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PROSPECTIVE FUNCTIONAL PERFORMANCE TESTING AND RELATIONSHIP TO LOWER EXTREMITY INJURY INCIDENCE IN ADOLESCENT SPORTS PARTICIPANTS

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ABSTRACT

Background: Due to the high number of adolescent athletes and subsequent lower extremity injuries, improvements of injury prevention strategies with emphasis on clinic-based and practical assessments are warranted.

Purpose: The purpose of this study was to prospectively investigate if a battery of functional performance tests (FPT) could be used as a preseason-screening tool to identify adolescent athletes at risk for sports-related acute lower extremity injury via comparison of injured and uninjured subjects.

Methods: One hundred adolescent volleyball, basketball and soccer athletes (female, n = 62; male, n = 38; mean age = 14.4 ± 1.6) participated. The FPT assessment included: triple hop for distance, star excursion balance test, double leg lowering maneuver, drop jump video test, and multi-stage fitness test. Composite scores were calculated using a derived equation. Subjects were monitored throughout their designated sport season(s), which consisted of a six-month surveillance period. The schools certified athletic trainer (ATC) recorded all injuries. Subjects were categorized into groups according to sex and injury incidence (acute lower extremity injury vs. uninjured) for analysis.

Results: Mean FPT composite scores were significantly lower for the injured compared to the uninjured groups in both sexes (males: 19.06 ± 3.59 vs. 21.90 ± 2.44; females: 19.48 ± 3.35 vs. 22.10 ± 3.06 injured and uninjured, respectively)($p < .05$). The receiver-operator characteristic analysis determined the cut-off score at ≤20 for both genders (sensitivity = .71, specificity = .81, for males; sensitivity = .67, specificity = .69, for females)($p < .05$) for acute noncontact lower extremity injuries. Significant positive correlations were found between the FPT composite score and the multi-stage fitness test in male subjects (r = .474, $p = .003$), suggesting a relationship between functional performance, aerobic capacity, and potential injury risk.

Conclusion: A comprehensive assessment of functional performance tests may be beneficial to identify high-injury risk adolescents prior to athletic participation.

Keywords: Adolescent, injury risk, pre-participation, screening

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INTRODUCTION

In the United States of America, more than half of all high school students participate in some form of athletics each year, making up a population of over 7 million adolescent student-athletes.[1] High school athletes sustain an estimated 1.5 million injuries each year with the ankle and knee being the most common sites of injury.[2-5] Severe injuries negatively affect the injured athlete's health, result in the athlete missing a large part of his or her season, and often burden the health care system, as they are more likely to require advanced medical treatment such as surgery.[2] Due to the sheer number of injury occurrences and detrimental consequences, previous authors have suggested a need for implementation of specific injury prevention strategies for the ankle and knee joints via identifying modifiable injury risk factors.[2, 4-6]

Prior studies have commented on the importance of longitudinal research when evaluating injury risk factors (i.e., demographics, biomechanics, fitness level, etc.) through prospective injury surveillance.[7-10] A relationship between intrinsic static and dynamic factors that may contribute to increased risk of suffering acute lower extremity injuries in sports has been previously reported. [9,11,12] Intrinsic risk factors include demographics (previous history of injury)[13], anthropometric variables (BMI, age, gender),[13-15] postural stability (balance),[8,16] fatigue, [9,17,18] and physical performance measures (jump-landing, single leg hopping, core stability, cardiorespiratory fitness.[19-23] Functional performance tests (such as the drop-jump video test, star excursion balance test, double leg lowering maneuver, triple hop for distance test, and multi-stage fitness test) [19,24,25,27] have been presented in the literature as reliable and valid assessments for jump-landing mechanics, dynamic balance, core stability, lower limb strength and power, and cardiorespiratory fitness, respectively.[19,24-28]

Functional performance tests have been used to assess components of sport performance (strength, power, agility), determine readiness for return to sport, evaluate effectiveness of neuromuscular training interventions, and predict injury of the lower extremity.[29-33] An advantage of functional tests are that they require minimal personnel, are quick to administer, and require only minimal equipment.[31] Due to the high number of adolescent athletes and subsequent lower extremity injuries, improvements of injury prevention strategies with emphasis on clinic-based and practical assessments (time, equipment, finances, etc.) are warranted. Furthermore, assessments should be objective and include scores from validated clinical tests. Other screening programs have been proposed; however, many require subjective rating systems or singular variables. The purpose of this study was to prospectively investigate if a battery of functional performance tests (FPT) could be used as a preseason-screening tool to identify adolescent athletes at risk for sports-related acute lower extremity injury via comparison of injured and uninjured subjects. This investigation included comparisons of composite scores between injured and non-injured matched subjects and calculation of likelihood ratios to describe probabilities and assess risk. A second purpose was to investigate the relationship between aerobic capacity, functional performance, and potential injury risk. Hence, performance on the multi-stage fitness test (MSFT) was correlated with the FPT composite score.

METHODS

Subjects

One hundred male and female athletes between the ages of 12 and 17 years (14.44 ± 1.65 years) were recruited from a private school and were chosen as a sample of convenience. Sample size was determined by performing a *priori* power analysis using G*Power statistical software (Version 3.1.9.2) with power set at 0.8. As participants in middle and high school athletics, all subjects played at least one of three sports: soccer (n = 22), volleyball (n = 14), or basketball (n = 64). These specific sports were selected based upon the common occurrence of noncontact acute lower extremity injuries involved with sport participation and high-risk maneuvers.[2] Since soccer, volleyball, and basketball all share common athletic maneuvers and injury mechanisms, all three sports were grouped together for statistical analysis.

All subjects completed pre-participation health history questionnaires to rule out pathological conditions that were present at the time of the initiation of the study (any condition that would prohibit clearance to participate in athletics) and contraindications to study participation, which were evaluated by a physician. Exclusionary criteria included: incomplete pre-participation physical exam, and/or inability to physically perform any of the five required assessments. Prior to study participation all procedures were explained to each subject. Subjects and their parents/guardians read and signed assent and consent forms and video assent and consent forms that were approved by the university institutional review board for human subjects.

Injury Surveillance Protocol

Subjects were monitored throughout their designated sport season(s), which consisted of a surveillance period, which extended through the entire sporting season. The school's certified athletic trainer and principal investigator were responsible for documenting and recording all injuries that occurred throughout the sports seasons. Sports injury was defined as an acute injury during athletic practice or game that caused restricted participation or athletic time loss (inability to participate in the current or next scheduled practice or game) as described by Hagglund.[44] The present study was particularly concerned with reporting acute noncontact injuries to the lower extremity (e.g. ACL tear, ankle sprain) since research has shown potential in risk reduction through neuromuscular training for these types of injuries.[29,30,34] This study did not include chronic or over-use type injuries for analysis.

Following the injury surveillance, subjects were categorized into groups according to sex and injury incidence for analysis. Those who sustained an acute lower extremity injury were placed in the injured group and those who did not sustain an acute lower extremity injury were pooled in the uninjured group. Those who sustained an overuse-type injury were excluded from statistical analysis. Data were then analyzed for differences between groups. Additionally, the injured subjects were then matched with an equal number of uninjured subjects based on sex, age, height, and body mass for further analysis.

Procedures

Data were collected by the same four examiners at all testing sessions. All examiners were graduate-level NATABOC certified athletic trainers. Anthropometric data were recorded before all testing procedures and included height, body mass, BMI (body mass index), age, date of birth, grade, sport, and level of sport participation by the principal investigator. All testing was performed in the school's gymnasium. Before testing, subjects conducted a dynamic warm-up led by the principal investigator. The dynamic warm up included jogging, backpedaling, side-stepping, and walking stretches. Subjects were then divided into four different groups, two for each gender. Each group started at a different test station. The starting (test) position was randomly assigned and included synchronous clockwise rotation of all groups. Standardized oral instructions for each test were rehearsed and read by the examiners to all test groups. Standardized instructions were designed to maintain consistency of testing procedures, decrease instructional time, and allow concise and precise data collection. Incorrect test performance required that the test be restarted after a minimum 30-second rest period. No corrective feedback was given to subjects.

Functional Performance Tests

The Triple Hop for Distance Test (THD) evaluated maximal hopping distance on a single limb and was assessed in centimeters (cm) with a standard tape measure fixed to the ground, perpendicular to the starting line**.** [27] Subjects stood on the designated testing leg with the great toe on the starting line and performed three consecutive maximal hops forward on the same limb. Arm swing was allowed, and the investigator measured the distance hopped from the starting line to the point where the heel struck the ground upon completing the third hop with stability. The test was then repeated on the contralateral limb. Previous authors have offered no normalization of this test, since height or leg length may not necessarily affect hop distance. The maximum distance (MaxD) achieved during three trials was recorded in centimeters and used for analysis.[27]

The Star Excursion Balance Test (SEBT) was used to record single-leg reach distance in cm(s) on each leg, in three directions, assessed with a standard vinyl tape measure according to Gribble et al**.**[35] Subjects stood on the center of the testing grid with one limb and reached with their ipsilateral limb in the anterior, posterior, and lateral directions. Average and maximum reach distances (MaxD) in each direction were recorded in centimeters and normalized according to leg length of the stance leg in order to adjust for variances of different anthropometrical variables. The sum of the SEBT scores were expressed as a percentage of leg length.[36]

The Double Leg Lowering Maneuver (DLLM) was assessed with a hand-held inclinometer (Johnson Tool 700 Magnetic Angle Locator) placed along the extended legs over the estimated middle of thigh as described by Kendall.[37] to assess slope of inclination of the lower extremities in degrees. The subject, beginning with the knees extended and the hips flexed to 90 ° was then asked to lower both legs while maintaining the lumbar spine parallel (neutral spinal position) to the test surface (performing an abdominal bracing procedure) to prevent anterior pelvic motion. The tester palpated at the anterior superior iliac spine (ASIS) and at the point when anterior pelvic rotation was observed, the test trial was concluded and the hip angle was measured with the inclinometer. The DLLM score was calculated by subtracting the average angle (in degrees) from 90° (starting position). The same examiner then measured and recorded leg length on one leg with a Gulick tape measure (cm) from ASIS to the distal edge of the medial malleolus; leg length was used for post-testing normalization procedures of the SEBT scores.

The Drop Jump Video Test (DJV) was performed according to Noyes et al.[19] A Sony Mini DV camcorder (Sony Corp of America, New York, NY) was used to record jump landing mechanics, placed on a 102 cm high stand, positioned approximately 366 cm in front of a box that was 30 cm in height and 38 cm in width. Jump landing mechanics were analyzed post-testing session via Dartfish Motion Analysis Software (ProSuite version 4.0.9.0) where lower limb separation distances at the hip and knee were calculated. Immediately before each subject performed the DJV test, the same examiner placed two sets of 4 x 4 cm florescent pink reference markers over the ASIS and center of patella for each limb. Hip separation distance (HSD) was measured while standing erect on top of the box and defined as the distance between the most prominent points of each anterior superior iliac spine. Knee separation distance was measured at the lowest point of each jump landing prior to transition to takeoff into the vertical jump and was defined as the distance between the centers of the patellae. The average absolute knee separation distance during three successful trials was recorded in centimeters and then normalized relative to HSD to yield a percentage for each subject. [19,38]

After completion of the four-abovementioned functional performance tests, a five minute rest period was provided before all subjects completed the Multi-Stage Fitness Test (MSFT) to evaluate maximal oxygen consumption (VO_2 max)[28,39] and provide field-based data regarding aerobic fitness and fatigue. The subjects were required to perform a shuttle run back and forth along 20 meters, keeping in time with a series of auditory signals (provided by an mp3 player) by touching the appropriate end line in time with each audio signal. The frequency of the auditory signals (and hence running speed) was progressively increased until the subjects reached volitional exhaustion and could no longer maintain pace with the signals. VO_2 max was estimated using correlation regression data described by Ramsbottom et al.[39]

The FPT composite score was calculated using the following equation (see full description below):

FPT Composite = (DLLM scaled) +
(SEBT mean of scaled right and left anterior reach) +
(THD mean of scaled right and left MaxD) +
(DJV absolute KSD scaled)

STATISTICAL METHODS

All data were analyzed using SPSS Statistics Version 22.0.0.0 (IBM, Armonk, New York, USA), with an alpha level set at .05 to determine statistical significance. Descriptive statistics were generated and Pearson product-moment correlation coefficients were established between variables of interest (FPT composite scores). Subjects were divided into groups according to gender and injury (acute lower extremity injury, non-injured). Subjects with chronic or overuse lower extremity injuries were excluded from statistical analysis. Univariate general linear model (GLM) was used to assess differences in each functional performance test variable using composite score data between injured and uninjured groups.

Results of all functional performance tests were then each scaled individually using linear regression, which allowed for the normalization of data for each test with scores ranging on a scale from 0 to 10. Scaling data involved computing the mean ± 3 standard deviations (SDs) for each test variable according to absolute scores for males and females. The data were then entered into regression equation models with the fixed notations: the mean equaling a score of '5 out of 10', – 3 SDs equaling a score of '1 out of 10', and + 3 SDs equaling a score of '10 out of 10'. Utilizing the scaled measurements, the scores for the four performance functional performance tests were added and the sum was characterized as the FPT composite score, as described above.

Receiver-operator characteristic (ROC) curves were used to determine cut-off scores for both males and females in the FPT composite score that maximized sensitivity and specificity. The area under the curve (AUC) was calculated using the ROC analysis to measure the accuracy of the FPT composite test as a predictor of injury. Positive predictive values (PPV) were defined in the present study as the probability that subjects with a positive screening test will truly sustain an acute lower extremity injury and were calculated using the following equation:

$$PPV = True\ Positive / (True\ Positive + False\ Positive).$$

Positive likelihood ratios (LR+) were calculated for both males and females to utilize established ranges to interpret the results.

$$LR+ = sensitivity / (1\text{-}specificity).$$

Simple regression was used to correlate composite scores and MSFT shuttle level.

RESULTS

Demographic characteristics of injured and uninjured groups according to gender are provided in Table 1. There were no statistically significant differences in demographic variables between groups ($p > .05$). A total of 95 subjects (57 females, 38 males) were included in the statistical analyses at the end of the six-month injury surveillance period. Fifteen females and seven males sustained an acute lower extremity injury with no previous history of injury. Of the injured females, two suffered noncontact anterior cruciate ligament (ACL) tears confirmed by MRI and 13 suffered acute ankle sprains confirmed by physical examination using anterior drawer and talar tilt test. All seven males suffered acute ankle sprains. Forty-two females and thirty-one males were categorized as the uninjured group (no reported and no previous history of acute lower extremity injury). A total of five subjects were excluded from statistical analyses as a result of incurring other non-acute lower extremity injuries (overuse knee injuries) during the prospective injury surveillance period.

Regression equations used for scaling data for all subjects and according to gender are presented in Table 2.

Table 1. *Injured and uninjured subject demographic characteristics (mean ± SD).*

Females	**Overall, n = 57**	**Injured, n = 15**	**Uninjured, n = 42**
Age (years)	14.2 ± 1.6	14.7 ± 1.7	14.0 ± 1.5
Height (cm)	161.6 ± 6.6	164.1 ± 6.5	161.0 ± 6.4
Body Mass (kg)	55.9±13.4	57.1 ± 9.2	55.5±14.6
Body Mass Index (kg/m^2)	21.2 ± 4.2	21.2 ± 2.5	21.2 ± 4.6
Leg Length Right (cm)	86.6 ± 4.4	88.2 ± 4.8	86.1 ± 4.1
Leg Length Left (cm)	86.5 ± 4.4	88.1 ± 4.7	86.1 ± 4.1
Hip Separation Distance (cm)	22.9 ± 2.4	23.2 ± 1.8	22.8 ± 2.6
Sport Experience (years)	4.8 ± 2.7	5.2 ± 2.2	4.6 ± 2.9
Males	**Overall, n = 38**	**Injured, n = 7**	**Uninjured, n = 31**
Age (years)	14.8 ± 1.6	14.6 ± 1.7	14.9 ± 1.6
Height (cm)	168.1 ± 9.8	171.3 ± 6.6	167.3±10.4
Body Mass (kg)	62.9±14.9	70.8±14.4	61.1±14.6
Body Mass Index (kg/m^2)	22.0 ± 3.8	24.1 ± 4.8	21.5 ± 3.5
Leg Length Right (cm)	89.4 ± 5.5	92.2 ± 4.9	88.8 ± 5.5
Leg Length Left (cm)	89.4 ± 5.5	92.0 ± 5.4	88.9 ± 5.4
Hip Separation Distance (cm)	24.7 ± 2.6	26.6 ± 3.1	24.3 ± 2.3
Sport Experience (years)	5.8 ± 2.7	5.4 ± 2.9	5.8 ± 2.8

Table 2. *Regression equations used for scaling data for all subjects ($y = mx + b$).*

Functional Test Variable	Females (n = 47)	Males (n = 38)
DLLM	y = 0.1482(DLLM) + 0.8734	y = 0.1604(DLLM) + 1.0563
SEBT Right Anterior	y = 0.253(SEBTR) – 12.988	y = 0.2423(SEBTR) – 12.376
SEBT Left Anterior	y = 0.214(SEBTL) – 10.57	y = 0.2762(SEBTL) – 14.658
THD Right MaxD†	y = 0.0293(THDR) – 7.2108	y = 0.0144(THDR) – 3.2046
THD Left MaxD†	y = 0.0258(THDL) – 5.5665	y = 0.0134(THDL) – 2.4636
DJV Absolute KSD	y = 0.2841(KSD) + 0.5038	y = 0.173(KSD) + 0.3887
DJV NKSD	y = 0.0659(NKSD) + 0.4358	y = 0.0439(NKSD) + 0.249
MSFT	y = 1.0176(MSFT) – 0.7243	y = 0.6929(MSFT) – 1.0091

DLLM=Double leg lowering maneuver = (average of 3 trials) – 90; degrees
SEBT=Star excursion balance test = (average of 3 trials in cm) ÷ (Leg length) x 100; anterior direction for right/left legs reported as percentage of leg length
THD= Triple hop for distance
MaxD = maximum distance of 3 trials on right/left leg; centimeters
DJV= Drop jump video test
KSD= absolute knee separation distance, average of 3 trials, defined as the distance between the patellae measured via Dartfish in centimeters
NKSD = Normalized KSD (Avg Absolute KSD ÷ Hip separation distance) x100; reported as percentage of hip width
MSFT= Multi Stage Fitness Test, shuttle level reached during 20 meter volitional maximal exhaustion running test

Statistical means, standard deviations (SD), and ranges of the functional performance tests results for injured and uninjured subjects are presented in Table 3. Univariate GLM indicated significant differences between groups for the DLLM and the DJV tests in females and only with the DJV test in males are presented in Table 4. Results of the multi-stage fitness test (MSFT) are presented in Table 5. Univariate GLM failed to identify any significant differences on performance of the MSFT between the injured and uninjured groups ($p > .05$).

Means, SDs and ranges of the FPT composite scores are presented in Table 6. Mean FPT composite scores were significantly different for injured versus uninjured males and females (19.0 ± 3.5 vs. 21.9 ± 2.4 and 19.4 ± 3.3 vs. 22.1 ± 3.0, respectively) ($p < .05$). These scores are presented in Table 7. The ROC analysis determined the cut-off score of 20 (total scoring range: 1–40) for the FPT composite score in both males and females. Area under the curve (AUC) was statistically significant for both males and females (AUC = .765, $p = .030$ and AUC = .694, $p = .029$, respectively). The ROC analysis revealed that the sensitivity and specificity were 71% and 81% for males and 67% and 69% for females, respectively (Figure 1).

DISCUSSION

The main finding of the present study was that the prospectively measured FPT composite scores were significantly different between the injured and uninjured groups for males and females (p = .016, p = .008 respectively).Significant differences were found between the injured and the uninjured groups ($p < .05$) during the drop jump video test and the double leg-lowering maneuver, identifying jump-landing mechanics and core strength as potential injury risk factors.

When the injured males were matched with similar uninjured males (n = 7 injured, n = 7 uninjured), significant differences were found during the SEBT anterior reach direction between groups ($p = .019$). This finding is consistent with prior reports that poor balance and reach distance deficits found during the SEBT predicted lower extremity injury in high school athletes.[16,40]Additionally, the FPT composite score correlated positively with the MSFT ($r = .474$, $p = .003$), identifying a relationship between functional performance testing and aerobic fitness in male adolescent athletes.

The advantage of utilizing the functional performance tests described in the present study is the determination of a composite score that crosses categories of performance, and that can potentially measure function and give insight to injury-prone athletes. This proposed assessment consists of scaling data using gender based linear regression

Table 3. *Functional performance test scores, including absolute and normalized, categorized by injured and uninjured for both males and females.*

			DLLM	SEBT Anterior	SEBT Posterior	SEBT Medial	THD R MaxD	THD L MaxD	DJV Absolute KSD	DJV NKSD
Female	*Uninjured*	n=42								
		Mean	32.22	76.44	83.09	93.85	435.18	423.15	17.93	79.18
		SD	9.80	6.11	7.32	6.39	50.37	59.39	5.56	24.23
		Range	18–58	64–91	67–99	83–106	353-561	297-569	9–33	48–151
	Injured	n=15								
		Mean	23.55	76.34	87.86	96.50	419.26	426.21	14.35	59.23
		SD	9.69	9.50	10.10	8.91	50.89	55.72	3.47	11.70
		Range	5–43	57–91	68–107	76–111	345-498	335-516	9–21	45–91
Male	*Uninjured*	n=31								
		Mean	27.25	76.44	93.01	101.04	596.49	587.14	29.61	121.59
		SD	9.72	5.20	7.60	7.24	100.45	108.05	9.05	34.44
		Range	8–50	68–87	75–108	90–117	269-754	264-752	15–44	60–182
	Injured	n=7								
		Mean	24.04	72.23	92.90	98.92	584.92	545.37	22.92	86.68
		SD	8.43	4.73	13.03	8.73	134.39	136.89	3.71	14.57
		Range	8–30	67–80	78–109	90–111	294-701	269-681	17–28	67–108

DLLM= Double leg lowering maneuver = (average of 3 trials) – 90; degrees
SEBT= Star excursion balance test = (max distance of 3 trials in cm) ÷ (leg length of stance leg) x 100; reach directions were averaged between right/leg legs and reported as a single mean score; expressed as a percentage of leg length
THD= Triple hop for distance MaxD = maximum distance of 3 trials on right /left leg; centimeters
DJV= Drop jump video test absolute knee separation distance (KSD) = average of 3 trials; KSD defined as the distance between the patellae measured via Dartfish in centimeters
NKSD = normalized DJV= (Avg Absolute KSD ÷ Hip separation distance) x100; reported as percentage of hip width

Table 4. *Univariate General Linear Model results for significant functional test variables between injured and uninjured males and females (mean ± SD); n(%).*

Functional Test	Injured	Control	F	*p*
Females (n=57)	*n=15 (26%)*	*n=42 (74%)*		
DLLM	22.10 ± 9.69	32.63 ± 9.54	9.93	.003
DJV Absolute KSD	14.35 ± 3.47	17.93 ± 5.56	5.47	.023
DJV NKSD	61.73±13.70	78.88±24.45	6.58	.013
Males (n=38)	*n=7 (18%)*	*n=31 (82%)*		
DJV NKSD†	86.68±14.57	121.59±34.44	6.79	.013

DLLM= Double leg lowering maneuver = (average of 3 trials) – 90; degrees
DJV= Drop jump video test, absolute knee separation distance (KSD) = average of 3 trials;
KSD= knee separation distance defined as the distance between the patellae measured via Dartfish in centimeters
NKSD= Drop jump video test normalized KSD= (Avg Absolute KSD ÷ Hip separation distance) x100; reported as percentage of hip width

equations and computing the sum for the following variables: 1) DLLM average, 2) SEBT average anterior reach distance of right and left legs, 3) DJV absolute knee separation distance, and 4) THD average max distance of right and left legs. The criteria for selection of the functional performance tests used in the assessment were repeated-measures reliability, validity in assessing desired measures of function, clinical applicability of testing procedures and instrumentation, and theorized relationship between injury risk factor and neuromuscular association.[19,24-28]

Table 5. *Multi-stage fitness test (MSFT) variables according to gender and categorized by injured and uninjured.*

			MSFT Shuttle Level*	MSFT VO_2 Max**	Time to Fatigue†
Female	*Control*	n=42			
		Mean	6.00	33.14	5:16
		SD	1.49	4.68	1:51
		Range	2–9	22–43	1–8
	Injured	n=15			
		Mean	5.83	32.65	4:54
		SD	1.47	4.64	1:58
		Range	3–8	26–41	2–8
Male	*Control*	n=31			
		Mean	9.20	43.65	8:47
		SD	2.12	7.10	2:05
		Range	5–13	32–56	5–12
	Injured	n=7			
		Mean	8.98	42.94	8:39
		SD	2.52	8.31	2:57
		Range	4–12	27–51	3–11

*MSFT = shuttle level reached during 20 meter volitional maximal exhaustion running test

**MSFT VO_2 Max: estimated using shuttle level and linear regression reported by Ramsbottom[39]; mL/kg/min

†Time to fatigue: overall time to completion of test (volitional exhaustion); reported in minutes and seconds

Table 6. *Functional Performance Test (FPT) composite scores with scaled values of combined functional tests according to gender and categorized by injured and uninjured.*

			FPT Composite*	FPT Composite Aerobic†
Female	*Control*	n=42		
		Mean	22.10	27.45
		SD	3.06	3.40
		Range	16–29	20–34
	Injured	n=15		
		Mean	19.48	24.70
		SD	3.35	4.42
		Range	12–24	16–31
Male	*Control*	n=31		
		Mean	21.90	27.25
		SD	2.44	3.37
		Range	16–26	19–33
	Injured	n=7		
		Mean	19.06	24.28
		SD	3.59	4.92
		Range	12–23	13–29

*FPT Composite = (DLLM scaled) + (SEBT mean of scaled right and left anterior reach) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD scaled); scale 1–40

†FPT Composite Aerobic = (DLLM scaled) + (SEBT mean of scaled right and left anterior reach) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD scaled); + (MSFT shuttle level); scale 1–50

Table 7. *Univariate General Linear Model results for Functional Performance Test (FPT) composite scores between injured and uninjured males and females (mean ± SD). n(%).*

Functional Test	Injured	Uninjured	F	*p*
Females (n=57)	*n=15 (26%)*	*n=42 (74%)*		
FPT Composite	19.48 ± 3.35	22.10 ± 3.06	7.53	.008
FPT Composite Aerobic	24.70 ± 4.42	27.45 ± 3.40	6.23	.016
Males (n=38)	*n=7 (18%)*	*n=31 (82%)*		
FPT Composite	19.06 ± 3.59	21.90 ± 2.44	6.39	.016
FPT Composite Aerobic	24.28 ± 4.92	27.25 ± 3.37	3.73	.061

FPT Composite = (DLLM scaled) + (SEBT mean of scaled right and left anterior scaled) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD); scale 1–40

FPT Composite Aerobic = (DLLM scaled) + (SEBT mean of scaled right and left anterior scaled) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD) + (MSFT shuttle level); scale 1–50

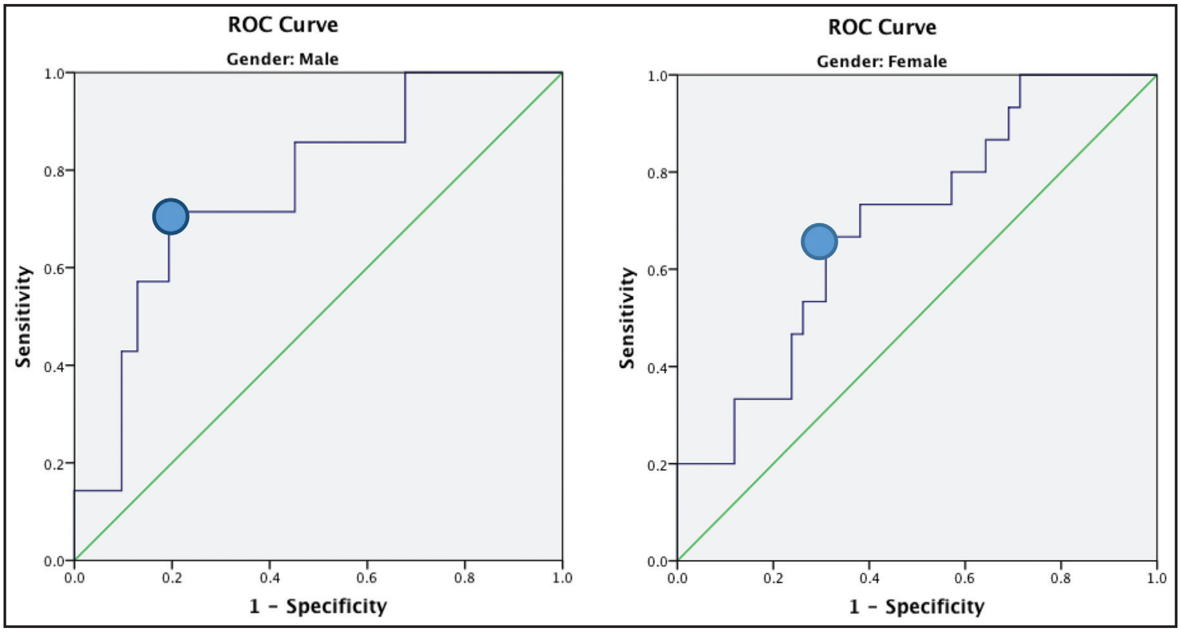

Figure 1. *Receiver-operator characteristic (ROC) curves for FPT composite scores in males and females. The green line represents the line of no-discrimination. The diagonal divides the ROC space. Points above the diagonal represent good classification results (better than random), points below the line represent poor results (worse than random). Blue dots represent points that maximize sensitivity and specificity on the ROC curve (FPT composite score ≤20).*

The creation of a FPT composite score and its ability to differentiate between the injured and uninjured groups are of clinical importance, as the value in assessing injury risk via a composite score has been described in literature examining the utility of the Functional Movement Screen™ (FMS ™) which has been shown to be able to identify injury risk in athletic and military populations.[23] The FMS™ has been described as an injury predictor with a composite score less than or equal to 14 (out of 21) associated with an increased risk of serious injury in professional football players (12 times more likely).[23]

In previous studies, the ROC curve was used to determine the validity of functional performance tests as predictors of injury risk.[40,41] The ROC analysis in the present study revealed that the FPT composite score at the cut-off of ≤ 20 demonstrated sensitivities and specificities of 71% and 81% for males and 67% and 69% for females, respectively. When examining frequency counts of injured and uninjured groups by the ROC cut-off score, results indicated that 71% of the injured and 29% of the uninjured males had prospective composite scores of ≤ 20; similarly, 67% of the injured and 31% of the uninjured females had prospective FPT composite scores of ≤ 20 (Figure 4).

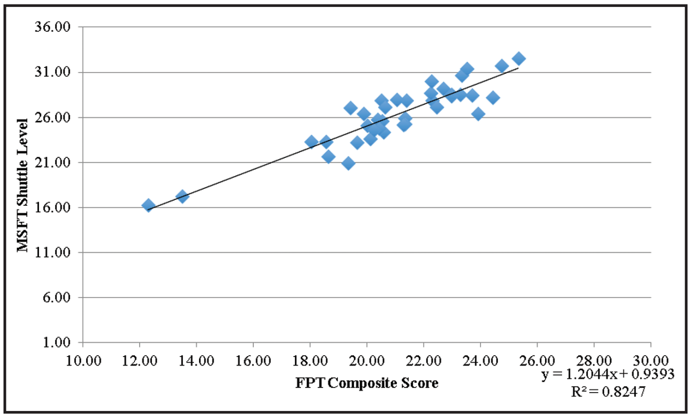

Figure 2. *Correlation of Functional Performance Test (FTP) composite score and MSFT shuttle level in male subjects (n = 38, r = .474, p = .003).*

FPT Composite Score = (DLLM scaled) + (SEBT mean of scaled right and left anterior scaled) + (THD mean of scaled right and left MaxD) + (DJV absolute KSD); scale 1–40

MSFT = Multi Stage Fitness Test shuttle level (shuttle level reached during 20 meter volitional maximal exhaustion running test)

Among those who had a positive FPT composite score (≤ 20), the probability of sustaining an acute lower extremity injury was 45% for males and 48% for females. Therefore, these results suggest that the FPT composite score of ≤ 20 has moderate predictability for acute lower extremity injuries in adolescent males and females. The positive likelihood ratios of 3.74 and 2.16 for males and females, respectively, describe a slight to moderate increase effect on post-test probability of acute lower extremity injury, and a >15% approximate change in probability for acute lower extremity injury,

Performance on the multi-stage fitness test (MSFT) was correlated with the FPT composite score in male subjects (*r* = .474, *p* = .003). Subjects who performed poorly overall on the functional performance tests tended to score low on the MSFT, thus reaching volitional maximal exhaustion earlier than subjects who scored higher on the functional performance tests (Figures 2 and 3).

Fatigue has been shown to adversely alter lower extremity landing biomechanics, decrease lower limb strength, and decrease dynamic balance:[17,18,21] all of which are reported risk factors for acute lower extremity injuries.[8,11,20] Furthermore, it has been reported that a high percentage (60%) of injuries

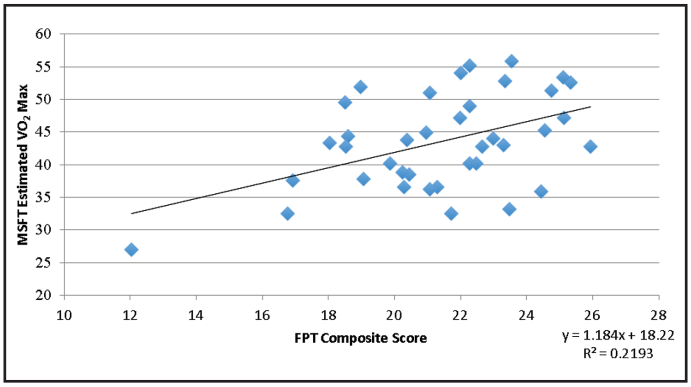

Figure 3. *Relationship of functional performance test (FPT) composite score* and Multi Stage Fitness Test (MSFT) estimated VO2 max† in male subjects (n = 38, r = .468, p = .003).*

*FPT Composite = (Double Leg Lowering Maneuver (DLLM) scaled) + (Star Excursion Balance Test (SEBT) mean of scaled right and left anterior scaled) + (Triple Hop for Distance (THD) mean of scaled right and left Maximum Reach Distance (MaxD)) + (Drop Jump Video Test (DJV) absolute Knee Separation Distance (KSD)); scale 1–40

†MSFT VO2 Max: estimated using shuttle level and linear regression reported by Ramsbottom[39];

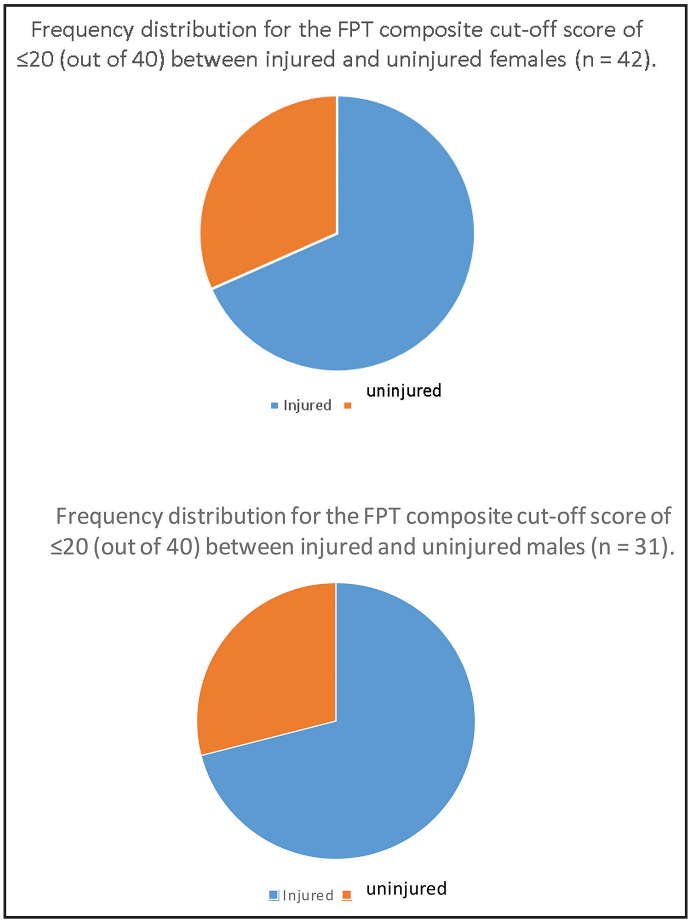

Figure 4. *Frequency distribution for the FPT composite cut-off score of 20 (out of 40) between injured and uninjured females (n = 42) and males (n = 31).*

occur during the latter stages of a game or practice and the risk of suffering moderate to severe injuries increases compared to minor injuries.[9] Therefore, subjects who performed low on the FPT composite score may benefit from improving aerobic endurance and VO_2 max and thus decreasing potential injury risk associated with fatigue.

The main limitations of the present study include: not controlling for activities that subjects may have been involved in before and/or after the functional testing, lack of reporting athletic exposures during the injury surveillance period, and subsequent calculation of hazard ratio's and relative risk between functional performance testing and acute lower extremity injury occurrence. Additionally, external devices (e.g. ankle braces, knee supports, etc.) and leg dominance/handedness were not recorded.

The limitations of the individual functional tests include the following: subjects kept their shoes on for the SEBT which may have affected their balance and overall scores; ankle separation distance was not measured during the DJV; and VO_2 max was evaluated with a 20 meter shuttle run performance (MSFT) to volitional exhaustion (scores may not be representative of true maximal aerobic capacity in the subjects tested).

Other general limitations include: relatively small sample size, short injury surveillance period, and a homogenous subject population (adolescent athletes in a single school in a particular geographic area). Also, the provided scaled data may not be used as norms for other populations (i.e. collegiate or professional athletes) as theoretically older and more elite athletes would perform better overall on the assessment thus requiring new regression equations for normative measures. Finally, only sports participants from soccer, basketball, and volleyball were included in this study.

CONCLUSION

The FPT composite utilized in the current study is an objective, quantifiable athletic assessment that combines reliable and valid functional performance tests and utilizes a normalization procedure to combine results into a single composite score. This composite score has demonstrated potential in identifying adolescent athletes at risk for acute lower extremity injuries, as significant differences were noted in the FPT composite scores between the injured and the uninjured groups in both females (p = .008) and males (p = .016).

Therefore, if the FPT composite score can identify at risk athletes prior to competition, prevention strategies could be employed based on an adolescent soccer, basketball and volleyball athletes specific scores. However, further research is needed to further explore the FPT composite utilizing larger sample sizes via a multi-institution approach with mass testing.

REFERENCES

1. Centers for Disease Control and Prevention. *Guidelines for school and community programs to promote lifelong physical activity among young people.* MMWR Recomm Rep, 1997. 46(RR-6):1-36.
2. Darrow CJ, et al. Epidemiology of severe injuries among United States high school athletes. *Am J Sports Med.* 2009;37(9):1798-805.
3. Rechel JA, Yard EE, Comstock RD. An epidemiologic comparison of high school sports injuries sustained in practice and competition. *J Athl Train*. 2008:43(2):197-204.
4. Le Gall F, Carling C, Reilly T. Injuries in young elite female soccer players: an 8-season prospective study. *Am J Sports Med*. 2008;36(2):276-84.
5. Nelson AJ, et al. Ankle injuries among United States high school sports athletes 2005-2006. *J Athl Train*. 2007;42(3):381-7.
6. Stracciolini A, et al. Pediatric sports injuries: a comparison of males versus females. *Am J Sports Med*. 2014;42(4):965-72.
7. Sman AD, et al. Predictive factors for ankle syndesmosis injury in football players: a prospective study. *J Sci Med Sport*. 2014;17(6):586-90.
8. Wang HK, et al. Risk-factor analysis of high school basketball-player ankle injuries: a prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. *Arch Phys Med Rehabil*. 2006;87(6):821-5.
9. Ostenberg A, Roos H. Injury risk factors in female European football. A prospective study of 123 players during one season. *Scand J Med Sci Sports*. 2000;10(5):279-85.
10. Hewett TE, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*. 2005;33(4):492-501.

11. Willems TM, et al. Intrinsic risk factors for inversion ankle sprains in male subjects: a prospective study. *Am J Sports Med*. 2005;33(3):415-23.
12. Beynnon BD, et al. Ankle ligament injury risk factors: a prospective study of college athletes. *J Orthop Res*. 2001;19(2):213-20.
13. Tyler TF, et al. Risk factors for noncontact ankle sprains in high school football players: the role of previous ankle sprains and body mass index. *Am J Sports Med.* 2006;34(3):471-5.
14. Nilstad A, et al. Risk factors for lower extremity injuries in elite female soccer players. *Am J Sports Med*. 2014;42(4):940-8.
15. Beynnon BD, et al. First-time inversion ankle ligament trauma: the effects of sex, level of competition, and sport on the incidence of injury. *Am J Sports Med.* 2005;33(10):1485-91.
16. McGuine TA, et al. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med*. 2000;10(4):239-44.
17. Dalton EC, et al. Neuromuscular changes after aerobic exercise in people with anterior cruciate ligament-reconstructed knees. *J Athl Train.* 2011;46(5):476-83.
18. Ortiz A, et al. Fatigue effects on knee joint stability during two jump tasks in women. *J Strength Cond Res*. 2010;24(4):1019-27.
19. Noyes FR, et al. The drop-jump screening test: difference in lower limb control by gender and effect of neuromuscular training in female athletes. *Am J Sports Med.* 2005;33(2):197-207.
20. Schmitt LC, et al. Strength Asymmetry and Landing Mechanics at Return to Sport after ACL Reconstruction. *Med Sci Sports Exerc*. 2014.
21. Augustsson J, et al. Single-leg hop testing following fatiguing exercise: reliability and biomechanical analysis. *Scand J Med Sci Sports*. 2006;16(2):111-20.
22. Wilkerson GB, Giles JL, Seibel DK. Prediction of core and lower extremity strains and sprains in collegiate football players: a preliminary study. *J Athl Train.* 2012;47(3):264-72.
23. Lisman P, et al. Functional movement screen and aerobic fitness predict injuries in military training. *Med Sci Sports Exerc*. 2013;45(4):636-43.
24. Kinzey SJ, Armstrong CW. The reliability of the star-excursion test in assessing dynamic balance. *J Orthop Sports Phys Ther.* 1998;27(5):356-60.
25. Krause DA, et al. Abdominal muscle performance as measured by the double leg-lowering test. *Arch Phys Med Rehabil*. 2005;86(7):1345-8.
26. Ladeira CE, et al. Validation of an abdominal muscle strength test with dynamometry. *J Strength Cond Res.* 2005;19(4):925-30.
27. Hamilton RT, et al. Triple-hop distance as a valid predictor of lower limb strength and power. *J Athl Train*. 2008;43(2):144-51.
28. Leger LA, et al. The multistage 20 metre shuttle run test for aerobic fitness. *J Sports Sci*. 1988;6(2):93-101.
29. Noyes FR, et al. A training program to improve neuromuscular and performance indices in female high school basketball players. *J Strength Cond Res.* 2012;26(3):709-19.
30. Noyes FR, et al. A training program to improve neuromuscular and performance indices in female high school soccer players. *J Strength Cond Res.* 2013;27(2):340-51.
31. Brumitt J, et al. Lower extremity functional tests and risk of injury in division iii collegiate athletes. *Int J Sports Phys Ther.* 2013;8(3):216-27.
32. Hegedus EJ, et al. Clinician-friendly lower extremity physical performance measures in athletes: a systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. *Br J Sports Med.* 2014.
33. Hegedus EJ, et al. Clinician-friendly lower extremity physical performance tests in athletes: a systematic review of measurement properties and correlation with injury. Part 2-the tests for the hip, thigh, foot and ankle including the star excursion balance test. *Br J Sports Med.* 2015.
34. McHugh MP, et al. The effectiveness of a balance training intervention in reducing the incidence of noncontact ankle sprains in high school football players. *Am J Sports Med.* 2007;35(8):1289-94.
35. Gribble PA, et al. The Effects of Fatigue and Chronic Ankle Instability on Dynamic Postural Control. *J Athl Train.* 2004;39(4):321-329.
36. Kendall F, McCreary E, Provance PG, et al. *Muscles Testing and Function With Posture and Pain 5th ed.* Baltimore, MD: Williams & Wilkins; 2005.
37. Barber-Westin SD, et al. Assessment of lower limb neuromuscular control in prepubescent athletes. *Am J Sports Med*. 2005;33(12):1853-60.
38. Ramsbottom R, Brewer J, Williams C. A progressive shuttle run test to estimate maximal oxygen uptake. *Br J Sports Med*. 1988;22(4):141-4.
39. Sigward SM, Havens KL, Powers CM. Knee separation distance and lower extremity kinematics during a drop land: implications for clinical screening. *J Athl Train.* 2011;46(5):471-5.
40. Zazulak BT, et al. Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. *Am J Sports Med*. 2007;35(7):1123-30.

41. Haladay DE, et al. Responsiveness of the double limb lowering test and lower abdominal muscle progression to core stabilization exercise programs in healthy adults: a pilot study. *J Strength Cond Res.* 2014;28(7):1920-7.
42. Gribble PA, et al. Interrater reliability of the star excursion balance test. *J Athl Train.* 2013;48(5):621-6.
43. Plisky PJ, et al. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther*. 2006;36(12):911-9.
44. Hagglund M, et al. Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *Br J Sports Med.* 2005; 39: 340-346.