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Original Research Article

Relationship Between Single Leg Reactive Strength Index and Overuse Injuries in Collegiate Middle-Distance and Distance Runners

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ABSTRACT

Introduction: Single leg reactive strength index (RSI) is a measure of jump height over ground contact and is used to measure plyometric performance in athletes. The purpose of this study was to examine the relationship between RSI and injury rates in collegiate middle-distance and distance athletes. **Methods:** In a double blind, prospective correlation design that took place over an eight-week indoor track and field season, 42 middle-distance and distance athletes had their bilateral single leg RSI tested on a weekly basis. Injury questionnaires were handed out at the beginning of every week to collect location and severity of the athlete's injuries over the previous 7 days. **Results:** Athletes were found to have significantly higher rates of right leg injuries (N=197) as opposed to left leg injuries (N=86) ($p < .05$) over the eight-week period. Difference in RSI between event groups and sexes were shown to be significantly different ($p <.05$). Injury rates were shown to have no significant difference ($p >.05$) between event groups when combined and measured with only male or female subjects. When mean RSI values over the eight-week period were broken down into quartiles, the left leg RSI was shown to be a clear indicator for right leg injury. **Conclusion:** These results suggest that RSI can be used as predictor of injury in middle-distance and distance track and field athletes.

KEYWORDS: Running injury rates, reactive strength index, plyometric strength

Introduction

Collegiate middle-distance and distance runners invest considerable time and effort to become the best athletes as possible. These athletes are surrounded by coaches and school medical staff whose job it is to aid them in their quest for improved performance through training and treatment of injuries along the way. Unfortunately, much like modern medicine outside of collegiate sports, there is an emphasis on rehabilitation after injury/sickness rather than preventative care. While not ideal, this makes sense because a college track program can consist of upwards of 150-200 individuals. Performing a full preseason biomechanics and functional movement screening on all of those athletes would be quite daunting. This is especially true when smaller schools are taken into consideration, who only have a couple of athletic trainers that are shared amongst multiple sports.[1-3] This process ultimately becomes flawed as the season progresses and more and more athletes show up in the training room complaining of an injury that could have potentially been prevented.

Since epidemiological studies began looking into running injuries in the 1970's only a handful of research papers have been published on injury rates in elite track and field athletes. A recent study by Daoud et al.[4] looked at injury rates over four and a half year period amongst collegiate middle-distance and distance athletes and found that 75% of these athletes experienced at least one moderate or severe stress injury per year. This more recent study is in line with a few older studies looking at injury rates in professional track and field athletes. Bennell et al.[5] found that middle-distance athletes and distance athletes had injury rates of 76% per year. Further, in a study by Lysholm et al.[6] they found professional middle-distance and distance athletes had injury rates of 77% and 57% occurrence per year, respectively. Only one study found a lower occurrence of injury per year, D'souza[7] who showed injury rates of 55.6% for middle-distance and 62.5% for distance athletes. Obviously, the results by D'souza[7] are still higher than should be considered acceptable. An interesting note is that these injuries that occurred in elite middle-distance and distance athletes were not acute injuries but rather overuse injuries likely caused by muscular imbalances that developed over time, similar to general population running injuries as shown by Van Gent et al[8]. On the other hand, what is not similar is that general population runners are more likely to become injured in the knee[8] and elite athletes are more likely to become injured in the lower leg. [4-7] This could be due to a number of reasons but is most likely because elite runners have higher rates of using a forefoot strike 71-75%[4,9] while recreational runners are more likely to heel strike at 95.1%.[10] This difference in foot strike drastically changes loading mechanisms in the leg as described by Cavanagh et al.[11] and Lieberman et al.[12] Another factor includes significant changes in intensities and speeds for elite runners during training while general population runners are more likely stick to an easy or moderate pace for the vast majority of their runs. While the running speed for each independent general population runner varies very little depending on the day, the population of sub elite runners as a whole has much more diversity in running skill level than in elite runners. For instance, an easy run for a general population runner could vary from a walk/jog to closer to seven minute per mile pace while elite male runners can run faster than seven minute pace at an easy effort level. Elite track athletes also spend considerable time on a track, usually about three high intensity workouts a week, turning in only one direction (i.e., left). This repetitive left hand turn while running at high speeds currently has unstudied consequences, but one could infer that the loading in the left ankle, knee and hip joints is probably very different than the right ankle, knee and hip joints.

Because of the intense physical stress these athletes put on their bodies on a daily basis, and the lack of preventative/maintenance related medical availability at smaller colleges in particular, an easy way to determine if and where an athlete has potential for injury is needed by coaches and medical staff. Studies going back to the 1990's have described the high injury rates in distance runners[4,5,6,7,8,13,14] and even with that knowledge, injury rates do not seem to be going down. Clearly there needs to be implementation of a simple test that the coaching staff, weight training staff, and medical staff can implement and understand.

A quick test called single leg reactive strength index could potentially be a partial solution. This test has historically only been done with double leg plyometric jumps as a tool for coaches to see how explosive an athlete can be in a plyometric movement.[15-21] For most sports outside of powerlifting this makes no sense, especially for track athletes who spend their entire workouts on one leg at a time in series of what are basically single leg plyometric jumps while also turning in only one direction, theoretically loading each leg very differently. Therefore, the purpose of this prospective correlative study was to examine the relationship between single leg reactive strength index differences and overuse injury rates and anatomical location in collegiate middle-distance and distance runners. Our hypothesis was that there would be lower incidence of injury seen in athletes who have, and maintain, more symmetrical loading patterns between their legs when examined by a single leg depth drop plyometric jump. This reactive strength index protocol was paired with an injury questionnaire proposed by Clarsen et al.[22] that has been shown to be far more effective in capturing injury data than traditional methods

Methods

Participants

Forty-two male and female Western Colorado University track and field athletes were recruited via email for this injury based correlation study. All subjects were middle distance (athletes who compete in the 800m up to the 1500m) or distance athletes (athletes who compete in the 1500m up to the 10,000m), averaging more than 30 miles per week, running over the past four months. Each subject filled out an informed consent, a medical history questionnaire, a physical activity readiness questionnaire (PAR-Q), and an athlete description questionnaire. Subjects were excluded if they were averaging less than 30 miles per week over the past four months and if they were at moderate- or high-risk determined by ACSM screening. Subjects were also excluded if they were pregnant or planning on becoming pregnant during the duration of the study. Athletes that were injured at the start of the study were included. If an athlete was not able to complete the RSI test due to pain, they were marked down as did not complete due to injury. All data collection took place in the Western Colorado University Mountaineer Field House and High Altitude Performance Laboratory (HAP Lab). This study was approved by the Human Research committee of Western Colorado University [HRC2018-01-03-R63].

Athletes then filled out an athlete description questionnaire (ht., wt., sex, event, etc.) (30minutes), and a current injury questionnaire (5 minutes). Once all the paperwork was filled out, the athletes were taken through a reactive strength index jump familiarization by the head researcher (5 minutes), and finally completed initial RSI testing which is shown in Figure 2, with research assistants (3 minutes). All following visits took place once a week for the duration of the study (8 weeks). During these visits, subjects met with research assistants before their first weights session of the week (either Monday or Tuesday) and completed the RSI testing and the current injury questionnaire.

Experimental Design

In this prospective correlation study, as described in Figure 1, subjects met with research personnel 8 times over the course of the study. Two visits during the first week upon return from winter break, then once a week for the duration of the study until the first week of May. In the first session, subjects completed a consent to participate as well as a Par Q and health history questionnaire in order to determine if this study put them at an increased health risk.

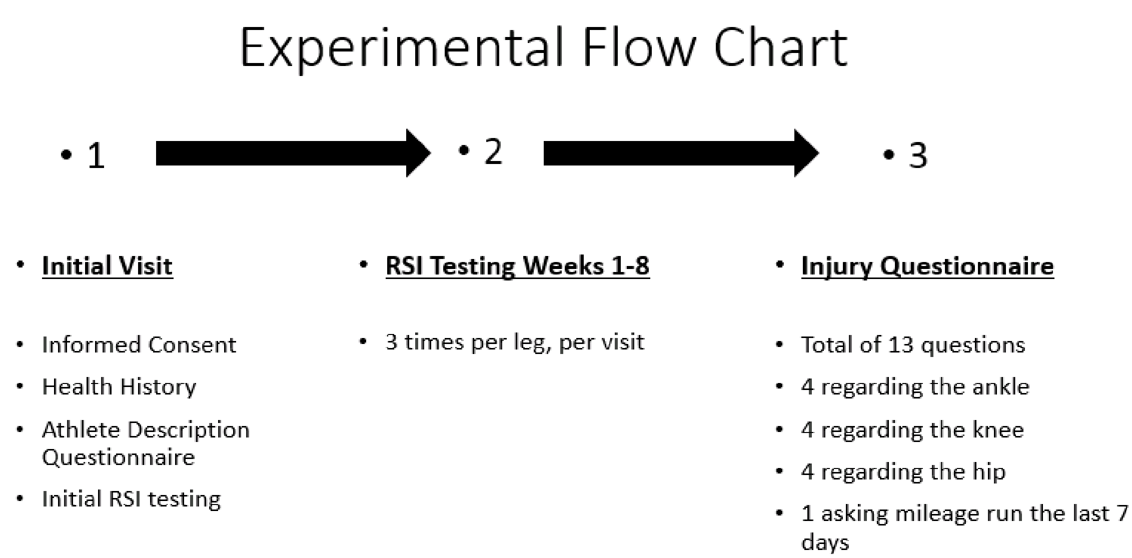

Figure 1. Experimental Flow Chart.

Protocols

Reactive Strength Index Procedures

All Reactive Strength Index measurements were collected using a jump height measuring devise (GFLIGHT by Exsurgo, Sterling, VA) and its accompanying mobile app. The devise uses Newtonian physics to determine reactive strength index (jump height/ground contact time). The testing for each athlete was done at the same time every week, preceding their first weights session. The test itself involved three barefoot single leg plyometric depth drop jumps per leg. All single leg depth drop jumps were performed from a four-inch box while maintaining hands on hips and keeping the jumping leg straight after the jump to limit any momentum not coming from the lower leg. Twenty to 30 seconds were allowed between each jump to allow for a resetting of position and to recover from the previous jump. This testing took roughly three minutes per person and was done in the HAP Lab, one athlete at a time. Both the head researcher and the athletes were blinded to their Reactive Strength Index results.

Figure 2. Reactive Strength Index Jumping Procedure.

Injury Rate and Occurrence Procedures

A questionnaire was given out to the subjects by research assistants on a weekly basis containing 14 total questions. Subjects were asked to fill out these questionnaires and hand them back before the weekly RSI testing. The questions were designed to identify general injury location and to what extent the injury/injuries inhibited the athlete. The questionnaire was broken down into three sets of four questions and one independent question. The first set of 4 questions pertained to injuries of the foot, ankle and shin, the second set of 4 questions pertained to injuries of the knee and the third set of 4 questions pertained to injuries of the hip. A final question asked for total mileage run over the last seven days. Each questionnaire contained the subject's confidential code and was stored until the end of the study. The head researcher was blinded to the results of the injury questionnaires for the duration of data collection.

Statistical Analyses

Statistical measurements were analyzed using the Statistical Package for the Social Sciences version 25.0 (IBM Corporation, Armonk, NY). Logistic regression analysis was used to predict odds of injury (DV) from RSI value (IV). Independent leg scores were compared to the side of the body the injury occurred. This comparison was measured as a whole group, and between sexes. RSI scores were also compared to anatomical location of injury to determine if higher or lower RSI values correlate to injuries of certain joints. Statistical significance was set at $p < 0.05$ for all analyses.

Results

Adherence

Of the 44 original subjects, 42 completed the study. One subject dropped out at week six due to personal reasons, and another subject's data was not used due to the season long immobilization of the right leg. This subject was never able to jump on his right leg and even cross training was minimized, resulting in his results being deemed irrelevant to the study.

Injury Rates

Over the eight-week period, athletes experienced injuries to the right side (197 injuries), significantly more often ($p < .05$) than injuries to the left side (86 injuries). This difference maintained significance when broken down between males and females, with their eight week injury means as displayed in Table 1. Although not statistically significant ($p > .05$), female subjects were shown to become injured at slightly higher rates than their male teammates. Over the eight-week testing period, female subjects were shown to have a mean of 7.69 weeks of injury, compared to 6.15 in males. If an athlete had more than one injury in a week, it was counted as multiple weeks of injury. For example, if an athlete experienced a right knee injury, a right shin injury and a left foot injury, in one week, that counted as two weeks of right injury and one week of left injury for that week.

Table 1. Male and female mean weeks of injury between sides.

Sex	Location of injury	Mean
Male N=26	Total Injuries	6.2
	Right side injuries 8 week average	4.2
	Left side injuries 8 week average	2.0
Female N=16	Total Injuries	7.7
	Right side injuries 8 week average	5.5
	Left side injuries 8 week average	2.2

Regarding injury location, male subjects were observed to have higher shin injuries and lower knee, thigh, and hip injuries than female subjects, yet no statistical significance was found ($p > .05$). These data are represented in Table 2 below.

Table 2. Mean location of injury between male and female subjects.

SEX		N	Mean	Std. Deviation
Foot Injuries	Male	26	2.1	2.8
	Female	16	2.2	2.9
Shin Injuries	Male	26	2.3	3.6
	Female	16	1.9	3.7
Knee Injuries	Male	26	1.0	3.0
	Female	16	1.3	2.4
Thigh Injuries	Male	26	0.0	0.2
	Female	16	0.7	2.1
Hip Injuries	Male	26	0.8	1.8
	Female	16	1.6	2.8

Reactive Strength Index Data

Male and female subjects had similar minimum RSI values, but male subjects were shown to have significantly higher ($p < .05$) maximum RSI values. This difference in maximum RSI values resulted in a larger range of values as well as increased overall mean, and mean values at the 25th, 50th and 75th percentile for male subjects as seen in Table 3. Injuries based on those quartiles are represented in Figure 3. RSI values, when broken down into quartiles, were observed to be linked to right leg injuries ($p < .05$) but not left leg injuries ($p > .05$). In particular, left leg RSI values were observed to have a strong relationship to right leg injuries ($p < 0.05$) as seen in Figures 3 and 4.

Table 3. Male and female minimum, maximum, mean, 25th, 50th, and 75th percentiles of 8 week single leg (RSI) measured in jump height/ground contact time.

Sex		Right RSI Mean	Left RSI Mean
Male N=26	Minimum	0.1	0.1
	Maximum	0.6	0.7
	Mean	0.3 (.13)*	0.3 (.13)
	25th percentile	0.2	0.2
	50th percentile	0.3	0.2
	75th percentile	0.3	0.3
Female N=16	Minimum	0.1	0.1
	Maximum	0.3	0.4
	Mean	0.1 (.07)*	0.2 (.08)
	25th percentile	0.1	0.1
	50th percentile	0.2	0.2
	75th percentile	0.3	0.2

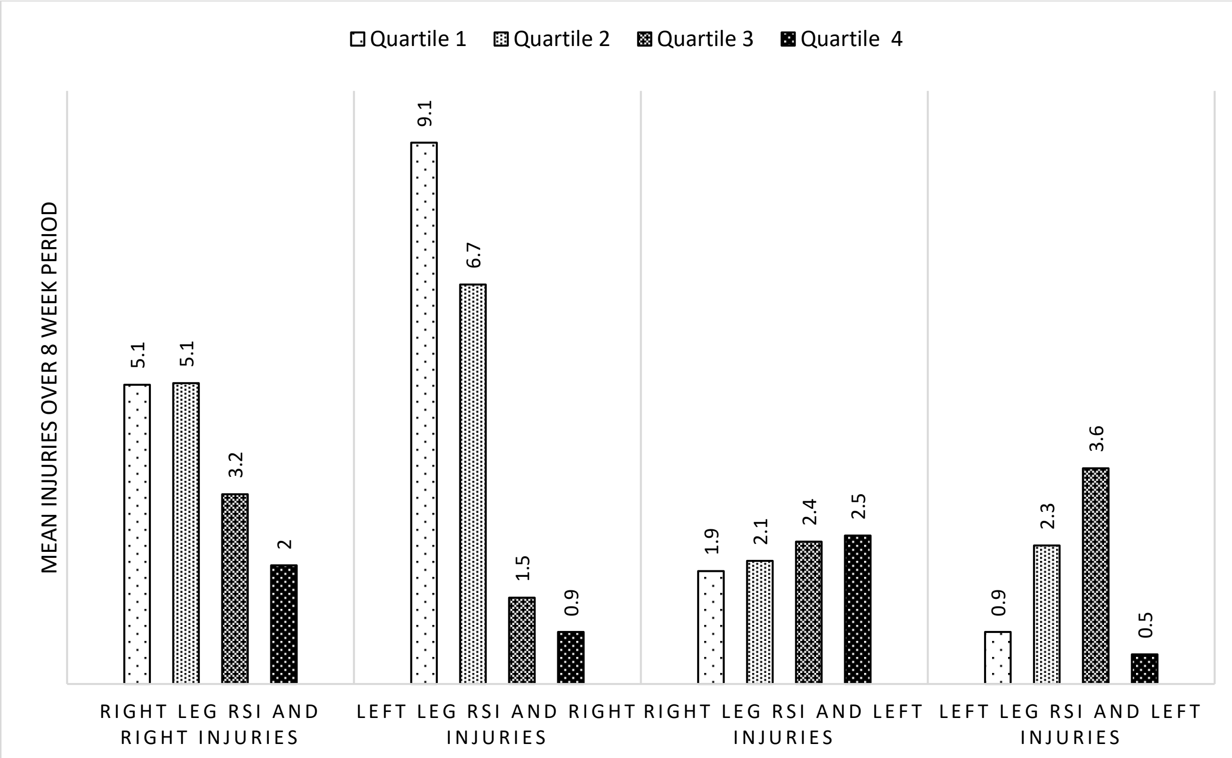

Figure 3. Total sample mean injuries over the 8-week period based on individual leg RSI quartiles.

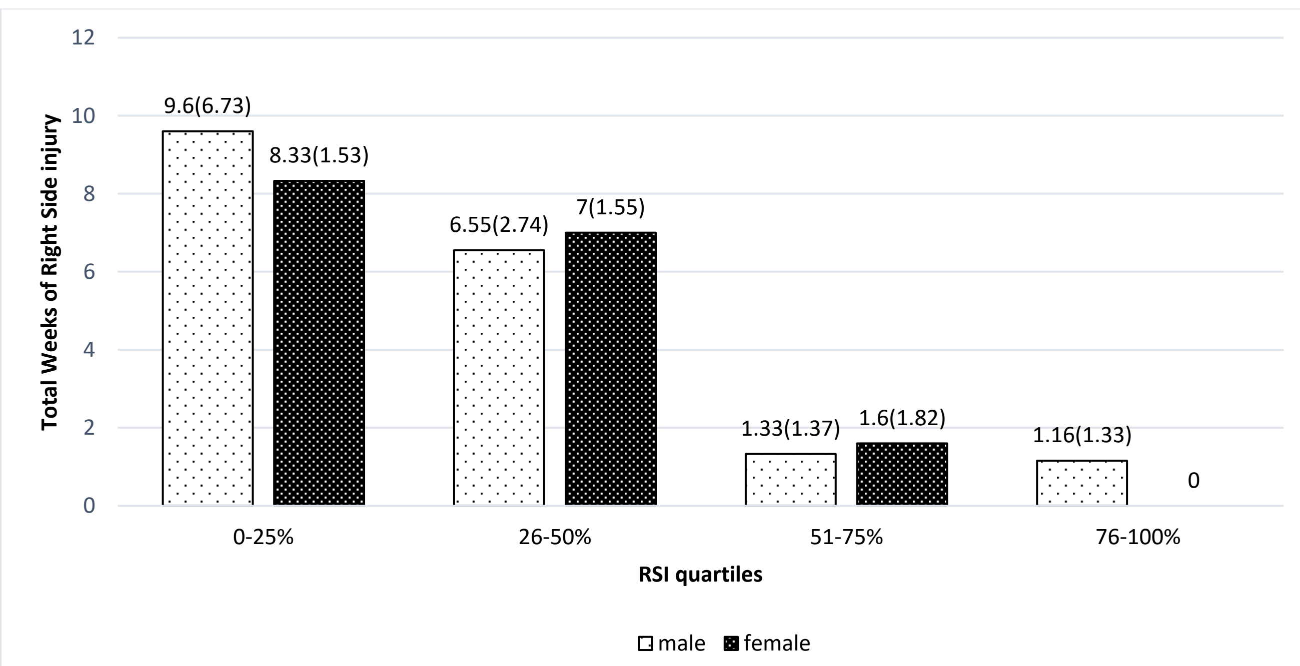

Figure 4. Total weeks of right-side injury for male and female subjects in relation to left leg RSI quartiles.

Table 4. Mean 8 week RSI of male and female subjects between event groups.

Event Group		Sex	N	Mean	Std. Deviation
800-1500	RRSI	Male	7	0.4	0.1
		Female	2	0.2	0.1
	LRSI	Male	7	0.4	0.2
		Female	2	0.2	0.2
1500-3k	RRSI	Male	5	0.3	0.0
		Female	9	0.2	0.1
	LRSI	Male	5	0.3	0.1
		Female	9	0.2	0.1
3k-5k	RRSI	Male	14	0.2	0.1
		Female	5	0.2	0.1
	LRSI	Male	14	0.2	0.1
		Female	5	0.2	0.1

Note: *Significant at p<.05

Event Type Differences

Difference in RSI between event groups was shown to be statistically significant (p <.05) when male and female subjects were combined. RSI maintained significant difference (p <.05) when looking at just male subjects but was not statistically different (p > .05) when looking at only female subjects. Injury rates were shown to have no significant difference (p >.05) between event groups when combined and measured with only male or female subjects. See Table 5.

Discussion

The main findings in this study are 1) right leg injuries are far more common than left leg injuries in collegiate middle-distance and distance athletes, 2) RSI values were not statistically different between the right and left leg, 3) left leg RSI appears to be an indicator for right leg injuries in this population group, 4) RSI values differ between males and females as well as between event groups, 5) injuries occurred at a statistically higher rate in the lower leg within this population group than in the knee or hip, 6) injuries between males and females were not statistically different, although trends were shown. No relationship was found in developmental strength between the right and left leg and resulting injuries, therefore the hypothesis was rejected. RSI did still prove useful in its potential for indication of injury. In particular, left leg RSI showed clear statistical significance in its relationship to right leg injuries.

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Injury Rates and types

Of the 42 subjects, 38 (90.5%) experienced an injury over the eight-week period. These findings were at a much higher rate than found in previous studies, both sub elite runners[8,14,23-25] and elite runners[4-7,14,26] which found anywhere between 19.4%-79.3% injury in sub elite runners and 55-84% injury rate in elite runners. This difference in findings becomes even more powerful when you consider most of the studies done in the past have been one-year studies and this study was only over an eight-week period. An explanation for the discrepancy would be that the majority of the studies mentioned above were retrospective rather than prospective. In the retrospective studies, subjects also may only have remembered and or noted the injuries that limited or completely took them out of training, where minor injuries were recorded in this study.

Regarding injury location, the results from the current study showed similar results to previous studies on elite runners[4-7,13,26] in that this population group was more likely to become injured in the lower leg rather than the knee. This is in contrast to injury rate studies on sub elite populations groups[8,14,23-25], where the knee has been shown to be the most highly injured anatomical feature.

Of the studies above only three examined collegiate middle-distance and distance athletes and only two of them were prospective. The first, a study by Daoud et al.[4] looked at collegiate distance runners, but over a three-month period during the cross-country season rather than the indoor track season. In the study by Daoud et al.[4] injury rates were shown to be 84% overall (88% in females and 79% in males) which was fairly similar to the results found in this study. Interestingly, Daoud et al.[4] found, when minor injuries were not noted, injury rates were 74% (79% in females and 68% in males) which is very similar to the retrospective studies, possibly because over a one-year period athletes just may have forgotten when, where and if they had minor injuries. Similar to those results, when minor injuries were eliminated from the current study, injury rates were only 74% (81% in females and 69% in males).

The second by study Kerr et al.[27], looked into cross country injury rates in 25 male and 22 female collegiate NCAA teams over the timeframe from 2009 to 2014. Injury rate results from the study by Kerr et al. were measured in the ratio of injuries for one individual per 1000 athlete exposures (NCAA sanctioned practices and races) and were found to be 4.66/1000 for men and 5.85/1000 for women. Ultimately, this data says that if an athlete were to train/race every day for 1000 days, the likelihood of an injury was just 4.66-5.85 percent, which is dramatically lower than what has been found in previous studies as well as the current study. This extreme difference in data could be due to a number of reasons. First, in the study by Kerr et al. athletic trainers from the selected institutions were used to collect and report injury data. This method has potential flaws because athletic trainers have already been shown to be overworked[1-3] possibly leading to lack of, or minimal participation when given another task. Another potential flaw was that collegiate athletes might be wary to report injuries to the athletic training staff in fear of loss of practice and or racing time, when collegiate roster spots are highly competitive. In the current study this was mitigated because athletic trainers, coaching staff, and even research staff were blinded to the injury questionnaires and athletes were educated on that fact.

A third study by Reinking et al.[26] examined lower leg injuries in 44 male and 44 female collegiate cross country runners. The methodology of this study differed from the current study in that only a preseason and post-season questionnaire were handed out to collect injury data. The preseason questionnaire asked about history of exercise related leg pain and the post-season questionnaire asked about incidence of injury over the season. Unlike the vast majority of studies, Reinking et al.[26] looked into not just total injuries but injuries between legs. The results were far different from the current study though in that Reinking et al. found similar rates of injury between the right and left leg. This difference in results could be due to a number of reasons. First Reinking et al. only looked into injuries in the shin, disregarding injuries to the foot, ankle, knee, thigh and hip. Second, the current study took place over the indoor track season where the athletes are always turning the same direction on sharp turns where Reinking's study took place over the cross-country season. A third difference is the retrospective questionnaires that may have allowed for loss of information through forgetfulness.

Although not statistically significant, the results from the current study show a slightly increased injury rate among female runners in comparison to male runners which is in agreement with previous studies[26,28] (Reinking et al., 2007; Taunton et al., 2002). In the current study, female subjects incurred an average of 7.69 weeks of injury over an 8-week period as opposed to the male subjects who experienced an average of 6.15 weeks of injury. Again, if an athlete experienced more than one injury in a week that counted as multiple weeks of injury for that athlete. In the study by Reinking et al., which looked only at incidence of injuries below the knee, male subjects reported injury rates of 33% over a cross country season and females reported injury rates of 44% but the results were not statistically significant. In the study by Taunton et al.,[28] researchers found no conclusive evidence that there was any difference between total injury rates between male and female runners but found significant difference in types of injuries incurred between the sexes. In the current study, no significance was found but clear trends were observed that agreed with Taunton et al.[28] Taunton[28] found that females incurred statistically higher rates of hip injuries and medial and lateral knee injuries as opposed to men who incurred statistically higher rates of plantar, meniscal, patellar, achilles, gastrocnemius, and adductor injuries. In the current study, males experienced slightly higher shin injuries than females but female's experiences slightly higher knee, and hip injuries than males. As mentioned above the study by Taunton et al.[28] was looking at injury rates in general population runners rather than elite runners altering the proportion of knee and lower leg injuries.

Reactive Strength Index

RSI testing in this population group was a novel idea, but the results do seem to relate to previously studied phenomena. One such phenomena is foot strike and its effect on running related injuries. Daoud et al.[4] found that runners who heel strike were 2.5 times more likely to sustain an injury over a cross country season when compared to athletes who had a mid-foot/forefoot strike. Similarly, but with even more dramatic of a difference, athletes in the current study who had high RSI values were far less likely to experience an injury than athletes with low RSI values. A relationship between high RSI values and fore foot/mid foot striking could possible exist because athletes that have a mid-foot/fore foot strike experience increased eccentric loading in the lower leg as opposed to heel strikers who experience increased eccentric loading into the knee.

Limitations

The main limitation of this study was the lack of criteria to determine a maximal jump. Subjects were instructed to perform to the best of their ability, but early morning testing and perceived importance, or lack thereof, of the jumps may have resulted in sub maximal jump efforts. Subjects and research personnel met Monday mornings at 6:45am before team mandated weightlifting. College athletes are prone to being stretched thin on time due to school, practice, and competition. Because of this, adding another test every Monday morning may have led to variable and likely decreased effort levels.

Another limitation was the restricted field in which the subject was required to jump from and land on perfectly. The subject needed to enter and exit the Gflight's field of view with their ball of the foot/toe during first contact and second contact. If the subject landed with their ball of the foot/toe out of the field of view, either no disruption of light would occur, or the heel would disrupt the light leading to incorrect ground contact time and or flight time. Both research assistants and subjects were educated about this and negative effects were mitigated as best as possible.

Conclusion

In conclusion, RSI testing could be a viable option for identifying middle-distance and distance athletes that are at risk for injury during the indoor track and field season. Because of the novelty of using RSI as a measure for predicting injury, much future research is needed. This research should include clearly defining quartile ranges among male and female athletes, perfecting the testing procedures in order to mitigate potential lack of effort, looking into how to properly treat/train athletes with low RSI and if increasing and maintaining RSI even has an effect on injury rates, testing runners during others seasons such as cross country an outdoor track, testing other event groups as well as other sports.

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