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Joint Motions of the Knee, Hip, and Trunk during a Single-Leg Step-Down Test and Running

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By

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Accepted in Partial Completion
of the Requirements for the Degree
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Master’s Thesis

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Presented to
The Faculty of
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Abstract

The purpose of this study was to examine the relationship between kinematic variables at the knee, hip, and trunk during a single-leg step-down test (SDT) and running. Twenty-five healthy subjects (12 male, 13 female) participated in the study; mean ± SD age, 32.8 ± 5.9 years; height, 173.9 ± 8.7 cm; body mass, 70.84 ± 11.3 kg; run volume, 59.5 ± 30.4 km/wk; cadence, 173.1 ± 11.5 steps/min). Dominant leg peak knee flexion was identified during the run (PKF-RUN) and used to find frontal plane knee and hip, and sagittal plane trunk angles. The same treadmill-matched knee flexion angle for the run was used to find the knee flexion angle identified during the SDT (TMKF-SDT). Knee, hip, and trunk angles were also identified at the point of the SDT where the heel made contact with the ground (HEEL-SDT). Two separate two-tailed paired samples *t*-tests were used to analyze the difference between the means of each test condition and Pearson Product Correlation coefficients were computed for each condition. Statistics revealed significant differences in frontal plane knee and hip angles between PKF-RUN (6.18 degrees ± 8.90) and TMKF-SDT (8.13 degrees ± 8.88), $t(24) = -2.21$, $p = 0.037$ for frontal plane knee adduction, and; PKF-RUN (11.14 degrees ± 3.22) and TMKF-SDT (6.48 degrees ± 4.53), $t(24) = 6.17$, $p < 0.0001$ for frontal plane hip adduction. There were significant differences between mean PKF-RUN (6.18 degrees ± 8.90) and HEEL-SDT (16.65 degrees ± 12.60), $t(24) = -6.79$, $p < 0.0001$ frontal plane knee adduction, and; PKF-RUN (11.14 degrees ± 3.22) and HEEL-SDT (17.84 degrees ± 5.63), $t(24) = -6.45$, $p < 0.0001$ for frontal plane hip adduction. No significant differences were found between mean PKF-RUN (6.44 degrees ± 3.67) and TMKF-SDT (6.33 degrees ± 6.46), $t(24) = 0.104$, $p = 0.918$ sagittal plane trunk flexion. There were significant differences between mean PKF-RUN (6.44 degrees ± 3.67) and HEEL-SDT (10.32 degrees ± 10.04), $t(24) = -2.19$, $p = 0.039$ sagittal plane trunk flexion. Correlations between PKF-RUN and TMKF-SDT were strong in the knee ($r = 0.88$, $p < 0.0001$, $R^2 = 0.768$) and moderate in the hip ($r = 0.57$, $p = 0.003$, $R^2 = 0.325$). Correlations between PKF-RUN and HEEL-SDT were strong in the knee ($r = 0.80$, $p < 0.0001$, $R^2 = 0.634$) and fair in the hip ($r = 0.42$, $p = 0.038$, $R^2 = 0.175$). For the trunk, correlations between PKF-RUN and TMKF-SDT were moderate ($r = 0.53$, $p = 0.006$, $R^2 = 0.285$) and correlations between PKF-RUN and HEEL-SDT were fair-to-moderate ($r = 0.49$, $p = 0.014$, $R^2 = 0.237$). The SDT and running may not be directly relatable to one another in the knee and hip. The trunk is also not relatable to running at the bottom of the SDT. Clinicians should use caution when utilizing the SDT.

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Chapter I

INTRODUCTION

Running is continuously growing as one of the most popular sports practiced by millions of athletes worldwide each year, with the level of training and experience ranging from the elite level to amateur alike.[6] With the population of worldwide runners continuing to increase every year, there has been a notable rise in the incidence of runners experiencing running-related injury that may affect their regular training.[6,25]

Running related injuries to the lower extremity account for up to 79% of all reported injuries in the literature, of which the predominant site of injury was the knee.[25] Benca and colleagues[6] also reported that the knee had the highest incidence of running-related injury, with patellofemoral pain (PFP) being among the most prevalent. Current understanding of peak frontal plane knee and hip kinematics suggest these areas as potential factors associated with PFP when comparing symptomatic populations with healthy populations.[20,21,28,44,55] However, these kinematic variables are commonly identified throughout the entire gait cycle and not at any specific point in time.[5,20,21,44,66]

Peak knee flexion during the stance-phase of running is commonly used to identify the instant that a person reaches the mid-stance of gait. This instant has been identified as the point of the highest patellofemoral joint stress, and is therefore an important time point during the gait cycle to assess when investigating the susceptibility to PFP when running.[24,66] In a clinical setting, clinicians rely on peak knee flexion to determine how much load could be occurring on the patient's knee during running gait to be causing him/her pain.[64,65] Many clinicians also rely on different types of functional performance and functional screening tests and clinical evaluations to determine the potential source of the knee pain that is present during the patient's runs. These functional performance tests typically refer to the use of a variety of single-leg squat tests.[23,33,36] These functional performance tests are meant to provide the clinician with a deeper understanding for why the patient may be experiencing pain, without having to ask them to run in the clinic.

The single-leg step-down test (SDT) is a functional performance test often used to assess knee, hip, and trunk motion in patients with and without knee pain.[4,33,36] This test is meant to provide a visual aid in identifying the source of patellofemoral pain that is present during day-to-day activities, stair ascent/descent, and during running.[7,33,64] Current research related to joint motion during the SDT in PFP population suggest they exhibit increased range of motion in the frontal and sagittal plane in the knee and hip when performing the test compared to an asymptomatic population.[33] Most literature utilizing the SDT examine joint moment at a specific instant during the SDT, such as the instant a specific knee flexion angle occurs, or the very bottom of the SDT.[33,64,65] The very bottom of the SDT has been identified in two different ways: when the heel taps the floor, or when peak knee flexion occurs.[33,64] The SDT is meant to increase the overall effectiveness and efficiency of patient care by allowing clinicians to understand running gait, simply by using the SDT for their assessment in the clinic.[10,23,33] The instants of knee flexion being analyzed in the SDT literature do not represent the peak knee flexion observed during running, where knee flexion values are reportedly as high as 91 degrees during a SDT and 45 degrees during a run.[11,12,64] Furthermore, the literature does not typically relate running kinematics with the peak knee flexion observed during a SDT to determine how strong the relationship is between the two movements. The inherent assumption clinicians make when performing a SDT is that joint motion at the instant of peak knee flexion or heel contact with the ground during SDT is related to the joint motion at instant of peak knee flexion when running. Interestingly, no research has examined the strength of such correlations at these instances. Not knowing the strength of the relationship between these two movements could provide clinicians with unreliable information on how a patient could be responding to load during a run.

Therefore the purpose of this study was to investigate the relationship between the SDT and running kinematics in the knee, hip, and trunk. The authors hypothesized that no significant differences exist in the frontal plane kinematics and no significant differences exist in the sagittal plane kinematics between the mid-stance phase of treadmill running at the point of peak knee flexion and the same knee flexion angle during the SDT in a healthy population, and that there is a strong positive correlation between the joint motions at these two points. Secondly, the authors hypothesized that no significant differences would exist in the frontal plane kinematics and no significant differences would exist in the sagittal plane kinematics between the mid-stance phase of treadmill running at the point of peak knee flexion and the SDT at the point where the heel makes contact with the ground in a healthy population, and that there was a strong correlation between the joint motions at these two points.

Chapter II

METHODOLOGY

Subject Demographics

Thirteen women and thirteen men (mean ± SD age, 32.8 ± 5.9 years; height, 173.9 ± 8.7 cm; body mass, 70.84 ± 11.3 kg; run volume, 59.5 ± 30.4 km/wk; cadence, 173.1 ± 11.5 steps/min) who were healthy moderately active runners (i.e. average 30 kilometers or more per week) volunteered as subjects (**TABLE 1**). Volunteer inclusion required they be between 18 and 45 years of age and have been running regularly for at least 6 months prior to the date of collection. Volunteers were excluded if they had history of musculoskeletal injury to either the lower extremity or lower back, a history of ligamentous or articular reconstruction surgery to either the lower extremity or lower back, and/or a history of neurological or systemic conditions that affect function of either the lower extremity or lower back. Volunteers were recruited via fliers posted on Western Washington University campus and in local run shops, through word-of-mouth at local group runs, and via posts in running clubs and forums on social media. A screening process was performed for each interested volunteer to determine if they met the eligibility requirements before a collection date was scheduled. Each subject signed an informed consent form approved by the Western Washington University Institution Review Board and their rights were protected. All procedures followed were in accordance with the ethical standards of the Western Washington University Institution Review Board.

Sex	Age (yrs)	Height (cm)	Body Mass (kg)	Run Volume (km/wk)	Cadence (steps/min)
13 Female	31.6 ± 6.14	168.9 ± 7.85	63.6 ± 7.48	54.5 ± 26.7	176.5 ± 10.8
12 Male	34.0 ± 5.67	179.2 ± 6.09	78.6 ± 9.59	65.0 ± 34.2	169.4 ± 11.4
Total	32.8 ± 5.93	173.9 ± 8.73	70.8 ± 11.3	59.5 ± 30.4	173.1 ± 11.5

TABLE 1. Subject Demographics.

Instrumentation

Kinematic data were collected using a 10-camera Vicon motion capture system setup (v1.3 Vantage, Vicon, Oxford Industrial Park, Yarnton, Oxford, United Kingdom). The camera setup was integrated with Nexus 2.6.1 software that was used to create a digital model of the subject performing the treadmill run and step-down test tasks. The kinematic sampling frequency was set at 250 Hz. Previous studies have not reported a sampling frequency this high when examining the SDT, but a sampling frequency up to 300 Hz has been reported in running gait analysis research.[17,21,22,44,55] The frame rate was chosen so that the highest frame rate possible would be captured during the collection sessions, while ensuring the frequency is still set to a common denominator with the force plate so that data could be down-sampled. This would ensure greater accuracy in identifying the closest knee flexion angle to the PKF observed during the run.

Kinetic data was collected using an AMTI force plate set within the floor of the lab (OR6-6-2000, AMTI, Watertown, MA, USA). The force plate was set at 1000 Hz for acquisition. Both the motion capture cameras and the force plate were plugged into a Vicon Lock+ used to capture data synchronously using the Nexus 2.6.1 software.

Procedures

Each collection session lasted approximately 90 minutes. All testing was conducted in the Applied Neuromechanics Laboratory at Western Washington University. Testing sessions began with a researcher taking measurements of multiple body segments to be used for creating the virtual skeleton for the subject in the motion capture software. The measurements recorded were left and right knee width, left and right ankle width, anterior-superior iliac spine (ASIS) distance, and left and right leg length. Knee and ankle width were measured using electronic calipers. The subject sat with knee flexed for these measurements so the joint space and epicondyles could be easily palpated and identified when measuring knee width. ASIS distance and leg length were measured with a tape measure with the subject standing in a neutral stance, legs square to the width of their hips. Leg length was identified as the distance from the ASIS to the medial malleolus of the ipsilateral leg. ASIS distance was identified as the distance between the left and right ASIS. Sex, height, weight, running volume, and footwear type of the subjects were also recorded. The type of footwear was not controlled for because recent literature suggests the type of footwear worn during a run does not impose a major effect on the kinematics of the knee and hip as much as previously thought,[40–43] and the researchers did not feel that manipulating footwear would encourage the subjects to run normally and comfortably while on the treadmill.

A warm-up protocol consisted of light dynamic stretching and familiarization to the treadmill that would be used for testing. The warm-up began with a 5-minute run on the treadmill, followed by 5 minutes of dynamic stretching across the laboratory room floor. The warm-up run required the subjects to run on the treadmill at 2.68 $m \cdot s^{-1}$ for three minutes and then increase the speed to 3 $m \cdot s^{-1}$ for the final two minutes. This would familiarize subjects with the pace they would be running during the data collection. Dynamic stretches were led by a lab researcher and were conducted in the same order for each subject: knee grabs, foot grabs, foot grabs with external rotation of the knee, calf raises, and single-leg lunges.

Twenty-one retro-reflective markers with a diameter of 14 mm were used for tracking 3D movement and were attached to the upper and lower extremities on the following landmarks: sternal notch, xiphoid process, 7th cervical spinous process, 10th thoracic spinous process, right spine of the scapula, left and right posterior-superior iliac spine (PSIS) , left and right ASIS, left and right lateral aspect of the thigh, left and right lateral epicondyles of the knee joint, left and right lateral aspect of the shank, left and right lateral malleoli of the fibula, left and right proximal head of the 2nd metatarsal, left and right heel (**FIGURE 1**). The marker on the right spine of the scapula was also used to help identify anterior/posterior sides of the body, as well as left and right. The toe marker was placed by palpating the metatarsal heads in shod subjects. The heel marker was placed on the heel of the shoe for reference to the calcaneus and was placed in parallel to the toe marker and at equal height from the ground.

Following a standing trial used for calibration, subjects were randomly assigned to perform the 10-minute run on a treadmill or the step-down test (SDT) (**FIGURE 2**).

The run protocol required subjects to run on a treadmill for 10 minutes at 3 $m \cdot s^{-1}$. Treadmill speeds cited in the literature generally standardize to speeds ranging from 2.55 $m \cdot s^{-1}$ to 3.5 $m \cdot s^{-1}$, so testing speed in this study was standardized to the general mean speed reported in these studies.[21,22,45,63] The treadmill was set in the middle of the motion capture volume. The subject was asked to run as comfortably as possible on the treadmill during the collection. The protocol for the SDT was adapted from Lewis et al.[33] and Whatman et al.,[64] and required subjects to tap the heel of the foot opposite of the stance leg five times onto the force plate, moving at a consistent speed throughout the trial. Subjects were asked to try to maintain a cadence of 4 seconds per rep, lowering for 2 seconds and then returning to the starting position for 2 seconds. Subjects received minimal instruction on form during the SDT but were asked to keep the heel of their stance leg flat on the box when lowering during the task. The box height was adjusted for each subject using multiple wood boxes and rubber mats. The box and mats were used to adjust the box height to as close to 10% of the subject's total body height rounding to the nearest centimeter. Box height varies in the literature, and can range from as low as 15 cm to as high as 24 cm.[3,7,17,28,33,47,49,64,65] Adjusting the box height to a subject's total body height allowed for more consistency in the range of motion observed in joint angles, regardless of height differences.[1,31,55] Box heights consisted of a 15 cm box and a 5 cm box. Rubber mats that were 2 cm thick were used to adjust the height of the box as needed.

Data Analysis

All data were exported from the Nexus 2.6.1 software into Excel (Excel, Microsoft, Redmond, WA, USA). For the treadmill run, five run trials were recorded for

15 second intervals. The first 5 minutes were meant for normalization. The intervals began on the last 15 seconds of each minute after 5 minutes of running. After being exported, the Excel file was run through a MatLab script (MATLAB 9.4 and Statistics Toolbox 8.1, The MathWorks, Inc., Natick, Massachusetts, USA) that identified the points of interest. The PKF was used to identify the mid stance phase of running. Per Gallow and Heiderscheit,[24] the mid-stance of running – the instant the body's center of mass is directly over the foot – are indicated by the PKF angle and peak ankle dorsiflexion.[24] At the instant PKF angle occurred, the joint angles of frontal plane hip and knee and sagittal plane trunk motion were given. Out of the five recorded trials, the joint angles in the middle three trials were averaged, including PKF, to give the average of the joint motions observed during the run at the point of PKF (PKF-RUN).

For the SDT, five step-down repetitions were recorded for the dominant leg. The SDT was recorded from the point the subject was given the cue to begin the SDT until the end of the fifth heel-tap when the subject returned to the starting position on the box. Of the five step-down repetitions recorded, the middle 3 trials were used for analysis. The PKF value from the run was used to match the knee flexion angle during the lowering phase of the SDT. Joint motion was analyzed at the instance at which this knee flexion angle occurred during the SDT. The second point analyzed during the SDT was the point when the heel made initial contact with the force plate during the lowering phase (HEEL-SDT), because this point was representative of how clinicians rely on visual assessment when performing the functional test.[65] This point was identified as the point in time that the force plate exceeds 20 N of applied force.

Statistical Analysis

A randomized repeated measures observational study protocol was employed to examine the within-subjects differences for the two testing conditions. Descriptive statistics (means and standard deviations) were calculated for each condition and a paired samples t-test was used to detect differences between PKF-RUN and TMKF-SDT, and PKF-RUN and HEEL-SDT. Pearson Product Moment Correlation coefficients (r) were calculated to test the strength of the linear relationship for each dependent variable between the conditions. Pearson correlation coefficients were interpreted as weak relationship (r = 0.00 - 0.25), fair relationship (r = 0.25 - 0.50), moderate relationship (r = 0.50 - 0.75), and strong relationship (r > 0.75).[33,38,64] All statistical analysis was performed with SPSS version 25 (SPSS Inc., IBM SPSS Statistics for Windows, Armonk, NY, USA), with an alpha level of 0.05.

The independent variables were the conditions (treadmill run and step down task) and the knee flexion angle. The dependent variables were the frontal plane knee adduction/abduction, the frontal plane hip adduction/abduction, and the sagittal plane trunk flexion/extension.

FIGURE 1. Marker placement.

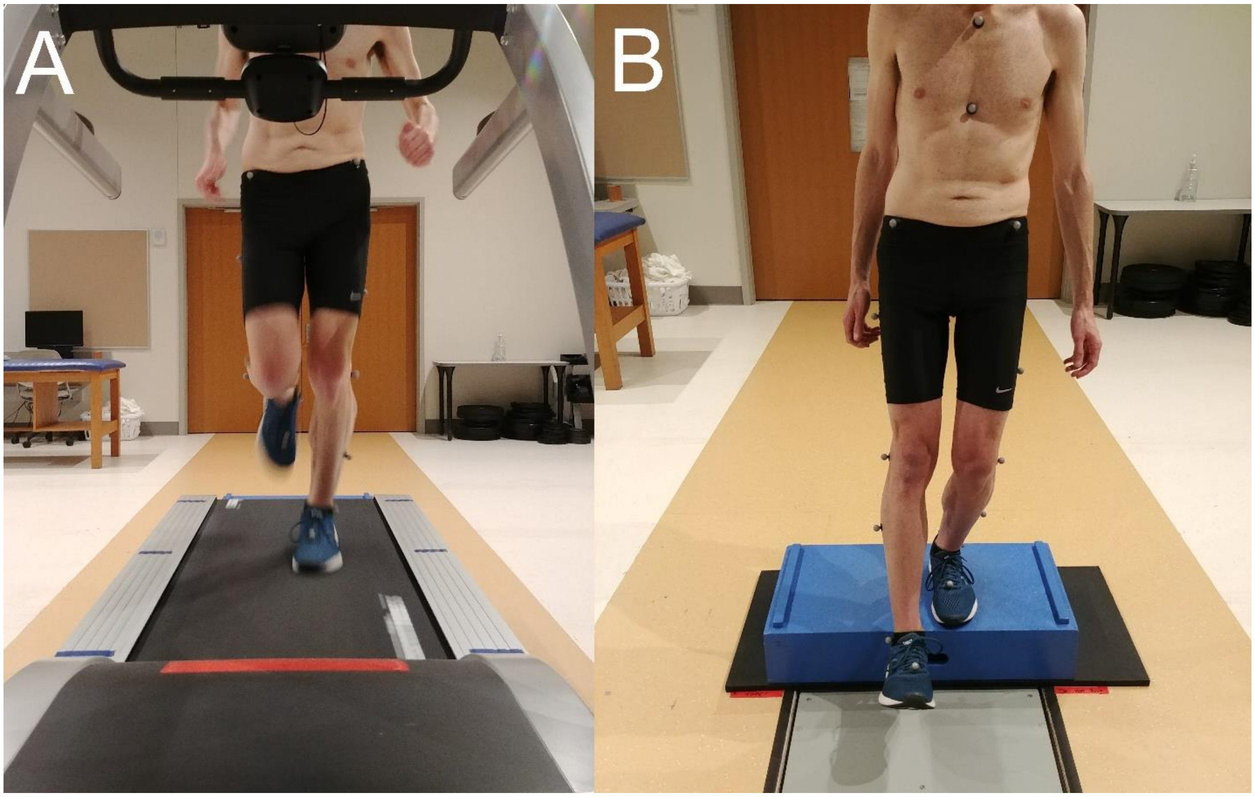


FIGURE 2. A) Treadmill run and B) Step-Down Test

Chapter III

RESULTS

Only one subject's data were omitted in the final analysis due to technical difficulties. Data for the remaining twenty-five subjects were analyzed to compute knee, hip, and trunk kinematic variables. The average peak knee flexion (PKF) for this cohort was 39.43 ± 5.03 degrees during the treadmill run. The knee flexion angle analyzed during the SDT was 39.45 ± 5.02 degrees. The joint angle in the knee at HEEL-SDT was 72.55 ± 6.09 degrees. For all subjects, box height was adjusted to be 10% of their body height. Box height adjustments resulted in 19 of the 25 subjects performing the SDT from a box height of 17 centimeters. Five subjects performed the test at 19 centimeters, 1 subject performed the test at 15 centimeters. Because sex differences have been reported in the literature, the data in this study was split between sexes during analysis to identify any sex-related differences. Differences were only identified in the trunk at TMKF-SDT and these differences were not meaningful. Data was then pooled after sex differences were confirmed to not exist for any other variable in this cohort. All data for each condition is represented in **TABLE 2**.

Variables	PKF-RUN Condition	TMKF-SDT Condition	HEEL-SDT Condition	PKF-RUN vs. TMKF-SDT Conditions T value (p-value)	PKF-RUN vs. HEEL-SDT Conditions T value (p-value)
Knee Adduction/Abduction Angle (degrees)	6.18 ± 8.90	8.13 ± 8.88	16.65 ± 12.60	-2.21 (0.037)	-6.79 (<0.0001)
Hip Adduction/Abduction Angle (degrees)	11.14 ± 3.22	6.48 ± 4.53	17.84 ± 5.63	6.17 (<0.0001)	-6.45 (<0.0001)
Trunk Flexion/Extension Angle (degrees)	6.44 ± 3.67	6.33 ± 6.46	10.32 ± 10.04	0.104 (0.918)	-2.19 (0.039)

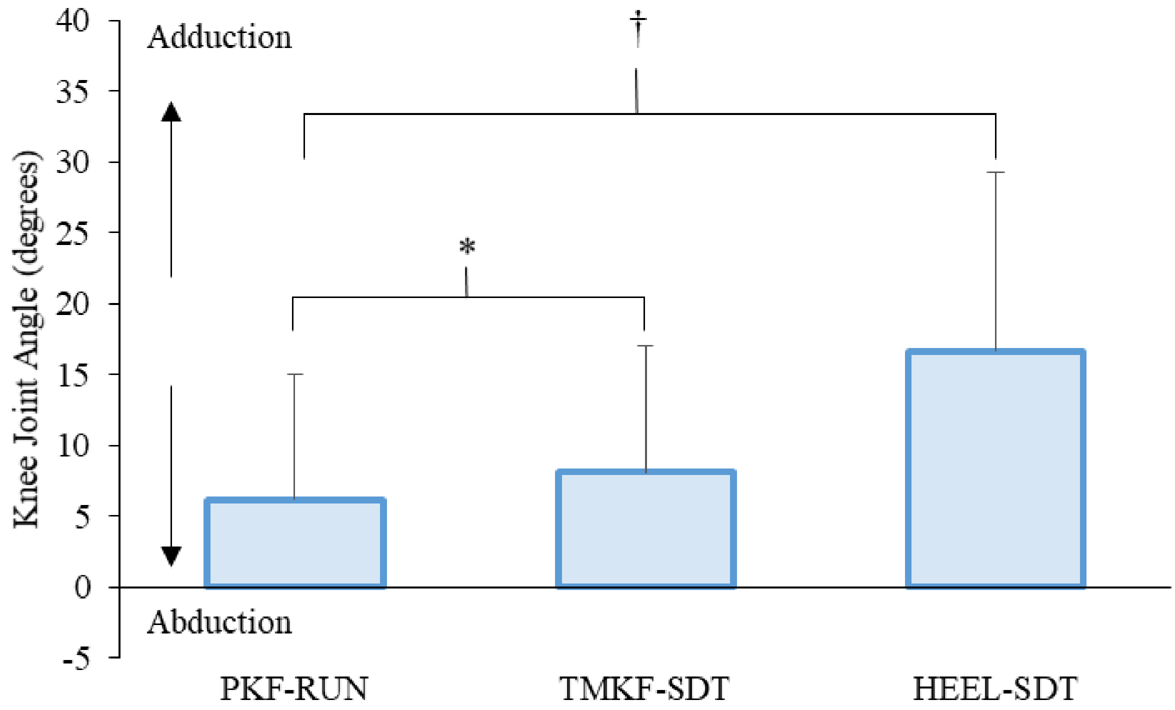
Note: Data provided as Mean ± SD.

TABLE 2. Kinematic Variables for the three Experimental Conditions

Knee Adduction/Abduction Angle

A significant difference was found in the frontal plane knee angle between PKF-RUN (6.18 degrees ± 8.90) and TMKF-SDT (8.13 degrees ± 8.88), t(24) = -2.21, p = 0.037 (**FIGURE 3**). On average, knee adduction angle in the frontal plane was 1.96 ± 4.42 degrees greater at TMKF-SDT versus PKF-RUN at the same knee flexion angle.

There was a positive and strong correlation between the frontal plane knee motion during the PKF-RUN and TMKF-SDT, $r = 0.88$, $p < 0.0001$, $R^2 = 0.768$ (**FIGURE 4)**.



*p < 0.05, †p < 0.0001.

FIGURE 3. Frontal plane motion of the knee during three different conditions.

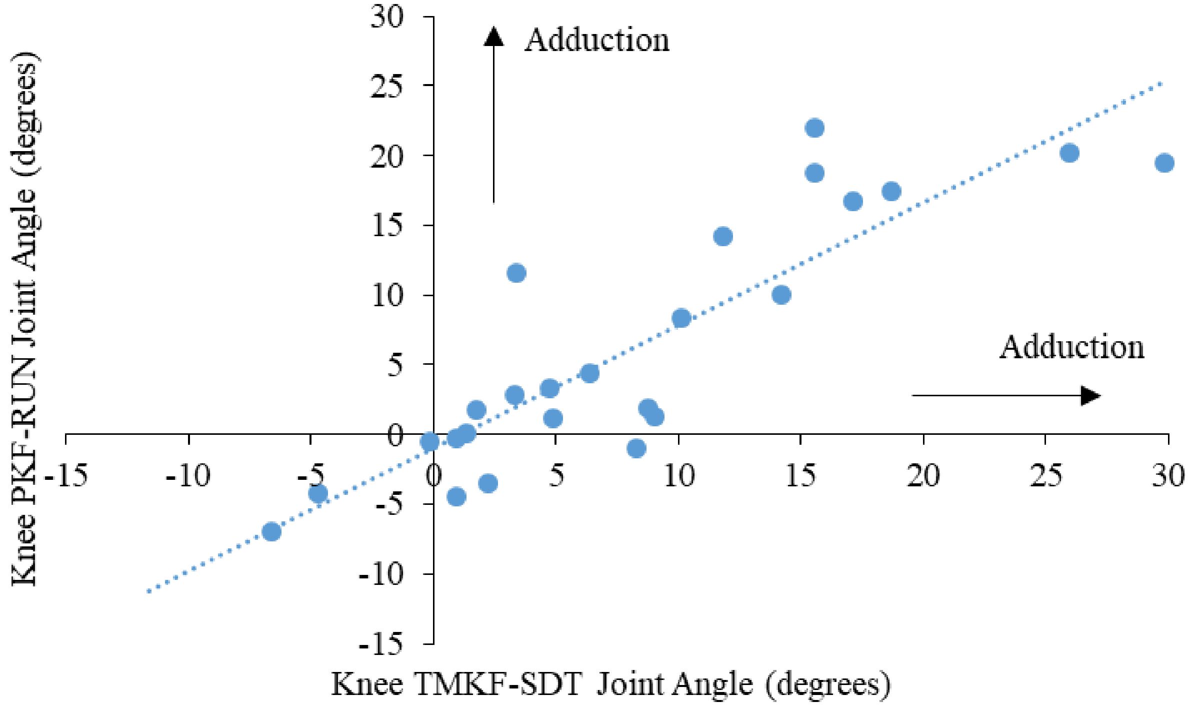


FIGURE 4. Relationship between the frontal plane knee joint angle for PKF-RUN and TMKF-SDT conditions.

A significant difference was found in the frontal plane knee motion between PKF-RUN (6.18 degrees ± 8.90) and HEEL-SDT (16.65 degrees ± 12.60), t(24) = -6.79, $p < 0.0001$. On average, knee adduction in the frontal plane was 10.47 ± 7.70 degrees greater in HEEL-SDT versus PKF-RUN (**FIGURE 3**). Pearson correlation coefficient suggests joint angles between the two conditions were related (**FIGURE 5**). There was a positive and strong correlation between the frontal plane knee motion during the PKF-RUN and HEEL-SDT, $r = 0.80$, $p < 0.0001$, $R^2 = 0.634$.

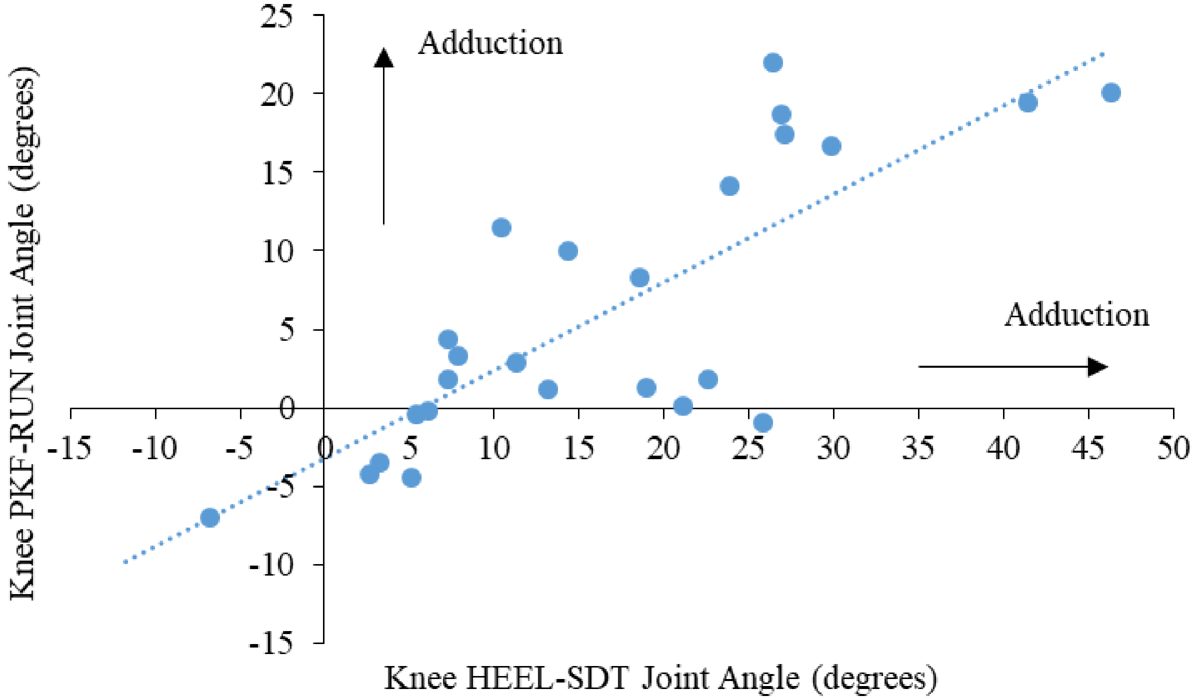
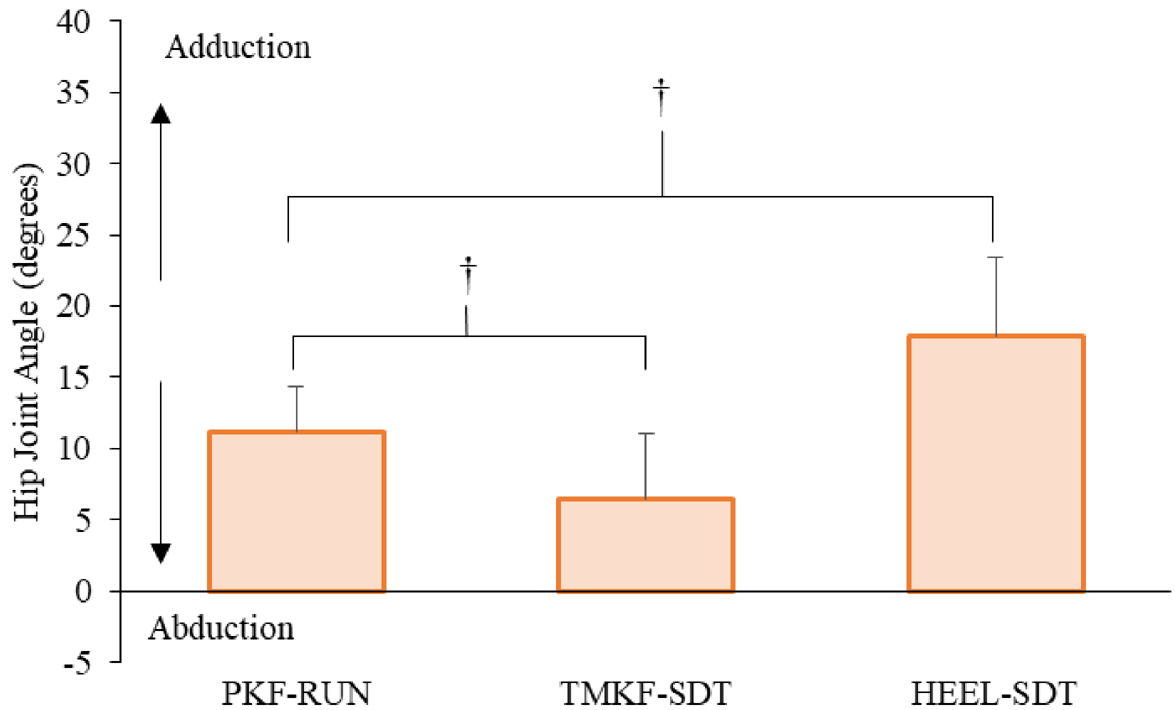


FIGURE 5. Relationship between the frontal plane knee angle for the PKF-RUN and HEEL-SDT conditions.

Hip Adduction/Abduction Angle

A significant difference was found in the frontal plane hip motion between PKF-RUN (11.14 degrees ± 3.22) and TMKF-SDT (6.48 degrees ± 4.53), $t(24) = 6.17$, $p < 0.0001$ (**FIGURE 6**). On average, hip adduction in the frontal plane was 4.66 ± 3.77 degrees less in the TMKF-SDT versus the PKF-RUN at the same knee flexion angle. There was a positive and moderate correlation between the two variables, $r = 0.57$, $p = 0.003$, $R^2 = 0.325$ (**FIGURE 7**).



†$p < 0.0001$.

FIGURE 6. Frontal plane motion at the hip during three different conditions.

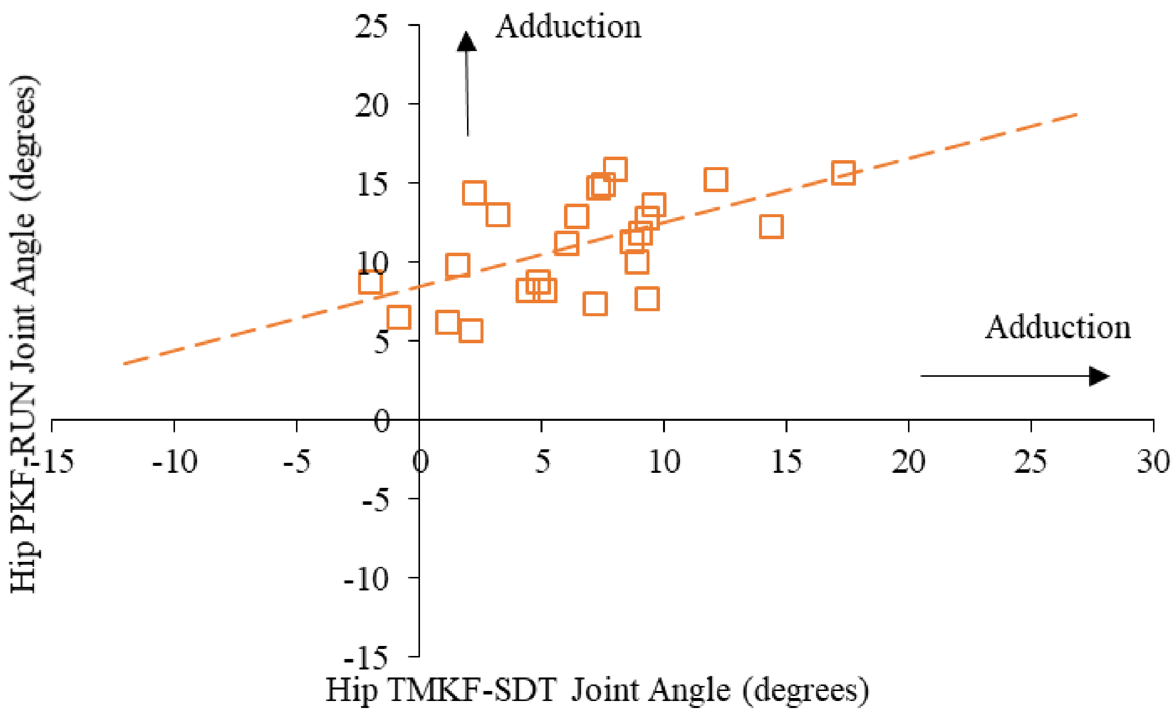


FIGURE 7. Relationship between the frontal plane hip angle for the PKF-RUN and TMKF-SDT conditions.

A significant difference was found in the frontal plane hip motion between PKF-RUN (11.14 degrees ± 3.22) and HEEL-SDT (17.84 degrees ± 5.63), $t(24) = -6.45$, $p < 0.0001$ (**FIGURE 6)**. On average, hip adduction in the frontal plane was 6.70 ± 5.19 degrees greater in the HEEL-SDT versus the PKF-RUN. There was a positive and fair correlation between the two variables, $r = 0.42$, $p = 0.038$, $R^2 = 0.175$ (**FIGURE 8**).

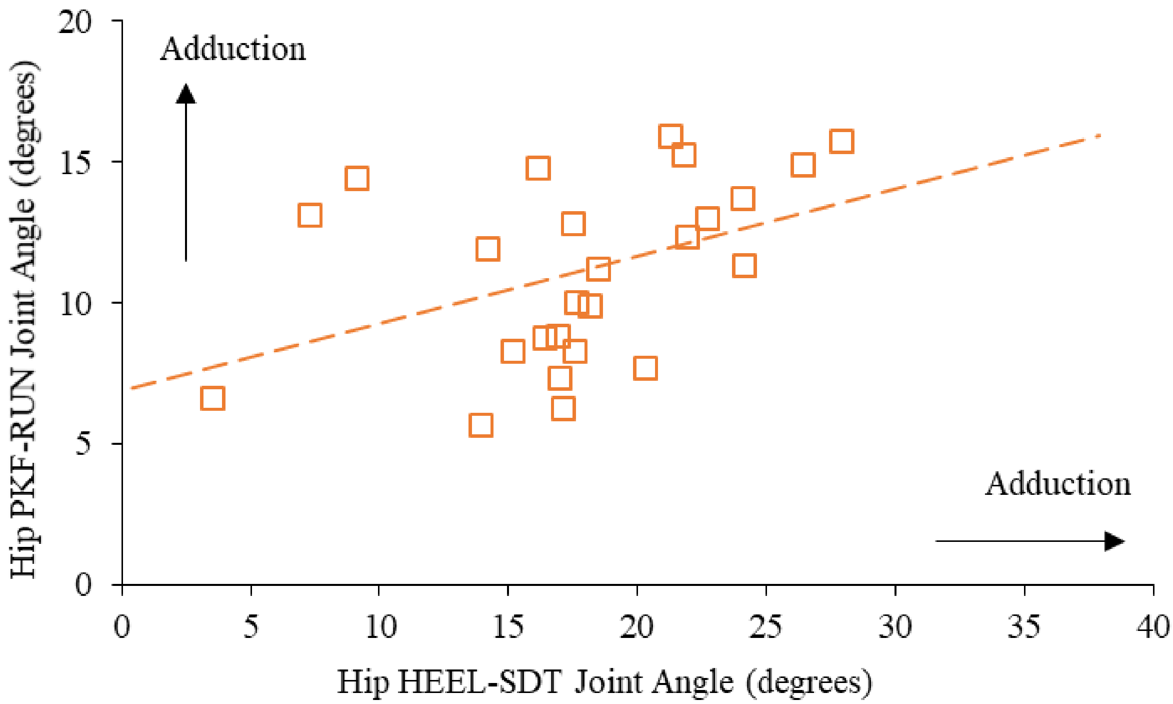
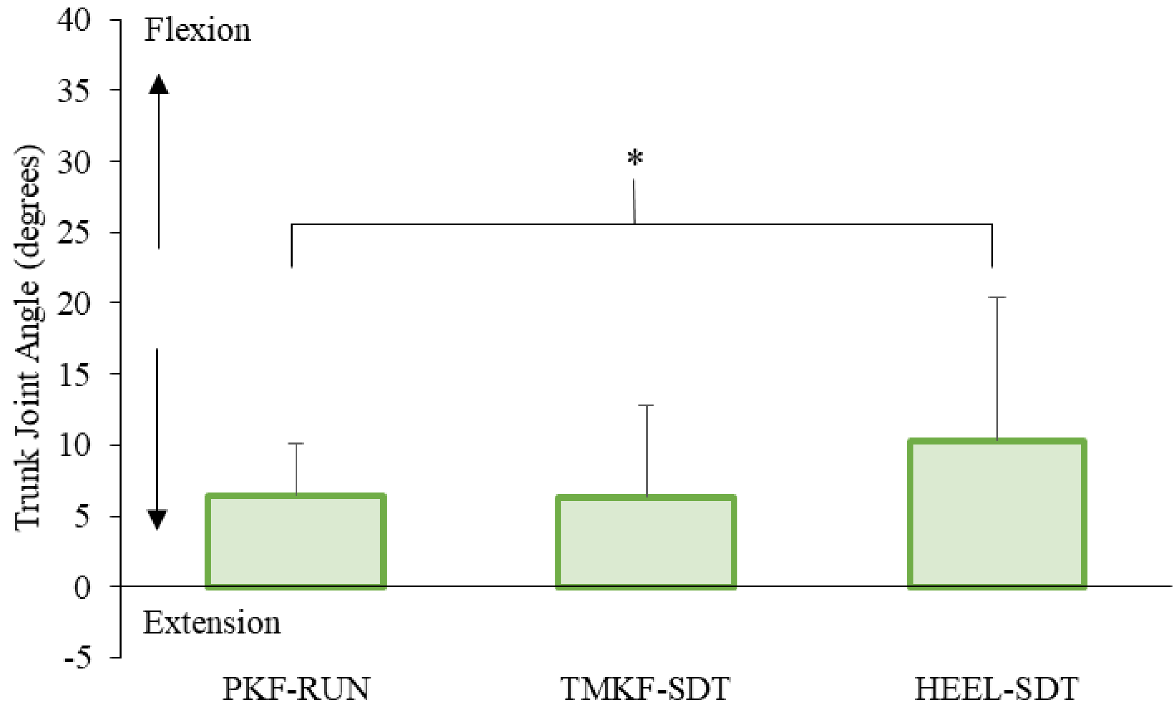


FIGURE 8. Relationship between the frontal plane hip angle for the PKF-RUN and HEEL-SDT conditions.

Trunk Flexion/Extension Angle

No significant difference was found in the sagittal plane trunk motion between PKF-RUN (6.45 degrees ± 3.67) and TMKF-SDT (6.33 degrees ± 6.46), t(24) = 0.104, p = 0.918 (**FIGURE 9**). On average, trunk flexion in the sagittal plane was 0.11 ± 5.47 degrees less in the TMKF-SDT versus the PKF-RUN at the same knee flexion angle. There was a positive and moderate correlation between the two variables, *r* = 0.53, p = 0.006, R^2 = 0.285 (**FIGURE 10**).



*$p < 0.05$.

FIGURE 9. Sagittal plane motion at the trunk during three different conditions.

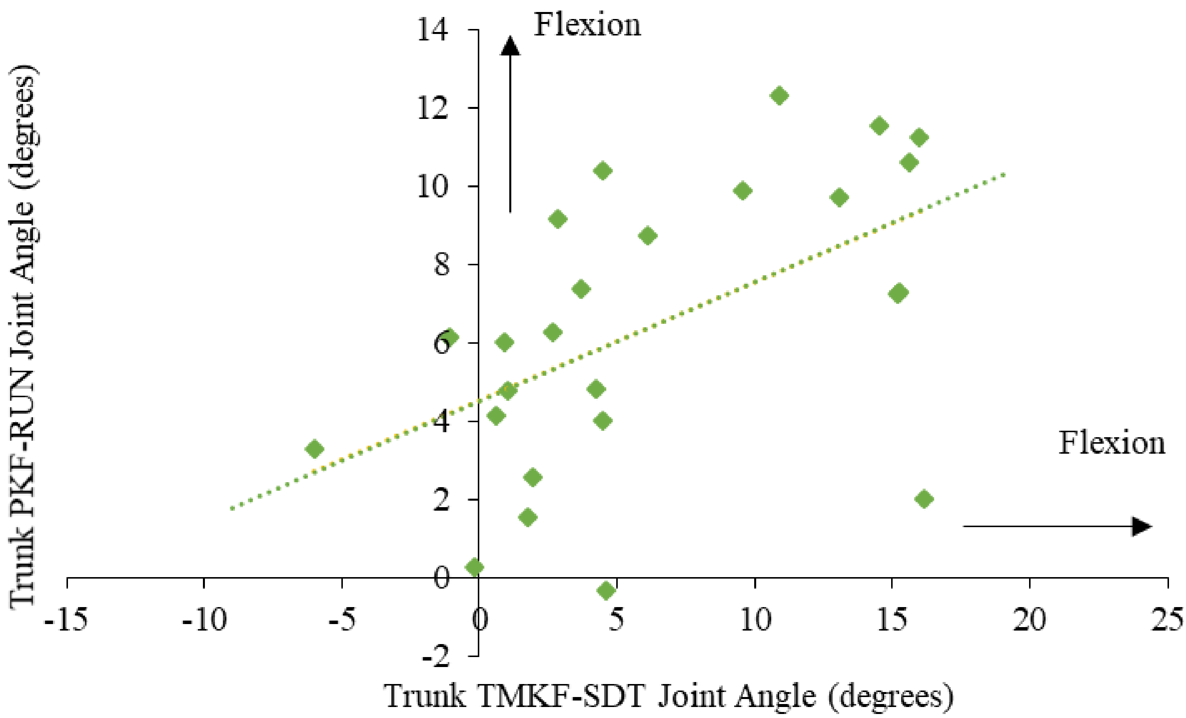


FIGURE 10. Relationship between trunk flexion/extension angle for the PKF-RUN and TMKF-SDT conditions.

A significant difference was found in the sagittal plane trunk motion between PKF-RUN (6.45 degrees ± 3.67) and HEEL-SDT (10.32 degrees ± 10.04), t(24) = -2.185, p = 0.039 (**FIGURE 9**). On average, trunk flexion in the sagittal plane was 3.87 ± 8.86 degrees greater in the HEEL-SDT versus the PKF-RUN at the same knee flexion angle. There was a positive and fair correlation between the two variables, r = 0.49, p = 0.014, R^2 = 0.237 (**FIGURE 11**).

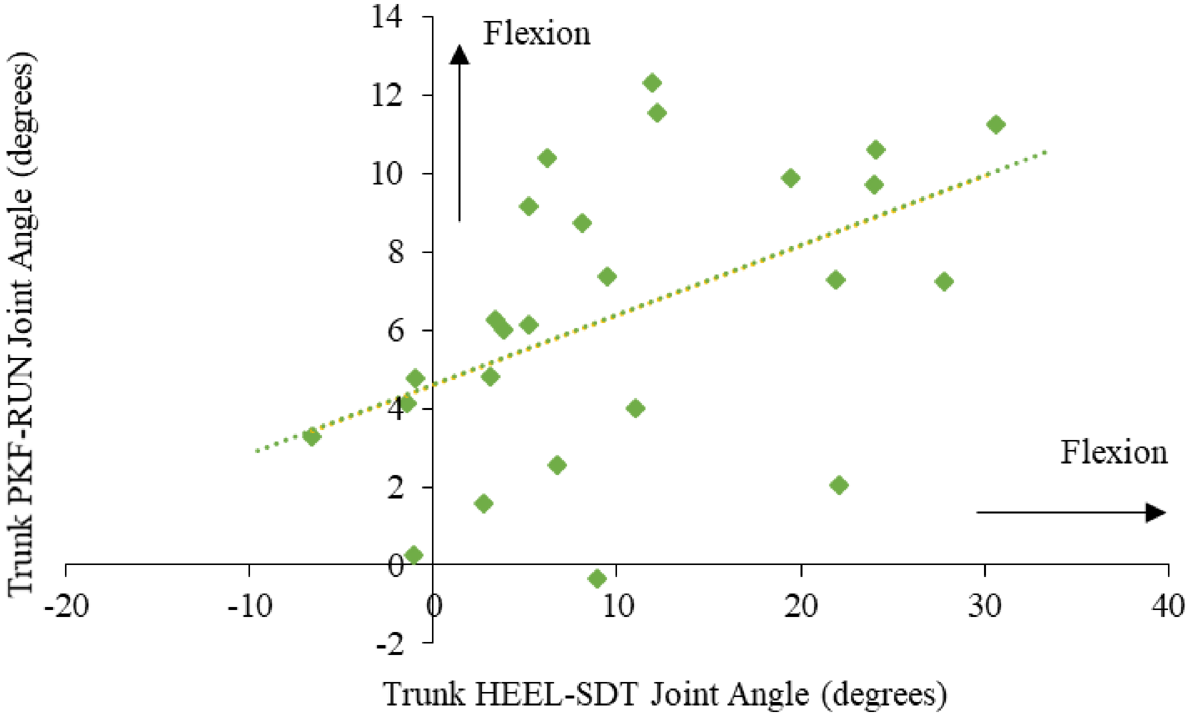


FIGURE 11. Relationship between trunk flexion/extension angle for the PKF-RUN and HEEL-SDT conditions.

Chapter IV

DISCUSSION

The step-down test (SDT) is a functional performance test that is used to infer an individual's ability to control the load being applied to the lower extremity during running gait.[36] The purpose of this study was to investigate the relationship between running kinematics and the SDT kinematics at the knee, hip, and trunk. The goal for this study was to support clinicians in sufficiently utilizing an evidence-based practice when using functional performance testing.

The results of this study show that subjects had an adducted knee and adducted hip during the mid-stance phase of running. Research related to running kinematics suggests this population had a similar range of knee flexion during the run as other cited literature, with peak knee flexion being reported around 40-45 degrees.[5,11,12] Subjects exhibiting valgus knee during running is commonly reported and has been observed in populations that are both asymptomatic and symptomatic with patellofemoral pain (PFP).[15,44,55,56] Dierks et al.[15] and Bazett-Jones et al.[5] discuss that when runners are asked to perform a prolonged run to exhaustion, frontal plane hip kinematics do not differ between populations with and without PFP. Both authors also report there is a marked decrease in the amount of hip abductor strength tested post-fatigue compared to pre-fatigue for the PFP group.[5,15] Dierks et al.[15] report that greater amounts of hip abduction were observed in the PFP population, while greater peak hip adduction was present in a healthy population. Additionally, Bazett-Jones et al.[5] found that kinematics remained the same between PFP and healthy runners, despite the decrease in hip abductor and hip external rotator muscle strength post-run. These authors note that significant increases in hip flexion, knee flexion, anterior pelvic tilt, and trunk forward flexion were all observed in the group exhibiting symptoms of PFP, suggesting there may be identifiable kinematic differences between healthy subjects and subjects with PFP.[5] Souza and Powers[55] also report that no kinematic differences exist in the hip for subjects with and without PFP, and while there were no differences in hip kinematics between the run and a SDT, there was an increase in gluteus maximus muscle activation in the PFP group. This could suggest that there may be compensatory strategies to stabilize the hip and reduce hip adduction and hip internal rotation in a group with PFP during a run. These compensatory patterns may be specific to muscle activation patterns and not easily identifiable with kinematic analysis.

During the SDT, subjects descended with knee adduction and hip abduction. Knee adduction observed was greater than reported during the run. The hip was in a position of adduction at the instant of treadmill-matched knee flexion during the SDT (TMKF-SDT), however while the joint angles may be similar to other literature, the joint movement pattern represented at the hip in the current study differs. While the hip was still in a position of adduction, it was more abducted at TMKF-SDT. There are several considerations that can be made on the increased hip abduction observed in this cohort at the instance of TMKF-SDT. First, while strength testing was not performed for this study, there is a small possibility that this cohort could exhibit greater hip abductor and external rotator muscle strength than a symptomatic population. Hip strengthening may influence the resting position of the hip, despite still adducting the hip during the step-down task.[3] Araújo et al.[3] suggest higher trunk and hip muscle strength can elicit changes in hip resting position and reduce overall hip adduction observed during a

SDT. The resting position observed in the hip before and after a strength-training intervention allowed the hip to rest in greater degree of abduction and external rotation than the values observed prior to the strength-training protocol.[3] Weakness in the hip abductors and external rotators has been shown to be a potential cause for PFP compared to subjects that are asymptomatic.[29]

Additionally, the subjects recruited for this study were healthy and active endurance athletes, and per the mileage classifications identified by Clermont et al.,[11] this cohort could be classified as a group of higher-mileage runners. It is possible that the differences observed in the hip at the instance of TMKF-SDT could be due to the hip musculature in this cohort being potentially stronger than the populations in other studies, allowing the subjects to better control the movement as they descend. This study did not test for strength, however, so it is not appropriate to make this conclusion without further investigation.

A more likely consideration that could be made is that the subjects in this study could be exhibiting a “compensated Trendelenburg sign” in an attempt to reduce the demand on the hip abductors during the beginning of the step-down task.[48] Powers[48] has discussed that pelvis stability may play a role in the amount of hip abduction observed in a subject performing a single-limb support task. Subjects may exhibit compensation due to hip abductor weakness by shifting the center of mass away from the stance limb, thereby increasing the varus moment at the knee.[48] This movement is identified by increased knee adduction, hip abduction, and trunk lateral flexion on the ipsilateral side. Frontal plane trunk motion was not statistically analyzed in this study, however, the subjects in this cohort did not exhibit compensation in trunk lateral flexion during the step-down task. Subjects in this study could be presenting the compensated Trendelenburg sign in an attempt to stabilize their center of mass over their stance leg as they begin the descent to the floor.

Compared to other literature, only one study is known to report the hip in a position of abduction during a SDT, however it is reported as a magnitude of displacement and not a peak value or a value at a specific time point. Shirey et al.[53] reported the amount of displacement and range of motion in hip abduction during a SDT for 14 healthy females, and reported a range as high as 15 degrees. While this study did not analyze the starting position of the joints prior to both conditions, the range of motion observed in Shirey et al.[53] is consistent with the magnitude of joint motion observed in the hip for this study.

In regards to the knee, similar movement patterns have been reported in studies testing with a single-leg squat, where knee adduction increased at the bottom of the squat.[69–71] These studies report peak knee adduction angles as high as 15 degrees.[71] While this study did not separate data by sex, the studies utilizing the single-leg squat report healthy males have a much greater amount of knee varus during testing compared to healthy females. These similarities are unsurprising because the TMKF-SDT angle was only 60% of the way down to the peak knee flexion observed, which would equate roughly to the same amount of knee flexion observed during most studies utilizing the single-leg squat instead of the SDT. One study utilizing the SDT found similar results in frontal plane knee motion, where knee adduction increased throughout the duration of the lowering phase of the SDT.[17] This observation of greater knee adduction during the SDT was reported to be higher in males than in females, however the range of these values were not different from the values found in this study. Similar to described by Zeller et al.,[71] females started in a position of knee valgus and then moved into a position of knee varus halfway through the descent during a deep single-leg squat.[17,71] Males, however, started in a position of slight knee varus and continued to exhibit knee varus throughout the entire single-leg squat movement.[17,71] This movement pattern may be related to the data in this study, where subjects started the movement with an adducted knee, and continued to adduct their knee throughout the step-down task.

The movement pattern in the hip at the point of treadmill-matched knee flexion during the step-down test may confirm speculation from other literature that the subjects performing the SDT may adduct their hip intentionally during the movement. This would allow the subject to extend their leg and get their foot to the ground easier and more efficiently to complete the task without requiring muscular demand to control the movement in the hip as they descend.[17,33,64] Hip adduction observed at HEEL-SDT may be due to what Lewis et al.[33] described as a result of the task and not a direct reflection of the subject's ability to control the movement as they lower. As the subject continued to the bottom of the SDT, knee adduction increased further while the hip adducted to a degree greater than that observed during the run and TMKF-SDT. The resultant joint angles for knee adduction are not representative of joint angles observed in studies reporting peak joint angles during a SDT, however hip adduction is consistent with the literature.[16,17,55] This may be due to multiple factors. First, these studies do not examine frontal plane motion of the knee and hip as variables dependent on the knee flexion angle or the point the heel touches the force plate. Instead, these studies investigated all peak joint angles, including peak knee adduction/abduction and peak hip adduction/abduction, throughout the down-phase of the SDT. This can make interpreting the risk of PFP difficult to deduce because it does not provide a clear guideline for where a clinician should be expecting the peak to occur during the SDT, or where during the task they should be most concerned with to get the information they need to help their patient. Second, these studies do not standardize the box height with one another, so box height differences may affect the differences in overall joint range of motion observed across studies. If each study design is determined to analyze peak joint motions, but the box they are testing is set to a different height, it could influence peak values observed. Especially in cases where peak knee flexion observed with a 24 cm box reaches 86.9 ± 8.3 degrees of knee flexion, while knee flexion observed from a 20.3 cm box reaches 59.5 ± 5.5 degrees of knee flexion in a healthy population.[16,33]

Lewis et al.[33] reported that variations in box height do not make joint angles significantly different and that movement patterns used by subjects remain consistent across step-down box height. Lewis et al.[33] further report that comparisons could therefore be made across slightly different step heights if the knee joint angle being analyzed was the same. If this were the case, it may not be necessary to test at multiple heights, and similar research could be comparable. This would also potentially make the data in this study more relatable to other data that has been produced because joint angles are reported at two very distinct points during the SDT. The results of HEEL-SDT support this statement. There was a strong correlation between the HEEL-SDT and PKF-RUN for the knee, suggesting that these two instances may be related. The results for the hip, however, were reported to have a fair correlation between HEEL-SDT and

PKF-RUN, suggesting that clinicians may need to be cautious when using the point of heel contact to gather information about their patient if they are examining the hip motion during the SDT, especially if the mean between these two conditions was significantly different.

The results for trunk flexion suggest that trunk kinematics between PKF-RUN and TMKF-SDT are not significantly different and are fairly correlated. Current literature discussing trunk flexion during a SDT is scarce. The trunk was investigated in this study because it has clinical implications. For instance, the aforementioned studies regarding a fatiguing protocol on PFP and pain free runners state that subjects compensating from PFP could exhibit excessive trunk forward flexion during a run.[5,14,15,44] Increases in sagittal plane trunk flexion has been discussed by Powers[48] as a mechanism to control demand on the lower extremity. An increase in forward trunk lean would move the ground reaction force vector more anteriorly during the task, resulting in greater demand on hip extensors and less demand on the knee extensors.[48] Powers[48] further discusses that a population exhibiting a more erect trunk posture would decrease the demand on the hip extensors and increase the demand on the knee extensors, allowing the knee and hip to respond to the load.[48] This statement has been supported in the literature, where increasing trunk forward flexion appears to increase demand on the hip extensors and decrease demand on knee extensors, regardless of sex,[60] thereby reducing the overall patellofemoral joint stress during running.[62]

The trunk flexion values did not change in this current study at TMKF-SDT, which may support the hypothesis that there were no differences between PKF-RUN and TMKF-SDT for sagittal plane trunk motion. During the run, this cohort exhibited a moderate amount of forward flexion that is representative of a self-selected flexion observed in Teng and Powers,[62] and still less than values observed in populations with high trunk flexion.[61] The angles observed at HEEL-SDT were greater than trunk flexion values observed during a SDT.[33] At HEEL-SDT, trunk flexion increased to values in the high-flexion range exhibited by Teng and Powers,[61] where the authors investigated differences in joint energy in relation to trunk motion. Teng and Powers[60–62] have observed in multiple studies that increasing forward trunk lean is directly related to reductions in the amount of stress on the knee, while a more upright posture or more extended posture are directly related to increases in the stress on the knee.

Numerous studies reporting frontal plane motion of the hip and knee have values in both the run or SDT that are greater in knee abduction, but similar for hip adduction, when compared to the present study.[5,11,12,16,17,28,44,55] The movement path exhibited in the current study at the point of TMKF-SDT is not consistent with the body of literature, suggesting there are periods of increased hip abduction during the SDT. Whatman et al.[64] have reported peak knee adduction and hip adduction values during a SDT similar to the range of motion the cohort in this study exhibited during the SDT at the point of TMKF-SDT and HEEL-SDT. Whatman et al.[64] state that the majority of the peak joint angles observed in the frontal plane occurred at some point during the mid-range and maximum knee flexion angle, which was reported to be at 91 degrees of knee flexion for their cohort.[64] The maximum knee flexion in this study was reported as 72.55 ± 6.09 degrees at HEEL-SDT, however, the peak knee adduction reported by Whatman et al.[64] was much less than the knee adduction reported in this study despite the knee flexion being greater. It could be likely that because the cohort in this study was healthy, and had a substantial amount of regular running experience, they experienced greater amounts of hip abductor and hip external rotator torque about the hip to stabilize the joint and pull the hip into abduction as they lowered to tap their heel. Subjects may be stabilizing the hip as they lower during the SDT, and subsequently dropping the hip to achieve the heel tap required during the task. Future research may require investigation of the internal and external rotation of the hip and knee, and frontal plane lateral flexion of the trunk to better understand the results exhibited from this cohort.

This is the first study of its kind that uses the point of peak knee flexion in running gait to analyze the frontal plane joint motion at the same knee flexion angle during a SDT. One consideration that can be made with the current study about the differences between the TMKF-SDT results and PKF-RUN is that the TMKF-SDT is a point identified only halfway through the movement of the step-down task, where the subject is at a point where they are beginning to respond to load as they descend. This instant is meant to reflect the very bottom of the loading phase in the knee during the run for each subject,[24,66] however, the way the body is controlling the load at the joint is different despite being the same instant of knee flexion. At the point of TMKF-SDT, the subject is continuing to respond and control the eccentric loading of the leg as they descend. While the joint motion in the knee at PKF-RUN and TMKF-SDT are statistically different, the mean values are only 2 degrees of motion apart from one another. Thus, a consideration for the strength of this relationship could be made in regards to utilizing the instant of knee flexion that matches the peak knee flexion observed during the run to predict the frontal plane motion of the knee during the SDT.

This study design selected healthy asymptomatic participants to better understand the normal kinematic patterns during the running protocol and how it related to the step-down. In order to gather more information about how the step-down task can be used to aid clinicians, more research is needed on a sample population dealing with PFP. A comparison between these two populations with the same study design could be useful in determining the strength of the relationship between the SDT in a healthy population when used for assessment for injury prevention, versus an injured population when used for assessing the source of pain.

Limitations

This study is not without limitations. There may be a potential error in the consistency of marker placement. In order to address this concern, marker placement for each subject was performed by the same investigator for each of the collections. The sample population in this study also included an age range of 40-45 years. This age range has been excluded from some studies investigating PFP due to a risk of knee osteoarthritis, however this cohort include higher-mileage runners and their inclusion was meant to provide more information to the body of literature investigating joint motion in masters-level runners. This sample population also reported broad training mileage, which could potentially influence the range of motion observed during the conditions if some subjects were significantly more or less trained than others. However, recruiting a population with a broad range in training volume could provide a better reflection of real-world comparisons. The treadmill speed for this cohort was standardized, which may have caused the kinematics to not be representative of the natural running pace for each participant, however, running speed was standardized in order to control for the confounding effects speed has on kinematic variables.

Conclusion

This study provides valuable information on how the step-down test is related to running kinematics. The current study indicates that there are differences in both the knee and the hip motion in the step-down test at the point where the heel makes contact with the ground, and the point of mid-stance during running. While the two movements are not identical, there is evidence to suggest they are associated with each other in the knee and trunk. Clinicians should be cautious when using the step-down test to gather information to help their patients, because the strength of this relationship between the two points does not necessarily imply that the movements are a direct reflection of one another.

Additionally, while a relationship exists between the mid-stance of running and the step-down test at the same knee flexion angle, this relationship is not strong enough to suggest the two movements are related. The information a clinician gathers from a patient performing the step-down test is not a direct reflection of the joint motions occurring during a run. More research is needed to strengthen the developing relationship between the kinematics observed at peak knee flexion during the run, and the point of heel contact during the step-down test. This information may provide a necessary link between the two movements. Strengthening information about this relationship could provide clinicians with more confidence in predicting the joint motions that would occur during a run when asking patients to perform the step-down test.

Recommendations

Functional performance tests for the lower extremity are researched with regard to their effect on factors surrounding populations dealing with an injury or discomfort. The SDT is used as a tool to assess pain and function in the ankle, knee, and hip. This study helps provide valuable information on how functional performance tests examining joint motion in the lower extremity are related to running kinematics. This information can sufficiently help and inform clinicians on how they can best continue to utilize an evidence-based practice approach to evaluation.

This study examined frontal plane knee and hip kinematics, and sagittal plane trunk kinematics, in healthy and active adults, and may serve as a foundation for normative range of motion in populations with healthy knee function. Future research should consider utilizing similar methods to a population dealing with PFP in order to provide more insight on the differences between typical and atypical joint motion for patients that are symptomatic and asymptomatic with PFP or other knee-related discomfort.

Chapter V

REVIEW OF PERTINENT LITERATURE

Running is continuously growing as one of the most common methods of regular exercise in the world.[6] As the sport becomes more accessible, so does the prevalence of running-related musculoskeletal injury, with the highest overall incidence of injury occurring in the knee.[25] The source of many of these injuries is still investigated, including the prevalence of patellofemoral pain (PFP).[1,5,7,15,18,19,54–56] The step down test (SDT) is a common test used in analyzing kinematics to determine the potential source of PFP that becomes present during a run.[4,55] Similar kinematics have been observed in individuals with PFP during a run,[44] however few studies exist that test the relationship between the SDT and the kinematics of running, specifically during the mid-stance phase of the run (MSTR) and at different points during the SDT that may provide insight for clinicians. This chapter will introduce the reader to relevant information about patellofemoral pain and the differences between healthy populations and populations with PFP during running and the SDT. This pertinent review of the literature provides evidence to support the testing protocol and procedures used in the current study.

Running-Related Injury

Running-related injuries are injuries that commonly affect athletes that are training specifically to the sport. They are typically considered to be common for runners because of a multitude of factors that are both intrinsic (poor flexibility, malalignment, anthropometry, previous injury, running experience, muscle weakness), extrinsic (training errors, old shoes, running surface), and due to the repetitive nature of running as a single-direction task occurring primarily in the sagittal plane.[24,30,37,58,66]

Weaknesses in abductor/adductor strength encouraging excessive movement in the frontal plane may be one of the major mechanisms responsible for running-related injury.[15,21,29] Repetitive-use injuries are commonly sustained during the stance phase of gait due to the amount of stress being exerted during the loading phase.[34]

Benca et al.[6] previously published a systematic review on the subject of injuries associated with running and their prevalence, along with the etiological and biomechanical factors associated with the injuries. The analysis reviewed sixty peer-reviewed articles cut down from 113 articles analyzing musculoskeletal injuries reported in the entire body for non-elite long distance runners. From this analysis, running-related injuries were sorted out by prevalence in the location in the body, where the highest incidence of injuries were reported to be in the knee. The most prevalent of injuries were identified as PFP (runner's knee), iliotibial band syndrome, medial tibial stress syndrome (shin splints), and plantar fasciitis. Lopes et al.[35] reported adverse findings in a systematic review of running-related musculoskeletal injury prevalence in 8 articles reduced from a pool of 2924 articles. Lopes et al.[35] found that the most prevalent injuries affecting their target population were medial tibial stress syndrome, Achilles tendinopathy, and plantar fasciitis were the most prevalent, with Achilles tendinopathy and PFP affecting the ultra-marathoning population. Overall incidence of these injuries were highest in medial tibial stress (22% of the population) and PFP (20% of the population). Despite these findings, Lopes et al.[35] state that no injury proved to be significantly more prevalent than others based off of the studies they reviewed unless they narrowed the scope of the volume of mileage ran in each of the studies and measured by the number of reported injuries per 1000 hours of running.[35] Similar findings have also been reported by van Gent et al.,[25] wherein the highest prevalence of injury present in the knee ranged anywhere from 7.2% to 50.0% in studies reporting the prevalence of injury, versus the foot (5.7% to 39.3%), upper leg (3.4% to 38.1%), and lower leg (9.0% to 32.2%). Even at the elite level, injury in the knee is still prevalent and considerably high.[59] A survey of 199 elite-level athletes running under elite regulation times in the marathon (2:35:00 for men and 3:00:00 for women) reported an incidence of injury as high as 75%, with many of the athletes reporting injury in multiple locations. The prevalence of knee pain is an issue that must be addressed as a larger percent of the population becomes invested in the sport each year.

Running and Patellofemoral Pain

Strength and fatigue

Individuals suffering from PFP have expressed gait characteristics that are different from healthy populations. Peak hip adduction coupled with hip internal rotation have been identified as being the most potential cause of knee pain,[44,55,56] as well as weakness in the hip abductors of the injured knee.[26,29,55] Dierks et al.[15] discuss that when runners with and without PFP are asked to perform a prolonged run, there is a noted difference in the amount of time the subjects with PFP are able to complete the run when compared to healthy runners. The runners dealing with PFP have a 10-minute average reduction in total run time when performing a prolonged run, where 60% of the runners with PFP had to stop the run protocol due to the amount of discomfort they were experiencing in the knee. In addition to run duration, strength testing before and after a run was tested in this study, and weaknesses in hip abductor strength were noted as run duration increased.[15] Evidence contrary to these findings in the PFP group have been reported, where exhaustive running appeared to have no effect in reducing hip adduction and hip internal rotation kinematics despite a significant decrease in strength as run duration increased for subjects with PFP.[5] These authors report significant increases in hip flexion, knee flexion, anterior pelvic tilt and trunk forward lean when compared to the control group. The authors discuss these findings may potentially offer insight into how runners may dramatically increase the amount of forward lean during an exhaustive run to reduce the amount of pain present in the knee to meet the demands of the running task.[5] These two studies operated under the same testing methodology despite reporting conflicting results. In the latter study, the subjects did not stop the exhaustive run due to knee pain, but were forced to stop due to ratings of perceived exertion, while subjects in the former study were noted to have stopped the run due to increasing levels of discomfort. The healthy population in the former study exhibited run times that continued for an average of 45 minutes, until they reached 85% of their heart rate max or a rate of perceived exertion of 18 or higher on a 20-point scale.[15] No healthy subjects ended the run due to knee pain and exhibited lesser amounts of hip adduction and weakness in hip abductor strength in either study,[5,15] however the latter study by Bazett-Jones et al.[5] reported that all healthy controls performed the run testing to match a specific PFP-group runner's testing. Despite this, all healthy controls in both studies exhibited greater run velocities during the run, greater run durations, less reported pain, less body mass, a lower age range, and a lower max heart rate at the time of stopping.[5,15] Similar findings to the aforementioned study by Dierks et al.[15] have been noted by multiple authors regarding decreases in hip strength and increased range of motion.[20,29] When isometric strength measurements were recorded for 15 females with PFP and compared to healthy controls, subjects with PFP demonstrated 26% less hip abduction strength and 36% less hip external rotation strength.[29] It is possible that these results support the reasoning that weakness in hip abductor and external rotator strength maybe be to blame for increased knee valgus witnessed during a run in sample populations dealing with PFP, however, while there is supporting evidence that strengthening the hip abductors may reduce pain and increase strength, Ferber et al.[21] reported evidence that peak knee valgus does not change after a training intervention. Fifteen men and women with PFP were put through a 3-week strengthening program focused on increasing muscle strength in the hip abductors. Subjects performed baseline strength testing and a treadmill run to measure differences in peak knee valgus, pain levels, and overall strength. Subjects with PFP demonstrated significantly weaker hip abductor strength and increases in stride-to-stride knee variability during a treadmill run when compared to healthy individuals. The authors report there were no differences between the groups in peak knee valgus angles at baseline. After the 3-week training intervention, subjects reported decreases in pain, decreases in stride-to-stride knee variability, and increases in hip strength. Peak knee valgus angles did not change, which could potentially be a cause of a training program not long enough to elicit kinematic adaptations from strength training, or that hip kinematics should not be expected to change during a strength training protocol.[69] Alternatively, it could also be a possibility that hip strength may not necessarily be a cause of PFP, but a result of PFP.[51] There is conflicting evidence to suggest that strength training may not be necessary to reduce the hip adduction and hip internal rotation witnessed during a run.[45] When kinematic feedback is provided to a sample population of 11 females with PFP over multiple training sessions, subjects are able to reduce the peak hip adduction and contralateral pelvic drop when running.[45] Gait retraining significantly reduced hip adduction and contralateral pelvic tilt during running after 8 sessions, and invoked a non-significant 23% reduction in hip internal rotation. Scores regarding pain and function also were remarkably less after the intervention as well, which seems to suggest that strength training with no changes in kinematics and gait retraining without strength training are both potential methods for reducing the severity of pain in the knee for runners with PFP. The investigation on gait retraining by Noehren et al.[45] could be limited due to multiple factors. First, the lack of a control population to examine in contrast with the intervention group severely limits the ability to trust the changes in the variables being tested. Secondly, these authors state that subjects were not allowed to run during the 2 week testing period, which could have a significantly greater effect on the reductions in knee pain over the intervention period than the actual intervention itself. By reducing the sample population's training volume from a reported 16.1 ± 5.5 miles/week (25.91 ± 8.85 km/wk) to four 15-30-minute sessions/week the authors could be unintentionally biasing their results.

Sex differences

Ferber et al.[20] examined sex-specific differences in runners to provide insight into the etiology of different injury patterns seen between men and women. Healthy male and female subjects were instrumented with motion capture markers and ran across a 25m runway onto a force plate at 3.65 $m \cdot s^{-1}$. When compared to healthy males, healthy females demonstrated greater hip adduction and knee abduction (knee valgus) throughout most of the stance phase, and absorbed greater amounts of energy at the hip joint during the loading phase of stance. In the transverse plane, women also expressed greater amounts of hip internal rotation and knee external rotation, and absorbed greater amounts of hip and knee energy compared to men.[20] Similar sex differences have been supported in the literature in a population with PFP, where male kinematics differ considerably from female kinematics.[70] Males with PFP have greater peak contralateral pelvic tilt than healthy male controls, but express no differences in peak hip adduction and peak hip internal rotation. Instead, males with PFP express greater increases in peak knee adduction and peak external knee adduction moments compared to male controls. When comparing males with PFP to females with PFP in the same study group, males exhibited greater peak knee adduction and less peak hip adduction, which may offer insights regarding the source of PFP being sex-specific.[70] Despite the differences observed in the hips for females and the knee for males, no differences are observed between sexes when investigating the differences between running mechanics and patellofemoral joint kinetics when operating under the same exhaustive running protocol that has been previously discussed.[5,15,68] Willson et al.[68] discuss that 18 healthy females and 17 healthy males do not express any sex-specific kinetic differences in peak patellofemoral joint contact force and stress, patellofemoral contact force and stress loading rates, hip adduction excursion, and hip and knee joint frontal plane angular impulse, but instead express an increase in all tested variables for all participants by a small but statistically significant amount at the end of the run.[68] If sex differences exist, it may be difficult to identify the differences between runners with and without PFP if sex differences are not considered in the analysis of the literature. If researchers are not capable of recruiting a large sample population, it is likely that they should recruit subjects by sex to limit the number of variables that may affect the outcome measures. In a review by Barton et al.,[4] research surrounding sex differences is regarded as being inconclusive, however, single-sex sample populations may still be necessary to contribute to identification of specific differences in females with and without PFP and males with and without PFP if a large enough sample population is not recruited. Barton et al.[4] suggest that there are still not enough studies with strong enough methodology to warrant the exclusion of one sex over another when analyzing the differences between healthy and unhealthy populations.

When examining a population of female runners with and without PFP, similarities in PFP and injury-free runners are present, where female runners with PFP still have a greater amount of hip adduction and hip internal rotation when running compared to healthy controls.[44,67] Contralateral pelvic tilt and contralateral trunk lean were not present with the observed increases in hip adduction and hip internal rotation in a female population with PFP. These hip and trunk mechanics may suggest that the subjects have poor hip control compared to their healthy counterparts, and compensate by shifting their trunk towards their stance leg to decrease the demand on their hip abductors when running.[44] When including additional forms of testing, the mechanics of the lower extremity remain consistent in females with PFP compared to healthy controls, where observed increases in knee external rotation, increases in hip adduction, and decreases in hip internal rotation remained consistent between groups performing single leg squats, a run, and repetitive single-leg jumps.[67]

A review of clinical gait characteristics of running discusses that the point of mid-stance during a run on a treadmill is typically identified by two kinematic time points: the point of the peak knee flexion angle in the sagittal plane, defined by the angle between the midline of the thigh and the midline of the leg, and the point of peak ankle dorsiflexion angle, defined by the midline of the leg relative to vertical.[24] Gallow and Heiderscheit[24] advise that research investigating the point of peak patellofemoral load should analyze the point of the MSTR because of the research Wille et al.[66] reported regarding the implications PKF has on identifying peak patellofemoral joint force and the risk of PFP. Wille et al.[66] investigated sagittal plane kinematic variables and how they reliably estimate ground reaction force and joint kinetics during running, and reported that the PKF angle may be useful in determining the maximum load on the knee joint during running.[66] While literature discussing PFP analyzes all of the peak joint motions occurring during the stance phase,[20,21,55,57] the point of PKF has been identified as the point of peak patellofemoral joint force occurring during a run,[24,66] and is therefore the point of running kinematics that this study will most concern itself with due to the focus this study has on understanding the relationship between running and the SDT for runners with and without PFP.

In lieu of the body of literature regarding running kinematics in runners with and without PFP, more research is needed. Barton et al.[4] suggests that many of the studies regarding subjects present with PFP are inconclusive and require stronger methodological designs and extensive data analysis to better-interpret and identify difference in kinematics of the knee, hip, and foot/ankle. Barton et al.[4] suggest that many studies lack a control, are single gender, have low mileage runners, or do not examine a necessary age range.

The Step-Down Test

As defined by Loudon et al.,[36] the step-down test (SDT) is a unilateral test performed from a platform. Subjects step forward and down toward the floor. The limb going down only brushes the floor with the heel and then returns to the starting position where the stance limb returns to full knee extension. This single-leg lowering-and-raising counts as one repetition. Each repetition must be completed such that the step limb is not used to accelerate back onto the step, but is controlled during the entire repetition from beginning to end for as many repetitions as required during testing. The test is typically meant to assess the source of knee pain and mimic the demands of weight-bearing sports on the entire lower limb kinetic chain, and is considered a typical form of functional performance testing to test the physical demands on the lower extremity to prevent re-injury.[10,23,33] The height of the box being used for the SDT has varied in the literature, with heights ranging from 15 to 24 centimeters (cm),[3,17,28,33,47] and in multiple cases being adjusted to 10% of the subject's body height.[1,31,55] The test has also been utilized as a method to mimic stair descent.[2,7–9,13,52] Researchers investigating knee pain in relation to stair ascent/descent have used a small set of stairs for analyzing knee pain,[7,13,52] or a single step,[2] with stair and step heights typically between 20 cm or 50% of tibia length.[7,13,52] A lateral SDT has also been used for similar purposes, with heights ranging between 15 and 30 cm,[27,46,49,50] and is considered to have reliable knee and hip joint kinematics with the forward-facing SDT that is more often cited.[64]

Clinicians may use the SDT in their practice to test for weakness or lack of control in the ankle, knee, and hip during the eccentric loading of the quadriceps.

Loudon et al.[36] have examined the SDT in conjunction with other tests to determine how reliable it is in a healthy population as compared to a population with PFP. The 4 alternative testing methods were the anteromedial lunge, the single-leg press, bilateral squat, and balance and reach test. All 5 tests were found to have no significant differences between limbs in a healthy population, with the SDT having the most limb symmetry when testing from a 20 cm box. When testing a group with PFP, there were significant differences for all within-group tests for the performance of the healthy limb and the PFP-involved limb, with the SDT having the most significant difference.[36] The SDT was found to be the only test that was significantly different between groups from 4 other testing methods used to analyze limb symmetry and pain in the knee using the visual analog scale for pain (VAS). As pain level decreased on the VAS, the number of repetitions of the SDT increased, and the SDT ultimately resulted in the highest level of reliability when compared to other tests. Loudon et al. state that the number of reps is not as important as the strength in symmetry between limbs, and the SDT is a reliable functional tool for clinicians when testing populations dealing with knee pain.[36]

Current research testing both running kinematics and the SDT in sample populations with and without PFP is limited. To date, only two articles exist that the authors are familiar with that expand on how running kinematics and the SDT are related to one another.[55,64] Whatman et al.[64] investigated differences between 5 functional performance tests and how they relate to running to determine whether clinical tests are related to running performance and whether they have within-day or between-day reliability. These authors found that within-day reliability is much higher amongst subjects performing SDT and running than between-day testing, especially in trunk lateral flexion. The authors also reported that there are correlations between the peak joint motions in the ankle, knee, hip, pelvis, and trunk that range from being strongest in the knee and hip to weakest in the trunk. There are major limitations to this study, however. Peak knee flexion in the SDT in their cohort was 91 degrees, which is not a direct reflection of the peak knee flexion that would be seen in a running population. The increase in peak knee flexion may be due to the height of the box, which was not standardized for subject height. Furthermore, these authors did not apply these methods to a population dealing with PFP, and they state that more research on the reliability of these tests to running should be done in a population with PFP.[64] Souza and Powers[55] reported on the relationship between running and the SDT in female runners with and without PFP. Subjects performed a run on a 15m walkway, a SDT from a box adjusted to 10% of their body height, and isometric hip strength testing on a separate day. These researchers found that the sample population present with PFP had significant increases in peak hip internal rotation with concomitant increases in gluteus maximus muscle activation, with weaker overall muscle strength during isometric testing. There were no reported differences in hip adduction between PFP runners and healthy runners, suggesting that runners with PFP could potentially be utilizing strategies to compensate for weakness in the hips by getting more gluteus maximus activation to pull the hip into external rotation.[55] It has been suggested in the literature that increases in hip internal rotation results in significant increases in patellofemoral joint contact pressure, which may be indicative of risk for PFP, or a potential cause of the presence of PFP, but more research is needed.[32]

When considering the joint motions expected during the SDT for healthy controls versus populations with PFP, healthy controls should expect less overall range of motion and less peak joint motion compared to a population with PFP.[36,55,56,64] The joint motions of the knee, hip, and trunk in a healthy population would exhibit less ipsilateral trunk lean, less contralateral pelvic drop, less hip adduction, and less knee abduction.[33,39,55] Lewis et al.[33] examined the differences between the SDT and an alternative functional test to examine how much range of motion might be anticipated during the SDT at two different step heights in a healthy population. Step heights of 16 cm and 24 cm were examined at peak knee flexion and 60 degrees of knee flexion with dependent variables being the joint motions of the knee, hip, and trunk in the frontal, sagittal, and transverse planes. The subjects of this cohort exhibited 72 degrees of peak knee flexion during testing on the 16 cm box, which was only 10 degrees different from the 60 degrees of knee flexion that was used as the second point of analysis. All joint motions were no more than 2 degrees apart at a 16 cm step height, however the 10 degree difference in knee flexion did encourage a 10 degree difference in hip flexion.[33] Peak knee flexion from the 24 cm box was as high as 86 degrees, which exhibited a 20 degrees increase in hip flexion at the same box height. Joint angles at 60 degrees when lowering from a 24 cm box were strongly correlated for every motion occurring in all three planes. Lewis et al.[33] reported that while the two step heights have differences in the peak joint motions, all of the joint motions occurring were still strongly correlated to one another, concluding that increasing box height may encourage increases in peak joint motion, but will not affect the expectation that a clinician should have on the joint motion that should occur in a healthy population if they do not have variable box heights available to them. Per the results of Lewis et al.,[33] as box height increases, a healthy population should exhibit slight increases in peak joint motion values, but should remain consistent in joint motion values if a clinician were analyzing the joint motions at a specific knee flexion angle. At peak knee flexion during a SDT, the knee should be slightly abducted and internally rotated, the hip should be in flexion relative to the demand from the step height and in adduction and external rotation. The pelvis should be anteriorly tilted, and may drop slightly depending on step height, while the trunk may be leaning forward slightly and should be leaning towards the stance leg to maintain stability and control of the center of mass as the subject lowers to perform the task.[33]

The step-down test and patellofemoral pain

Research surrounding sex differences between runners with and without PFP have been generally accepted by researchers.[1,7,20,55,56] Studies surrounding the SDT therefore do not typically include male participants.[1,7,28,55] Females, however, have shown to not only be more susceptible to PFP, but have also been reported to have kinematic differences between individuals that are healthy and individuals that are present with PFP.[20] Most studies investigating PFP using the SDT are therefore limiting the research to female subjects. As previously stated, a review of the literature surrounding the SDT refutes the omission of men in studies,[4] arguing that a review of the literature shows that only 10 out of 24 acceptable studies investigating PFP looked at sex differences, wherein many of these differences were weak or required further investigation to fully understand what differences could be identified. Some studies investigating kinematics in females during running or a SDT also do not have a sample population of controls to compare the effects of the intervention, limiting the validity of their results.[1,28,49,63]

An 8 week strength training program may have potential to reduce excessive range in shank, hip, and pelvis range of motion.[3] A study by Araújo et al.[3] investigate the differences in shank, hip, and pelvis kinematics when 16 subjects undergo a strength training program requiring them to perform 3 sessions/week for 8 weeks with lifts set at up to 80% of the subject's 1-repetition max. Subjects performed 3 sets of 8 reps during each sessions and if they were able to do two consecutive sets of 9, the trainer would increase the load by 5-10%. This is the longest study examining a strength training intervention with higher loads, and while there was not a group present with PFP in this study, the authors recruited females with a presence of high dynamic knee valgus during a SDT.[3] They report that the intervention group exhibited significant changes in the resting position of the hip, such that the hip was more laterally rotated after strength training. The authors also found significant decreases in shank abduction during the SDT and decreases in thigh and hip adduction, suggesting that heavier loads and longer strength training intervention periods may have an effect on dynamic knee valgus during a SDT.[3] More research on applying these methods to a population with PFP is needed to provide insight on how it may affect discomfort and pain after intervention. A second study involving the use of a SDT to determine if hip muscle strength and range of motion could provide insight on if individuals with PFP may be lacking in flexibility, strength, or both.[47] Two raters scored subjects during a SDT based on movement quality, and then strength and flexibility testing were performed. Park et al. reported that subjects with good movement quality had higher amounts of strength in the hip than subjects with moderate or poor movement quality, however the number of participants rated with poor movement quality was 1.[47] While Park et al.'s[47] study involving hip muscle strength and quality of movement provides insight on how individuals with PFP may have pain and discomfort due to the level of flexibility and strength in the hip, the sample population is asymptomatic and their testing protocol is not objective. Clinicians may be able to infer on their own what good, moderate, and poor range of motion is during a SDT, however there is no research to date that provides a defined range of motion that identifies someone at higher risk for PFP. More research is needed to help clinicians achieve an evidence-based practice approach to benefit the patient and the physical therapy profession.

Stair ascent/descent

When ascending and descending stairs, individuals with PFP do not display significantly different kinematics from healthy populations.[2,7,8,13,52] While there are no major kinematic differences, there are noticeable differences in hip strength and torque between populations with and without PFP. Bolgla et al.[7] investigated stair descent for a population with and without PFP and reported subjects with PFP generate 24% less hip external rotation torque and 26% less hip abductor torque, with no differences in hip frontal and transverse plane movement.[7] Interestingly enough, Bolgla et al.[7] provide data suggesting their sample population had a trend to significance in the amount of hip and knee movement, where subjects with PFP had more knee varus and less hip adduction than the control group, despite having weaker hip abductor and hip external rotator musculature. It could be likely that stair descent offers subjects with PFP potential strategies to compensate during the slow-lowering task, however this is not confirmed because Bolgla et al.[7] did not include the use of a visual analog scale (VAS) to assess pain and discomfort before and after testing. Schwane et al.[52] included the VAS to assess PFP individuals and found that pain and discomfort is higher at pre-test compared to controls, and does increase at post-test. As previously stated, Schwane et al.[52] did not observe major kinematic differences in subjects with and without PFP during stair descent when analyzing the trunk and hip, however they did report a 30% difference in knee internal rotation displacement with the PFP group. Post-hoc analysis of the knee kinematics report that peak knee internal rotation was not different, however peak knee external rotation was, suggesting the group with PFP may be making initial contact with a slightly more externally rotated knee and achieving a slightly greater peak knee internal rotation.[52]

The amount of torque and muscle activation surrounding the knee in stair descent may provide insight into the demand on the knee and hip flexors during the lowering-phase. Patients present with PFP present differences in the quadriceps muscle activation timing to activation[13] and isokinetic performance.[2] When subjects are asked to perform both stair ascent and descent during testing, groups with PFP have slightly less peak knee flexion during stair descent with an increased amount of time in delayed vastus medialis oblique activation compared to healthy controls. This finding may suggest subjects with PFP perform potential strategies to reduce strain on the knee during stair ambulation.[13,32] This could be due to a person's ability to smoothly control and activate the quadriceps when applying the eccentric load to the muscle during stair descent, and may be a potential factor involved in breaks and perturbations in quadriceps isokinetic torque seen in subjects with PFP compared to healthy controls.[2]

Breaks, in this case, are defined as 10% drops in smoothness of a torque curve in angular velocity during isokinetic testing of the knee, while perturbations are described as breaks that do not exceed the 10% dropping moment.[2] Furthermore, the decreases found in peak knee flexion during the stance phase of the stair descent reported in Crossley et al.[13] may be potentially due to the earlier increases in peak patellofemoral joint stress found in subjects with PFP.[8]

It is important that a clinician take into consideration that there may be differences in variability in the PKF angles during the MSTR and SDT for every patient,[20,33] and that these differences may affect the reliability of the SDT being utilized as a functional screening test. As previously mentioned by Loudon et al.,[36] the SDT is beneficial because it requires very little space in a clinic to perform the test, it requires very little equipment, is cost-effective, and it does not require the patient to perform a running task to be helped. It is important to note however, that if a clinician does not watch a patient run, there is no way for them to know what an expected PKF angle would be for the person's gait, and can make it difficult for them to determine which point of knee flexion should be analyzed during the SDT. If there is a strong relationship between the joint motions of the knee, hip, and trunk at varied box heights,[33] a clinician should be able to use the PKF of the SDT to get an accurate and reliable understanding of what is happening for the patient during a run. The relationship between the PKF of running must therefore be tested at the same point of knee flexion during the SDT, and then compared with the PKF during the SDT. Information on the reliability of testing the PKF during a SDT compared to the PKF during the run would provide insight on if clinicians should be analyzing the very bottom of the SDT or at a specific point during the slow-lowering phase of the task.

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Appendices

Appendix A

Journal of Orthopaedics and Sports Physical Therapy
https://www.jospt.org/

Manuscript Formatting Guide:
The following is a guide to the way in which the *JOSPT* formats articles in MS Word.

General Requirements

All manuscripts must meet the following basic requirements to be eligible for review by *JOSPT*®.

- Written in English
- Include a cover letter
- Present findings or data that have not been previously published either in print or electronic (online) format or widely disclosed in a form other than published abstracts of oral presentations at scientific conferences and meetings
- Undergoing exclusive review by *JOSPT*
- Address scientific, clinical, or professional issues relevant to musculoskeletal or sports-related physical therapy practice
- Written in accordance with the recommendations found in the ***Uniform Requirements for Manuscripts Submitted to Biomedical Journals: Writing and Editing for Biomedical Publication*** by the International Committee of Medical Journal Editors, April 2010 (http://www.icmje.org/urm_main.html and http://www.icmje.org/urm_full.pdf)
- Formatted according to AMA style guidelines (*American Medical Association Manual of Style, 9th Edition*)

Submissions that do not meet the above essential requirements will be returned to the author without review. For additional guidance, please review *JOSPT*'s **Author and Reviewer Tools**.

NOTE: In the peer-review process, *JOSPT* reviewers are unaware of the author's identity and institutional affiliation. Associate editors are not blinded to author identity and vice versa.

Protection of Human Subjects

The name of the Institutional Review Board or Ethics Committee that approved the research protocol involving human subjects must be included on the title page and in the Methods section. The Methods section must also contain a statement that informed consent was obtained and that the rights of the subjects were protected.

It is mandatory that clinical trials initiated on or after January 1, 2013 be prospectively registered in a public trials registry. In these cases, authors should provide the name of the registry and the registration number on the title page. For clinical trials initiated prior to January 1, 2013, prospective clinical trial registration is desirable but not mandatory.

When required by the appropriate Institutional Review Board or Ethics Committee, case reports should include either a statement that each subject was informed that data concerning the case would be submitted for publication or a statement indicating approval by the Board. In all cases, patient confidentiality must be protected.

Use of Animals

Manuscripts with experimental results in animals must include a statement on the title page and in the Methods section that an animal utilization study committee approved the study.

Use of Cadavers

When applicable, manuscripts with experimental results on cadavers must include a statement on the title page and in the Methods section that a relevant utilization study committee approved the study.

Preparing Your <u>NEW</u> Manuscript

All manuscripts submitted to *JOSPT* should be double-spaced and have 2.54-cm (1-in) margins on all sides of the page. Pages should be consecutively numbered, starting with the title page. Pages should be continuously line numbered, with line numbers starting at 1 on the abstract. The font should be 12-point Arial, Times New Roman, or Courier. All measurements in the manuscript should be presented in SI units, except for angular measures, which should be presented in degrees rather than radians.

The manuscript should be arranged as follows:

Title Page (separate page)

- Title of manuscript
- Names of each author with their highest academic credential (i.e., PhD), or most relevant professional designation (e.g., PT), or both (e.g., PT, PhD). Limit credentials to these 2 items only
- Institution, city, state/province, country for each author
- Statement of the sources of grant support (if any)
- Statement of Institutional Review Board or Ethics Committee approval of the study protocol
- Name of the public trials registry and the registration number
- Corresponding author's name, address, and e-mail address

Anonymous Title Page (separate page)

- Title of manuscript
- Statement of financial disclosure and conflict of interest (see item 6 of the **Author Agreement and Publication Rights Form**)
- Acknowledgements (on a separate page)

Abstract

- **Structured Abstract:** *<u>Research reports (including systematic literature reviews) and brief reports</u>* require an abstract containing a maximum of 250 words, divided into 6 sections with the following headings in this order: Study Design, Background, Objectives, Methods, Results, Conclusion. Abstracts for *case reports* should have 5 sections with the following headings and order: Study Design, Background, Case Description, Outcomes, and Discussion. Abstracts for *resident's case problems* should have 4 sections with the following headings and order: Study Design, Background, Diagnosis, and Discussion.

- **Unstructured Abstract:** *Clinical commentaries and narrative literature reviews* require an abstract (called synopsis) that is not structured and that contains a maximum of 250 words.
- **All abstracts should include, where appropriate, a line item called "Level of Evidence,"** which indicates the study type and level of evidence, according to the classification system listed at the Oxford Centre for Evidence-based Medicine website (http://www.cebm.net). This final line in the abstract should be in the following format example: "Level of Evidence: Therapy, level 2a." When the study does not fit any of the study type and level of evidence descriptors included in the above classification system, this line may be omitted. A list of suggested study design names and the Oxford Center for Evidence-Based Medicine levels of evidence table are provided for reference **here**.
- **All abstracts should end with a Key Words section,** containing 3 to 5 key words that do not appear in the manuscript title.

Text

- *Research reports, systematic literature reviews, and brief reports* require the body of the manuscript to be divided into 5 sections: Introduction, Methods, Results, Discussion, and Conclusion.
- *Case reports* require the body of the manuscript to be divided into 4 sections: Background, Case Description, Outcomes, and Discussion.
- *Resident's case problems* require the body of the manuscript to be divided into 3 sections: Background, Diagnosis, and Discussion.
- *Clinical commentaries and narrative literature reviews* do not have specific mandatory subdivisions or sections.

For all of these manuscript categories except brief reports, the text should be less than 4,000 words and be supplemented by a reasonable number of figures and tables. Brief reports should be less than 2,000 words (excluding no more than 20 references) and have no more than 4 tables or figures.

Key Points

The brief Key Points section of the manuscript is needed for *research reports only, including systematic literature reviews*. Key Points should be provided at the end of the text, prior to the references. These points should be written in user-friendly language, consist of brief sentences, and summarize the most important information related to the findings, implications, and caution directly resulting from the work. These 3 subheading should be used:

- **Findings:** One or 2 statements on what the study adds to current knowledge.
- **Implications:** A statement on how the results impact clinical practice or research on this topic.
- **Caution:** A statement on the most important limitations of the study, especially external validity (what may prevent wide utilization of the results).

References

- References should be numbered consecutively in alphabetical order, according to author last name and initials, title, and year. Where the first-author names are identical, references with 1 author precede those with multiple authors. Where all the author names are identical, the title is the next ordering component, followed by the year.

- All references in the References section must be cited in the text.
- References must be cited in the text by using the reference number in superscript at the end of the sentence or the referenced portion of the sentence. The reference goes after the author's name when the author's name is listed (e.g., Davies[1]). If there are only 2 authors in the reference, then the text should include both authors (e.g., Davies and Ellenbecker[1]). If the reference has more than 2 authors, the text should include "et al" after the first author's name (e.g., Davies et al[1]).
- In the Reference section, when a reference has 7 or more authors, list the first 3 authors, followed by "et al."
- References must include only material that is retrievable through standard literature searches. References to papers accepted but not published or published ahead of print should be designated "in press" or use the PubMed/MEDLINE [Epub ahead of print] status until an updated citation is available. Doctoral and master's theses are considered published material. Information from manuscripts not yet accepted for publication and personal communications will not be accepted. The use of abstracts and proceedings should be avoided unless they are very recent and the sole source of the information.
- Abbreviations for the journals in references must conform to those of the National Library of Medicine in Index Medicus (http://www.ncbi.nlm.nih.gov/journals).
- References that have CrossRef Digital Object Identifiers (doi) should include them at the end of the citation.
- References must be verified by the author(s) against the original documents.

Reference style and punctuation should conform to the examples that follow:

Journals
Wilson T. The measurement of patellar alignment in patellofemoral pain syndrome: are we confusing assumptions with evidence? *J Orthop Sports Phys Ther* 2007;37(6):330-341. http://dx.doi.org/10.2519/jospt.2007.2281

Books
Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice.* 3rd ed. Upper Saddle River, NJ: Prentice Hall Health; 2009.

Organization as Author and Publisher
US Food and Drug Administration. Guidance for industry: patient-reported outcome measures: use in medical product development to support labeling claims. Rockville, MD: FDA; 2006.

Chapter in a Book
Jones MA, Rivett DA. Introduction to clinical reasoning. In: Jones MA, Rivett DA, eds. *Clinical Reasoning for Manual Therapists.* Edinburgh, UK: Butterworth-Heinemann; 2004:3-24.

Master's or Doctoral Thesis
Langshaw M. *Cervical Spine Mobilisation: The Effect of Experience and Subject on Dose* [thesis]. NSW, Australia: The University of Sydney; 2001.

Published Abstract of a Paper Presented at a Conference
Chen YJ, Powers CM. The dynamic Q-angle: a comparison of persons with and without patellofemoral pain [abstract]. Proceedings of the North American Congress on Biomechanics. Ann Arbor, MI: 2008.

Universal Resource Locator (URL)
NFHS Associations. 2007-2008 National Federation of State High School Associations Participation Survey. Available at: http://www.nfhs.org. Accessed May 17, 2010.

Paper Presented at a Symposium

Nelson-Wong E, Gregory DE, Winter DA, Callaghan JP. Postural control strategies during prolonged standing: is there a relationship with low back discomfort? American Society of Biomechanics Annual Conference. Palo Alto, CA: American Society of Biomechanics; 2007.

Preparing Your Tables and Figures

Tables

- Each table must be self-contained and provide standalone information independent of the text.
- See *AMA Manual of Style* (9th ed.), section 2.13, to organize and format tables.
- Table titles should list the table number in uppercase bold (e.g., "**TABLE 1.**"), followed by a period, then the title of the table in sentence case.
- Abbreviations used in each table must be spelled out below the table.
- Footnotes must be listed below the table, after the abbreviations, in order of occurrence in the table (left to right, row to row). According to AMA style, footnotes are cited with the following superscript symbols in this order: *, †, ‡, §, ||, ¶, #, **, ††, ‡‡. Where these symbols are unavailable, superscript numbers may be used.
- All tables must be referred to somewhere in the text.
- All tables go after the reference list.

Figures

- Figure captions should list the figure number in uppercase bold (e.g., "**FIGURE 1.**") followed by a period, and continue with the text of the caption in sentence case.
- All abbreviations appearing in the figures should be defined in the caption for each respective figure, and abbreviations appearing only in the figure caption must be defined at first use.
- Digital figures must be at least 350 dots per inch (dpi).
- Charts and graphs generated from spreadsheet programs must accompany, or allow access to, the data.
- Photographs must be in JPEG file format (JPG) and graphic art in GIF file format and at a resolution of at least 350 dpi.
- All figures must be referred to in the text.
- Each view (e.g., A, B, C) within the figure must be defined in the figure caption.
- Color figures and graphics are welcome.
- All figures go after the tables at the end of the manuscript.

Preparing Your Supplementary Material

Videos

Authors may wish to consider including supplemental videos to be published online with their manuscript. These videos can describe intervention or examination techniques as well as surgical procedures or other material pertinent to the manuscript. Intent to include videos may be mentioned in the cover letter with the initial manuscript submission or may be discussed with the editor-in-chief once the manuscript is accepted.

Videos should be:

- MPEG-1, MPEG-2, or AVI files
- No longer than 2.5 minutes
- Introduced with a title screen and include audio narration

There is no limit on the number of videos that may be submitted with a manuscript.

Additional Required Documents

For manuscript submissions to qualify for review, the following documents must be submitted along with your manuscript on *JOSPT*'s manuscript submission website here or sent directly to the editorial office by e-mail (manuscripts@jospt.org), mail (*JOSPT*, 1033 N Fairfax St, Ste 304, Alexandria, VA 22314-1540), or fax (703-891-9065):

- **Author Agreement and Publication Rights Form:** This document must have original signatures of all authors. Author signatures may be on separate copies or 1 copy of the form.
- **Photograph/Video Release Statement:** Signed photograph/video release forms should accompany photographs/videos of patients and subjects. A photograph/video release statement should contain the following (1) manuscript title; (2) names of all authors; (3) statement placed below the manuscript title and author names as follows: *"I hereby grant to the Journal of Orthopaedic & Sports Physical Therapy the royalty-free right to publish photographs and/or videos of me for the stated journal and the above manuscript in which I appear as subject, patient, or model, and for the stated Journal's website (www.jospt.org). I understand that any figure in which I appear may be modified."*; and (4) the original signature and date signed by each subject who appears in the figures.
- **Patient/Author Release Statement:** A release form should accompany all Musculoskeletal Imaging cases, Case Reports, and Resident's Case Problems. This release must be signed either by the patient/subject or by the submitting author, accompanied by a proxy declaration by the author(s) that all necessary efforts have been made to ensure that Standards for Privacy of Individually Identifiable Health Information have been upheld, and that the author accepts any and all liability for any failure to uphold the necessary Standards for Privacy of Individually Identifiable Health Information in the final version of the manuscript. The release statement should contain the following: (1) manuscript title; (2) names of all authors; (3) a statement from the submitting author, placed below the manuscript title and author names, as follows: "I hereby declare that the patient/subject has granted the author(s) permission to report his or her case in this report; or, in the absence of such permission, that all necessary efforts have been made to ensure that Standards for Privacy of Individually Identifiable Health Information have been upheld, and accept any and all liability for any failure to uphold the necessary Standards for Privacy of Individually Identifiable Health Information in the final version of the manuscript"; and either (4a) the original signature and date signed by each patient/subject presented in the report or: (4b) the original signature and date signed by the submitting author. This original signed statement must be submitted to the JOSPT office with the manuscript. Important notes on the Standards for Privacy of Individually Identifiable Health Information, from the US Department of Health & Human Services, can be found here under De-Identified Health Information.

Preparing Other Contributions—Musculoskeletal Imaging, Letters, Invited Commentaries

- **Musculoskeletal Imaging:** This feature focuses on the use and interpretation of medical imaging related to a case scenario relevant to musculoskeletal or sports physical therapy practice. In most instances, these cases will emphasize how information from imaging can affect physical therapy management of the patient. In some instances, however, this feature may be used to share information on unusual medical conditions, or to simply illustrate commonly used imaging techniques and their interpretation. Contributions should include no more than 3 authors, 250 words, 3 figures, and 3 references (if any). See the Figures section above for instructions on preparing the images for submission.

- **Letter to the Editor-in-Chief:** Letters should relate to professional issues or articles published in the *Journal*. Letters will be reviewed and selected for publication by the editor-in-chief based on the relevance, importance, appropriateness, and timeliness of the topic. Letters to the editor-in-chief are copy edited, and the correspondent is not typically sent a version to approve. Letters should include a summary statement of any conflict of interest, including financial support related to the issue addressed.
- **Invited Commentary:** Invited commentaries are expert points of view concerning articles published in *JOSPT*. Commentaries are invited by the editor-in-chief and immediately follow the article discussed. Authors of the manuscript under commentary are given the opportunity to respond to the expert's point of view.

Preparing Your REVISED Manuscript

When the editors suggest that a manuscript be revised and resubmitted, the same guidelines outlined above for the preparation of the original manuscript apply. All resubmitted manuscripts must be accompanied by a cover letter. The cover letter must include a list of all revisions made in response to suggestions from reviewers and editors contained in the review materials provided to you by the editorial office. Changes made to the text and tables must be highlighted in the manuscript.

Manuscript Checklist

When submitting a new or revised manuscript, please use the checklist below to ensure you have included the following items in your submission:

COMPLETED (yes/no/NA)	ITEM
	Cover letter identifying the phone, fax, and e-mail address of the corresponding author and the manuscript category
	Author Agreement and Publication Rights Form(s) with original signatures of all authors
	Photograph/Video Release Statement signed by the individual(s) in the photograph/video
	Patient/Author Release Statement signed by either the patient/subject or the submitting author
	Full title page and anonymous title page including a statement of financial disclosure and conflict of interest
	Name of the Institutional Review Board or Ethics Committee that approved the protocol for the study on the title page
	Name of the public trials registry and the registration number on the title page, if applicable
	Statement in the Methods section that informed consent was obtained and the rights of subjects were protected
	Properly structured abstract

	Line numbering for each page of the manuscript
	References listed and numbered in alphabetical order and cited with superscripts in the text
	Inclusion of the appropriate checklist (e.g., CONSORT, STARTD, PRISMA), if applicable

A.)

Joint Motions of the Knee, Hip, and Trunk During a Single-Leg Step-Down Test and Running

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The study protocol was approved by the Institution Review Board of the Western Washington University Health and Human Development department, Bellingham, WA.

The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

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B.)

Study Design: Randomized repeated-measures observational study.

Background: The step-down test has been utilized as a tool for assessing risk of injury to the lower extremity for runners with and without patellofemoral pain. However, there is a paucity of evidence on this relationship in individuals that run, and the link between the two movements is not well-defined. The strength of the relationship between kinematic variables at the knee, hip, and trunk during a single-leg step-down test (SDT) and running is unclear in the literature.

Objectives: To investigate the relationship between the SDT when compared to the mid-stance of running in healthy individuals.

Methods: Twenty-five subjects (12 male, 13 female) participated in the study; mean ± SD age, 32.8 ± 5.9 years; height, 173.9 ± 8.7 cm; body mass, 70.84 ± 11.3 kg; run volume, 59.5 ± 30.4 km/wk; cadence, 173.1 ± 11.5 steps/min). Dominant leg peak knee flexion was identified during the run (PKF-RUN) and used to find frontal plane knee and hip, and sagittal plane trunk angles. The same treadmill-matched knee flexion angle for the run identified the knee flexion angle during the SDT (TMKF-SDT). Joint angles were also identified at the point of the SDT where the heel made contact with the ground (HEEL-SDT). Two separate two-tailed paired samples *t*-tests were used to analyze the difference between the means of each test condition and Pearson Product Moment Correlation coefficients were computed for each condition.

Results: Statistics revealed significant differences in frontal plane knee and hip angles between PKF-RUN (6.18 degrees ± 8.90) and TMKF-SDT (8.13 degrees ± 8.88), $t(24) = -2.21$, $p = 0.037$ for frontal plane knee adduction, and; PKF-RUN (11.14 degrees ± 3.22)

and TMKF-SDT (6.48 degrees ± 4.53), $t(24) = 6.17$, $p < 0.0001$ for hip adduction. There were significant differences between mean PKF-RUN (6.18 degrees ± 8.90) and HEEL-SDT (16.65 degrees ± 12.60), $t(24) = -6.79$, $p < 0.0001$ knee adduction, and; PKF-RUN (11.14 degrees ± 3.22) and HEEL-SDT (17.84 degrees ± 5.63), $t(24) = -6.45$, $p < 0.0001$ for hip adduction. No significant differences were found between mean PKF-RUN (6.44 degrees ± 3.67) and TMKF-SDT (6.33 degrees ± 6.46), $t(24) = 0.104$, $p = 0.918$ sagittal plane trunk forward flexion. There were significant differences between mean PKF-RUN (6.44 degrees ± 3.67) and HEEL-SDT (10.32 degrees ± 10.04), $t(24) = -2.19$, $p = 0.039$ trunk forward flexion. Correlations between PKF-RUN and TMKF-SDT were strong in the knee ($r = 0.88$, $p < 0.0001$, $R^2 = 0.768$) and moderate in the hip ($r = 0.57$, $p = 0.003$, $R^2 = 0.325$). Correlations between PKF-RUN and HEEL-SDT were strong in the knee ($r = 0.80$, $p < 0.0001$, $R^2 = 0.634$) and fair in HABD ($r = 0.42$, $p = 0.038$, $R^2 = 0.175$). For the trunk, correlations between PKF-RUN and TMKF-SDT were moderate ($r = 0.53$, $p = 0.006$, $R^2 = 0.285$) and correlations between PKF-RUN and HEEL-SDT were fair-to-moderate ($r = 0.49$, $p = 0.014$, $R^2 = 0.237$).

Conclusion: Results of this study suggest there are kinematic differences between the SDT and running. Differences observed could be due to differences between the demands on the lower extremity during the tasks. Further investigation should compare the relationship between the SDT and mid-stance of running for frontal plane pelvis and trunk kinematics, and make considerations for hip strength and muscle activation between the two conditions.

Level of Evidence: Screening, level 2g. *J Orthop Sports Phys Ther 2018;xx(x):xxx-xxx.*

Key Words: *kinematics, knee pain, patellofemoral pain, physical therapy*

Appendix B

Subject Entrance Form

Subject ID: ________________
Date: ________________

Informed Consent: [ ] Collection Order: C1 - Run C2 - Step Down

History:

Age: ________________ History of Knee Pain: Yes No

Present in: Left Right Scale of Pain: 1 2 3 4 5 6 7 8 9 10

Gender: Male Female Average Running Volume (miles/week): ____________

Footwear Make: _________ Model: _________ Stack: _________ Drop (mm): _________

Segment Distances:

Height (cm): ____________ Height (mm): ____________ 10% of Height (cm): ____________

Weight (kg): ____________ Box Height (cm): ____________ Dominant Leg: Left Right

	Left Side:	Right Side:
Leg Length (mm):		
Knee Width (mm):		
Ankle Width (mm):		
Inter-ASIS Distance (mm):		

Warm-up: Force Treadmill

3 Minutes at 6 MPH on Treadmill (10 min pace), then 2 Minutes at 6.6 MPH (9:05 pace)
5 Minutes of Dynamic Stretching [ ]

Initial Contact Pattern: Rearfoot Midfoot Forefoot

Dynamic Stretches (30 seconds each side):
- Hamstrings, knee grabs [ ]
- Quads, foot grabs [ ]
- Hips, foot grab w/ external rotation [ ]
- Calves, lean against wall, pulses [ ]
- Hip Flexors/Groin, lunge leg forward, lean forward at hips [ ]

Instrumentation: Kinetics, Kinematics, Electromyography

Vicon 3D calibrated (< 2mm margin of error). [ ]
Force plate on and calibrated. [ ]

Electromyography, Electrode Placement:

Circle the Instrumented Side [ ]

	Lower Body:	*Left 1-5*	*Left 6-10*	*Right 1-5*	*Right 6-10*	*MVC*
1.	Tensor Fascia Latae	– 200 C	– 2015	– 200 C	– 2015	[ ]
2.	Gluteus Medius	– 200 D	– 2016	– 200 D	– 2016	[ ]
3.	Biceps Femoris	– 200 E	– 201 A	– 200 E	– 201 A	[ ]
4.	Gluteus Maximus	– 200 F	– 201 B	– 200 F	– 201 B	[ ]
5.	Vastus Lateralis	– 2010	– 2040	– 2010	– 2040	[ ]

Kinematics, Marker Placement:

Upper Body:

Clavicle (jugular notch)	[ ]
Sternum (xiphoid process)	[ ]
C7	[ ]
T10	[ ]
Right Scapula (spine)	[ ]

Lower Body:	Left Side:	Right Side:
ASIS	[ ]	[ ]
PSIS	[ ]	[ ]
Thigh (L: lower 1/3, R: upper 1/3)	[ ]	[ ]
Knee (lateral joint space)	[ ]	[ ]
Shank (L: lower 1/3, R: upper 1/3)	[ ]	[ ]
Lateral Malleolus	[ ]	[ ]
Heel (posterior of calcaneus)	[ ]	[ ]
Toe (2nd Met., proximal)	[ ]	[ ]

Equipment Calibration/Normalization:

Electromyography: MVC [ ]

Kinematics: Standing trail (motorcycle pose) [ ]

Condition 1: Running Protocol

10 Mins of running on force treadmill at 6.6 MPH (9:05 min/mi pace) [ ]

Record on last 15 seconds of each minute after 5 minutes of running.

Practice		[ ]
1	5:45	[ ]
2	6:45	[ ]
3	7:45	[ ]
4	8:45	[ ]
5	9:45	[ ]

Condition 2: Step-Down Protocol

5 Trials of Step-Down on each leg. Box Adjusted to 10% of Body Height: [ ]

Box Height (cm): _____________

Practice [ ] [ ] [ ]

Trial #	Left Leg	Right Leg
1	[ ]	[ ]
2	[ ]	[ ]
3	[ ]	[ ]
4	[ ]	[ ]
5	[ ]	[ ]

Cool-down: COP Treadmill

3 Minutes at 2.5 MPH (24 min/mi pace). [ ]

Appendix C

Western Washington University
Informed Consent

Motions of the Hip and Knee during Single-Leg Step-Down Test and Running

Purpose and Benefit:

This research aims to examine the relationship of the leg motion between the single leg step down and running. The connections between the motion of the leg and knee pain and ligament injuries, particularly, are still being investigated world-wide. Due to the influence of the hip muscles on knee position, this study will help better understand the motion of the leg during a functional test and running.

I UNDERSTAND THAT:

1. This research will involve completion of a series of tasks including a 5-minute, low-intensity warm-up on a treadmill, a 10-minute run on a treadmill, five step-downs on each leg in front of multiple motion analysis cameras, and a 5-minute, low-intensity cool-down. My participation will require approximately 90 minutes of my time.

2. This research will require the placement of reflective markers on both hips, the outside of both knees, the middle of both thighs, the middle of both calves, the outside of both ankles, and on the forefoot and heel of both feet for the step-down test and run. I will also have a total of five electrodes on my hips and front and back of my thigh for my dominant leg. For marker visibility, I will be asked to wear shorts or tights and a sports bra (women), and to remove my shirt for the running trials and step-down test.

3. There are minimal risks possible for participants. I may experience acute muscle soreness due to the step-down test, a raising and lowering task where I will tap my heel to the ground. I understand that this step-down task may include some additional pain or discomfort if I am currently experiencing pain in the knee. There is also a low falling risk associated with standing on the box for the step-down test and running on the treadmill.

4. Potential benefits of participation will include an increased understanding of my running form. A student participating in this research may benefit from extra credit up to two points in participating classes.

5. My participation is completely voluntary. I am able to withdraw from this research at any time.

6. All information is confidential. This signed consent form will be kept in a locked filing cabinet separate from any other information tying me to this research. Only the primary investigator and graduate researcher will have access to any data collected in this study. My name will not be associated with any data collected in this project.

7. I must be at least 18 years of age to participate in this study.

8. My signature on this form does not waive my legal rights of protection.

9. This research is conducted by Cody Brocato under the supervision of Dr. Jun San Juan. Any questions that you have regarding the study or your participation may be directed to Dr. Jun San Juan at (360) 650-2336, jun.sanjuan@wwu.edu.

If you have any questions about your participation or your rights as a research participant, you can contact Janai Symons at the WWU Human Protections Administrator (HPA), (360) 650-3220, janai.symons@wwu.edu. If during or after participation in this study you suffer from any adverse effects as a result of participation, please notify the researcher directing the study or the WWU Human Protections Administrator.

I have read the above description and agree to participation in this study.

____

Participant's Signature Date

____ Research Copy

Participant's PRINTED NAME

Participant Copy

Note: Please sign both copies of the form and retain the copy marked "Participant"

Appendix D

Raw Data

RAW DATA		RUNNING DATA			STEP-DOWN, TREADMILL-MATCHED			STEP-DOWN, HEEL TAP		
DOMINANT LEG	SEX	HIP	KNEE	TRUNK	HIP	KNEE	TRUNK	HIP	KNEE	TRUNK
R	F	14.941	0.134	7.284	7.498	1.322	15.232	26.368	21.078	21.883
R	F	12.995	14.194	10.630	6.413	11.781	15.608	22.671	23.833	24.069
R	F	13.117	19.493	1.559	3.166	29.809	1.781	7.295	41.466	2.772
R	F	15.762	2.868	11.245	17.259	3.345	15.968	27.875	11.328	30.578
R	F	9.890	20.130	12.335	1.539	25.928	10.903	18.126	46.323	11.908
R	M	12.361	1.291	10.419	14.321	9.059	4.510	21.892	18.908	6.239
R	F	11.942	-3.526	8.723	9.000	2.254	6.108	14.188	3.208	8.089
R	F	15.918	11.534	9.730	7.998	3.379	13.066	21.223	10.437	23.988
R	M	5.676	3.258	6.266	2.066	4.749	2.655	13.908	7.849	3.395
R	F	13.708	-4.234	6.156	9.528	-4.686	-1.107	24.037	2.688	5.238
R	M	8.852	18.743	6.029	4.846	15.561	0.920	16.863	26.925	3.825
L	M	10.039	1.836	2.566	8.831	8.765	1.954	17.641	22.587	6.701
L	M	15.259	-0.943	4.788	12.056	8.303	1.027	21.753	25.857	-0.985
R	M	11.224	8.332	2.037	6.009	10.104	16.148	18.438	18.586	22.118
R	F	6.616	-0.215	4.812	-0.850	0.923	4.212	3.506	6.047	3.112
R	M	7.735	1.790	7.361	9.296	1.778	3.701	20.303	7.288	9.421
R	M	7.374	21.983	3.299	7.119	15.584	-6.002	16.980	26.454	-6.566
R	M	14.442	16.721	4.148	2.181	17.108	0.620	9.069	29.820	-1.468
R	M	8.296	1.211	9.909	4.370	4.865	9.567	17.538	13.170	19.434
R	F	8.297	-7.028	0.265	5.067	-6.628	-0.200	15.129	-6.748	-1.046
R	F	11.368	-4.479	7.260	8.651	0.934	15.169	24.098	5.111	27.797
R	F	8.780	9.962	11.532	-2.019	14.209	14.508	16.353	14.338	12.229
R	F	12.854	-0.467	4.000	9.270	-0.132	4.501	17.468	5.369	11.050
R	M	14.790	17.439	-0.330	7.261	18.675	4.586	16.116	27.075	8.951
R	M	6.255	4.357	9.147	1.145	6.363	2.875	17.076	7.265	5.235

SUBJECT	AGE	HEIGHT (CM)	BODY MASS (KG)	RUN VOLUME (KM/WK)	CADENCE (STEPS/MIN)
1	25	161	65.5	56.33	188.9
2	21	173.9	52.7	32.19	179.4
3	29	171.1	72	32.19	162.2
4	32	178.5	65	52.30	176.7
5	44	169.5	70.7	32.19	178.1
6	43	181.5	85.55	64.37	171.3
7	34	164	67.2	52.30	181.7
8	37	162.5	52	32.19	171.9
9	30	171	70	96.56	181.5
10	26	157.5	58.1	48.28	189.5
11	37	176	76	24.14	183.3
12	28	175.25	77.3	32.19	163.9
13	34	189.5	93.9	80.47	161.9
14	35	177.5	73.4	80.47	167.6
15	29	174	69.8	64.37	173.1
16	30	177.5	79	56.33	173.6
17	42	186.5	88.6	40.23	156.8
18	37	177.5	78.7	32.19	167.9
19	34	187.5	90	80.47	184.4
20	39	165.5	66.3	40.23	178.1
21	34	163.5	60.5	120.70	186.7
22	30	186	73.6	96.56	150.3
23	31	168.5	54	48.28	178.3
24	35	181.5	70.5	48.28	145.3
25	23	171	60.6	144.84	174.6

Sex	Age (yrs)	Height (cm)	Body Mass (kg)	Run Volume (km/wk)	Cadence (steps/min)
13 Female	31.6 ± 6.14	168.9 ± 7.85	63.6 ± 7.48	54.5 ± 26.7	176.5 ± 10.8
12 Male	34.0 ± 5.67	179.2 ± 6.09	78.6 ± 9.59	65.0 ± 34.2	169.4 ± 11.4
Total	32.8 ± 5.93	173.9 ± 8.73	70.8 ± 11.3	59.5 ± 30.4	173.1 ± 11.5

Appendix E

Statistical Results

T-Test, Data Identifying Sex-Differences

Group Statistics

	Female 1, Male 2	N	Mean	Std. Deviation	Std. Error Mean
RUNKNEE Ad+, Ab-	1	13	4.489702608	9.421656591	2.613097380
	2	12	8.001619083	8.309847922	2.398846467
RUNHIP Ad+, Ab-	1	13	12.01437877	2.914892761	.8084457932
	2	12	10.19196533	3.383512087	.9767358071
RUNTRUNK Flex+, Ext-	1	13	7.348516515	3.858530305	1.070163759
	2	12	5.469761142	3.344351513	.9654311232
TMKFKNEE Ad+, Ab-	1	13	6.341417400	11.08990615	3.075786559
	2	12	10.07622642	5.459709326	1.576082325
TMKFHIP Ad+, Ab-	1	13	6.347633562	5.089108783	1.411464820
	2	12	6.625032417	4.051623960	1.169603092
TMKFTRUNK Flex+, Ext-	1	13	8.903823100	6.518670057	1.807953780
	2	12	3.546838192	5.341580516	1.541981475
HEELKNEE Ad+, Ab-	1	13	14.19049820	15.43024495	4.279579952
	2	12	19.31520389	8.489162857	2.450610230
HEELHIP Ad+, Ab-	1	13	18.33360564	7.201825562	1.997427026
	2	12	17.29816139	3.469287190	1.001496946
HEELTRUNK Flex+, Ext-	1	13	13.97438454	10.51735027	2.916988130
	2	12	6.358415922	8.170021774	2.358482135

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
RUNKNEE Ad+, Ab-	Equal variances assumed	.363	.553	-.985	23	.335	-3.51191648	3.565755009	-10.8882427	3.864409760
	Equal variances not assumed			-.990	22.960	.332	-3.51191648	3.547216132	-10.8506051	3.826772136
RUNHIP Ad+, Ab-	Equal variances assumed	.644	.431	1.446	23	.162	1.822413436	1.260101028	-.784304145	4.429131016
	Equal variances not assumed			1.437	21.839	.165	1.822413436	1.267910658	-.808197261	4.453024132
RUNTRUNK Flex+, Ext-	Equal variances assumed	.227	.638	1.296	23	.208	1.878755374	1.449855428	-1.12049909	4.878009838
	Equal variances not assumed			1.304	22.920	.205	1.878755374	1.441286829	-1.10335204	4.860862785
TMKFKNEE Ad+, Ab-	Equal variances assumed	4.354	.048	-1.054	23	.303	-3.73480902	3.545103657	-11.0684147	3.598796643
	Equal variances not assumed			-1.081	17.791	.294	-3.73480902	3.456081372	-11.0018875	3.532269434
TMKFHIP Ad+, Ab-	Equal variances assumed	.319	.578	-.150	23	.882	-.277398855	1.850307611	-4.10505178	3.550254066
	Equal variances not assumed			-.151	22.543	.881	-.277398855	1.833086013	-4.07368778	3.518890067
TMKFTRUNK Flex+, Ext-	Equal variances assumed	3.563	.072	2.236	23	.035	5.356984908	2.395784949	.4009261402	10.31304368
	Equal variances not assumed			2.254	22.703	.034	5.356984908	2.376216265	.4378431417	10.27612667
HEELKNEE Ad+, Ab-	Equal variances assumed	2.382	.136	-1.016	23	.320	-5.12470569	5.042900030	-15.5567392	5.307327839
	Equal variances not assumed			-1.039	18.939	.312	-5.12470569	4.931561119	-15.4488496	5.199438245
HEELHIP Ad+, Ab-	Equal variances assumed	5.398	.029	.452	23	.656	1.035444252	2.293280297	-3.70856749	5.779455992
	Equal variances not assumed			.463	17.580	.649	1.035444252	2.234437481	-3.66698974	5.737878243
HEELTRUNK Flex+, Ext-	Equal variances assumed	2.403	.135	2.009	23	.056	7.615968616	3.790075432	-.224399771	15.45633700
	Equal variances not assumed			2.030	22.383	.054	7.615968616	3.751167516	-.155771681	15.38770891

T-Test, Sex-Pooled Data Between Conditions

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	RUNKNEE Ad+, Ab-	6.175422516	25	8.901690032	1.780338006
	TMKFKNEE Ad+, Ab-	8.134125728	25	8.875916404	1.775183281
Pair 2	RUNHIP Ad+, Ab-	11.13962032	25	3.218521415	.6437042829
	TMKFHIP Ad+, Ab-	6.480785012	25	4.526959664	.9053919328
Pair 3	RUNTRUNK Flex+, Ext-	6.446713936	25	3.672624485	.7345248970
	TMKFTRUNK Flex+, Ext-	6.332470344	25	6.464148214	1.292829643
Pair 4	RUNKNEE Ad+, Ab-	6.175422516	25	8.901690032	1.780338006
	HEELKNEE Ad+, Ab-	16.65035693	25	12.60574098	2.521148196
Pair 5	RUNHIP Ad+, Ab-	11.13962032	25	3.218521415	.6437042829
	HEELHIP Ad+, Ab-	17.83659240	25	5.632795229	1.126559046
Pair 6	RUNTRUNK Flex+, Ext-	6.446713936	25	3.672624485	.7345248970
	HEELTRUNK Flex+, Ext-	10.31871960	25	10.04895574	2.009791149

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	RUNKNEE Ad+, Ab- & TMKFKNEE Ad+, Ab-	25	.876	.000
Pair 2	RUNHIP Ad+, Ab- & TMKFHIP Ad+, Ab-	25	.570	.003
Pair 3	RUNTRUNK Flex+, Ext- & TMKFTRUNK Flex+, Ext-	25	.533	.006
Pair 4	RUNKNEE Ad+, Ab- & HEELKNEE Ad+, Ab-	25	.796	.000
Pair 5	RUNHIP Ad+, Ab- & HEELHIP Ad+, Ab-	25	.418	.038
Pair 6	RUNTRUNK Flex+, Ext- & HEELTRUNK Flex+, Ext-	25	.487	.014

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	RUNKNEE Ad+, Ab- - TMKFKNEE Ad+, Ab-	-1.95870321	4.424897089	.8849794177	-3.78521096	-.132195465	-2.213	24	.037
Pair 2	RUNHIP Ad+, Ab- - TMKFHIP Ad+, Ab-	4.658835308	3.774210499	.7548420997	3.100917784	6.216752832	6.172	24	.000
Pair 3	RUNTRUNK Flex+, Ext- - TMKFTRUNK Flex+, Ext-	.1142435920	5.472136908	1.094427382	-2.14454351	2.373030691	.104	24	.918
Pair 4	RUNKNEE Ad+, Ab- - HEELKNEE Ad+, Ab-	-10.4749344	7.708868721	1.541773744	-13.6569990	-7.29286980	-6.794	24	.000
Pair 5	RUNHIP Ad+, Ab- - HEELHIP Ad+, Ab-	-6.69697208	5.190093565	1.038018713	-8.83933741	-4.55460675	-6.452	24	.000
Pair 6	RUNTRUNK Flex+, Ext- - HEELTRUNK Flex+, Ext-	-3.87200567	8.862283100	1.772456620	-7.53017633	-.213834997	-2.185	24	.039

Pearson Product Correlation, Correlation Between PKF-RUN + TMKF-SDT

Descriptive Statistics

	Mean	Std. Deviation	N
RUNKNEE Ad+, Ab-	6.175422516	8.901690032	25
RUNHIP Ad+, Ab-	11.13962032	3.218521415	25
RUNTRUNK Flex+, Ext-	6.446713936	3.672624485	25
TMKFKNEE Ad+, Ab-	8.134125728	8.875916404	25
TMKFHIP Ad+, Ab-	6.480785012	4.526959664	25
TMKFTRUNK Flex+, Ext-	6.332470344	6.464148214	25

Correlations

		RUNKNEE Ad+, Ab-	RUNHIP Ad+, Ab-	RUNTRUNK Flex+, Ext-	TMKFKNEE Ad+, Ab-	TMKFHIP Ad+, Ab-	TMKFTRUNK Flex+, Ext-
RUNKNEE Ad+, Ab-	Pearson Correlation	1	.046	-.044	.876**	-.338	-.063
	Sig. (2-tailed)		.828	.836	.000	.098	.764
	N	25	25	25	25	25	25
RUNHIP Ad+, Ab-	Pearson Correlation	.046	1	-.003	.067	.570**	.307
	Sig. (2-tailed)	.828		.988	.751	.003	.135
	N	25	25	25	25	25	25
RUNTRUNK Flex+, Ext-	Pearson Correlation	-.044	-.003	1	-.050	.054	.533**
	Sig. (2-tailed)	.836	.988		.812	.799	.006
	N	25	25	25	25	25	25
TMKFKNEE Ad+, Ab-	Pearson Correlation	.876**	.067	-.050	1	-.323	-.055
	Sig. (2-tailed)	.000	.751	.812		.115	.794
	N	25	25	25	25	25	25
TMKFHIP Ad+, Ab-	Pearson Correlation	-.338	.570**	.054	-.323	1	.067
	Sig. (2-tailed)	.098	.003	.799	.115		.751
	N	25	25	25	25	25	25
TMKFTRUNK Flex+, Ext-	Pearson Correlation	-.063	.307	.533**	-.055	.067	1
	Sig. (2-tailed)	.764	.135	.006	.794	.751	
	N	25	25	25	25	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

Pearson Product Correlation, Correlation Between PKF-RUN + HEEL-SDT

Descriptive Statistics

	Mean	Std. Deviation	N
RUNKNEE Ad+, Ab-	6.175422516	8.901690032	25
RUNHIP Ad+, Ab-	11.13962032	3.218521415	25
RUNTRUNK Flex+, Ext-	6.446713936	3.672624485	25
HEELKNEE Ad+, Ab-	16.65035693	12.60574098	25
HEELHIP Ad+, Ab-	17.83659240	5.632795229	25
HEELTRUNK Flex+, Ext-	10.31871960	10.04895574	25

Correlations

		RUNKNEE Ad+, Ab-	RUNHIP Ad+, Ab-	RUNTRUNK Flex+, Ext-	HEELKNEE Ad+, Ab-	HEELHIP Ad+, Ab-	HEELTRUNK Flex+, Ext-
RUNKNEE Ad+, Ab-	Pearson Correlation	1	.046	-.044	.796**	-.262	-.141
	Sig. (2-tailed)		.828	.836	.000	.205	.500
	N	25	25	25	25	25	25
RUNHIP Ad+, Ab-	Pearson Correlation	.046	1	-.003	.237	.418*	.374
	Sig. (2-tailed)	.828		.988	.255	.038	.066
	N	25	25	25	25	25	25
RUNTRUNK Flex+, Ext-	Pearson Correlation	-.044	-.003	1	-.032	.425*	.487*
	Sig. (2-tailed)	.836	.988		.881	.034	.014
	N	25	25	25	25	25	25
HEELKNEE Ad+, Ab-	Pearson Correlation	.796**	.237	-.032	1	-.134	-.126
	Sig. (2-tailed)	.000	.255	.881		.522	.549
	N	25	25	25	25	25	25
HEELHIP Ad+, Ab-	Pearson Correlation	-.262	.418*	.425*	-.134	1	.597**
	Sig. (2-tailed)	.205	.038	.034	.522		.002
	N	25	25	25	25	25	25
HEELTRUNK Flex+, Ext-	Pearson Correlation	-.141	.374	.487*	-.126	.597**	1
	Sig. (2-tailed)	.500	.066	.014	.549	.002	
	N	25	25	25	25	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).