

Original Research

Evaluation of the Back-in-Action test Battery In Uninjured High School American Football Players

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Background

Return to sport testing is an established routine, especially for athletes who have ruptured their anterior cruciate ligament (ACL). Various tests are performed, often combined in test batteries, such as the Back-in-action (BIA) test battery. Unfortunately, pre-injury performance is often unknown, and only few athletes pass the high demands of these test batteries.

Purpose

The aim of the study was to determine the performance of under 18 American football players on the BIA to establish pre-injury sport specific benchmarks for future RTS testing and to compare these values to data from an age-matched reference group.

Methods

Fifty-three healthy male American football players underwent a functional assessment using the "Back-in-action" test battery evaluating agility, speed (Parkour-Jumps and Quick-Feet test), balance (using a PC based balance board), and power (Counter-Movement-Jump [CMJ]) as objective measures. Their results were compared with a previously tested reference group (RP) and within the american football players (AF) through three subgroups according to field playing position.

Results

Overall, the American football (AF) athletes showed lower balance scores for both legs (AF: 3.71/3.57/3.61; RP: 3.4/3.2/3.2; $p < 0.002$) compared to the reference population (RP). CMJ height and Quick-Feet results were not statistically different ($p > 0.05$), Parkour-Jump times (AF: 8.18/ 8.13 sec.; RP: 5.9/5.9sec.; $p < 0.001$) were significantly slower. Power output in all CMJ's (AF: 46.86/36.94/37.36 W/kg; RP: 43.2/29.5/29 W/kg; $p < 0.001$) was significantly higher than the RP. Passing and running game involved players (G2 & G3) showed significantly better balance scores (G2+G3: 3.36/3.27/3.33; G1: 4.22/4.06/4.10; $p < 0.001$), higher jump height (G2&G3: 38.87/24.02/24.96 cm; G1: 32.03/19.50/18.96 cm; $p < 0.001$) and more watts/kg (G2&G3: 48.83/37.21/37.64 W/kg; G1: 43.95/36.88/36.53 W/kg; $p < 0.001$) compared to blocking players like Linemen (G1) and to the age matched reference population (RP).

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Conclusion

Only 53% of the healthy athletes would have been cleared for sport using the BIA test criteria, which highlights the challenging passing criteria. Despite significantly greater power measurements, scores of balance and agility were poorer compared to the reference group, especially for linemen. These data may serve as sport and position specific reference for high school American football players, instead of using the non-specific reference group data.

Study design

cross-sectional study-

Level of evidence

IIb

INTRODUCTION

American Football is the most popular contact team sport, especially at the high school level. Nevertheless, injury profile and injury risks are high. The knee is most commonly affected by injury (20%) and overuse conditions (39% in under 14-year aged players, 19% in high-school players), mainly involving structures such as the ACL, MCL and meniscus.¹⁻⁴ While technical and tactical teaching reduces risk of injury due to contact, performance training may effect intrinsic risk factors positively.⁵ Therefore, performance and skill training counteracts intrinsic factors for injury. This is especially important in young athletes as repetitive trauma or overuse may lead to early osteoarthritis in adulthood.⁶

Commonly, drills and exercises such as quick changes of direction, fast movements on toes, jumping jacks, and strength training have become a part of routine training in American football. Strength, speed, and power are known to have an impact on becoming a starter and are tested in athletes on a regular basis and are important components of the NFL combine test.⁷ Balance as indicator for subsequent injuries is not included, despite the known effect of injury on an American football career.⁸⁻¹⁰

Moreover, within the course of return to sport after injury, balance measures, such as the Y- Balance test, or the single leg hop test are proposed to be predictors for a safe return.¹¹⁻¹⁵ Unfortunately, these tests rely partly on subjective impression of the evaluator and are criticized as uncertain as predictive tools.^{16,17} In contradiction, computerized wobble boards have shown a good reliability compared to conventional tests.^{17,18} Consequently, various test batteries which include strength, agility, and balance measures have been suggested and implemented, but recent research has questioned the value of these batteries.¹⁹⁻²² The "Back-in-Action" (BIA) field test battery uses data derived from five functional tests (one-legged and two-legged balance; one-legged and two-legged Counter-Movement-Jumps; Plyometric Jumps; one-legged Parkour Jumps and Quick Feet), to provide objective cut-off values for return to sport (RTS) post injury.^{19,21,23} In the introduction of the BIA test battery, an unspecific reference group giving "normal" values was established for comparison and benchmarking. Unexpectedly, the proposed cut-off values for return to sport are hard to meet and limb symmetry demands

of >90 % are a matter of discussion.²⁴⁻²⁷ Several studies on healthy untrained boys as well as professional athletes have discovered significant limb symmetry differences as well, and with this in mind, achieving limb symmetry seems desirable, but may be unrealistic.^{28,29}

Normative performance values for American football players (outside of those reported from the NFL combine) test are missing, and cutoff values for the BIA, related RTS for these athletes are unknown. Due to the broad variety of physical demands of different field positions in football, athletes have widely variant physical properties/abilities matching these requirements. Commonly, athletes of different playing positions train separately.

Therefore, the aim of the study was to determine the performance of under 18 American football players on the BIA to establish pre-injury sport specific benchmarks for future RTS testing and to compare these values to data from an age-matched reference group. It was hypothesized that significant differences would exist in BIA performance among position-specific groups of which may help establish position-specific benchmarks.

MATERIALS AND METHODS

The study was approved by the local responsible ethic / IRB approval (AZ 19-8899-BO). Athletes (aged 16-17 years) were recruited from an American football state team. Participation was only granted with a signed informed consent of the parents. All athletes were tested during the first three days of the annual autumn training camp of the 2021/2022 season.

Athletes were divided into three groups according to field playing position. This was done due to the training differences as well as the position-specific requirements of the game. Therefore, playing positions with similar requirement profiles were combined and detailed description is outlined below:

Group 1 (G1) includes players of *defense (D-LM)* and *offense line (O-LM)*, *centers (C)*, *offensive guards (OG)*, *offensive tackles (OT)* and *defensive tackles (DT)*. They only cover short distances on the field and have no ball carrying tasks. Explosive movement and a stable stand in tackling are beneficial.

Group 2 (G2) includes *linebacker (LB)*, *defensive back (DB)* and *tight end (TE)*, *defensive ends (DE)* athletes with

limited movement on the field. These positions require blocking and tackling and rarely ball-carrying. Explosive movement and agility are beneficial.

Group 3 (G3) includes *running backs (RB)*, *wide receiver (WR)*, *quarterback (QB)* as well as *cornerbacks (CB)*, *safeties*. These athletes are the ball carrying athletes majorly involved in yard gain. High acceleration and agility are of importance.

PROCEDURE

All athletes answered a questionnaire just before participation. Anthropometric data including height, weight and dominant leg were obtained before testing. Prior to testing, participants completed their regular five-minute warm-up of jumping jacks, shuttle run, stretching and agility exercises. Athletes who were injured, undergoing rehabilitation, or those with less than three years of sports experience were excluded from the study. The assessment was performed according to the guidelines without footwear on plain firm ground without rebound property. In case of an invalid trial, the (sub-)test was repeated once.

TEST SETUP

The study was conducted with the Back-in-Action (BIA) test battery (CoRehab,Trento,Italy). This assessment was originally designed for patients after ACL surgery to guide the return to sport process. Moreover, this series of test offers objective cut-off values for athletes before a return to competition. A detailed description of the test- battery has been published, with an observer independent test-retest reliability that varies between 0.688 and 0.921.^{19,21}

The test battery determines agility, strength, balance, and speed. Subtests are performed two-legged and one-legged with the dominant (d) and non-dominant (nd) leg in the following order.

The dominant leg was defined as the leg, which an athlete described as his stronger leg in the questionnaire before participation.

BALANCE

Balance was measured for 20 seconds by a computer-based balance board (MFT Challenge Disc, TST, Trendsport, Grosshöflein, Austria) with biomechanical feedback given on a screen. A moving point on a target indicated the actual center of gravity. Increasing distance to the center (of the target) results in higher and thereby worse balance scores (1 to 5). Two-legged (TL Bal.) and one-legged balance (OL d/nd Bal.) was evaluated separately.

STRENGTH

Counter-movement-jumps were recorded by a sensor (Myotest S.A., Sion, Switzerland) placed on the iliac crest, recording jump height (cm) and calculating power (W/kg). Good reliability regarding the placement and max. velocity measurements have been demonstrated by others before.³⁰⁻³² The use of arms while jumping was prohibited,

and the hands were placed on the waist. In the one-legged CMJ, athletes were asked to jump off with the respective leg but were allowed to land with both legs. Two-legged (TL CMJ) and one-legged (OL d/nd CMJ) counter-movement-jumps were recorded separately.

SPEED AND AGILITY

The Parkour Jumps include four alternating forwards/backwards and sideways jumps (sequence: 4x forward-backward-forward-sideways) over 1cm wide soft bars for time. Correct execution of the jump sequence was a mandatory requirement, a failed trial (falling, setting the opposite foot down) resulted in a restart. Time (sec.) was monitored by the test operator. One-legged Parkours jumps (OL d/nd Pk.) with the dominant and non-dominant leg were recorded sequentially.

The Quick-feet exercise (QF) requires completing fifteen alternating steps with the feet, inside and outside a box (40x40cm), which was built of soft bars. Repetitions (sequence: inside-inside-outside-outside) was performed as quickly and accurately as possible. Only a correct execution was counted as repetition. A failed trial resulted in a restart. Repetition counting and time monitoring (seconds) was done by the test operator.

The test battery compared the results of the single-leg tests and calculated a symmetry index between the limbs for each assessment. LSI was calculated by dividing the measured value of the non-affected leg by the value of the injured side and multiplying by 100. LSI indicates equivalence in performance (%) between the legs. A symmetry of 100% implies that there are no differences in performance between both limbs.

The respective results are compared with a healthy, untrained age and gender matched reference population (no American football athletes), collected by Herbst et. al.¹⁹ The procedure and exercise set-up used for this investigation are previously described in detail by Herbst et al. and Hildebrandt et al. and were accordingly undertaken without variation.^{19,21}

STATISTICAL ANALYSIS

The collected data were processed and analyzed using SPSS 26.0 (IBM Statistics, Armonk, NY, USA). Normal distribution was tested using the Kolmogorov-Smirnov-test. Depending on the results analysis of variance (ANOVA), Mann-Whitney-U test (2 groups), or the Kruskal-Wallis test (3 groups) were used for further analysis. For correlation analyses, Pearson correlation was applied. The correlational values (r = Pearson's r) were interpreted as negligible (0.00- 0.30), low (0.30- 0.50), moderate (0.50- 0.70), strong positive (0.70- 0.90) and very strong positive (0.90- 1.00). Statistical significance was determined at $p < 0.05$.

RESULTS

A total of fifty-three male athletes were included in this investigation. Among these, 19 athletes had to be assigned to

Table 1. Anthropometric data of the U18 Football athletes overall and the data of the particular position groups

	U18 (n=53)	Group 1 (n=19)	Group 2 (n=20)	Group 3 (n=14)
Weight (kg)	90.70 ± 19.92	110.4 ± 16.3	79.25 ± 11.8	80.29 ± 11.1
Height (cm)	184.85 ± 6.8	188.37 ± 6.9	181.35 ± 5.4	185.07 ± 6.3
BMI (kg/m ²)	26.42 ± 5.0	31.13 ± 4.3	24.06 ± 3.1	23.39 ± 2.8

Anthropometric data of the U-18 athletes overall and of the three position-specific groups; kg= kilograms; cm= centimeter

Table 2. Balance scores of wobble board performance (1= best score; 5= worst score)

	Reference Population RP (n=430)	U 18 (n=53)	Group 1 (n=19)	Group 2 (n=20)	Group 3 (n=14)
Balance TL	3.4	3.71 ± 0.7 ** ↓	4.22 ± 0.5 ** ↓	3.46 ± 0.6	3.36 ± 0.7
Balance OL d	3.2	3.57 ± 0.8 ** ↓	4.06 ± 0.6 ** ↓	3.30 ± 0.7	3.27 ± 0.7
Balance OL nd	3.2	3.61 ± 0.7 ** ↓	4.10 ± 0.6 ** ↓	3.34 ± 0.5	3.33 ± 0.6

Balance results of the reference population, U18 overall and the 3 position-specific groups in the BIA Balance-Tests; higher balance scores represent a worse balance; "***" highlight p-values <0.001 and therefore statistical significant differences, "↑" indicates a better result than the reference population, while "↓" indicates a worse result than the reference population; TL= two-leg; OL= one-leg; d= dominant leg; nd= non-dominant leg; RP= reference population

group 1 (G1: n=19). Position group 2 consists of 20 athletes (G2: n=20). 14 athletes were selected for group 3 (G3: n=14). All athletes were able to participate in the test battery, no acute injuries occurred, therefore no athlete had to be excluded from the study.

ANTHROPOMETRICS

Pre-testing anthropometric data is presented in [Table 1](#). Group 1 (G1) athletes were significantly heavier with an elevated BMI compared to G2 and G3 ($p < 0.001$), whereas G2 and G3 showed comparable body weight and BMI. Significant differences in height were shown between G1 and G2 ($p < 0.001$), but not when compared with G3.

BALANCE

Balance measures of one-legged and two-legged wobble board performances are subsumed in [Table 2](#). The results of the entire group of football athletes demonstrate significantly poorer balance scores for two-leg test ($p < 0.002$) and significantly poorer scores for each leg separately (OL/d: $p < 0.001$; OL/nd: $p < 0.001$) in comparison with the reference population (RP).

For subgroups, G1 showed significantly worse scores in the two-legged and one-legged balance tests compared to the RP (TL; OL/d; OL/nd: $p < 0.001$) as well as to G2 (TL; OL/d; OL/nd: $p < 0.001$) and G3 (TL; OL/d; OL/nd: $p < 0.001$).

G2 and G3 showed no statistically significant differences in the two-legged and one-legged balance tests, equivalent to the results of the RP.

Correlation (Pearson r) of Balance scores to anthropometric data showed a low correlation for body height and wobble board performance (r : TL Bal.: +0.36; OL/d: +0.37; OL/nd: +0.4; $p < 0.05$).

For leg symmetry, 25 of 53 athletes (47%) showed a leg difference of over 10%.

COUNTER-MOVEMENT-JUMPS

A summary of all CMJ measurements is presented in [Table 3](#) for height measures (cm) and [Table 4](#) for power measures (watt/kg). Absolute jump height was not significantly different between all of the football athletes and the untrained subjects (RP) in the CMJ TL, OL/d and OL/nd ($p > 0.05$). In the TL-CMJ, G3 achieved significantly higher jump heights than G1 ($p < 0.001$), but not in comparison to G2 ($p > 0.05$) or the RP ($p > 0.05$). G1 and G2 showed not statistically different jump heights compared to each other and to the RP ($p > 0.05$).

Jump heights of the OL-CMJ d showed no significant differences between all groups (G1 vs. G2 vs. G3 vs. RP: $p > 0.05$). For the non-dominant limb (OL-CMJ nd) G1 showed significantly lower jump heights than G2, G3 and the RP ($p < 0.001$), which were not significantly different.

The football players overall generated a significant higher power output in all jump tests (CMJ TL: $p < 0.001$; OL/d: $p < 0.001$; OL/nd: $p < 0.001$) than the RP.

CMJ jump height symmetry over 90% was achieved by 18 of 53 athletes (34%).

The power as measured during the TL-CMJ showed no significant differences in G1, G2, G3 ($p > 0.05$). However, G2 and G3 showed significantly better power output values compared to the RP ($p < 0.001$), while G1 did not ($p > 0.05$). Regarding the power output in the single-leg CMJ, no differences were found between the groups OL/d and OL/nd, but athletes were superior to the RP (G1 vs. RP: $p < 0.001$, G2 vs. RP: $p < 0.001$, G3 vs. RP: $p < 0.001$).

53% (28 of 53) of the tested subjects achieved a symmetry index of >90% for power development in the CMJ.

Table 3. Jump height results in the CMJ

	Reference Population RP (n=430)	U18 (n= 53)	Group 1 (n=19)	Group 2 (n=20)	Group 3 (n=14)
CMJ TL Height (cm)	35	36.3 ± 7.4	32.03 ± 6.2	38.56 ± 7.3	38.87 ± 6.9
CMJ OL d Height (cm)	22.4	22.21 ± 5.6	19.50 ± 4.7	23.52 ± 5.6	24.02 ± 5.6
CMJ OL nd Height (cm)	21.75	22.80 ± 5.8	18.96 ± 4.7 ** ↓	24.92 ± 4.8	24.96 ± 5.8

Jump height results in centimeter in the CMJ of the reference population, U18 overall and the 3 position-specific groups; **** highlight p-values <0,001 and therefore statistical significant differences, "↑" indicates a better result than the reference population, while "↓" indicates a worse result than the reference population; CMJ= Counter-Movement-Jump; TL= two-leg; OL= one-leg; d= dominant leg; nd= non-dominant leg; RP= reference population

Table 4. Power Development: results in the CMJ

	Reference Population RP (n=430)	U18 (n=53)	Group 1 (n=19)	Group 2 (n=20)	Group 3 (n=14)
CMJ TL Strength (W/kg)	43.2	46.86 ± 5.3 ** ↑	43.95 ± 3.4	48.55 ± 6.1 ** ↑	48.43 ± 4.8 ** ↑
CMJ OL d Strength (W/kg)	29.5	36.94 ± 3.9 ** ↑	36.68 ± 3.0 ** ↑	37.00 ± 4.3 ** ↑	37.21 ± 4.5 ** ↑
CMJ OL nd Strength (W/kg)	29	37.36 ± 3.7 ** ↑	36.53 ± 2.7 ** ↑	37.95 ± 3.8 ** ↑	37.64 ± 4.7 ** ↑

Power development in Watts per kilogram in the CMJ of the reference population, U18 overall and the 3 position-specific groups; ****highlight p-values <0,001 and therefore statistical significant differences, "↑" indicates a better result than the reference population, while "↓" indicates a worse result than the reference population; CMJ= Counter-Movement-Jump; TL= two-leg; OL= one-leg; d= dominant leg; nd= non-dominant leg; RP= reference population

Table 5. Results of the Parkour Jump and the Quick-feet assessments

	Reference population RP (n=430)	U18 (n=53)	Group 1 (n=19)	Group 2 (n=20)	Group 3 (n=14)
Parkours d time (sec)	5.9	8.18 ± 3.2 ** ↓	9.70 ± 4.7 ** ↓	7.42 ± 1.3 ** ↓	7.17 ± 1.2 ** ↓
Parkours nd time (sec)	5.9	8.13 ± 4.1 ** ↓	10.21 ± 6.3 ** ↓	6.99 ± 1.0 ** ↓	7.05 ± 1.3 ** ↓
Quick Feet time (sec)	8.9	8.96 ± 1.3	9.50 ± 1.4	8.82 ± 1.3	8.42 ± 0.9

Time performance of the reference population, U18 overall and the 3 position-specific groups in the Parkours-jumps and the Quick-Feet test; **** highlight p-values <0,001 and therefore statistical significant differences, "↑" indicates a better result than the reference population, while "↓" indicates a worse result than the reference population; d= dominant leg; nd= non-dominant leg; RP= reference population

PARKOUR JUMP AND QUICK-FEET (SPEED AND AGILITY)

Time measure results of the Parkour and Quick feet task are presented in [Table 5](#). In the Parkour jumps, American football athletes overall and each group individually were slower than the RP (p<0.001).

G1 performed significantly slower compared to G2 and G3 with the dominant (G2 vs G1: p<0.001; G1 vs. G3: p<0.001) and non-dominant legs (G2 vs. G1: p<0.001; G3 vs. G1: p<0.001).

Regarding the Quick-Feet test completion times between football athlete and RP groups (p>0.05) were not significantly different. However, G3 was significantly faster than G1 (p<0.05), while no other significant differences between the groups occurred (G1 vs. G2: p>0.05; G2 vs. G3: p>0.05).

For correlation measures, a low correlation was found for on legged balance scores with increased time in the parkour test. (OL/d Bal-OL/d Park.: r = +0.46, p<0.05; OL/nd Bal - OL/nd Park.: r = +0.43, p<0.05). A Correlation for power

measures of the CMJ and parkour times of the same limb was not found.

SYMMETRY

Average symmetry index measures are given in [Table 6](#). Mean measures of the differences in performance between the two legs (symmetry index) of the American football athletes for the one-legged balance and one-legged CMJ jump height were over 10% (mean under 90%) for all three position groups. There were no significant differences between the position groups (p>0.05).

DISCUSSION

BIA performance measures of 53 high level U-18 American football players were reported in order to establish benchmark levels to consider for cutoff values for return to sport test decisions. These young football players showed deficits

Table 6. Symmetry-index (in %) of the one-legged performed subtests

	U18 (n=53)	Group 1 (n=19)	Group 2 (n=20)	Group 3 (n=14)
Symmetry Balance (%)	88.54 ± 7.9	88.58 ± 9.5	87.35 ± 7.2	89.79 ± 6.9
Symmetry CMJ jump height (%)	84.37 ± 12.0	83.74 ± 12.3	82.50 ± 14.2	87.57 ± 8.1
Symmetry CMJ power (%)	93.3 ± 5.8	94.89 ± 5.3	91.45 ± 7.1	93.64 ± 4.03
Symmetry Parkour Jumps (%)	91.46 ± 7.3	90.00 ± 9.9	92.10 ± 5.2	92.36 ± 5.7

Symmetry index (%) for one-legged performed assessments: balance, Counter-Movement-Jump height & power and parkours time; symmetry shows the equivalence in performance between both legs. An index of 100% indicates no difference in performance between both legs. CMJ= Counter-Movement-Jump

in balance and rapid/complex movements, while showing comparable results in counter-movement-jumps (jump height), and greater power compared to an untrained reference population. Significant performance differences were also found among the different position groups in several parameters.

FOOTBALL PLAYERS PRESENT ONLY WITH HIGHER POWER OUTPUT DURING COUNTER MOVEMENT JUMPS COMPARED TO THE REFERENCE POPULATION

For counter-movement jumps, football players generated about 46.86W/kg (TL), 36.94 W/kg (OL/d) and 37.36W/kg (OL/nd), which significantly greater than the reference population. For American Football, explosive power in movement is an important performance parameter, as it is a discontinuous sport with a series of recurrent intense anaerobic power peaks.^{33,34} Vertical jumps, broad jumps, the 40m Dash, and CMJ are part of the NFL Combine and therefore a fundamental part of the training routine used by football players, which likely affects the development of power.^{33,35} The fact that jump heights of 36.3cm (TL), 22.21cm (OL/d) and 22.8cm (OL/nd) were similar to untrained individuals, is probably due to the elevated body weight of players.

Although the power measures of the American football athletes were superior to the untrained reference group, they are worse when compared to values seen in prior studies. Leutzinger et al. evaluated high school athletes (15-17y) using the NFL Scouting Combine tests, including the vertical jump. Their athletes achieved a vertical jump height of 62.9 cm.^{35,36} This may be due to the fact that the vertical jump test of the NFL combine (as investigated by Leutzinger et al.) is executed with help of the arms, which can lead to about 25% increase in jump height of CMJs according to Sayers.^{37,38} Still, after multiplication by 1.25, the current results add up to 45.28 cm, which is still diminished, but comparable to 12-year-old players.³⁹ This may be due to the methods used in the current study: the digital Myotest accelometer versus Leutzinger's analogue Vertec jump trainer are different and accuracy might be impaired.³² Unfortunately, only a limited number of studies depict power development in Watt/kg of CMJ in 16-17 years old American football players. McKay and Leutzinger reported approx. 6008 watts, 64.99 W/kg body weight.^{35,36} When applying Sayers formula, peak anaerobic power output averaged at approximately 4806 watts, about 53 W/kg in

this investigated population of American football players.³⁷ Once again, different measurement devices may partly account for these differences or even hide greater differences, as calculation of watt/kg with the Myotest sensor remains unanalyzed and Vertec measurements in an analogue manner rely on half inch increments only.³⁰ Power development itself is the most useful performance parameter in football: it is associated with the career longevity, a predictor for injury risk and the RTS capability.⁴⁰ As the BIA test battery was originally designed to discriminate athletes recovering from an ACL injury regarding their readiness to return to sport, this aspect may be particularly interesting. Regarding ACL injury, the quadriceps to hamstring ratio is an important indicator of function in ACL deficient knees.⁴¹ Additionally, quadriceps strength predicts the long term function after ACL reconstruction.^{42,43} Clearly, isometric measures of strength were not undertaken in this field test investigation and therefore comparison is insufficient. Worth mentioning, power development ratio in counter movement jumps measured by a force platform was most recently correlated to ACL injury in the future by Pontillo.⁴⁴

FUNCTIONAL TESTS REVEAL MAJOR DEFICITS IN KNEE CAPABILITY MEASURES

In comparison to an untrained population (RP), the American football players of this study performed significantly worse in multiple subtests. The results in the one-legged balance test (Bal. OL d/nd) were particularly notable, in which American football players performed significantly worse. Previous researchers report ambiguous data on wobble board performances in association with body height, limb length, and the related center of gravity.⁴⁵⁻⁴⁸ In the current study there was only a low correlation between body height and worse balance scores. During NFL Combine testing balance is not measured, but agility, coordination, and explosiveness are with a three-cone drill, which is similar to the Parkour Jumps used in the BIA test battery. It is debatable whether single-leg balance or the single-leg CMJ results are associated with the results in the single-leg Parkour Jumps. A low correlation between worse one-legged balance scores and higher Parkours times was found in our athletes. However, there is no correlation between power measures in the respective OL CMJs and parkour times, even though the parkour consists of a sequence of repetitive single-leg jumps.

The results of the Quick-Feet test are not significantly different to the results of the reference population. This is surprising, as similar exercises like the Quick-Feet Ladder are an elementary part of football training routine.⁴⁹ A better result for football players was expected in this assessment as was seen in the power results from the CMJ.

In addition to the performance parameters mentioned above, the symmetry values regarding balance, jump height, jump force and parkour times are also relevant for the evaluation of the RTS permission of the BIA test battery. Moreover, this measure has been proposed by many researchers before with varying target values between 85-95%.^{28,50} Unexpectedly, the symmetry indices of the BIA test battery were commonly not met by athletes nine months post ACL reconstruction surgery.²⁶ Further research on limb symmetry has shown decrements in physical performance in athletes with inter-limb symmetries as measured by the balance test.⁵¹ In contradiction, regained limb symmetry after ACL injury may overestimate knee function.²⁶ For the BIA test battery, a interlimb difference >10% (symmetry index<90%) is set as cut off for the RTS, which was validated by testing healthy, uninjured athletes.^{19,52} Only 53% of the American football athletes in the current study (28 of 53) achieved a symmetry index of >90% for power development in the CMJ, only 18 (34%) in jump height measures, only 25 (47%) in balance scores. This may also be relevant to performance parameters, as Fort-Vanmeerhaeghe et al. demonstrated that increased asymmetry is associated with lower acceleration and consequently slower 30m sprint times, as well as increased risk of injury.⁵¹ This relationship is illustrated in the current results, as G1 players with low symmetry indices and overall worse BIA results have also been considered in the literature to be the most injury-prone playing position.⁷

Research on healthy high-level athletes in Judo and Taekwondo has revealed interlimb differences in a different test, the so called “3-hop test”, of over 10 percent in almost 25% of the athletes and the significance of interlimb differences in uninjured trained athletes remains a matter of debate.^{28,50,52,53} Therefore, it remains questionable whether interlimb symmetry is a reliable marker for a RTS decision.^{54,55} Also, the ratio between the extremities does not consider absolute performance results. Normalized data for jump and hop tests are necessary.⁵²

Considering the original purpose of the BIA-assessment, the results of the current study are particularly interesting. The test battery sets a threshold of a BIA-score of 3.0, a calculated score after all tests, for a RTS permission. This score has a scale from 1 (best) to 5 (worst) in all four qualities/categories: balance, agility strength and speed. Among these qualities, different tests used to form a score for each quality, which is later averaged in the BIA-Score.^{19,21} In the hypothetical case of injury or rehabilitation, only 17% (9 out of 53) of the athletes would achieve RTS permission.^{19,21} Herbst et al. applied even more restrictive thresholds for high-risk sports (e.g. alpine skiing, soccer, handball or American football), requiring at least a BIA-score of 4.0 to receive RTS permission.¹⁹ Considering these cut-off values, none (0%) of the athletes would reach RTS criteria

with their performance, although none of the athletes were recovering from injury, but were participating in routine practice and games. This is consistent with results from Australia and the Netherlands, where the RTS criteria of this test battery were met by only 2.5 % and 17.5% 9 months / 11 months post ACL surgery respectively.^{24,27} There are two possible explanations for these unexpected results. It may be that the BIA test battery has too high standards for RTS and therefore may have limited utility. This is consistent with the low passing rates post ACL surgery as described above. Or, in contradiction, the examined American football players just did not perform well at all which may be a warning signal for coaches and staff. Uncovered deficits should be addressed by specific training to minimize the potential risk of injury. In this context, the BIA test battery can be used as a training tool as well for progress measurement.^{19,21}

POSITION-DEPENDENT DIFFERENCES IN TEST-PERFORMANCE AND INJURY RISK

Significant differences in performance were noted among the respective position groups in certain tests. Athletes from G2 and G3 had similar anthropometry and achieved equivalent results in the tests, whereas differences in anthropometric characteristics and results were noted with G1, which performed significantly worse in most assessments, but not in power development (CMJ) and the Quick-feet task. It is likely that these assessments are most likely to be part of the training routine and therefore well known to most of the athletes.^{36,49}

BMI itself appears to correlate with outcomes and injury risk, as has been postulated for the NFL roster status of linebackers and defensive linemen.^{40,56} The current results affirm these findings, as low to moderate significant correlations were found between increased BMI and worse results in the assessments. As expected, lower BMI (G2 and G3) was associated with better results in balance and agility, which is contrary to the power measurements. When calculating anaerobic peak performance according to Sayers, athletes from G1 showed significantly higher absolute values in anaerobic peak force development ($p<0.05$), but not with respect to body weight (power per kg). These findings are consistent with results by Leutzinger et. al, where athletes of the offensive line and defensive line (G1) performed worse in the pro-agility drill and L-cone drill, which also require good agility and balance.³⁵ These results are interesting as they present in the early stage of the career, not only in athletes joining the NFL combine. Playing positions that require tackling (G1) had heavier athletes and showed higher power outputs. This is likely due to the requirements of this position which demands explosive power in just a few steps and in one direction. Players, who participate more in the passing and running game, are lighter, show better agility and balance, and similar power when normalized by mass (kg).

Within the context of injury and prevention, the categorization among these three groups is relevant, as well. In youth and professional football, linemen have a three-fold increased risk of injury, followed by running backs and

wide receivers, possibly due to frequent involvement in play actions and tackling.^{2,57-62} The current measurements reveal impaired results for the above listed position Group 1 including linemen (G1), which were alarmingly even below results of an age matched reference population. Comparably, recent studies have found a correlation between injury risk of the lower extremity and BMI >26 kg/m² in high school aged linemen.⁵⁶ In recent studies, high quadriceps strength has been determined as an important predictor of a safe RTS ability.^{63,64} In the assessments that determine power (CMJ), G1 achieved high power-output performance values with a high inter-limb symmetry over 93%. Contrary to this, other symmetry values of G1 athletes and assessment results are below the thresholds of a safe RTS. Further investigation is needed to determine which predictor (e.g. symmetry of power or balance) has the strongest influence and how performance parameters as well as functional assessment results should relate to each other for a safe RTS. The usefulness of the BIA test battery with the existing cut off values for high school American football players has to be questioned.

LIMITATIONS

This study has several limitations. The study was only performed on a small sample of 53 uninjured athletes. In the context of performance measurement, focus is mostly on the knee and influence of the neighboring joints or core stability are not well assessed.

The study was done during the pre-season, so it cannot be assumed that all athletes had already reached their high-

est fitness level at that time. Currently, the BIA test battery results have no proven predictive value for injury. Future research should therefore clarify the effect of the BIA test battery performance on injury risk and reevaluate the threshold for a RTS in high school American football players.

CONCLUSION

The results of the current study provide detailed performance measures of high school American football players with the BIA test battery. Measurements vary broadly from measures of the reference population and it remains questionable if athletes' performance is alarmingly insufficient or if the BIA is of limited use among American football athletes. Especially heavier players including linemen, guards, and tackles, showed impaired results and may be at risk for later injury. Nevertheless, this data gives sport specific benchmarks for high-school American football players and results may serve as reference in case of injury.

DISCLOSURE OF INTEREST

The authors report no conflicts of interest.

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