Rotational and peak torque stiffness of rugby shoes

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1. Introduction

Rugby is a high impact sport but it is relatively unique due to the differing roles, and thereby different forces are encountered by players in different positions. Preatoni et al. [1] demonstrated that during scrimmaging these forces where mainly head on and lateral compression forces. However rucking and mauling are inherent parts of the forwards' game which will generate higher rotational forces. It has previously been demonstrated that there are significant differences in rotational stiffness in different football boot design [2–6]. The effect of this is that differing designs of football boots have been shown to be associated with higher rates of anterior cruciate ligament injury [7].

The aim of this study is to measure the peak torque and rotational stiffness of different designs of rugby boots as this may be significant in choosing the correct boot for players in different positions.

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2. Materials and methods

This is a laboratory-based biomechanical study. Five different types of rugby shoes typically worn by scrum players were selected and used in the study. These shoes were all cleated with 8 screw-in metal studs designed for soft ground.

2.1. Shoes design

The five shoes were:

- Adidas AdiPure Regulate (A).
- Canterbury Stampade Club 8 stud (C).
- KooGa EVX II LCST Boot (K).
- Mizuno Fortuna SI Rugby (M).
- Puma Esito Finale H8 (P).

Each shoe had eight metal studs on the shoe with the layout of the studs being similar in all shoes with six studs on the forefoot and two on the heel part of the sole (Fig. 1). The characteristics of the shoes are summarized in Table 1.

Fig. 1. Rugby shoes models.

Table 1
Characteristics of the different rugby shoes.

Shoe model	Upper	Outsole	Studs number and type	Studs dimensions
Adidas AdiPure Regulate (A)	Synthetic leather	Thermoplastic polyurethane	8 screw-in metal	Length: 15 mm Tip diameter: 10 mm
Canterbury Stampade Club 8 stud (C)	Soft synthetic	Nylon	8 screw-in metal	Length: 18 mm Tip diameter: 6 mm
KooGa EVX II LCST Boot (K)	Evapourex fabric	Venom/nylon	8 screw-in metal	Length: 16 mm Tip diameter: 6 mm
Mizuno Fortuna SI Rugby (M)	Soft synthetic	Thermoplastic polyurethane	8 screw-in metal	Length: 16 mm Tip diameter: 8 mm
Puma Esito Finale H8 (P)	Synthetic leather	Lightweight polyurethane	8 screw-in metal	Length: 15 mm Tip diameter: 6 mm.

2.2. Surfaces description

A natural grass (Paradello Vivai, Italy, Brescia) made of a mixture of *Lolium perenne* and *Poa pratensis* cultivated on a layer of sand and soil (4 cm thickness), was provided in form of turfs (60 cm × 40 cm; mass: 19.23 ± 0.89 kg). In order to investigate the possible variability of composition and water content of each turf, prior to testing, each turf was weighted verifying that the weights were comparable among the different turfs. The mean weight was 17.7 kg with a standard deviation of 1.6 kg, thus confirming that the surfaces were not a confounding variable.

The turf was housed within a wooden box. In order not to allow any rotation of the turf within the box during the tests, two wooden plates were pressed on the turf and constrained to the inferior part of the box using grips.

2.3. Artificial foot

An artificial left foot (EU size 42–43) was prepared filling a silicon foot cosmetic cover (Road runner foot Engineering, Milano, Italy) with a silicone rubber in which an angled metallic core structure was immersed (Fig. 2). The internal structure is composed by an iron pin with rectangular section rigidly bound throughout screwed connections to two angled plates. The distal part of the iron pin (11 cm in length), which was only partially inserted into the foot, was used as the interface element for gripping to the loading machine.

2.4. Testing machine

Tests were performed on a MTS 858 Bionix servohydraulic testing machine (S/N 1015457, MTS, Minneapolis, MN) installed in the Laboratory of Biological Structure Mechanics of the Politecnico di Milano. The MTS testing machine was equipped by an axial–torsional hydraulic actuator, with 25 kN axial capacity and 250 Nm torsional capacity, a ±100 mm range LVDT displacement transducer and a ±140° range ADT angular transducer mounted on the actuator. The loads applied were measured by means of a MTS axial/torsional load cell (model 662.20D-05, S/N 1007099, ±25 kN maximum axial load, ±250 Nm maximum torsional load). The tests were conducted in air at room temperature (24 ± 2 °C).

2.5. Test procedure

Prior to testing the wooden base housing different turfs was secured to the inferior grip of the MTS through a T bar located at the inferior side of the panel. The shoe was dressed on the synthetic foot, then it was assured to the superior grip of the MTS through the pin (Fig. 3).

Tests were performed applying a quasi-static preload vertical force of 1000 N on the foot using the MTS testing machine, than the test was carried out under angular control at a rotation speed of 45°/s, until a maximum angular rotation of 140° was reached.

Fig. 2. Artificial foot used in rotational tests.

Fig. 3. Experimental set-up used in rotational tests.

These values were defined to reproduce a condition similar to those experienced by players involved in rugby scrums. Tests were performed applying both internal (IR) and external rotation (ER) with support on the tip (Fig. 3), to simulate wheeling of the scrum in both directions. Foot orientation with respect to the ground was adjusted using a 45° angulated platform lying on the ground. In order to assess repeatability of the results, each test was repeated six times, paying attention not to repeat the test on a previously used part of the turf.

Peak torque and rotational stiffness (slope of the torque–angle curve between 10° and 30°) were obtained for each test to sufficiently describe the linear section of the shoe–surface interface response curve (Fig. 4).

2.6. Data analysis

The torque and the angle, measured by the load cell and the ADT respectively, were zeroed before testing and then sampled at the frequency of 500 Hz. For statistical analysis, two-way repeated measures ANOVAs (≤0.05) were employed, using cleat design as factor. If the ANOVA revealed significant differences, the corresponding data-sets were compared using an unpaired Student's *t*-test. Normality was tested with the Shapiro–Francia test, assuming a level of significance of 0.05. Effect size in ANOVA analysis is a measure of the degree of association between the effect (e.g. type of shoe) and a dependent variable (e.g. peak torque and rotational stiffness) across different testing conditions (i.e. internal and external rotation). In accordance with a previous publication (Ref. [5]), we calculated Eta-squared (η^2) to express the proportion of variance in the dependent variable that is attributable to each effect: this parameter ranges between 0 and 1 and it indicates a variable degree of strength (0–0.2 for a weak effect, 0.3–0.5 for a moderate effect and values greater than 0.5 indicates a significant effect).

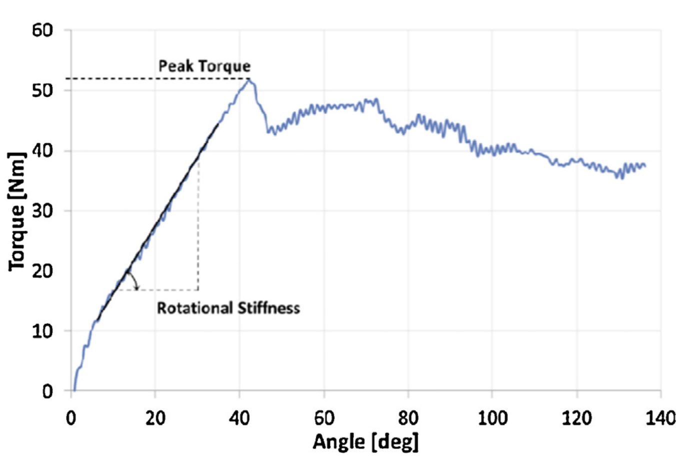

Fig. 4. Measured parameters.

Table 2
Summary of the peak torque and rotational stiffness data (mean ± standard deviation).

Shoe model	Rotational stiffness [N m/deg] ± SD	Peak torque [N m] ± SD
A		
IR	0.68 ± 0.08	60.59 ± 8.04
ER	0.73 ± 0.07	62.21 ± 4.38
C		
IR	0.82 ± 0.23	68.39 ± 12.74
ER	0.81 ± 0.07	65.61 ± 4.60
K		
IR	0.58 ± 0.04	52.08 ± 4.37
ER	0.57 ± 0.03	49.05 ± 5.28
M		
IR	0.66 ± 0.08	51.78 ± 2.69
ER	0.71 ± 0.09	55.61 ± 4.01
P		
IR	0.74 ± 0.07	55.95 ± 3.47
ER	0.72 ± 0.04	50.29 ± 3.54

IR, internal rotation; ER, external rotation.

3. Results

Mean and standard deviation obtained for both rotational stiffness and peak torque are summarized in Table 2. Once the peak torque is reached at 40°, the turf was destroyed as a result and needed to be replaced for subsequent tests.

The internal rotation peak torque of the shoes ranged between 51.78 ± 2.69 and 68.39 ± 12.74 N m, while the external rotation peak torque ranged between 49.05 ± 5.28 and 65.61 ± 4.60 N m. Shoe C (Canterbury Stampade Club 8 stud) had the highest peak torque in both internal and external rotations. Shoe M (Mizuno Fortuna Rugby) had the lowest peak torque in internal rotation and this was significantly lower than shoes A, C, and P while Shoe K (KooGa EVX II LCST Boot) had the lowest external rotation peak torque and this was significantly lower than shoe A, C, and M ($p < 0.05$).

With regards to rotational stiffness, the internal rotation stiffness ranged between 0.58 ± 0.04 and 0.82 ± 0.23 N m/deg while external rotation stiffness ranged between 0.57 ± 0.03 and 0.81 ± 0.07 N m/deg. Again shoe C (Canterbury Stampade Club 8 stud) had the highest internal and external rotational stiffnesses while shoe K (KooGa EVX II LCST Boot) has the lowest rotational stiffness in both internal and external rotation. Shoe K (KooGa EVX II LCST Boot) had statistically significant lower internal and external rotational stiffnesses compared to shoes A, C, and shoe P ($p < 0.05$).

4. Discussion

Brooks and Kemp reported that rugby had a higher incidence of injuries than many other contact sports [8]. In general, rugby players tend to sustain more upper limb and head and neck injuries compared to football players, whom on the other hand sustain higher rate of lower limb injuries compared to rugby players [9]. Bathgate et al. found that the incidence of ankle injuries in rugby was relatively low, at only 6% [10]. In a review of published literature on rugby injuries, Kaplan et al. reported that 36–56% of injuries occur during the tackle phase with the incidence of injuries during the set pieces being 1–13% [11].

O'Connor and James provided a key study on the association of lower limb injuries and boot design in elite football players [2]. One of their key points is that in football, foot and ankle non-contact injury is associated with the player–boot–surface interaction [2]. They recommended that sports medical teams should ensure that players boot selection is appropriate to the players physiology and position to prevent this becoming a potential injury risk factor. For this reason a naturally simulated surface was chosen for our study to avoid a potential confounding factor.

Obviously scrums can wheel in either direction as well as progressing forwards, backwards or laterally. It is not possible to produce a laboratory-based scenario encompassing every force that takes place. The test procedure is aimed to reproduce the forces most likely encountered during the scrum phase. This involved applying a quasi-static vertical load of 1000 N on the shoe and then a fast rotation of 40°/s both internally and externally. These forces represent a typical force that would be produced by in-line scrumming with the rotational forces representing forces that would be produced with wheeling of the scrum. We accept, due to the interaction between the facing teams pushing and rotating in different ways, tangential force components will also be produced. However, the multitude of all possible forces that could be produced are too numerous to be tested in this study.

All shoes used in the study had screw-in round metal studs with the same number of studs in each shoe in a distribution of 6 studs in the forefoot area and 2 studs in the heel area. The overall peak torques of the five rugby shoes used in our study showed that the internal rotation peak torque was 57.75 ± 6.26 N m while that of external rotation was 56.55 ± 4.36 N m. The Peak internal and external rotational stiffness were 0.696 ± 0.1 and 0.708 ± 0.06 N m/deg respectively. Model C (Canterbury Stampade) yielded the highest peak torques and rotational stiffness in both internal and external rotation while shoe model K (KooGa EVX II LCST Boot) showed the lowest rotational stiffness as well as lowest peak torque in external rotation. The high rotational stiffness and peak torques recorded in shoe model C when compared to the other shoes could be due to the fact they had the longest studs (18 mm) with a small tip diameter compared to the other shoes which meant that these dimensions allow more studs penetration in the ground surface thus more rotational stiffness and increased peak torque. All boots were tested with their original supplied studs.

Galbusera et al. performed a study on the rotational interaction in three types of soccer shoes on two types of playing surfaces using very similar testing setups [6]. The cleat design in their study was a 6 detachable metal studs, 12 molded rubber studs and 13 blades cleat shoes. The tested shoes in their study were put on an artificial foot which was connected to the test machine. They applied a static preload of 1000 N after which the tests were carried out under angular control at a rotation speed of 45°/s, until a maximum angular rotation of 140° was reached. They tested each shoe at tip and full sole loading support. We compared our results which were tip support to their tip support results, as the tip loading support represents the scrum phase foot position. We compared our results, which were tip support, to their tip support results which is the scrum phase foot position. The peak torque of the three soccer shoes in internal rotation ranged between 34.3 ± 2.6 and 45.0 ± 5.3 N m while that of external rotation ranged between 34.9 ± 3.7 and 39.8 ± 3.0 N m. The rotational stiffness in their study ranged between 0.42 ± 0.03 and 0.57 ± 0.07 N m/deg for internal rotation and 0.40 ± 0.06 and 0.48 ± 0.08 N m/deg for external rotation. These peak torques and rotational stiffnesses are lower than the values we recorded from the rugby shoes indicating that the rugby shoes used in our study showed higher stiffness and more resistance to torque forces than the football shoes tested on natural playing surface.

The marked difference in stiffness and peak torques between rugby shoes and football shoes confirm that good design practices have been used to provide the appropriate level of flexibility or stability necessary for each sport. The rugby shoes tested in our study are commonly used by scrum forwards. However different positions in the scrum will have differing main functions, although obviously there will be some crossover. Front and second row players will likely perform more with in-line forces whereas back row forwards are likely to be subjected to more rotatory forces. It is therefore our opinion that if the stiffer boots are chosen then it may hamper the more mobile players movement or not aid them by providing stability. If there is correlation with results from football studies, there may be a correlation with sustaining injuries.

We believe that the risk of non-contact injury in rugby is a combination of many factors of which the interaction between the shoe–surface interaction has a role in. This interaction depends on the shoes design, cleat design, type of playing surface and position of the foot on the ground. It is therefore imperative that the boots with the correct mechanical properties are chosen for players dependent upon their main function within the sport.

5. Conclusion

Rugby boots show higher stiffness and peak torques than previously reported results from football boot studies. There is great variance between different designs. In our opinion, to maximize potential performance and lower the potential of non-contact injury, care should be taken in choosing boots with stiffness appropriate to the players main playing role.

Conflict of interest

We would like to declare that there are no conflict of interest.

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