# Age Is More Predictive of Safe Movement Patterns Than Are Physical Activity or Sports Specialization

## A Prospective Motion Analysis Study of Young Athletes

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**Background:** Movement quality and neuromuscular balance are noted predictors of acute injury. Early sports specialization and extremely high activity levels have been linked to elevated risk of injury.

**Purpose:** To investigate for any relationships among quality of physical movement, quantity of physical activity, and degree of sports specialization in a healthy cohort of active children and adolescents.

**Study Design:** Cross-sectional study with prospectively collected data.

**Methods:** Healthy children between the ages of 10 and 18 years were recruited and completed the Hospital for Special Surgery Pediatric Functional Activity Brief Scale to assess quantity of physical activity and the Jayanthi scale to assess degree of sports specialization (high, score of 2 or 3; low, score of 0 or 1). Movement quality was assessed using motion analysis sensors during 5 repetitions of 4 different jumping and squatting motions, with a maximum score of 100 per participant. Independent-samples *t* tests were used to compare participants with high versus low specialization on physical activity and movement quality. A Spearman correlation was used to determine the relationship between quantity of physical activity and movement quality, and linear regression was used to assess for the effect of participant age on relevant covariables.

**Results:** Final analyses included 147 participants (72% male) with a mean ± SD age of 13.4 ± 2.2 years. Participants who were highly specialized displayed better movement quality than did participants with low sports specialization (27.6 ± 14.0 vs 19.8 ± 10.1; $P < .01$). Participants who were highly specialized had significantly higher activity levels (24.6 ± 5.9 vs 18.1 ± 6.9; $P < .001$). Movement quality was moderately correlated with physical activity level ($r = 0.335$; $P < .001$). Physical activity; hours of organized sports activity; hours of free, unorganized physical activity; and specialization level were not significant predictors of movement quality when controlling for age. Age alone predicted 24.2% of the variance in the overall movement quality score ($R^2 = 0.242$; $B = 3.0$; $P < .001$).

**Conclusion:** This study found that sports specialization and physical activity levels were not associated with movement quality when controlling for age, which was the most important variable predicting athletic movement quality. Although all participants displayed movement patterns that were associated with high risk for injury, overall movement quality improved with advancing chronological age.

**Clinical Relevance:** All young athletes should ensure that neuromuscular training accompanies sport-specific training to reduce risk of injury.

**Keywords:** pediatric; adolescent; acute injury; lower extremity

The incidence of overuse injuries (ie, stress fractures or tendinitis) and acute, traumatic injuries (ie, fractures or ligament tears) in pediatric populations has increased in recent years.[5,20,23,40] Concurrently, youth athletes have been specializing in a single sport at an earlier age rather than engaging in multiple different sports throughout the year.[3,4,27] Several studies have linked early sports specialization to increased risk of injury,[19,24,30] but no study to date has investigated additional contributing factors that may underlie this association.

One potential mechanism for the increased risk of injury in specialized athletes is poor quality of their athletic movement patterns. Previous studies have suggested that early sports specialization may limit the development of fundamental

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motor skills.[2] Several previous studies have found significant kinematic and biomechanical differences between injured and healthy participants.[15,34,41] Additionally, interventions aimed at improving movement quality through neuromuscular training can reduce the risk of noncontact acute injuries,[16,18,29,32] indicating that movement quality is an important risk factor for traumatic injuries.

Determining contributing causes to the increased risk of injury in sport-specialized youth athletes is essential to developing strategies to reduce injury risk. The purpose of this study was to investigate for any relationships among lower extremity movement quality, quantity of physical activity, and degree of sports specialization in a healthy cohort of children and adolescents. This study hypothesized that a higher degree of sports specialization would be associated with greater physical activity levels but worse movement quality. This study also hypothesized that movement quality would improve with age.

## METHODS

After obtaining institutional review board approval, participants from local schools and sports teams were prospectively enrolled in this study. Healthy athletes between ages 10 and 18 years without any illness, injury, or condition limiting sports, athletic, or recreational activities were included, while athletes who were unable to complete the questionnaire or physical tests were excluded.

Coaches, physical education teachers, and administrators were contacted to determine interest and feasibility of study participation. Then, researchers obtained parental consent and participant assent/consent for study participation. All study protocols were completed at the participants' home athletic facilities.

### Questionnaires

Participants completed a questionnaire to record participant and physical activity information. Participant information included age, sex, race, ethnicity, height, and weight. Each sport that participants played, their primary sport (if applicable), and average hours of organized sports and free play each week were also obtained at the time of testing. To quantify physical activity, participants completed the Hospital for Special Surgery Pediatric Functional Activity Brief Scale (HSS Pedi-FABS), a validated pediatric activity scale that is scored from 0 to 30, with a higher score indicating a higher level of physical activity.[11] Participants also completed the Jayanthi scale to determine level of sports specialization, which consists of 3 questions: (1) Can you pick a main sport? (2) Did you quit other sports to focus on a main sport? (3) Do you train greater than 8 months in a year?[19] The scale is scored from 0 to 3, with a higher score indicating a greater level of specialization.[19]

### Motion Analysis

Movement quality was assessed using tibial motion analysis sensors (dorsaVi Ltd) that have been validated for lower extremity motion analysis testing and identifying movement quality associated with an increased risk of injury.[13,17,35] Based on the height of each participant,[26] adhesive sensors were attached to the skin of the leg at standardized tibial landmarks. After sensors were attached, each test was described and demonstrated to participants. Participants completed 5 repetitions of 4 different jumping and squatting motions including single-leg squats, double-leg squats, single-leg hops, and double-leg box drops (Figure 1). For the single-leg hops, participants were instructed to jump as high as they could off of 1 foot and land on that same foot. For the single- and double-leg squats, participants were instructed to squat as deep as they could comfortably. For the double-leg box drops, participants stood on 1 leg on the top of an 18 inch (45.72 cm)-tall box[21] and then stepped off the box and landed on both feet simultaneously. All single-leg motions were completed on each leg for 5 repetitions per leg.

### Data Processing

For each movement, anterior tibial inclination, varus/valgus tibial inclination, and squat speed were recorded at the greatest squat depth on each leg for each repetition. Tibial inclination is defined and reported by dorsaVi as the angle of the tibia (in degrees) in relation to the foot while performing a test.[22] For the single-leg hop, these metrics were recorded at the greatest depth of the squat for the landing phase of the hop. The mean value for each movement quality metric within each motion was reported as an average of the 10 repetitions (5 repetitions per leg).

To determine overall movement quality for each participant, each repetition on each leg was assessed independently according to dorsaVi criteria (Table 1), which have been previously used and validated for assessing lower extremity injury risk.[8,13,17] One point was assigned for each repetition that was considered at low risk of injury, while zero points were given if a repetition was considered at high risk of injury. Scores from each repetition were summed, and a higher score indicated more frequent low-

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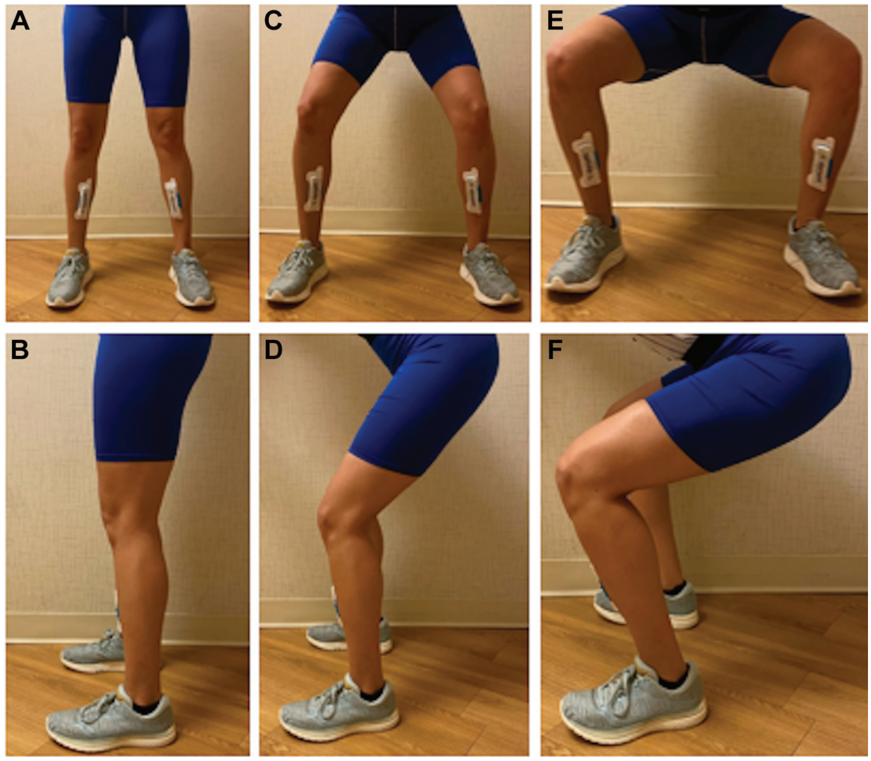


**Figure 1.** dorsaVi (dorsaVi Ltd) motion analysis sensors were placed on each leg, at the inner margin of the midshaft of each tibial crest. Sensors captured varus/valgus and anterior tibial inclination in 3-dimensional space, as noted in the double-leg stance (A and B), squat initiation (C and D), and full squat (E and F).

TABLE 1
Characterization of High-Risk Movement Quality Based on Each Type of Movement Using dorsaVi Technology[a]

| Movement | High-Risk Movement Quality |
| --- | --- |
| Single-leg and double-leg squat | |
| Anterior tibial inclination | 25°-35° and squat speed is 20 deg/s or less |
| Varus/valgus tibial inclination | 9° or less medially or laterally |
| Double-leg box drop and single-leg hop | |
| Anterior tibial inclination | 25°-35° and squat speed is 100 deg/s or less |
| Varus/valgus tibial inclination | 9° or less medially or laterally |

[a]From K. Whitehead, DPT, MSPT, ATC, CSCS, personal communication, 2020. All metrics are measured at the greatest depth of the squat. dorsaVi, dorsaVi Ltd.

risk movement quality. For 1 repetition, a maximum score of 2 could be achieved if the repetition had low-risk anterior tibial inclination with appropriate squat speed and had low-risk varus/valgus tibial inclination. For each motion, a maximum score of 20 could be achieved by scoring of 2 for all 5 repetitions on each leg. Overall, a maximum score of 100 could be achieved by each participant, assuming low-risk movement pattern on every repetition of every task.

## Statistical Analysis

Specialization level was dichotomized as high specialization with a score of 2 or 3 and low specialization with a score of 0 or 1 on the Jayanthi sports specialization scale. An a priori power calculation was performed to determine the number of participants with high and low specialization needed to find significant differences between the 2 groups. Based on a small subset of previously collected unpublished data, it was estimated that 75% of athletes with moderate or high specialization would demonstrate high-risk quality of movement compared with 52% of athletes with low specialization. Group sample sizes of 50 athletes with low specialization and 100 with moderate to high specialization would achieve 80% power to detect an estimated 23% difference in high-risk movement quality, using chi-square analysis between participants with high and low specialization and high- and low-risk movement quality, where statistical significance was defined as $P \leq .05$ in a 2-tailed analysis. However, after initiation of data collection, movement quality was analyzed as a continuous variable rather than a dichotomized categorical variable, and an independent-samples *t* test was used to compare the movement quality between participants with high versus low specialization.

Cohort characteristics were reported as frequencies and percentages for categorical variables and as means and standard deviations for continuous variables. Chi-square analysis was used to determine if significant sex differences existed between specialization groups. Additionally, an independent-samples *t* test was used to determine if age was significantly different between specialization groups. To assess the relationship among specialization, physical activity, and each movement quality metric, independent-samples *t* tests were used to compare means between low- and high-specialization groups. Spearman correlation was calculated to determine the relationship between quantity of physical activity and movement quality. Finally, linear regression analyses were used to determine how age, sports specialization, and physical activity predicted movement quality. Significance was set at $P \leq .05$ for all tests, and all analyses were 2-tailed. Data were analyzed using SPSS version 22.0 (IBM Corp).

## RESULTS

A total of 147 participants were included in this study. Of these, 72% (n = 106) were male and the mean age was 13.4 ± 2.2 years (Table 2). There were 4 participants with repetitions that were not adequately captured by the dorsaVi sensors, so these participants were removed from movement quality analyses. There were significantly more male participants in the high-specialization group than in the low-specialization group (82% vs 46%; $P < .001$), and participants in the high-specialization group were significantly older (12.1 ± 1.5 vs 13.9 ± 2.2 years; $P < .001$). A subset of 56 specialized participants was able to recall their age of specialization, with 5 reporting they were always specialized in a single sport and 51 participants reporting they had specialized for an average of 3.2 ± 2.1 years at the time of the study.

On average, participants displayed movement quality that was associated with a high risk of injury, with anterior tibial inclination greater than 35° and varus/valgus tibial inclination greater than 9° (Table 3). Overall movement quality was normally distributed with scores ranging from 1 to 55. The highly specialized group displayed more frequent low-risk anterior tibial inclination with appropriate squat speed on the single-leg squat, double-leg squat, and double-leg box drop and varus/valgus tibial inclination on the double-leg squat ($P < .05$ for all) (Table 4). Additionally, the highly specialized group reported higher physical activity levels on the HSS Pedi-FABS scale (24.6 ± 5.9 vs 18.1 ± 6.9; $P < .001$). Physical activity level was moderately correlated with movement quality ($r$ = 0.335; $P < .001$).

Age displayed significant positive correlations with physical activity level and movement quality ($r$ = 0.498 and $r$ = 0.456, respectively; $P < .001$ for both). Additionally, the number of hours engaged in organized sports activity per week was correlated with physical activity level ($r$ = 0.313; $P < .001$) and was significantly higher in the highly specialized group (9.5 ± 10.5 vs 3.1 ± 2.8 h/wk; $P$ = .007). The number of hours participants engaged in unorganized, free play per week was not correlated with their physical activity levels, and there was no significant difference in hours of free play between high- and low-specialization groups. There was no correlation between movement quality and hours of organized or unorganized physical activity. In a linear regression analysis for predicting movement quality, physical activity; hours of organized sports activity; hours of free, unorganized physical activity; and sports specialization level was not significant when controlling for age. A secondary linear regression analysis including only age, physical activity, and sports specialization as predictors of movement quality also found that physical activity and sports specialization were not significant predictors when controlling for age. Age alone predicted 24.2% of the variance in the overall movement quality score ($R^2$ = 0.242; $B$ = 3.0; $P < .001$).

TABLE 2
Participant and Cohort Characteristics[a]

| | Value |
|---|---|
| Sex | |
| Male | 106 (72) |
| Female | 41 (28) |
| Race | |
| White/Caucasian | 71 (48) |
| Black/African American | 54 (37) |
| Native American | 1 (1) |
| Multiracial | 17 (12) |
| Preferred not to answer | 4 (3) |
| Ethnicity | |
| Hispanic | 39 (27) |
| Non-Hispanic | 108 (73) |
| Age, y, mean ± SD | 13.4 ± 2.2 |
| HSS Pedi-FABS, mean ± SD | 22.9 ± 6.8 |
| Overall movement quality, mean ± SD | 25.5 ± 13.5 |
| Jayanthi sports specialization | |
| Low (0 or 1) | 39 (27) |
| High (2 or 3) | 108 (73) |
| Main sport | |
| Soccer | 59 (40) |
| Basketball | 27 (18) |
| Football | 17 (12) |
| Other | 22 (15) |
| No main sport | 22 (15) |

[a]Data are provided as n (%) unless otherwise noted. HSS Pedi-FABS, Hospital for Special Surgery Pediatric Functional Activity Brief Scale.

## DISCUSSION

The purpose of this study was to investigate the relationship among physical activity, youth sports specialization, and physical movement quality. This study found a higher degree of sports specialization was associated with greater physical activity and an overall movement quality was associated with a lower risk of lower extremity injury. Additionally, this study found that the amount of physical activity was positively correlated with movement quality. However, linear regression analysis revealed that chronological age was a strong predictor of movement quality (predicted

TABLE 3
Tibial Inclination and Squat Speed Based on the Average of 10 Repetitions for Each Move (5 per Leg)[a]

| | Low Specialization | High Specialization | Entire Cohort |
|---|---|---|---|
| Single-leg squat | | | |
| Anterior tibial inclination, deg | 39.6 ± 6.7 | **37.1 ± 5.5** | 37.7 ± 5.9 |
| Varus/valgus tibial inclination, deg | 12.4 ± 4.9 | **10.7 ± 4.2** | 11.1 ± 4.5 |
| Squat speed, deg/s | 33.5 ± 8.5 | 30.8 ± 9.9 | 31.5 ± 9.6 |
| Double-leg squat | | | |
| Anterior tibial inclination, deg | 44.6 ± 11.3 | **36.9 ± 10.6** | 38.9 ± 11.3 |
| Varus/valgus tibial inclination, deg | 13.3 ± 8.8 | **9.8 ± 5.7** | 10.8 ± 6.8 |
| Squat speed, deg/s | 30.6 ± 9.8 | **26.6 ± 10.3** | 27.7 ± 10.3 |
| Double-leg box drop (left leg first) | | | |
| Anterior tibial inclination, deg | 40.4 ± 6.5 | 39.4 ± 6.1 | 39.7 ± 6.2 |
| Varus/valgus tibial inclination, deg | 14.2 ± 6.1 | 12.4 ± 5.4 | 12.9 ± 5.6 |
| Squat speed, deg/s | 80.9 ± 25.0 | 78.5 ± 31.1 | 79.1 ± 29.6 |
| Double-leg box drop (right leg first) | | | |
| Anterior tibial inclination, deg | 42.1 ± 6.2 | **39.6 ± 5.8** | 40.3 ± 6.0 |
| Varus/valgus tibial inclination, deg | 13.8 ± 4.6 | 12.4 ± 4.9 | 12.8 ± 4.8 |
| Squat speed, deg/s | 88.2 ± 36.8 | 80.0 ± 30.2 | 82.2 ± 32.1 |
| Single-leg hop (landing phase) | | | |
| Anterior tibial inclination, deg | 26.1 ± 4.4 | **29.2 ± 5.9** | 28.4 ± 5.7 |
| Varus/valgus tibial inclination, deg | 8.0 ± 2.0 | **9.1 ± 4.1** | 8.8 ± 3.7 |
| Squat speed, deg/s | 93.8 ± 23.9 | **104.2 ± 32.8** | 101.4 ± 30.9 |

[a]Data are presented as mean ± SD. Boldface type indicates significant differences between high- and low-specialization groups at the $P \leq .05$ level.

TABLE 4
Tibial Inclination and Squat Speed Scores for Entire Cohort
Based on the Average of 10 Repetitions for Each Move (5 per Leg)[a]

| | Low Specialization | High Specialization | Entire Cohort |
|---|---|---|---|
| Single-leg squat | | | |
| Anterior tibial inclination and squat speed | 0.6 ± 0.97 | **1.3 ± 2.0** | 1.1 ± 1.8 |
| Varus/valgus tibial inclination | 4.2 ± 2.9 | 5.3 ± 3.0 | 5.0 ± 3.0 |
| Double-leg squat | | | |
| Anterior tibial inclination and squat speed | 0.5 ± 1.2 | **2.0 ± 2.9** | 1.7 ± 2.6 |
| Varus/valgus tibial inclination | 4.4 ± 3.4 | **6.1 ± 3.5** | 5.7 ± 3.6 |
| Double-leg box drop (left leg first) | | | |
| Anterior tibial inclination and squat speed | 1.6 ± 1.6 | **2.5 ± 2.1** | 2.2 ± 2.0 |
| Varus/valgus tibial inclination | 3.9 ± 2.2 | 4.4 ± 3.0 | 4.3 ± 2.8 |
| Double-leg box drop (right leg first) | | | |
| Anterior tibial inclination and squat speed | 1.6 ± 1.2 | 2.0 ± 1.8 | 1.9 ± 1.7 |
| Varus/valgus tibial inclination | 3.4 ± 2.7 | 4.1 ± 3.1 | 4.0 ± 3.0 |
| Single-leg hop (landing phase) | | | |
| Anterior tibial inclination and squat speed | 3.3 ± 2.4 | 3.0 ± 2.3 | 3.1 ± 2.3 |
| Varus/valgus tibial inclination | 7.1 ± 2.0 | 6.4 ± 2.6 | 6.6 ± 2.4 |
| Total quality score | 19.8 ± 10.1 | **27.6 ± 14.0** | 25.5 ± 13.5 |

[a]Data are presented as mean ± SD. Higher scores indicate more repetitions with low-risk movement quality. The maximum movement quality score of 10 was possible for anterior tibial inclination with squat speed and for varus/valgus tibial inclination for each movement, which yielded a maximum score of 100 for total movement quality. Boldface type indicates significant differences between high- and low-specialization groups at the $P \leq .05$ level.

24.2% of the variance in movement quality score) and was also associated with sports specialization and physical activity. Therefore, when controlling for age, sports specialization and physical activity levels were not independent predictors of movement quality. This finding indicates that although movement quality improves as people mature, it may not be affected independently by sports specialization or physical activity levels alone.

Previous studies have indicated that early sports specialization increases risk of injury.[12,19,28,30,33] Jayanthi et al[19] found that compared with adolescents with low levels of sports specialization, highly specialized athletes were at a higher risk of overuse injury but not acute injury when controlling for age and hours of training in sports. However, DiCesare et al[9] found that sport-specialized athletes exhibited greater variability in their motion in jump-landing tasks than did their peers who played multiple sports, which may indicate less dynamic stability and higher risk of injury in these athletes. While the results of this study found no difference in movement quality based on the frequency of low risk of injury movements in jump-landing and squatting tasks, the age of early sports specialization is likely an important risk factor contributing to poor movement quality.

The current study found that increasing chronological age significantly predicted movement quality such that older athletes displayed high-risk motion less frequently than did younger athletes. Because youth athletes are specializing in a single sport at earlier ages,[3,4,27] the rise in sport-related acute injuries could be related to the greater quantity of young athletes with poor movement quality engaging in more frequent and advanced physical activity. Previous studies have reported mixed results on the relationship between age and acute sports injuries. A study of Canadian youth ice hockey players found that relatively older players were at higher risk of injury than were their younger peers,[38] which is potentially due to their greater body mass and ability to generate greater force on contact.[7] Another study of female gymnasts found that older gymnasts competing at higher levels had a higher risk of severe injury than did younger athletes likely because of the elevated technical difficulty at these levels.[6] Conversely, studies of youth soccer players found the younger players were more at risk of injury.[10,25] Specializing in a single sport at a younger age increases athlete exposures and engagement in more advanced sport-specific skills while overall movement quality is still poor, leading to a rise in acute sports-related injuries. Based on the results of the current study and taken together with those of previous studies, young athletes and their parents should be wary of early sports specialization and ensure that neuromuscular training accompanies sport-specific training to reduce risk of injury.

Another important finding of this study was that levels of physical activity, hours of organized sports activity, and hours of free, unorganized physical activity were not related to movement quality when controlling for age and that overall movement quality in all participants was low (highest score, 55/100). Previous studies have indicated that elite youth athletes in organized sports[10,36] through the least physically active children[1,31] are at high risk of injury depending on the sport or activity but risk can be reduced through neuromuscular training to improve movement quality.[16,18,29,32,41] For example, many ACL tears are the result of neuromuscular imbalances and excessive ligament dominance, causing large valgus knee moments and high ground-reaction forces.[29] Instruction and practice of proper joint positioning have been effective at reducing ground-reaction forces and lower extremity injury rates.[18,32] Based on movement quality, this study suggests that children at all levels of physical activity engagement may benefit from neuromuscular training to reduce acute injury risk.

One of the strengths of this study was the use of standardized validated pediatric questionnaires and objective digital motion analysis technology to investigate the mechanism behind the association between sports specialization and injury risk. While several studies have reported on this association,[19,24,30] few have examined potential contributing causes. Future prospective studies should investigate movement quality of young athletes longitudinally and in a multitude of sports to determine how specific aspects of movement quality in addition to sports specialization and participant risk factors (eg, age, sex) predict risk of acute or overuse injuries. Furthermore, it may be possible to leverage newer wearable technologies to determine the effect of overall activity, sleep, and biometric data on injury risk.

In addition to its strengths, this study had several limitations. An a priori power calculation was performed before beginning enrollment for this study, but enrollment for this study was terminated early because of safety concerns amid the COVID-19 pandemic. Significant associations were found between predictor variables and outcomes of interest, so a possible type 2 error resulting from low power could not have occurred in this study. Furthermore, our study was adequately powered to perform the included linear regression analyses, given the rule that N should be greater than $8k + 50$, where $k$ is the number of variables.[14,39] Given the 147 participants, our study was powered to perform linear regression analyses with up to 12 covariables. Additionally, the early termination of this study resulted in an unequal proportion of male and female participants. Because previous studies have indicated that women have a higher risk of acute knee injuries than do men,[37] potential differences in movement quality between male and female athletes may be present and may or may not affect the results of this study. Also, few participants in this study were able to recall their age of specialization, so no analyses on the effect of years of specialization on movement quality were performed. Another limitation is that specialization was dichotomized, grouping together athletes with moderate and high levels of specialization according to the Jayanthi scale. It is possible that athletes with the highest degree of specialization had different movement quality patterns compared with other athletes, and future studies may investigate for these potential differences. Additionally, movement quality testing was done from a resting state; therefore, athletes were not fatigued, and results may not be generalizable to the movement quality athletes display during practice or competition for their sports. In a fatigued state, however, movement quality likely degrades, so the results of this study may overestimate the usual movement quality of participants. In actuality, this would result in worse movement quality than was demonstrated in the current study.

## CONCLUSION

This study found that sports specialization and physical activity levels were not associated with movement quality when controlling for age, which was the most important variable predicting athletic movement quality. Although all participants displayed frequent movement patterns that were associated with high risk for injury, overall movement quality improved with advancing chronological age.

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