Running Readiness Scale as an assessment of kinematics related to knee injury in female novice runners

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Abstract

CONTEXT
Frontal and transverse plane kinematics were 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 assess reliability and validity of the RRS as an assessment of frontal and transverse plane running kinematics.

DESIGN
Cross-sectional

SETTING
University research laboratory.

PATIENTS OR OTHER PARTICIPANTS
56 female novice runners.

MAIN OUTCOME MEASURES
3D kinematics were collected during running and RRS tasks: hopping, plank, step-ups, single-leg squats, and wall-sit. RRS performances were assessed by 5 assessors, 3 times each. Inter- and intra-rater reliabilities of total RRS score and individual tasks were calculated using intraclass correlation coefficient and Fleiss kappa, respectively. Pearson correlation coefficients between
peak joint angles measured during running and the same angles measured during RRS tasks were calculated. Peak joint angles of high vs. low scoring participants were compared.

RESULTS

Inter- and intra-rater reliabilities of assessment of the total RRS scores were good. Reliability of the assessment of individual tasks were moderate to almost perfect. Peak hip adduction, pelvic drop, and knee abduction during running were correlated with the same angles measured during hopping, step-ups, and single-leg 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.

CONCLUSIONS

The RRS may be an effective evaluation of knee abduction in novice runners, but evaluation criteria or tasks may need to be modified for effective assessment of pelvis and transverse plane knee kinematics.

Keywords: hip adduction, knee abduction, knee internal rotation

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KEY POINTS

- The intra- and inter-rater reliability of the assessment of Running Readiness Scale 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 Running Readiness Scale tasks.

• Runners who scored high on the Running Readiness Scale demonstrated less knee abduction during running than those who scored low.
1. Introduction

Running carries a high risk of injury, particularly for novice runners. Among all runners, the knee is the most common site of injury. Previously identified kinematic risk factors for knee injury in runners included hip adduction and knee internal rotation. Hip adduction may affect the knee in two 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. A test that can identify runners with excessive hip adduction, contralateral pelvic drop, knee abduction, and/or knee internal rotation may aid in injury prevention.

Unfortunately, equipment and technical experts to conduct 3D gait analysis are not widely available in clinical settings. Visual observation of running is difficult due the complexity and fast pace of movement; as such, reliability of visual assessment of 2D video of running is often low to moderate. Assessment of 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 to assess in a clinical setting. Further, breaking down important skills into separate tasks may help clinicians determine which interventions might be most likely to help a client.

Previous research aimed to develop movement screens, visually assessed by practitioners, to determine whether an athlete is at risk of injury due to her or his movement patterns. The Functional Movement Screen (FMS) includes a series of seven movements thought to be important to sports performance. However, the FMS has poor predictive value for injury among competitive male runners (sensitivity 0.73, specificity 0.54). Interestingly, consideration
of only the active leg raise and deep squat components of the FMS resulted in improved specificity (0.74). Function of the lower extremity in the sagittal plane, which is assessed via the active leg raise and deep squats, is important to runners, while upper body tests such as shoulder mobility may be less meaningful. Those extraneous tasks likely detract from the utility of the total FMS score to assess a runner’s ability to control injurious frontal and transverse plane motion during sagittal plane tasks. For example, total FMS score was not associated with biomechanics during forward step downs. Therefore, we assumed the FMS would also not be associated with kinematics of running that were previously identified as risk factors for injury. A functional test designed to assess a runner’s ability to maintain control of frontal and transverse plane motion during sagittal plane tasks and landings may prove better able to detect injurious movement patterns among runners.

The Running Readiness Scale (RRS) was developed to assess these running-specific skills. The five tasks included in the assessment are: hopping, plank, step-ups, single-leg squats, and wall sit. Observation of step-ups, single-leg squats and hopping allow assessment of the ability to stabilize the lower extremity in the frontal plane during dynamic sagittal plane tasks. In previous research, frontal plane projection angles (i.e., a two-dimensional measure of knee abduction) measured during single-leg squats and running were significantly correlated in asymptomatic runners. That suggests that single-leg squats and hopping may be valid tasks to assess whether a runner would display aberrant frontal plane kinematics during running. Frontal plane projection angle was also significantly correlated with knee internal rotation during single-leg squats. That suggested that assessment of frontal plane movement patterns may be indicative of transverse plane movement patterns.
The wall sit is included to assess function of the quadriceps muscle group. McCurdy et al. found that 3-repetition maximum squat strength was a strong predictor of knee valgus during landings. Similarly, female soccer players who displayed limited knee flexion during a drop landing also displayed greater knee valgus than those who used greater knee flexion. Those studies suggested that function of the quadriceps, 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 intended to assess strength and control of the trunk. Powers demonstrated that anterior lean of the trunk reduced knee joint loads, while a posterior trunk placed a potentially excessive load on the knee. A runner who places a large load on the knee may not have the strength capacity in her or his knee extensors to absorb that load in the sagittal plane and may compensate with increased knee abduction. In support of that premise, Burnham et al. reported that plank endurance was negatively associated with knee valgus during the step down task in females.

The purpose of the current study was to confirm inter- and intra-rater reliability of the RRS and investigate RRS validity through its relation 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 who scored high on the RRS (i.e., successfully completed at least four of the five tasks) would demonstrate less contralateral pelvic drop, hip adduction, knee abduction, and knee internal rotation compared to those who scored low (i.e., completed two or less of the RRS tasks successfully).
2. Material and methods

2.1 Participants

Participants enrolled as part of a training study. The measurements for this study came from their baseline data collection visit, before training commenced. All participants provided written Informed Consent prior to beginning study procedures. The University Institutional Review Board approved this study. To be eligible for the study, participants had to be female, 18-60 years old, and sufficiently healthy to participate in moderate activity according to the American College of Sports Medicine Physical Activity Readiness Questionnaire (PAR-Q+, 2017 Version). In addition, participants must have reported no previous history of regular running (i.e., 3 or more months of running 3 or more times per week). We excluded males for this study since: 1) males and females differ in running biomechanics—particularly frontal plane kinematics, 2) the biomechanical etiology of injuries appeared to differ between males and females, and 3) females experience greater incidence of knee injury than males.

To assess correlation between peak joint angles during running and RRS tasks, power analysis showed that 29 participants would be necessary to detect a moderate correlation (r=0.5, α=0.05, β=0.2). Therefore, the sample from the training study (n=56) was ample to address this question. To compare running kinematics between participants who scored high and those who scored low on the RRS, we divided participants into groups based on their RRS score (Low: 0, 1 and 2 vs. High: 4 and 5). We chose these groups to create larger differentiation in movement skill between groups, by omitting those who scored a 3. A power analysis based on a previous comparison of female runners who developed ITBS, vs. female runners who remained healthy was used to be able to detect a clinically meaningful difference between groups. The calculated
sample size was eight participants per group. Thus, the high (n=20) and low (n=20) scoring

groups from the training study were considered ample to make the kinematic comparisons.

2.2 Data collection

Study visits took place at the University gait laboratory. Participants wore their own

athletic attire and were provided with standard neutral running footwear (New Balance 680, New

Balance, Boston, MA). Although recent research suggested standardized running shoes may

influence running biomechanics, the participants in this study—enrolled before beginning a run

training program—and did not have habitual running footwear. Reflective markers were placed

on subjects according to a modified lower extremity Cleveland Clinic model. Specifically, joint

markers were placed bilaterally on the greater trochanters, iliac crests (i.e., directly superior to

greater trochanters), medial and lateral femoral epicondyles, medial and lateral malleoli, and

heads of the first and fifth metatarsals. Clusters of four tracking markers were fixed to the

posterior pelvis, thighs, and shanks, and three tracking markers to the heel counter of each shoe.

Data collected during a standing trial established joint centers and anthropometrics. Joint

markers were then removed, and subjects ran on a treadmill (Treadmetrix, Park City, UT).

Kinematic data were collected using a 7-camera 3D motion analysis system (Qualysis, Goteborg,

Sweden) 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 s to

acclimate to treadmill running. When the participant indicated she was comfortable and ready to

increase the pace, we increased the pace to 2.68 m/s. When each subject indicated she was

comfortable running at the 2.68 m/s pace, we captured 20 s of running for analysis. That pace

was similar to the previously reported preferred running pace of recreational female runners.
Since the participants in this study had not yet begun a run training program, they did not have a habitual running pace. Therefore, the pace selected for this study was one 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.

Once the participants indicated they were ready to resume testing, they performed the RRS tasks. All participants performed the tasks in the same order: 2-foot hopping, plank, step-ups, single-leg squats, and wall sit. The order of tasks was not randomized between participants, as order of the tasks could influence the skills being assessed. For example, if wall sits were performed before single-leg squats, that may have challenged the endurance of the quads more than dynamic control. Participants performed dynamic tasks (i.e., hopping, step-ups, and single-leg squats) on the treadmill surface while the belt was stationary and fixed, so that 3D motion could be recorded. Videos were recorded for all tasks on a handheld tablet (Samsung, San Jose, CA), from a distance that allowed for each participant’s entire body to be captured within the frame. For hopping, step-ups, and single-leg squats, the camera was positioned directly behind the participant to capture lower extremity kinematics in the frontal plane. For planks, the camera was aligned parallel to the length of each participant’s body, centered at her hips. For the wall squats, videos were taken from in front of the participant.

The assessor gave one point for each of the five tasks if the participant was able to maintain good form for one minute without breaks (Table 1). Evaluation criteria for good form based on visual assessment of kinematics have, to our knowledge, only been previously established for single-leg squats. As suggested by Crossley et al., our evaluation criteria for single-leg squats were based on overall performance (e.g., ability to maintain balance), as well as assessment of knee, pelvis/hip, and trunk kinematics. We adopted similar criteria as appropriate
for the remaining four tasks of the Running Readiness Scale (Table 1). The 1-minute time period
was chosen to assess muscular endurance, which ostensibly was important for maintaining form
during a run. If a subject did not maintain good form or stopped before the minute was over, she
received no points for that task. We totaled points for each participant as a score out of five.

2.3 Reliability

To assess inter- and intra-rater reliabilities, we used a series of 10 videos of volunteers
performing all the RRS tasks. Five clinicians participated in the reliability portion of this study;
each was a licensed athletic trainer and/or physical therapist with <3 years’ experience. The
clinicians assessed the videos three times each within a week but on non-consecutive 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 one point. If the participant did not meet all good form criteria or did not
maintain good form for a full continuous minute, the clinician rated the trial as a fail, worth zero
points. Prior to rating study videos, clinicians were provided with criteria (Table 1) for good
form for each task, and they watched example videos of the tasks being performed with both
good and poor form (as determined by the developer of the RRS; a licensed physical therapist
with >15y experience) for visual demonstration. Trainees were told when watching the example
videos whether the athlete in the video demonstrated passing or failing form, along with reasons
for the pass/fail score. The videos allowed trainees to associate visual examples of athletes
performing the RRS with both good and bad form. The training on how to rate the videos lasted
approximately 1 hour. During the evaluation, clinicians were provided with a scoring sheet to
track assessment criteria.²⁴
2.4 Data processing

Kinematic marker trajectory data were exported to motion analysis software (Visual3D, C-Motion, Germantown, MD) for processing. Marker trajectories were filtered using a 4th order dual-pass Butterworth filter with a cut-off frequency of 10 Hz. Subsequently, foot, shank, thigh, and pelvis segments were reconstructed, and joint angles were calculated using Cardan sequencing. Left or right side of the body randomly selected for analysis for each participant. 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.25 Toe off was identified as the point of peak knee extension following initial contact. Peak joint/segment angles (hip adduction, contralateral pelvic drop, knee abduction, knee internal rotation) were calculated for all steps (stance phase) during running, or repetitions during RRS tasks, for each participant and averaged across all steps/repetitions for statistical analyses. During running, hopping, and step-ups, the window for identification of peak angles was from initial contact to toe-off. 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 above 0.15 m from the landing surface. For single-leg squats were separated each repetition by the maxima of the L5/S1 pelvic marker.

2.5 Statistical Analysis

Inter- and intra-rater reliabilities were assessed for the total RRS scores using the 2-way random effects intra-class correlation coefficient, as this is an ordinal variable (SPSS version 26, IBM, Armonk, NY).26 Inter- and intra-rater reliabilities were assessed for each of the 5 RRS tasks using Fleiss’ Kappa, since those were categorical variables (Microsoft Excel, Redmond,
Reliability of total scores and scores for individual tasks were assessed, and the total scores were used as a measure of injury risk. Understanding the reliability of each individual task was central to understanding if and where criteria for assessment needed to be adjusted to improve overall reliability.

All demographic data and peak joint angles were evaluated for normality using a Shapiro-Wilk test. Demographic data were not normally distributed, so they are reported using median and interquartile range, and were compared between high- and low-scoring groups using an Independent Samples Kruskal-Wallis test.

To assess validity of the RRS as an assessment of running kinematics, Pearson correlation coefficients were calculated between peak joint/segment angles measured during running, with the same angles measured during hopping, step-ups (i.e., both up and down), and single-leg squats ($\alpha=0.05$). That generated a total of 9 correlations. All peak joint angle data were normally distributed.

To assess the ability of raters to identify excessive joint/segment angles, peak joint/segment angles of interest measured during dynamic RRS tasks and running between high and low-scoring groups were compared using independent samples t-tests ($\alpha=0.05$). To better understand the complete movement patterns that lead to the measured peak joint angles, comparisons of joint angle time series are provided in the Supplementary File.

3. Results

For the total RRS score, both inter- and intra-rater reliability were good (ICC=0.75 and 0.80, respectively). Inter-rater reliability for the individual tasks of the RSS ranged from $k=0.58$ to 1.00, indicating moderate to nearly perfect agreement according to interpretation.
recommended by Landis and Koch.\textsuperscript{30} Intra-rater reliability for the individual tasks ranged from $k = 0.87 - 1.00$, indicating reliability was almost perfect (Table 2). Participants who scored high had a significantly lower BMI than those who scored low (Table 3).

With respect to validity of the RRS as an assessment of running kinematics, correlation coefficients for 3D joint angles measured during RRS tasks and running ranged from $r = 0.113$ to $r = 0.936$. Moderate to strong significant correlations were found for peak frontal plane joint angles during running with hopping, step-ups, and single-leg squats, as well as for peak knee internal rotation with the step-up task. Correlations, however, were insignificant between peak knee internal rotation during running and the hopping and single-leg squat tasks (Table 4).

High-scoring participants demonstrated significantly less knee abduction than low-scoring participants during all dynamic RRS tasks as well as running (Table 5). Low-scoring runners had a more elevated contralateral pelvis during single-leg squats, although on average, neither the high or the low-scoring groups had a peak contralateral pelvic drop below 0 (i.e., their pelvis did not drop below horizontal).

4. Discussion

The purpose of our study was to confirm the reliability of the RRS and investigate whether RRS performance was a good indicator of running kinematics. Our results showed that the RRS had good inter-rater reliability and intra-rater reliability.\textsuperscript{29} Further, reliability of individual RRS tasks was moderate to almost perfect.\textsuperscript{30} That indicated that clinicians can become proficient in RRS assessment in a brief period of time, even early in their career. The demonstration of reliability is a significant first step in determining whether this assessment will be acceptable and efficacious for clinical use. Those results, for individual tasks, were supported
by previous studies showing strong reliability of visual assessment of single-leg squats \(^{31}\) and planks. \(^{32}\) Reliability of assessments of double-leg wall sit performance has not, to our knowledge, been previously reported. Wilkerson and Colston, however, found strong reliability of single-leg wall sit assessment. \(^{33}\) To our knowledge, other studies reporting reliability of 2-foot hopping and step-up assessments do not exist. Differentiating between a runner’s ability to perform each component of the RRS is important as it may allow clinicians to determine which qualities a runner needs to improve (e.g., trunk vs. leg strength or endurance vs. dynamic control). Future research is needed to determine whether targeted intervention based on performance on specific tasks has an effect on running kinematics.

Results from the current study suggest the RRS has potential to be a valid assessment of frontal plane running kinematics. Peak joint angles of the hip, pelvis, and knee in the frontal plane during all three dynamic RRS tasks were moderately to strongly correlated with the same angle measured during running. Consistent with those results, frontal plane projection angle—a 2-dimensional measure of knee abduction—was significantly correlated between running and single-leg squats in healthy runners. \(^{11}\) That relation, however, was not significant in injured runners. Ostensibly, in injured runners, the higher loads during running elicit pain, which may alter their movement patterns during running.

In the transverse plane, knee internal rotation angle during running was only significantly correlated with step-ups, but not with hopping or single-leg squats. The lack of a strong relation between knee internal rotation angles observed during running and single-leg squats and hopping may have been because hopping and single-leg squats were performed primarily in the vertical direction, with minimal force applied in the anteroposterior direction. We expect vertical forces have limited action in the transverse plane compared to antero-posterior and mediolateral forces,
as the vertical ground reaction force is essentially parallel to the transverse axis of rotation
between the thigh and shank when the leg is straight. The mini-squat required of this task means
that the vertical component of the GRG should still only have limited effect on the thigh-shank
transverse plane moment and the deepest point of the squat. In contrast, step-ups required
participants to step forward up onto a box, and then backwards back down to the floor. Thus,
step-ups require greater anterior and posterior ground reaction forces to translate the center of
mass. Since antero-posterior forces contribute a larger proportion to the transverse plane, they
likely elicit transverse plane kinematics more like running. It is also possible that step-ups elicit
transverse plane similar to running because there are phases of the task which require single-limb
stance. This likely presents a greater challenge to stability than double limb support tasks, such
as hopping.

By comparing running kinematics between runners who scored high on the RRS vs. those
who scored low, the study’s hypotheses were only partially supported. As expected, the high-scoring group had a smaller degree of peak knee abduction than those who scored low. A lower
knee abduction angle has been proposed to be protective of the knee.\(^5\)

Contralateral pelvic drop is a criterion for evaluation of the single-leg squat, and thus we
expected pelvis motion—in conjunction with hip motion—to differ between high- and low-scoring participants during running. Peak hip adduction and contralateral pelvic drop, however,
did not differ between high and low scoring groups. On average, neither group displayed
contralateral pelvic drop below horizontal during single-leg squats (i.e., the only RRS task that
was performed entirely on one foot). Tasks such as single-leg hopping may be a greater
challenge to pelvis 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-leg squats. The high-scoring group in the current study, however, had similar peak knee internal rotation angles to the low-scoring group. Addition of 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, since knee internal rotation angles during step-ups and running were correlated.

In the current study, runners who scored high on the RRS had lower body mass index (BMI) than those who scored low. Time to failure in a plank task has been negatively correlated with BMI and waist circumference. The influence of anthropometric measures on performance of single-leg squats, hopping, wall sit, and step-up tasks has not been previously reported. Current results indicated that BMI is 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 the current study should be interpreted with caution, since participation was limited to asymptomatic, novice females. Future studies need to evaluate the reliability and validity of the RRS in injured, experienced, and/or male runners. In the current study, participants ran on a treadmill, and while there are some differences in running biomechanics between overground and treadmill running in recreational runners, it is unknown whether novice runners would display divergent kinematics on a treadmill compared to overground running. Videos were used for reliability analysis, to be able to assess intra-rater reliability in addition to inter-rater reliability. Future studies are needed to confirm test-retest and inter-rater
reliability of real-time 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 the current study may contribute to injury. We selectively focused on those that had been related to injury risk via prospective studies. Potentially ankle and trunk kinematics contribute to injury, but we do not know if the RRS is an effective assessment of ankle and trunk motion during running.

5. Conclusion

The Running Readiness Scale 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 if these relations hold for other populations of runners and to investigate whether RRS scores are predictive of future injury.
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| Task                  | Instructions to participants                                                                 | Good form (must be maintained for 1 min without breaks to pass)                                                                 |
|----------------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| Hopping (on two 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 (i.e., 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/forearms  
• Neutral head alignment (i.e., held in line with trunk) |
| Step-ups             | Step up onto the box in front of you, one foot after the other, and then step down from the box, one foot after the other, in an Up, Up, Down, Down pattern. Each step should be 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 (i.e., no apparent knee collapse toward midline)  
Upright trunk (i.e., no excessive forward or lateral lean) |
| Single-leg squat     | Stand on one 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 bpm (down on 1st beat, up on 2nd)  
• Maintains balance  
• Level hips  
• Knee aligned (i.e., no apparent knee collapse toward midline)  
• Upright trunk (i.e., 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 the one minute. | • Thighs parallel to floor  
• Upright trunk (i.e., no excessive forward or lateral lean)  
• Equal weight-bearing on left and right feet |
Table 2. Reliability Assessment of RRS Tasks Calculated Using Fleiss Kappa

| Task          | Inter-rater reliability | Intra-rater reliability |
|---------------|-------------------------|-------------------------|
|               | k(95% CI) | p  | k(95% CI) | p  |
| Single-leg squats | 0.72(0.48-0.98) | <0.001 | 0.87(0.51-1.22) | <0.001 |
| 2 Foot Hopping   | 0.58(0.33-0.84) | <0.001 | 1.00(0.64-1.36) | <0.001 |
| Plank          | 0.87(0.61-1.12) | <0.001 | 0.87(0.51-1.22) | <0.001 |
| Wall sit       | 1.00(0.75-1.25) | <0.001 | 1.00(0.64-1.36) | <0.001 |
| Step-ups       | 0.87(0.61-1.12) | <0.001 | 0.87(0.51-1.22) | <0.001 |
|                    | Age (yr)  | Body mass index (kg/m²) | Weekly physical activity (min) |
|--------------------|-----------|-------------------------|-------------------------------|
| All participants   | 34(26-47) | 29.0(25.4-34.1)         | 120(60-223)                   |
| RRS high (n=20)    | 29(22-38) | 25.8(25.4-28.4)         | 135(96-213)                   |
| RRS low (n=20)     | 42(32-48) | 34.4(30.9-40.9)         | 60(30-180)                    |
| P (high vs. low)    | 0.216     | 0.003                   | 0.193                         |
### Table 4. Pearson Correlation Coefficients Between Peak Joint Angles Measured During Stance Phase of Running and RRS Tasks

|                      | 2 Foot Hopping | Single-leg squats | Step-ups |
|----------------------|----------------|-------------------|----------|
| Hip adduction        | 0.669**        | 0.586**           | 0.627**  |
| Contralateral pelvic drop | 0.537**      | 0.558**           | 0.613**  |
| Knee abduction       | 0.939**        | 0.858**           | 0.825**  |
| Knee internal rotation | 0.113 (N.S.) | 0.519 (N.S.)     | 0.831**  |

** p<0.01
Table 5. Peak joint / segment angles (in degrees) during running and Running Readiness Scale tasks. Reported as mean(sd)

|                          | Overall (n=56) | High-scoring | Low-scoring | p-value (High vs. Low) # |
|--------------------------|----------------|--------------|-------------|--------------------------|
| **Run**                  |                |              |             |                          |
| Peak hip adduction       | 15.4(3.9)      | 15.1(3.5)    | 15.6(5.3)   | 0.77                     |
| Peak CLPD                | -4.4(3.0)      | -4.4(2.8)    | -4.9(3.8)   | 0.71                     |
| Peak knee abduction      | -7.0(4.1)      | -5.3(3.6)    | -9.5(4.1)   | 0.01                     |
| Peak knee internal rotation | 5.0(5.3)    | 5.4(5.0)     | 6.3(5.8)    | 0.69                     |
| **Hopping**              |                |              |             |                          |
| Peak hip adduction       | 5.0 (3.9)      | 3.9(3.1)     | 5.4(4.1)    | 0.32                     |
| Peak CLPD                | -1.0(2.6)      | -1.3(2.0)    | 0.2(2.9)    | 0.10                     |
| Peak knee abduction      | -7.0(4.1)      | -5.3(3.6)    | -9.8(4.0)   | 0.007                    |
| Peak knee internal rotation | -9.0(6.3)   | -9.7(5.4)    | -8.1(8.9)   | 0.58                     |
| **Step-ups**             |                |              |             |                          |
| Peak hip adduction       | 14.7(3.2)      | 14.0(2.4)    | 16.1(4.4)   | 0.22                     |
| Peak CLPD                | -8.9(3.4)      | -9.1(2.9)    | -8.9(3.8)   | 0.89                     |
| Peak knee abduction      | -6.3(6.3)      | -3.7(4.5)    | -13.5(4.8)  | 0.00005                  |
| Peak knee internal rotation | 2.6(4.0)    | 0.8(4.2)     | 2.9(3.8)    | 0.47                     |
| **Single-leg Squats**    |                |              |             |                          |
| Peak hip adduction       | 10.8(4.9)      | 11.0(4.1)    | 8.7(5.6)    | 0.28                     |
| Peak CLPD                | 1.6(4.6)       | 0.6(3.1)     | 5.5(5.7)    | 0.008                    |
| Peak knee abduction      | -6.8(4.9)      | -5.0(4.1)    | -10.5(5.6)  | 0.008                    |
| Peak knee internal rotation | -5.0(8.3)   | -5.7(8.5)    | -3.0(9.8)   | 0.47                     |

CLPD = contralateral pelvic drop. # Independent Sample T-Test