Journal of Athletic Training 2023;58(2):120–127
doi: 10.4085/1062-6050-404-21

www.natajournals.org

The Running Readiness Scale as an Assessment of Kinematics Related to Knee Injury in Novice Female Runners

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Context: Frontal- and transverse-plane kinematics have been prospectively identified as risk factors for running-related injuries in females. The Running Readiness Scale (RRS) may allow for clinical evaluation of these kinematics.

Objectives: To determine the reliability and validity of the RRS as an assessment of frontal- and transverse-plane running kinematics.

Design: Cross-sectional study.

Setting: University research laboratory.

Patients or Other Participants: A total of 56 novice female runners (median [interquartile range] age = 34 years [26–47 years]).

Main Outcome Measure(s): We collected 3-dimensional kinematics during running and RRS tasks: hopping, plank, step-ups, single-legged squats, and wall sit. Five clinicians assessed RRS performances 3 times each. Interrater and intrarater reliabilities of the total RRS score and individual tasks were calculated using the intraclass correlation coefficient and Fleiss κ, respectively. Pearson product moment correlation coefficients between peak joint angles measured during running and the same angles measured during RRS tasks were computed. Peak joint angles of high- and low-scoring participants were compared.

Results: Interrater and intrarater reliabilities of assessment of the total RRS scores were good (intraclass correlation coefficients = 0.75 and 0.80, respectively). Reliability of assessing individual tasks was moderate to almost perfect (κ = 0.58–1.00). Peak hip adduction, contralateral pelvic drop, and knee abduction during running were correlated with the same angles measured during hopping, step-ups, and single-legged squats (r = 0.537–0.939). Peak knee internal rotation during running was correlated with peak knee internal rotation during step-ups (r = 0.831). Runners who scored high on the RRS demonstrated less knee abduction during running ($P \leq .01$).

Conclusions: The RRS may effectively assess knee abduction in novice runners, but evaluation criteria or tasks may need to be modified to effectively characterize pelvic and transverse-plane knee kinematics.

Key Words: hip adduction, knee abduction, knee internal rotation

Key Points

- The intrarater and interrater reliability of the assessment of Running Readiness Scale (RRS) tasks was good.
- Moderate to strong correlations existed between kinematics previously identified as risk factors for knee injury measured during running and those same angles measured during RRS tasks.
- Runners with high scores on the RRS demonstrated less knee abduction during running than those with low scores.

Running carries a high risk of injury, particularly for novice runners.[1] Among all runners, the knee is the most common site of injury.[2] Previously identified kinematic risk factors for knee injury in runners include hip adduction and knee internal rotation.[3,4] Hip adduction may affect the knee in 2 ways: (1) hip adduction due to femoral adduction may contribute to an abducted knee position, increasing patellofemoral joint contact forces or (2) hip adduction due to contralateral pelvic drop may shift the center of mass laterally, increasing the moment about the knee in the frontal plane.[5] A test that can identify runners with excessive hip adduction, contralateral pelvic drop, knee abduction, or knee internal rotation (or a combination of these) may aid in injury prevention.

Unfortunately, equipment and technical experts to conduct 3-dimensional (3-D) gait analysis are not widely available in clinical settings. Visual observation of running is difficult due to the complexity and fast pace of movement; as such, visual assessment of 2-dimensional video of running often has low to moderate reliability.[6] Evaluating movement tasks designated as subset skills important to running, such as dynamic control of the pelvis and knee and muscular strength and endurance of the legs and trunk, may be more feasible in a clinical setting. Furthermore, dividing important skills into separate tasks may help clinicians determine which interventions might be most likely to help a client.

Previous researchers[7,8] have aimed to develop movement screens, visually assessed by practitioners, to identify whether an athlete is at risk of injury due to her or his movement patterns. The Functional Movement Screen (FMS) consists of a series of 7 movements thought to be important to sports performance.[7,8] However, the FMS has poor predictive value for injury among competitive male runners (sensitivity = 0.73, specificity = 0.54).[9] Yet considering only the active leg-raise and deep-squat components of the FMS resulted in improved specificity (0.74).[9] Lower extremity function in the sagittal plane, which is assessed via the active leg raise and deep squat, is important to runners, whereas upper body tests such as shoulder mobility may be less meaningful. These extraneous tasks likely detract from the utility of the total FMS score in assessing a runner's ability to control injurious frontal- and transverse-plane motion during sagittal-plane tasks. For example, de Oliveira et al[10] reported that the total FMS score was not associated with biomechanics during forward step-downs. Therefore, we assumed the FMS also would not be associated with kinematics of running that were previously identified as risk factors for injury. A functional test designed to evaluate a runner's ability to maintain control of frontal- and transverse-plane motion during sagittal-plane tasks and landings may be better able to detect injurious movement patterns among runners.

The Running Readiness Scale (RRS) was developed to assess these running-specific skills. The RRS consists of 5 tasks: hopping, plank, step-ups, single-legged squats, and wall sit. Observing hopping, step-ups, and single-legged squats allows the clinician to determine the individual's ability to stabilize the lower extremity in the frontal plane during dynamic sagittal-plane tasks. In previous research,[11] frontal-plane projection angles (ie, a 2-dimensional measure of knee abduction) quantified during single-legged squats and running were correlated in asymptomatic runners. This finding suggests that single-legged squats and hopping may be valid tasks for identifying whether a runner would display aberrant frontal-plane kinematics during running. Willson and Davis[12] observed that the frontal-plane projection angle was also correlated with knee internal rotation during single-legged squats. This result indicated that frontal-plane movement patterns may also provide information about transverse-plane movement patterns.

The wall sit is included in the RRS to assess the function of the quadriceps muscle group. McCurdy et al[13] noted that 3-repetition maximum squat strength was a strong predictor of knee valgus during landing. Similarly, female soccer players who displayed limited knee flexion during a drop landing also demonstrated greater knee valgus than those who used greater knee flexion.[14] These findings suggest that function of the quadriceps muscles, in controlling knee flexion, can be an important factor in a runner's ability to control frontal-plane movement during dynamic activities.

The plank task is used to assess strength and control of the trunk. Powers[5] showed that anterior lean of the trunk reduced knee joint loads, whereas a posterior trunk lean placed a potentially excessive load on the knee. The knee extensors of a runner who places a large load on the knee may not have the strength capacity to absorb that load in the sagittal plane, and the individual may compensate with increased knee abduction.[13,14] Supporting this premise, Burnham et al[15] described plank endurance as negatively associated with knee valgus during the step-down task in female participants.

The purpose of our study was to confirm the interrater and intrarater reliability of the RRS and investigate the validity of the RRS via its relationship with running kinematics associated with knee injuries in novice runners. We hypothesized that peak joint angles measured during the stance phase of running—which were previously implicated in the development of running-related injury—would be correlated with the same peak angles measured during RRS tasks. Furthermore, we expected that runners with high scores on the RRS (ie, successfully completed at least 4 of the 5 tasks) would demonstrate less contralateral pelvic drop, hip adduction, knee abduction, and knee internal rotation compared with those with low scores (ie, completed $\leq$2 of the RRS tasks successfully).

METHODS

Participants

Participants were enrolled as part of a training study. The measurements for this study came from their baseline data-collection visit before training began. Eligible participants were women, aged between 18 and 60 years and sufficiently healthy to engage in moderate activity according to the American College of Sports Medicine Physical Activity Readiness Questionnaire (PAR-Q+, 2017 version)[16] who reported no history of regular running (ie, $\geq$3 months of running $\geq$3 times per week). We excluded men from this study because (1) men and women differ in running biomechanics—particularly frontal-plane kinematics,[17] (2) the biomechanical causes of injuries appear to differ between men and women,[18,19] and (3) women experience a greater incidence of knee injury than men.[2] All participants provided written informed consent before the study, and the Virginia Commonwealth University Institutional Review Board approved all procedures.

To assess the relationship between peak joint angles during running and RRS tasks, we conducted a power analysis and determined that 29 participants would be necessary to detect a moderate correlation ($r = 0.5$, $\alpha = .05$, $\beta = 0.2$). Therefore, the sample from the training study (N = 56) was sufficient to address this question. To compare running kinematics between participants who scored high or low on the RRS, we divided individuals into groups on the basis of their RRS score (*low*: 0, 1, or 2; *high*: 4 or 5). We chose these groups to create a larger differentiation in movement skill between groups by omitting those whose score was 3. A power analysis based on a previous comparison of female runners who developed iliotibial band syndrome with female runners who remained healthy[3] was used to detect a clinically meaningful difference between groups. The calculated sample size was 8 participants per group. Thus, the high-scoring (n = 20) and low-scoring (n = 20) groups from the training study were considered ample for the kinematic comparisons.

Table 1. Running Readiness Scale Evaluation Criteria

Task	Instructions to Participants	Good Form (Must Be Maintained for 1 min Without Breaks To Pass)
Hopping (on 2 feet)	Hop on both feet in the same spot in time with the beat of the metronome. You may hop in front of a wall to provide a visual reference to avoid moving. You don't need to hop very high, just enough so your toes leave the ground.	• Maintain pace of 160 hops/min • Hop off toes • Knees aligned (ie, no apparent knee collapse toward midline)
Plank	Hold a plank, on your forearms and toes, so that you make a straight line from your ankles to your head, and hold as still as possible.	• Body in straight line • Equal weight-bearing between left and right feet and forearms • Neutral head alignment (ie, held in line with trunk)
Step-ups	Step up onto the box in front of you, 1 foot after the other, and then step down from the box, 1 foot after the other, in an up-up-down-down pattern. Each step should fall on a metronome beat. Halfway through the minute, we will tell you to switch your lead leg.	• Maintain pace of 160 steps/min • Knees aligned (ie, no apparent knee collapse toward midline) • Upright trunk (ie, no excessive forward or lateral lean)
Single-legged squat[22]	Stand on 1 foot, with the opposite foot held off the ground in front of you. With each beat of the metronome, you will perform a mini-squat. Halfway through the minute, we will tell you to switch legs.	• Maintain pace of 80 beats/min (down on first beat, up on second) • Maintain balance • Level hips • Knee aligned (ie, no apparent knee collapse toward midline) • Upright trunk (ie, no excessive forward or lateral lean)
Wall sit	Place the stability ball behind you against the wall so it is held in place between the wall and your backside. Squat down so your thighs are parallel to the ground and the ball is against your lower back. Hold as still as possible for 1 min.	• Thighs parallel to floor • Upright trunk (ie, no excessive forward or lateral lean) • Equal weight-bearing on left and right feet

Data Collection

Study visits took place at the university's gait laboratory. Participants wore their own athletic attire and were provided with standard neutral running footwear (model 680; New Balance). Although researchers[20] have recently suggested standardized running shoes may influence running biomechanics, our participants, who were enrolled before beginning a run training program, did not have habitual running footwear. Reflective markers were placed on participants according to a modified lower extremity Cleveland Clinic model. Specifically, joint markers were placed bilaterally on the greater trochanters, iliac crests (ie, directly superior to the greater trochanters), medial and lateral femoral epicondyles, medial and lateral malleoli, and heads of the first and fifth metatarsals. Clusters of 4 tracking markers were affixed to the posterior pelvis, thighs, and shanks, and 3 tracking markers were affixed to the heel counter of each shoe. Data collected during a standing trial were used to establish joint centers and anthropometrics. Joint markers were then removed, and participants ran on a treadmill (model 3DI; Treadmetrix). Kinematic data were collected using a 7-camera 3-D motion-analysis system (model OQUS 3; Qualysis) at 100 Hz. Participants began by walking on the treadmill. When they indicated they were comfortable, the pace was increased to a jog (2.23 m/s) and maintained for at least 30 seconds to allow them to acclimate to treadmill running. When participants signaled that they were comfortable and ready to increase the pace, we increased the pace to 2.68 m/s. When they indicated they were comfortable running at the 2.68 m/s pace, we captured 20 seconds of running for analysis. This pace was similar to the previously reported preferred running pace of recreational female runners.[21] Given that these participants had not yet begun a running training program, they did not have a habitual running pace. Therefore, we selected a pace that was a reasonable target for the participants at the end of their introductory running program.

After the running trial, the participants were allowed a rest break of several minutes. When they indicated they were ready to resume testing, they performed the RRS tasks. All tasks were performed in the same order: 2-footed hopping, plank, step-ups, single-legged squats, and wall sit. The order of the tasks was not randomized among participants because the order of the tasks could influence the skills being assessed. For example, if wall sits were performed before single-legged squats, the endurance of the quadriceps muscles might have been challenged more than dynamic control. Participants performed dynamic tasks (ie, hopping, step-ups, and single-legged squats) on the treadmill surface while the belt was stationary and fixed so 3-D motion could be recorded. We recorded videos for all tasks using a handheld tablet (model A8.0; Samsung Electronics Co, Ltd) from a distance that allowed each person's entire body to be captured within the frame. For hopping, step-ups, and single-legged squats, the camera was positioned directly behind participants to capture lower extremity kinematics in the frontal plane. For planks, the camera was aligned parallel to the length of participants' bodies, centered at their hips. For the wall sits, videos were recorded from in front of participants.

The assessor gave 1 point for each of the 5 tasks if the participant maintained good form for 1 minute without breaks (Table 1). To our knowledge, evaluation criteria for good form based on visual assessment of kinematics have only been established for single-legged squats. As suggested by Crossley et al,[22] our evaluation criteria for that task were based on overall performance (eg, ability to maintain balance), as well as evaluation of knee, pelvis and hip, and trunk kinematics. We adopted similar criteria as appropriate for the remaining 4 tasks of the RRS (Table 1). The 1-minute period was chosen to assess muscular endurance, which ostensibly was important for maintaining form during a run. If the individual did not maintain good form or stopped before the minute was over, she received no points for that task. Points were summed for a total score out of 5.

Reliability

To assess interrater and intrarater reliabilities, we used a series of 10 videos of volunteers performing all the RRS tasks. Five clinicians (not authors) were involved in the reliability portion of this study; each was a licensed athletic trainer or physical therapist with <3 years of experience. The clinicians assessed the videos 3 times each within 1 week but on nonconsecutive days. If the participant in the video displayed all criteria for good form for the full minute, the clinician gave the trial a pass, worth 1 point. If the participant did not meet all good form criteria or did not maintain good form for 1 minute without breaks, the clinician rated the trial as a *failure*, worth zero points. Before rating the study videos, the clinicians were provided with the criteria for good form for each task (Table 1), and they watched example videos of the tasks being performed using both good and poor form (as determined by the developer of the RRS, a licensed physical therapist with >15 years of experience [D.S.B.W.]) for visual demonstration. While watching the example videos, trainees were told they demonstrated passing or failing form, along with the reasons for the passing or failing score. The videos allowed the trainees to associate visual examples of athletes performing the RRS with both good and bad form. The training on rating the videos lasted approximately 1 hour. During the evaluation, clinicians were provided with a scoring sheet to track the assessment criteria.[23]

Data Processing

Kinematic marker trajectory data were exported to motion-analysis software (Visual3D, version 6; C-Motion, Inc) for processing. Marker trajectories were filtered using a fourth-order, dual-pass Butterworth filter with a cutoff frequency of 10 Hz. Subsequently, we reconstructed the foot, shank, thigh, and pelvic segments and calculated joint angles using Cardan sequencing. The left or right side of the body was randomly selected for analysis for each participant. Peak joint or segment angles (hip adduction, contralateral pelvic drop, knee abduction, knee internal rotation) were computed for all steps (stance phase) during running or repetitions during the RRS tasks for each participant and averaged across all steps or repetitions for statistical analyses. During running, hopping, and step-ups, the window for identifying peak angles was from the initial contact to toe-off. For running, *initial contact* was identified as the minimum velocity of the midpoint of proximal and distal ends of the foot segment after the foot fell below a vertical height of 0.15 m.[24] *Toe-off* was identified as the point of peak knee extension after initial contact. For hopping and step-ups, *initial contact* was defined as the minimum velocity of the midpoint of the foot segment after the foot fell below 0.15 m from the landing surface. *Toe-off* was when the midpoint of the foot rose more than 0.15 m from the landing surface. For single-legged squats, we separated repetitions using the maxima of the L5/S1 pelvic marker.

Statistical Analysis

Interrater and intrarater reliabilities were assessed for the total RRS scores using the 2-way random-effects intraclass correlation coefficient because this is an ordinal variable (SPSS version 26; IBM Corp).[25] Intraclass correlation coefficients were interpreted according to the recommendations of Koo and Li[26] as *poor* (<0.5), *moderate* (0.5–0.75), *good* (0.75–0.9), or *excellent* (>0.9) reliability.

Interrater and intrarater reliabilities were assessed for each of the 5 RRS tasks using the Fleiss κ because they were categorical variables (Excel version 16; Microsoft Corp).[27] The Fleiss κ was interpreted according to the recommendations of Landis and Koch[28] as *poor* (<0), *slight* (0–0.2), *fair* (0.21–0.4), *moderate* (0.41–0.6), *substantial* (0.61–0.8), or *almost perfect* (0.81–1.00) *agreement*. We evaluated the reliability of the total scores and scores for individual tasks and used the total scores as a measure of injury risk.[29] Understanding the reliability of each task was central to identifying if and how the assessment criteria needed to be adjusted to improve the overall reliability.

All descriptive data and peak joint angles were evaluated for normality using the Shapiro-Wilk test. Descriptive data were not normally distributed, so they were reported using the median and interquartile range and were compared between the high- and low-scoring groups using the independent-samples Kruskal-Wallis test.

To determine the validity of the RRS as an assessment of running kinematics, we calculated Pearson product moment correlation coefficients between peak joint or segment angles measured during running and the same angles measured during hopping, step-ups (ie, both up and down), and single-legged squats ($\alpha = .05$). A total of 9 correlations were generated. Correlation coefficients were interpreted as *negligible* (<0.25), *weak* (0.25–0.5), *moderate* (0.5–0.75), or *strong* (>0.75). All peak joint-angle data were normally distributed.

To assess the ability of raters to identify excessive joint or segment angles, we compared peak joint or segment angles of interest measured during dynamic RRS tasks and running between the high- and low-scoring groups using the independent-samples *t* test ($\alpha = .05$). To better illustrate the complete movement patterns that led to the measured peak joint angles, comparisons of joint-angle time series are provided in the Supplemental Material (see Supplemental Text and Figure, available online at http://dx.doi.org/10.4085.1062-6050-2020-20.S1).

RESULTS

For the total RRS score, both the interrater and intrarater reliability were good (intraclass correlation coefficients = 0.75 and 0.80, respectively).[26] Interrater reliability for the individual tasks of the RSS ranged from $\kappa = 0.58$ to 1.00, indicating moderate to almost perfect agreement according to the interpretation recommended by Landis and Koch.[28] Intrarater reliability for the individual tasks ranged from κ

Table 2. Reliability Assessment of Running Readiness Scale Tasks Calculated Using the Fleiss κ

Task	Interrater Reliability		Intrarater Reliability	
	κ Value (95% CI)	*P* Value	κ Value (95% CI)	*P* Value
2-Footed hopping	0.58 (0.33, 0.84)	<.001	1.00 (0.64, 1.36)	<.001
Plank	0.87 (0.61, 1.12)	<.001	0.87 (0.51, 1.22)	<.001
Step-ups	0.87 (0.61, 1.12)	<.001	0.87 (0.51, 1.22)	<.001
Single-legged squats	0.72 (0.48, 0.98)	<.001	0.87 (0.51, 1.22)	<.001
Wall sit	1.00 (0.75, 1.25)	<.001	1.00 (0.64, 1.36)	<.001

= 0.87 to 1.00, indicating the reliability was almost perfect (Table 2). Participants in the high-scoring group had a lower body mass index (BMI) than did those in the low-scoring group ($P = .003$; Table 3).

With respect to the validity of the RRS as an evaluation of running kinematics, the correlation coefficients for 3-D joint angles measured during the RRS tasks and running ranged from $r = 0.113$ to $r = 0.936$. Moderate to strong correlations were found between peak frontal-plane joint angles during running and hopping, step-ups, and single-legged squats, as well as for peak knee internal rotation with the step-up task. However, peak knee internal rotation during running was not correlated with the hopping and single-legged squat tasks (Table 4).

The high-scoring group displayed less knee abduction than the low-scoring group during all dynamic RRS tasks as well as running ($P \leq .01$; Table 5). The low-scoring group had a more elevated contralateral pelvis during single-legged squats ($P = .008$), although on average, neither the high- nor the low-scoring group had a peak contralateral pelvic drop <0 (ie, the pelvis did not drop below horizontal).

DISCUSSION

The purpose of our study was to confirm the reliability of the RRS and investigate whether RRS performance was an appropriate indicator of running kinematics. Our results showed that the RRS had good interrater and intrarater reliability.[26] Furthermore, the reliability of individual RRS tasks was moderate to almost perfect,[28] which indicated that clinicians can become proficient in RRS assessment in a brief period, even early in their careers. Demonstrating reliability is an important first step in determining whether this assessment will be acceptable and effective for clinical use. Our findings for individual tasks were supported by previous studies in which researchers showed strong reliability for visually assessing single-legged squats[30] and planks.[31] The reliability of assessments of double-legged wall-sit performance has not, to our knowledge, been reported. However, Wilkerson and Colston[32] noted strong reliability of single-legged wall-sit assessment. To our knowledge, the reliability of 2-footed hopping and step-up assessments has not been described. Differentiating between a runner's ability to perform components of the RRS is important because it may allow clinicians to determine which qualities a runner needs to improve (eg, trunk versus leg strength or endurance versus dynamic control). Future investigation is needed to determine whether targeted interventions based on performance of specific tasks affect running kinematics.

Our results suggest the RRS has the potential to provide a valid assessment of frontal-plane running kinematics. Peak joint angles of the hip, pelvis, and knee in the frontal plane during all 3 dynamic RRS tasks were moderately to strongly correlated with the same angles measured during running. Consistent with these results, Rees et al[11] reported that frontal-plane projection angle—a 2-dimensional measure of knee abduction—was correlated with running and single-legged squats in healthy runners. However, this relationship was not significant in injured runners. Ostensibly, in injured runners, the higher loads during running elicit pain, which may alter their movement patterns.

In the transverse plane, knee internal-rotation angle during running was correlated with step-ups but not with hopping or single-legged squats. The lack of a strong relationship between knee internal-rotation angles during running and hopping and single-legged squats may have reflected the hopping and single-legged squats being performed primarily in the vertical direction, with minimal force applied in the anteroposterior direction. We expect that vertical forces have more limited action in the transverse plane than anteroposterior and mediolateral forces because the vertical ground reaction force is essentially parallel to the transverse axis of rotation between the thigh and shank when the lower limb is straight. The mini-squat required of this task means that the vertical component of the ground reaction force should still only have a limited effect on the thigh-shank transverse-plane moment and the deepest point of the squat. In contrast, step-ups require participants to step forward up onto a box and then backward down to the floor. Thus, step-ups require greater anterior and posterior ground reaction forces to translate the center of mass. Given that anteroposterior forces contribute a larger proportion to the transverse plane, they likely elicit transverse-plane kinematics more similar to running. It is also possible that step-

Table 3. Participant Characteristics, Median (Interquartile Range)

Participants	Age, y	Body Mass Index	Weekly Physical Activity, min
All (N = 56)	34 (26–47)	29.0 (25.4–34.1)	120 (60–223)
Running Readiness Scale			
High-scoring group (n = 20)	29 (22–38)	25.8 (25.4–28.4)	135 (96–213)
Low-scoring group (n = 20)	42 (32–48)	34.4 (30.9–40.9)	60 (30–180)
P value[a]	.22	.003	.19

[a] High- versus low-scoring group.

Table 4. Pearson Product Moment Correlation Coefficients Between Peak Joint Angles Measured During the Stance Phase of Running and Running Readiness Scale Tasks

Angle	2-Footed Hopping	*P* Value	Step-Ups	*P* Value	Single-Legged Squats	*P* Value
Hip adduction	0.669	<.001[a]	0.627	<.001[a]	0.586	.008[a]
Contralateral pelvic drop	0.537	<.001[a]	0.613	<.001[a]	0.558	<.001[a]
Knee abduction	0.939	<.001[a]	0.825	<.001[a]	0.858	<.001[a]
Knee internal rotation	0.113	.46	0.831	.003[a]	0.519	.52

[a] Correlation ($P < .05$).

ups elicit similar transverse-plane kinematics to those in running because phases of the task require single-limb stance. This likely presents a greater challenge to stability than double-limb support tasks, such as hopping.

The results of the comparison of running kinematics between low- and high-scoring RRS groups only partially supported our hypotheses. As expected, the high-scoring group had a smaller degree of peak knee abduction than the low-scoring group. A smaller knee-abduction angle has been proposed to protect the knee.[5]

Contralateral pelvic drop is a criterion for evaluating the single-legged squat, and thus we expected pelvis motion—in conjunction with hip motion—to differ between the high- and low-scoring groups during running. Peak hip adduction and contralateral pelvic drop, however, did not differ between the high- and low-scoring groups. On average, neither group displayed contralateral pelvic drop below horizontal during single-legged squats (ie, the only RRS task that was performed entirely on 1 foot). Tasks such as single-legged hopping may be a greater challenge to pelvic control and allow for improved assessment of contralateral pelvic drop.

In the transverse plane, participants who demonstrated greater knee abduction during running were also expected to demonstrate greater knee internal rotation, as has been demonstrated for single-legged squats.[33] The high-scoring group in our study, however, had similar peak knee internal-rotation angles to those of the low-scoring group. Adding a transverse-plane assessment criterion for the step-up task, in the future, may help to better address this injury risk factor. Such criteria could include assessing the direction of the tibial tuberosity or foot-progression angle during step-ups because knee internal-rotation angles during step-ups and running were correlated.

In our study, runners who scored high on the RRS had a lower BMI than those who scored low. Time to failure in a plank task has been negatively correlated with BMI and waist circumference.[31] The influence of anthropometric measures on performing hopping, step-up, single-legged squats, and wall-sit tasks has not been previously reported. Our results indicated that BMI was related to a person's performance on the RRS tasks and may influence a person's ability to control frontal-plane motions associated with knee injury during running.

The results of our study should be interpreted with caution because participation was limited to asymptomatic novice women runners. Future studies should be done to evaluate the reliability and validity of the RRS in runners who are injured, experienced, or male (or a combination of these characteristics). In our study, participants ran on a treadmill, and, although there are some differences in running biomechanics between overground and treadmill running in recreational runners,[34] it is unknown whether novice runners would display divergent kinematics on a treadmill compared with overground running. Videos were used for reliability analysis to assess intrarater reliability in addition to interrater reliability. Future studies are needed to confirm test-retest and interrater reliability of real-time

Table 5. Peak Joint or Segment Angles During Running and Running Readiness Scale Tasks, Mean ± SD

Variable	Overall, N = 56	High-Scoring Group, °	Low-Scoring Group, °	*P* Value[a]
Run				
Peak hip adduction	15.4 ± 3.9	15.1 ± 3.5	15.6 ± 5.3	.77
Peak contralateral pelvic drop	−4.4 ± 3.0	−4.4 ± 2.8	−4.9 ± 0.38	.71
Peak knee abduction	−7.0 ± 4.1	−5.3 ± 3.6	−9.5 ± 4.1	.01[b]
Peak knee internal rotation	5.0 ± 5.3	5.4 ± 5.0	6.3 ± 5.8	.69
Hopping				
Peak hip adduction	5.0 ± 3.9	3.9 ± 3.1	5.4 ± 4.1	.32
Peak contralateral pelvic drop	−1.0 ± 2.6	−1.3 ± 2.0	0.2 ± 2.5	.10
Peak knee abduction	−7.0 ± 4.1	−5.3 ± 3.6	−9.8 ± 4.0	.007[b]
Peak knee internal rotation	−9.0 ± 6.3	−9.7 ± 5.4	−8.1 ± 8.9	.58
Step-ups				
Peak hip adduction	14.7 ± 3.2	14.0 ± 2.4	16.1 ± 4.4	.22
Peak contralateral pelvic drop	−8.9 ± 3.4	−9.1 ± 2.9	−8.9 ± 3.8	.89
Peak knee abduction	−6.3 ± 6.3	−3.7 ± 4.5	−13.5 ± 4.8	<.001[b]
Peak knee internal rotation	2.6 ± 4.0	0.8 ± 4.2	2.9 ± 3.8	.47
Single-legged squats				
Peak hip adduction	10.8 ± 4.9	11.0 ± 4.1	8.7 ± 5.6	.28
Peak contralateral pelvic drop	1.6 ± 4.6	0.6 ± 3.1	5.5 ± 5.7	.008[b]
Peak knee abduction	−6.8 ± 4.9	−5.0 ± 4.1	−10.5 ± 5.6	.008[b]
Peak knee internal rotation	−5.0 ± 8.3	−5.7 ± 8.5	−3.0 ± 9.8	.47

[a] Independent-samples *t* test (high-scoring versus low-scoring group).
[b] Between-groups difference ($P < .05$).

analysis. It could be that other sagittal-plane tasks are equally or more effective in identifying potentially injurious movement patterns. Finally, kinematic factors other than those reported in our study may contribute to injury. We selectively focused on those that had been related to injury risk via prospective studies. Ankle and trunk kinematics potentially contribute to injury, but we do not know if the RRS can be used to effectively assess ankle and trunk motion during running.

CONCLUSIONS

The RRS is a reliable and valid tool for clinicians to evaluate knee abduction in asymptomatic novice female runners. Modifications to scoring criteria should be considered to improve assessment of contralateral pelvic drop and knee internal rotation. More research, however, is needed to verify whether these relationships hold for other populations of runners and to investigate whether RRS scores predict future injury.

ACKNOWLEDGMENTS

We thank Zayd Abdul-Ali, Lauren Beshada, Kaitlyn Gregaitis, Colton Hust and Daniel Shull for their important contributions to data collection and processing for this study.

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