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Cover Page Footnote
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Performance Motion Analysis Unable to Predict Running-Related Injury in Collegiate Distance Runners

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Purpose: Running-related injury (RRI) is common among competitive collegiate distance runners who participate in the sport of cross country and long distance track and field. Many factors contribute to RRI. Therefore, the purpose of this study was to determine if a 3D motion capture system's performance motion analysis (PMA) report is capable of identifying factors predictive of RRI among collegiate distance runners during a cross country season. **Methods:** Thirty-one collegiate cross country runners (17 male, 14 female, mean age = 20.5 ± 1.4 years) gave their consent to participate in the investigation. Subjects were screened in the motion capture system and provided with PMA reports assessing their movement quality using several variables (composite score, power, strength, dysfunction, and vulnerability, based on measurements of 192 kinetic and kinematic variables). The athletes were then monitored throughout their 13-week competitive season for incidence of RRI. At the end of the season, participants were sorted into injured (n=17) and uninjured (n=14) groups. Injury was defined as appearing on the team injury report as missing or being limited in practice or competition for a week or more, in accordance with prior RRI research. Each sex was also separated into groups based on injury status. **Results:** Independent samples t-tests. **Conclusion:** The findings identified in this prospective study suggest that the movement screen was unable to identify runners at risk of injury. Future investigations isolating lower extremity movement characteristics in runners may prove more effective at predicting RRI. **Keywords:** *movement screen, motion capture, cross country running.*

INTRODUCTION

Running-related injury (RRI) is a common occurrence among distance runners. Researchers report that lower extremity injury rate in long distance runners (recreational or competitive individuals running at least five kilometers per session) ranges from 19.4% to 79.3% yearly.[1, 2,3] In the lower extremities, the knee is most commonly injured -- reportedly at a rate of 7.2% to 50% of incidents for runners -- followed by the lower leg at 9.0% to 32.2% and the foot at 5.7% to 39.3%.[2] It is important for these athletes and their support groups to be able to identify and correct modifiable factors contributing to increased risk of injury.

Variables attributed to increased risk of RRI include poor nutrition habits, excessive training volume, history of past injury, poor lower extremity biomechanical characteristics of the athlete such as excessive knee internal rotation during running.[4,5,6,7,8,9,10,11,12] Several of these factors are modifiable and can be addressed and corrected with the proper strategies. For example, Fredericson et al. demonstrated a reduction in iliotibial band syndrome symptoms after a hip abductor strengthening program.[13] Similarly, Heiderscheit et al. reported lower magnitudes of force absorbed at the hip and knee during running when athletes simply increased their step rate.[14] These studies illustrate the capability of runners to reduce likelihood of injury when equipped with proper strategies.

A valid and reliable method of assessment is required in order to properly address injury risk factors. The Functional Movement Screen™ (FMS) is commonly used for this purpose.[15] The FMS is a standardized testing system scoring individuals on performance in seven tasks fundamental to human movement. These tests include deep squat, hurdles step, in-line lunge, active straight leg raise, shoulder mobility, rotary stability, and a trunk stability push-up. The FMS has been shown to be capable of identifying injury risk in athletic populations of football players and military officers.[16,17]

The FMS composite score has not been a reliable screening tool for identifying injury risk factors in running populations.[18,19] Collegiate runners, along with their coaches and sports medicine staff, could benefit from a movement screening system that allow them to identify characteristics contributing to greater likelihood of injury.

Three-dimensional motion capture systems (MCS) may be of use in RRI screening. These systems can be used to analyze movement performance variables. A markerless system does not require the subject to place tracking markers on anatomical landmarks in order for the system's cameras to locate human joint segments. The 3D MCS used in this investigation analyzes kinetic and kinematic variables to provide a Performance Motion Analysis (PMA) report. The PMA report provides an assessment of the subject's muscular power, functional strength, and dysfunction. The resulting report provides an overall composite score, a measure of the athlete's overall performance in the screening. Finally, the report also offers a 'vulnerability' measurement, intended to reflect an individual's susceptibility to injury. Scores from the PMA report do not have specific units. Rather, each score is composed of aggregate calculations from variables associated with each task performed by the subject. Each performance assessment variable is influenced more heavily by certain sets of tasks. Power scores are derived mostly from performance variables associated with jump tasks, while single- and double-limb squat characteristics weigh heavily for functional strength, and imbalances and asymmetries throughout the screening compose the dysfunction scores. Additionally, the PMA normalizes strength and power scores in order to place them on the same scale and allow for direct comparisons. The overall composite score reported by the PMA is calculated by subtracting the dysfunction score from the sum of the strength and power scores. The PMA aggregates vulnerability score based on the individual's scores in relation to normative data sets. This measure is reported in terms of a percentage and is intended to reflect the likelihood that an individual experiences a non-contact soft tissue injury due to their biomechanical tendencies.

The MCS can be a valuable tool for risk assessment in athletes. Recently, Mosier et al. conducted research examining the ability of the MCS to serve as an injury risk screening system for NCAA Division I football players.[20] Out of the sample of 68 athletes screened, the group identified five 'at-risk' individuals based on PMA scores. Three of the five "at-risk" individuals later suffered season-ending non-contact injuries, while zero of the 63 "not at-risk" individuals suffered season-ending non-contact injuries. The findings of the Mosier study suggest the PMA report from an MCS may be a valid tool for injury-risk assessment in football players.

Research using the 3-D markerless MCS to assess injury risk is still in its early stages. Injury is a common occurrence among collegiate distance runners and there is a lack of a valid injury screening tool for these athletes. Since previous research suggests that movement screening can be used to identify injury risk factors in athletic populations, the purpose of this investigation was to determine if a 3D MCS PMA could identify factors predictive of running-related injury among collegiate distance runners. The researchers hypothesized that the performance variables of power, functional strength, and composite score would be lower in the injured group, and that dysfunction, vulnerability, and peak knee valgus would be higher.

METHODS

Participants

A total of 31 healthy collegiate distance runners (14 female, 17 male, mean age = 20.5 ± 1.4 years) participated in this study. In order to be eligible on their National Collegiate Athletics Association (NCAA) Division I cross country team, athletes were subject to routine physicals conducted by the sports medicine staff. These physicals are a requirement for all student-athletes at the school and were not unique to participants. Prior to enrollment each participant performed a Dynamic Athletics Research Institute Motion Capture System (Overland Park, KS) screening, which was requested by their coaches and medical personnel. Participants signed a consent form approved by the University Institutional Review Board allowing the investigators to use their screening results and medical information appearing on the team injury report for the 2018 NCAA cross country season. The pre-season motion screening and signed consent form were required for participation in the study.

Protocol

Screenings using a markerless MCS took place during the first week of practice of the 2018 NCAA cross country season. The principle investigator administered every screening in order to prevent variability amongst test administrators. Standardized minimal cues were given to limit influence on natural performance in the screening. After each screening, a PMA report was generated using the MCS program software. The PMA report evaluates 192 kinetic and kinematic variables based upon performance in 19 functional movements common in sport, providing an assessment of the athlete's strengths and weaknesses. These variables are reported in composite measures of power, functional strength, dysfunction, exercise readiness, and vulnerability. The PMA report does not give specific units in its assessment of performance.

The study followed a prospective longitudinal design. Per team protocol, incidence of RRI amongst the participating athletes was tracked throughout the 13-week season on an injury report. RRI was defined as any non-contact induced lower limb musculoskeletal injury that limited or prevented participation in team activity for 7 or more days. This definition is in line with prior research conducted by Buist and colleagues.[21] Information taken from the report included injury type and location, and time of limitation in days.

Statistical Analysis

Once PMA and injury report data was compiled, individuals were sorted into "injured" (experiencing at least one RRI) and "uninjured" (experiencing no RRIs) groups. Statistical analysis was performed using IBM SPSS Statistics (Version 25). Mixed-factorial ANOVAs were conducted to examine the interactions between groups. Independent samples t-tests ($p<0.05$) were used to compare the mean difference between "injured" and "uninjured" groups, between sexes, and within sex based on injury status for PMA variables (composite, power, strength, dysfunction, vulnerability, and peak knee valgus scores).

Improper nutrition may play a large role in occurrence of bone stress injuries.[6] In order to minimize influence of nutrition, a separate analysis removed individuals experiencing bone injuries during the season from the subject population and used the same test procedure as above.

RESULTS

The data displayed in table 1 summarizes subject characteristics, which were collected at their screening session. Data is presented as mean ± standard deviation.

Group	Body Weight (kg)	Height (m)
Subject group (n=31)	61.4 ± 4.98	1.76 ± .068
Males (n=17)	64.0 ± 4.01	1.81 ± .046
Females (n=14)	58.2 ± 4.44	1.71 ± .048

Table 1. Participant demographics (X̄±SD)

Table 2 displays the results compiled from PMA reports. Average MCS composite and sub-scores are shown for groups analyzed during the study in mean ± standard deviation format.

Group	MCS Composite Score	Power	Functional Strength	Dysfunction	Vulnerability (%)	Peak Knee Valgus (°)
Sample Group (n=31)	1450 ± 196	812 ± 124	751 ± 138	105 ± 43.1	41.0 ± 9.90	4.61 ± 2.08
Injured (n=14)	1430 ± 138	792 ± 133	741 ± 131	104 ± 55.0	42.7 ± 12.4	4.13 ± 1.97
Uninjured (n=17)	1480 ± 240	828 ± 121	760 ± 151	106 ± 33.9	39.6 ± 7.8	5.01 ± 2.14
Males (n=17)	1500 ± 211	880 ± 117*	734 ± 129	109 ± 51.2	42.2 ± 11.4	4.11 ± 2.27
Females (n=14)	1400 ± 175	729 ± 80.4	772 ± 156	100 ± 34.1	39.5 ± 8.4	4.84 ± 1.94
Injured Males (n=7)	1480 ± 167	887 ± 93.2	712 ± 142	117 ± 72.3	45.6 ± 14.8	3.39 ± 2.16
Uninjured Males (n=10)	1520 ± 244	875 ± 137	749 ± 134	104 ± 33.0	39.9 ± 8.4	4.62 ± 2.32
Injured Females (n=7)	1380 ± 80.0	696 ± 93.3	769 ± 123	91.0 ± 30.1	39.9 ± 10.0	4.87 ± 1.58
Uninjured Females (n=7)	1430 ± 41.0	762 ± 52.3	775 ± 194	110 ± 37.5	39.1 ± 7.4	4.80 ± 2.37

Table 2. Performance Motion Analysis Variable Comparison (X̄±SD)
**significant at p<.01*

A total of 24 incidences of non-contact running-related injury appeared on the team's injury report during the 13-week competitive season. Of the 24 total injuries reported, 16 led to a week or more of missed and/or limited participation. A total of 14 of the 31 (45.1%) athletes screened experienced the 16 limiting injuries. There were 3 season-ending injuries, each attributed to bone stress fractures. Table 3 shows the 16 injuries that led to a week or more of missed time on the team injury report.

Injury Type	Body Site
Tenosynovitis	Achilles Tendon
Nerve Involvement	Iliopsoas
Bursitis	Infrapatellar Bursa
Strain	Soleus
Tendinosis	Peroneals
Stress Reaction	Navicular
Stress Reaction	Tibial Shaft
Sprain	Talonavicular Joint
Stress Reaction	Tibial Shaft
Soreness	Sacrum
Tenosynovitis	Achilles Tendon
Soreness	3rd Metatarsal
Tendinitis	Iliopsoas
Impingement	Infrapatellar Bursa
Pain	General Hip
Sprain	Anterior Talofibular Ligament

Table 3. Injuries that led to a week or more of missed time during the competitive season

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Comparison between Groups

At a significance level of α = 0.05, mixed factorial ANOVAs revealed no significant two-way interaction between injury status and sex for composite score (p = 0.919), power (p = 0.306), functional strength (p = 0.773), dysfunction (p = 0.326), vulnerability (p = 0.514), or peak knee valgus angle (p = 0.722). There was no main effect for injury status for composite score (p = 0.537), power (p = 0.481), functional strength (p = 0.695), dysfunction (p = 0.870), vulnerability (p = 0.402), or peak knee valgus angle (p = 0.203). There was no main effect for sex for composite score (p = 0.185), functional strength (p = 0.442), dysfunction (p = 0.536), vulnerability (p = 0.396), or peak knee valgus angle (p = 0.112). The only main effect observed was for power between sexes (p<0.000).

Independent samples t-tests revealed no significant difference between injured (n=14) and uninjured (n=17) groups for MCS composite score (p = 0.463), power (p = 0.429), functional strength (p = 0.718), dysfunction (p = 0.894), vulnerability (p = 0.401), or peak knee valgus angle (p = 0.246).

Independent samples t-tests between injured females (n=7) and uninjured females (n=7) revealed no significant difference between groups for composite score (p = 0.596), power (p = 0.127), functional strength (p = 0.950), dysfunction (p = 0.313), or vulnerability (p = 0.882), or peak knee valgus angle (p = 0.948). The same analysis for injured (n=7) and uninjured males (n=10) revealed no significant difference between groups for composite score (p = 0.726), power (p = 0.838), functional strength (p = 0.582), dysfunction (p = 0.652), vulnerability (p = 0.328), or peak knee valgus angle (p = 0.285).

In a separate analysis between individuals with injuries not described as “bone-related” (n=11) and uninjured individuals (n=17) independent samples t-tests revealed no significant difference between groups for composite score (p = 0.480), power (p = 0.595), functional strength (p = 0.666), dysfunction (p = 0.704), vulnerability (p = 0.285), or peak knee valgus angle (p = 0.490).

DISCUSSION

The purpose of this study was to determine if the 3D MCS PMA report is capable of identifying factors predictive of running-related injury among collegiate distance runners during a collegiate cross country season. It was hypothesized that individuals affected by running-related injuries will exhibit poor movement quality scores on a 3-D motion screening assessment.

No significant findings were observed between any of the groups used in the statistical analysis. The inconclusive findings suggest that the movement screen lacks validity when screening for injury factors in these collegiate runners. It should be noted that the composite scores observed in this investigation are similar to those seen in unpublished normative data on NCAA Division I cross country athletes held by Fry et al.

Although the 3D MCS movement assessment was not shown to be effective in the present study, data from our laboratory has shown the system to be capable of identifying athletes at risk of injury.[20] These athletes were collegiate football players. Since the screening system reports its scores based off short bouts of activity (i.e. “single-leg hop,” and “depth-jump”) its performance ratings may be better suited for assessment of risk in activities more similar in nature. Football is a sport consisting of several brief, explosive movements that demand high amounts of power and strength, which could explain the effectiveness of the system as a risk-screening tool in prior observations. Distance running, on the other hand, is a task that requires greater volume of work, relying more heavily on muscular endurance and less on maximal power and strength. This could explain the lack of findings in the present context.

The 3-D motion capture system reports its scores based on performances in all 19 movements it records. Some of these tasks involve only lower limb movement (i.e. "lunge," and "squat"), however some call solely for upper limb movement (i.e. "shoulder abduction," and "shoulder flexion"). Thus, performance measurements integrate full body biomechanical characteristics in the final score report. Previous research has shown that a full body movement screen may not be effective in assessing injury risk for runners.[18,19] However, researchers have found lower limb sub scores of the same movement screen to be more effective indicators of injury risk for runners.[18] Keeping these findings in mind, it is reasonable to suggest that a performance report based on scores from only lower limb movements might yield significant results.

Knee adduction and internal rotation while running have been linked to running-related injury.[4,5] In addition to measures of athletic performance, the MCS assessment also reports biomechanical variables such as joint angle and torque measurements for several of the tasks performed. Although the system's screenings are not capable of screening running gait, the researchers wanted to determine if knee valgus during a single-limb squat task could similarly predict injury. A runner exhibiting high valgus in this task may be at a higher risk of RRI, and could reduce risk of injury by using corrective exercises to address the flawed movement pattern. However, based on the current results, the researchers were unable to distinguish a significant relationship between occurrence of injury and peak knee valgus during the single-limb squat.

One of the limitations to this investigation was the relatively low sample size. The sample of 31 individuals from the same team was chosen in order to control for factors including training volume, intensity, equipment, and terrain, all reported to be important in determining injury risk among runners.[2,7] Although important to control for these factors, the tradeoff of a small sample may have hindered the researchers from being able to find significance in the present context. Dudley and colleagues arrived at a similar conclusion in their recent investigation of RRI in collegiate runners. The researchers also had a sample size of 31 individuals from the same NCAA D1 cross country team and reported underpowered results when studying their sample's running characteristics in relation to injury prospectively.[5] A more robust sample of athletes from teams with similar training regimen could be more effective in determining the quality of the MCS as a risk assessment tool. It should also be noted that the findings of this investigation cannot be generalized to the running population as a whole, given the lack of variability in participant demographics and training characteristics.

Further limiting the present investigation was the fact that the researchers did not have access to a comprehensive medical history of the participants. History of prior RRI is shown to place runners at a greater risk of becoming injured.[7] Thus, adjustments were not made in the statistical analysis to control for the injury history of the athletes screened.

Lack of control for nutritional factors was a limiting factor. In performing a separate statistical analysis without including individuals who experienced bone injuries, the researchers attempted to minimize the impact of this potentially confounding variable. However, there was still no significance found in the analysis and it is still uncertain whether factors such as bone mineral density or iron status of the athlete may have played a role in the investigation.

Factors leading to running-related injury are complex and multifactorial. This complexity makes it difficult to identify the exact cause of any given injury. Although research has shown lower extremity biomechanical characteristics to be indicative of RRI risk, the current investigation was unable to accurately identify RRI risk factors using a 3-D motion capture system.

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