWB ankle DF ROM seems greater among women ($r = -0.66$ and -0.68, respectively,[16] compared with $r = -0.44$ and -0.43, respectively, among men). It is possible that DF ROM is more strongly associated with lower extremity movement pattern among females compared with males. This association may be explained by a more limited ankle DF ROM among females. However, as we are unaware of any previous investigations into sex differences in ankle DF ROM, this hypothesis needs further testing.

Our findings are also in agreement with those of Sigward et al[14] and Bell et al,[15] which associated decreased ankle DF with a faulty movement pattern during a drop landing and a squat maneuver, respectively.[14,15] Our methods, however, were somewhat different in that we asked our participants to try to perform the LSD with an "ideal" movement pattern. One instruction we gave our participants before performing the LSD was to try to maintain the knee over the second toe during the test. Because movement pattern may simply reflect one's choice,[18] we believed that instructing our participants to perform the LSD with an ideal movement pattern was more likely to unveil impairments that might prevent such a movement pattern. More specifically, we hypothesized that participants with less available ankle DF would not be able to perform the LSD while maintaining this ideal movement pattern despite attempting to do so. This could explain the clearer association between DF ROM and movement pattern in our investigation compared with these 2 other studies.[14,15]

The data of 3 participants with poor quality of movement (2 on the dominant-side LSD and 1 on the nondominant side) were not included in the primary analysis. The average NWB DF on the dominant side of the 2 participants with poor quality of movement on the dominant-side LSD seemed to differ from that of the participants with good quality of movement (18.0° versus 29.6°) or moderate quality of movement on that side (18.0° versus 25.7°). These findings further suggest the association between DF and movement pattern among men.

Although our results generally support the association between ankle DF ROM and lower extremity movement pattern among healthy men, several of our findings warrant further consideration. First, the magnitude of the correlation between DF (WB or NWB) and movement pattern, as well as the ES for the difference in DF ROM between participants with different qualities of movement, can be considered moderate at best. This is not surprising, given the multiple factors that have been previously associated with lower extremity movement patterns.[4–8] It is more than likely that movement pattern is a multifactorial construct.[27] In addition, the WB DF ROM of our sample was 4° to 11° greater than that found in previous investigations,[28–30] and the NWB ROM was 6° to 7° greater than that reported earlier.[15,31,32] As a result, the hypothesized adverse effect of limited ankle DF on the lower extremity movement pattern may have been limited in our sample.

Another interesting finding was that neither DF measurement (neither WB nor NWB) displayed a statistically significant difference between participants with good and those with moderate quality of movement on the nondominant side. This could be explained by less power of the analyses on the nondominant compared with the dominant side (post hoc power analysis: 0.37 versus 0.71 for WB DF and 0.62 versus 0.66 for NWB DF).

Finally, participants with good quality of movement on the dominant side were also taller than those with moderate quality of movement. Height could have affected the quality of movement in our study, as all participants performed the LSD on a standard 15-cm step. The LSD might have been less challenging for the taller participants, as it may have required less knee flexion or ankle DF (or both) to complete. However, participants with good quality of movement on the dominant side still demonstrated greater available ankle DF ROM. Future investigators using the LSD test may wish to consider adjusting the step height according to their participants' height.

The major strength of this study lies in its simplicity and clinical utility. We used inexpensive equipment that is

Table 4. Correlation (Spearman ρ) Between Dorsiflexion Range of Motion and Lateral Step-Down Test Movement Quality on the Dominant and Nondominant Sides

Variable	Correlation Coefficient	*P* Value
Dominant-side weight-bearing dorsiflexion and dominant-side lateral step-down score	−0.44	<.01
Dominant-side non–weight-bearing dorsiflexion and dominan-side lateral step-down score	−0.43	<.01
Nondominant-side weight-bearing dorsiflexion and nondominant-side lateral step-down score	−0.31	<.05
Nondominant-side non–weight-bearing dorsiflexion and nondominant-side lateral step-down score	−0.37	<.01

readily available in most settings. Furthermore, visual observation of movement quality is typically what clinicians and coaches rely on in everyday practice. Another strength of our study is the independent assessment of movement quality and DF ROM, which minimized observer bias. Finally, the bilateral measurements taken in this study are another unique factor compared with many other studies looking into lower extremity movement patterns. Typically, measurements have been taken on the dominant lower extremity of participants.[9,10,14,16] It is unknown whether leg dominance affects the association between movement quality and ROM or other physical measures. Our findings suggest that ankle DF ROM is associated with the quality of movement on either lower extremity. Nevertheless, our data also consistently demonstrated a weaker association between ankle DF and movement quality on the nondominant side. In future studies into lower extremity movement patterns and associated factors, researchers may wish to include both sides in the analyses.

Although we cannot infer that decreased ankle DF is the cause of an altered movement pattern based on this study, our results have several possible implications. First, ankle DF may need to be assessed when an altered movement pattern is identified visually. Second, interventions to increase ankle DF ROM may be indicated when improved quality of movement is the goal. Third, given the association between an altered movement pattern and knee disorders such as PFPS and anterior cruciate ligament tears,[1–3] increasing the available ankle DF may decrease the occurrence of such disorders.

A potentially useful line of future study would be to determine whether the association between movement pattern and ankle DF is also present among patients with disorders such as PFPS. Previous research[30,31] has yielded conflicting findings regarding the association between ankle DF and PFPS. Interestingly, Piva et al,[31] who did demonstrate this association, used a NWB DF measurement, whereas Barton et al[30] used a WB measurement and did not find an association. The different measurement techniques used may be responsible for these differences. Alternatively, as PFPS is considered a multifactorial disorder, it is possible that only a subgroup of patients with PFPS demonstrates limited ankle DF. This subgroup may also demonstrate a more altered movement pattern.

Our study possesses several limitations. First, our findings are applicable only to healthy male participants performing the LSD after receipt of instructions on the proper movement pattern. It is unknown whether patients with disorders such as PFPS or those not receiving instructions on how to perform the LSD would demonstrate similar findings. Second, no cause-and-effect relationship can be determined from this investigation because of its cross-sectional methods.

CONCLUSIONS

Healthy men with lower quality of movement on the dominant side demonstrated less available ankle DF ROM. Furthermore, ankle DF ROM was moderately correlated with movement quality in both lower extremities. Although the association between ankle DF and movement quality seems weaker among healthy men compared with women, assessment and possibly intervention to increase ankle DF should be considered when lower quality of movement is observed among men.

Future study into the association of ankle DF and quality of movement among clinical populations such as those with PFPS is recommended.

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