

Forces Generated in Rugby Union Machine Scrummaging at Various Playing Levels

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Abstract We studied the kinetics of machine scrummaging in rugby union by assessing three-dimensional forces and analyzing factors that might contribute to performance and influence injury risk during scrum engagement.

Thirty-four forward packs from six different playing levels performed machine scrummaging trials against an instrumented scrum machine under real environmental and normal scrum engagement conditions.

The peak (SD) of the overall compression forces during engagement ranged between 16.5 (1.4) kN (International and Elite) and 8.7 (0.1) kN (Women), while sustained compression forces spanned between 8.3 (1.0) kN (International) and 4.8 (0.5) kN (Women). The peak of the overall vertical force during the initial engagement phase was between -3.9 (0.7) kN (Elite) and -2.0 (1.0) kN (School), and the range of lateral forces was between 1.8 (0.3) kN (International) and 1.1 (0.3) kN (School). The forces measured across all playing levels, particularly during engagement, were generally higher than those measured in the most commonly cited previous studies.

The current study allowed the formation of a more comprehensive picture of scrummaging biomechanics, of the differences between different playing levels and of potential injury factors.

Keywords Biomechanics of rugby union, impact, sports injury, sports performance, scrummaging technique.

I. INTRODUCTION

In rugby union the scrum is a fundamental phase of the game whose aim is to “restart play quickly, safely and fairly, after a minor infringement or stoppage” [1]. The rugby scrum involves the formation of two forward packs (eight players from each team) who bind with teammates in three rows. The scrum forms when the pack engages with the opposition pack before binding with them at the front row interface to compete for possession of the ball primarily through pushing actions.

From a biomechanical perspective, scrummaging involves intense physical demands on the players' musculoskeletal structures. They experience a high initial impact at engagement and they need to maintain an intense sustained push for a few seconds after the two front rows have come together. Both actions have often to be accomplished in an unstable equilibrium condition. The occasional maximal and the repetitive submaximal stresses acting on the player's anatomical structures and on the spine in particular may be a factor for an increased risk of acute and chronic injuries. Previous epidemiological research on rugby injury has reported that the scrum contributes approximately 6-8% of the overall number of rugby injuries [2],[3]. Additionally, while the frequency of serious scrum-related injuries appears to have decreased in the recent years, scrummaging is implicated in about 40% of the catastrophic (typically spinal cord) injuries that occur in rugby [4]. Furthermore, there are a number of overuse pathologies that may be caused by repeated micro-traumas from scrummaging and that may emerge in the later years of playing activity or after the players have retired, including anatomical abnormalities [5],[6] and reduced mobility [7],[8] of the spine, or impaired proprioception [8],[9].

Little is known about the forces and motion involved in modern rugby scrummaging at any level, with even less quantitative information available after the advent of professionalism in 1995. A limited number of studies, some of which are now rather old, have shown that forces of a considerable magnitude may be generated

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during the engagement phase [10],[11],[12],[13]. However these reports are now limited in applicability due in various proportions to lack of ecological validity (e.g. scrummaging against rigid frames), measurement issues (e.g. sampling rates, players only analysed individually), and the fact that engagement techniques and playing styles have changed over the years.

Giving emphasis to players' welfare, the International Rugby Board (iRB) has underpinned the need for a more thorough understanding of the risk factors occurring during a scrum [14] and has promoted a comprehensive research programme whose overall aim is to carry out an objective analysis of the physical demands of scrummaging with a view to fostering injury prevention and effective performance.

This paper presents the findings related to a subsection of the "Biomechanics of the Rugby Scrum" project. The aim of the research was to: (1) measure and assess the forces developed during machine scrummaging using the standard engagement procedure; (2) consider the possible influence of playing level on their characteristics; (3) evaluate whether the magnitude and characteristics of the force load on players may represent a factor for potential injury.

II. METHODS

The study was a cross-sectional design and consisted in measuring the forces generated during repeated machine scrummaging trials to assess the differences between various playing levels.

Participants

Thirty-four forward packs from different playing levels participated in the study. Teams were grouped into six pre-determined categories (International, Elite, Community, Academy, Women and School), whose composition is reported in Table I together with average pack weights. Before participation each individual player was informed about the testing aims and procedures and provided written informed consent. Ethical approval was granted by the institutional ethics committee of the University of Bath.

TABLE I
FORWARD PACKS SUBDIVISION AND AVERAGE PACK WEIGHTS

| Code | Category | Competing Level (# teams) | Pack Weight* [N] |
|------|---------------|---|------------------|
| I | International | 6 Nations (4), Aviva Premiership (2) | 8749 (165) |
| E | Elite | RaboDirect Pro 12 (3), Aviva Premiership (2), RFU Championship (1) | 8523 (143) |
| C | Community | RFU Level 5-7 (6) | 8262 (325) |
| A | Academy | RaboDirect Pro 12 Academy (1), Aviva Premiership Academy (1), RFU Championship Academy (1), British Universities (3) | 7771 (197) |
| W | Women | 6 Nations (2), RFU Premiership (1), RFU Championship (1) | 6326 (257) |
| S | School | RFU Level 7 Colts & U17 (2), RaboDirect Pro 12 U18 (2), National Schools U18 Cup (2) | 6685 (637) |

*= mean (standard deviation)

Data Collection Procedures

Following a coach-directed warm-up which included both general (e.g. running, agility drills) and specific activities (e.g. submaximal engagements on the scrum machine) each team performed between 4 and 8 machine scrummaging trials. Proper recovery intervals (1-2 min) were respected between repetitions to avoid fatigue. Scrums were performed on natural turf against a commercial scrum machine (Dictator, Rhino Rugby, UK) and the measuring process was devised so that environmental conditions could mimic as effectively as

possible actual scrummaging conditions [15] (Fig. 1).



Fig. 1. Experimental set-up, including the force coordinate system: x= lateral; y= compression; z= vertical.

Instrumentation and Data Processing

Each of the four pusher arms of the scrum machine was instrumented with force sensors: eight strain gauge transducers in full bridge configuration for compression (R_y , >0 for pushing forces), and 4 pairs in full bridge configuration for lateral (R_x , >0 for forces directed to the right) and vertical bending (R_z , >0 for forces directed upward). The sensing elements were connected to an acquisition module (NI9237, National Instrument, USA) with a 24-bit resolution. Prior to its use on the pitch the force measuring system had been calibrated for the orthogonal components of applied force, showing RMS differences from an Instron testing system (Instron 5585H) that were less than 80 N (0.8%), 40 N (4%) and 15 N (1.5%) in compression, vertical bending and lateral bending respectively [15]. During data collection the scrum machine was fixed to the ground so that no appreciable movement could be registered and the hypothesis of static condition could be respected.

A bespoke control and acquisition system (cRIO-9024, National Instruments, USA) programmed (Labview 2010, National Instruments, USA) to work with deterministic timing was used to synchronously: (1) simulate the referee's call as during a real scrum by delivering consistently timed "crouch-touch-pause-engage" audio commands (duration of full sequence = 5.0 s); (2) excite strain gauge bridges and collect their signals at a frequency of 500 Hz; and (3) trigger other devices (e.g. video cameras, LED arrays) whose data are not presented here. Custom-written software (Matlab R2010b, MathWorks, USA) was used to filter data by applying an adaptive (4-80 Hz cutoff) zero-lag 4th order Butterworth filter [15],[16] and calculate a set of 195 parameters for each team and repetition. Parameters were selected with the aim of describing the kinetics of the pack-machine interaction across the subsequent phases of the push and its possible relation with performance and/or injury factors. Shock absorption (SABS) was defined as the interval between the instant of first contact of the forward pack with the pusher arms until 1 s after engagement; sustained push extended from the end of SABS for 1 s. The parameters included maxima and minima of force, impulses, average sustained pushes and relative timing. Fig.2 shows typical force traces with annotation of the principal calculated variables. In this paper, the overall forces (i.e. the sum of the forces on the four pusher arms) will be considered.

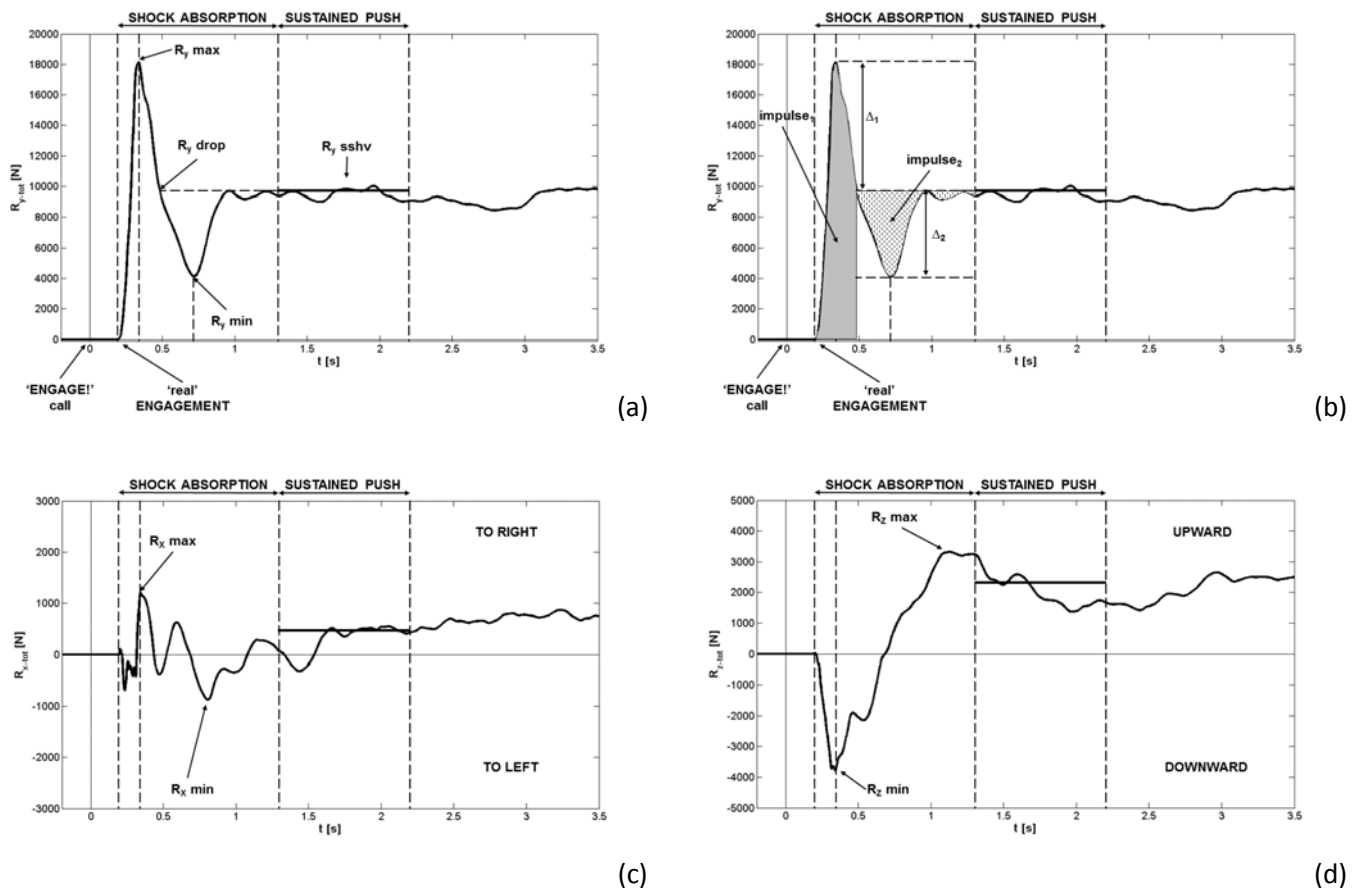


Fig. 2. Typical force patterns: (a)-(b) compression; (c) lateral; (d) vertical.

Statistics

Median values of measures from individual teams were grouped according to playing level and descriptive statistics were reported. One-way analysis of variance (with playing level as the between group factor) was used to assess the significance ($P < 0.05$) of possible differences across playing levels. At this stage of the research we followed the principle of being conservative and chose an ANOVA approach with Bonferroni post-hoc analysis, accepting the possibility some large effects may not emerge as significant differences given the relatively small size of the groups. Effect-size analysis will be added in the future progression of the investigation.

III. RESULTS

Compression Forces

Compression forces during scrum engagement exhibited a short-duration impact peak before a drop in force to a sub-optimal minimum level before compression forces rose to relatively consistent sustained levels (Fig. 2). The peak of overall compression forces during engagement ranged between 16.5 (1.4) kN (International and Elite) and 8.7 (0.1) kN (Women), while sustained compression forces spanned between 8.3 (1.0) kN (International) and 4.8 (0.5) kN (Women). The effect of playing level depicted a subdivision into three main sub-groups, with parameters of the International and Elite categories that generally showed increased magnitudes compared to the Community and Academy teams, and with these latter manifesting higher values than the Women and School packs (Table 2 and Fig. 3). For most of the measures, however, only the International and Elite levels were statistically different from the others.

When measures of compression force were normalized by the pack weight, the three-step subdivision remained, but many of the statistically significant differences disappeared (Table 3 and Fig. 3). Peak compression stayed greater for International and Elite, but, for example, the average sustained push in the Women group

was no longer less than in International and Elite. The drop of force from peak to sustained was greater for Elite than for Women and School. International showed an increased drop of force (Δ_2) between the level of sustained push and the minimum of force, and Elite reported a larger negative impulse compared to Community and School.

TABLE 2
COMPRESSION FORCE* PARAMETERS

| Variable\Category | I | E | C | A | W | S |
|--|-----------------------------------|-----------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| <i>Peak compression force</i> † [kN] | 16.5 ^{c,a,w,s} (1.4) | 16.5 ^{c,a,w,s} (1.4) | 12.0 ^{i,e} (1.6) | 11.7 ^{i,e} (2.0) | 8.7 ^{i,e} (0.1) | 9.1 ^{i,e} (3.2) |
| Δ_1 compression force † (= R_y peak – R_y drop) [kN] | 8.4 ^{w,s} (0.9) | 8.6 ^{w,s} (1.4) | 6.3 (1.6) | 6.0 (1.6) | 3.9 ^{i,e} (0.5) | 4.5 ^{i,e} (2.3) |
| Δ_2 compression force † (= R_y drop – R_y min) [kN] | 3.1 ^{c,a,w,s} (1.3) | 2.7 ^{w,s} (0.5) | 1.5 ⁱ (0.5) | 1.6 ⁱ (0.5) | 1.2 ^{i,e} (0.3) | 1.1 ^{i,e} (0.5) |
| <i>Impulse₁</i> † (positive impulse) [kN·s] | 3.1 ^{w,s} (0.3) | 3.3 ^{w,s} (0.4) | 3.0 ^{w,s} (0.8) | 2.8 (0.3) | 2.1 ^{i,e,c} (0.1) | 2.2 ^{i,e,c} (0.3) |
| <i>Impulse₂</i> † (negative impulse) [kN·s] | -1.0 ^s (0.7) | -1.1 ^{c,s} (0.4) | -0.4 ^e (0.2) | -0.5 (0.2) | -0.4 (0.2) | -0.3 ^{i,e} (0.2) |
| <i>Average sustained compression force</i> † [kN] | 8.31 ^{c,a,w,s} (0.99) | 7.98 ^{c,a,w,s} (0.73) | 5.78 ^{i,e} (0.42) | 5.94 ^{i,e} (0.78) | 4.79 ^{i,e} (0.50) | 4.88 ^{i,e} (1.34) |

* measures are the sum of the forces on the four pusher arms, and are reported as mean (standard deviation). Significant differences ($P < 0.05$) between playing levels (†) are reported by the following convention: i= different from International; e= different from Elite; c= different from Community; a= different from Academy; w= different from Women; s= different from School.

TABLE 3
NORMALIZED COMPRESSION FORCE PARAMETERS

| Variable\Category | I | E | C | A | W | S |
|--|-----------------------------------|-----------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| <i>Peak compression force</i> † [PW] | 1.88 ^{c,a,w,s} (0.15) | 1.94 ^{c,a,w,s} (0.16) | 1.45 ^{e,i} (0.18) | 1.50 ^{e,i} (0.25) | 1.37 ^{e,i} (0.07) | 1.34 ^{e,i} (0.35) |
| Δ_1 compression force † (= R_y peak – R_y drop) [PW] | 0.96 (0.29) | 1.01 ^{w,s} (0.16) | 0.77 (0.18) | 0.77 (0.20) | 0.62 ^e (0.08) | 0.66 ^e (0.29) |
| Δ_2 compression force † (= R_y drop – R_y min) [PW] | 0.35 ^{c,s} (0.15) | 0.32 (0.06) | 0.18 ⁱ (0.07) | 0.20 (0.06) | 0.18 (0.05) | 0.17 ⁱ (0.07) |
| <i>Impulse₁</i> (positive impulse) [PW·s] | 0.36 (0.03) | 0.39 (0.04) | 0.37 (0.09) | 0.36 (0.04) | 0.33 (0.01) | 0.33 (0.03) |
| <i>Impulse₂</i> † (negative impulse) [PW·s] | -0.11 (0.08) | -0.13 ^{c,s} (0.05) | -0.04 ^e (0.02) | -0.06 (0.03) | -0.06 (0.03) | -0.04 ^e (0.02) |
| <i>Average sustained compression force</i> † [PW] | 0.95 ^{a,c,s} (0.12) | 0.94 ^{c,s} (0.09) | 0.70 ^{i,e} (0.09) | 0.76 ⁱ (0.09) | 0.76 (0.10) | 0.72 ^{i,e} (0.14) |

* measures are the sum of the forces on the four pusher arms, and are reported as mean (standard deviation). Significant differences ($P < 0.05$) between playing levels (†) are reported by the following convention: i= different from International; e= different from Elite; c= different from Community; a= different from Academy; w= different from Women; s= different from School.

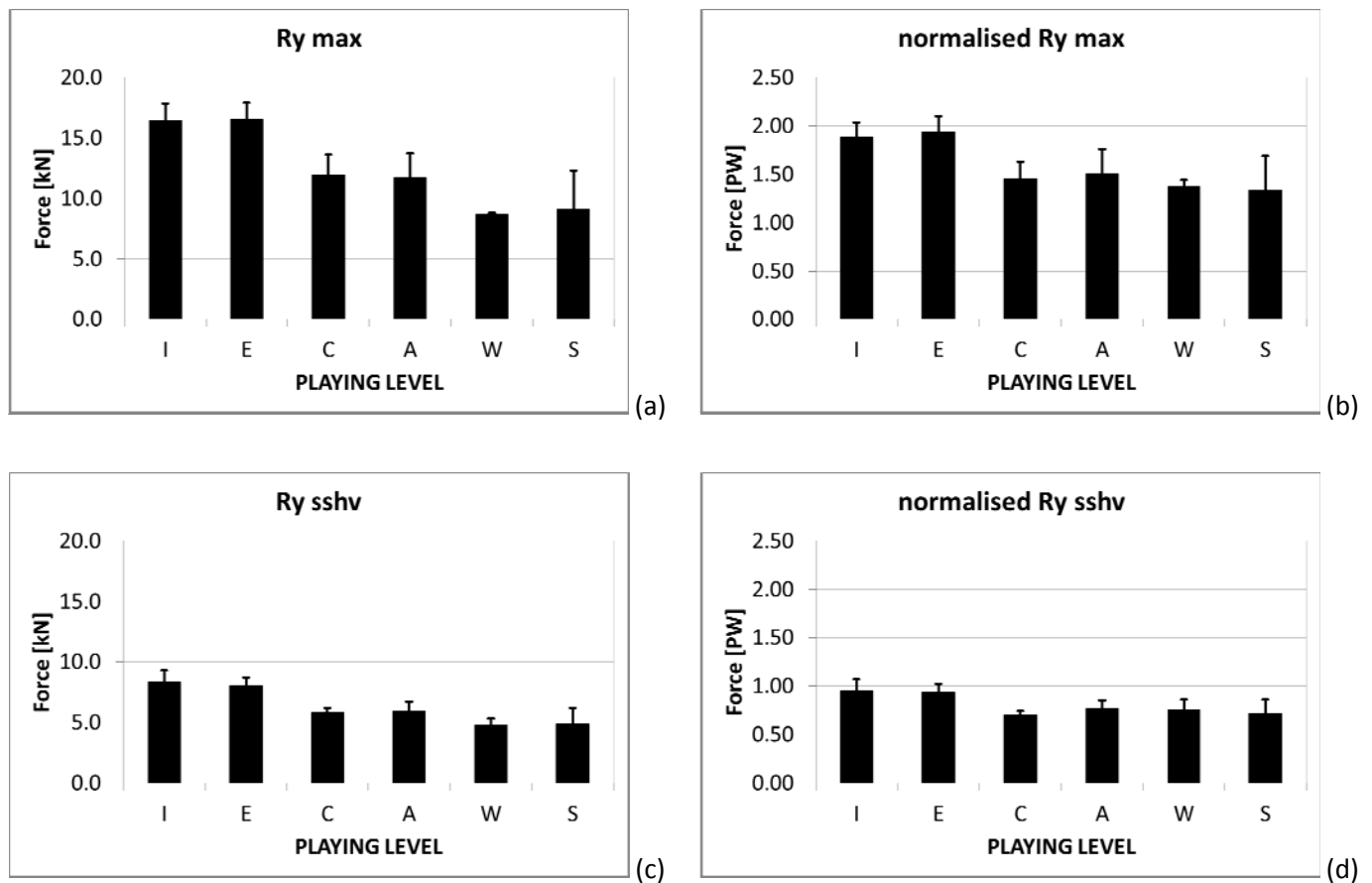


Fig. 3. Compression force parameters (mean and standard deviation) at engagement (a)-(b) and during the sustained push (c)-(d). (b) and (d) are the values normalised by pack weight (PW). I= international; E= elite; C= community; A= academy; W= women; S= school.

Lateral Forces

The range of lateral forces (Table 4) evidences significant differences only when the International and Elite levels, 1.8 (0.3) and 1.7 (0.1) kN, respectively, were compared against School level, 1.1 (0.3) kN. The average sustained push was very close to zero, with generally a slight tendency to positive values (right direction). The patterns of lateral forces were less consistent than the ones of compression and vertical forces, and their magnitudes were approximately 10% of compression forces.

TABLE 4
LATERAL FORCE PARAMETERS

| Variable\Category | I | E | C | A | W | S |
|--|---------------------------|---------------------------|--------------|--------------|---------------|-----------------------------|
| Range of lateral force † [kN] | 1.8 ^s (0.3) | 1.7 ^s (0.1) | 1.5 (0.4) | 1.3 (0.1) | 1.3 (0.3) | 1.1 ^{l,e} (0.3) |
| Average sustained lateral force [kN] | 0.6 (0.5) | 0.6 (0.4) | 0.1 (0.6) | 0.1 (0.3) | -0.1 (0.3) | 0.1 (0.3) |

* measures are the sum of the forces on the four pusher arms, and are reported as mean (standard deviation). Significant differences ($P < 0.05$) between playing levels (†) are reported by the following convention: i= different from International; e= different from Elite; c= different from Community; a= different from Academy; w= different from Women; s= different from School.

Vertical Forces

During engagement, the negative peak of the overall vertical force was between -3.9 (0.7) kN (Elite) and -2.0 (1.0) kN (School), evidencing significant differences only between Elite and School packs. No significant differences were reported in the average sustained vertical push, which tended to show positive values for the International and Elite categories and was close to zero for the other playing levels. The magnitude of vertical forces during the engagement phase was in the range of approximately 20% of compression forces.

TABLE 5
VERTICAL FORCE PARAMETERS

| Variable\Category | I | E | C | A | W | S |
|--|---------------|----------------------------|---------------|---------------|---------------|----------------------------|
| <i>Peak negative vertical force † [kN]</i> | -3.6 (1.4) | -3.9 ^s (0.7) | -2.3 (1.1) | -2.9 (1.1) | -2.4 (0.7) | -2.0 ^e (1.0) |
| <i>Average sustained vertical force [kN]</i> | 1.1 (1.3) | 0.7 (0.9) | -0.0 (0.9) | 0.1 (0.6) | 0.0 (0.5) | 0.1 (0.9) |

* measures are the sum of the forces on the four pusher arms, and are reported as mean (standard deviation). Significant differences ($P < 0.05$) between playing levels (†) are reported by the following convention: i= different from International; e= different from Elite; c= different from Community; a= different from Academy; w= different from Women; s= different from School.

IV. DISCUSSION

The aim of this research was to measure and evaluate the forces generated in machine scrummaging at various playing levels and hence to gain more insight into the factors that may play a role for injury prevention and performance.

The recorded forces showed patterns similar to the ones that had already been described in the literature [11], with a high compression peak at the initial engagement, followed by a drop in the force the pack is able to apply against the machine ('rebound effect'), and by a recovery of the pushing capacity during the last sustained phase (Fig. 2). The magnitude of forces was considerably higher than in Milburn's study [11] (e.g. 16.5 vs. 8.0 kN, 8.3 vs. 5.8 kN for, respectively, the peak compression force and the average sustained push in the International category), and more in line with other authors' findings referring to international youth [13],[17] or to top grade amateur teams [12]. The possible differences in force outcomes between studies may be a reflection of the different methodologies used in collecting data (e.g. scrum machine, measuring technologies), but may also be ascribed to the changes in scrummaging technique and players' anthropometrics over the last 20 years.

The present study is the first to systematically address the issue of measuring scrum forces across multiple playing levels, involving a consistent number of forward packs for each category and collecting multiple trials for each of them. It has thus allowed the formation of a more comprehensive picture of the differences in scrummaging biomechanics related to the different playing levels. The most meaningful effects for playing levels were reported for compression forces, for which the six categories could be visually split into three subgroups, International and Elite – Community and Academy – Women and School, for most of the analysed parameters. Statistics showed a more complex map of significant differences across groups, but generally distinguished the International and Elite from the other subgroups (peak compression and average sustained compression) or from the Women and School (drop of force during the 'rebound' phase). International and Elite produced peak compression forces that were about 40% higher than Community and Academy, which in turn reached peak values 30% higher than Women and School. Since it may be expected that players of higher body mass (i.e. forward packs of higher pack mass) would be able to produce more force in absolute terms thanks to larger inertia effects, measures normalised to pack weight were also calculated to assess whether higher forces could

be ascribed to anthropometrical factors only, or were the outcome of superior technique and/or better conditioning. Even when the increased pack mass was accounted for, the International and Elite categories generated higher maximum compression forces than all other categories. Therefore the higher level teams managed to produce a more effective action at the beginning of the engagement. However, this ability was not maintained throughout the subsequent phases of the push. The Elite category exhibited a greater drop in normalised compression force from the peak to the sustained push than the Women and School category. Therefore, the Elite category could produce higher forces during the initial phase of contact, but could not sustain those higher forces during the late shock absorption phase. Similarly, the International packs had larger excursion of normalised forces from the minimum point to the level of sustained force than the Women and School categories, thus showing patterns where the force drops to a relatively lower value at the end of the initial engagement before rising back to the level of sustained force. Normalised impulse parameters also confirmed that the International and Elite categories were not effective in translating higher peaks of compression force into increased propulsive impulses. In fact, other playing levels (Community, Academy, Women, School) did not generate as high peak forces but were able to generate as much relative impulse by keeping the forces relatively high for longer and by elongating the time period of initial force generation. The higher level teams also reported increased magnitudes of negative impulse (both in absolute and relative terms), which is a further indication of the existence of a period of sub-optimal force production and reversal in velocity. This may be the result of two different approaches to the engagement phase: an aggressive style versus a more continuous style, which would be in line with the 'impulsive push' and 'maintenance push' styles proposed by Rodano [13].

Irrespective of producing compression force traces which exhibited a greater drop from the peak and more negative impulse, the International and Elite categories were able to recover the force production to produce significantly higher normalized sustained force than the Academy, Community and School categories. The Women category (including elite representation in this group) produced lower but not significantly different normalised sustained forces than International and Elite, and the Academy (including elite youth players) force levels were not different from the Elite category. For this variable, there seems to be a strong relationship between playing level and higher sustained force production, and this goes some way to confirming the contention from previous research (e.g. [12]) that generation of sustained forces are much more a function of player technique and coordinated actions by the forward pack than the forces observed during engagement. The four playing categories which could be said to comprise elite representation for their playing category (International, Elite, Academy, Women) were able to produce higher normalized sustained forces than the Community and School categories. The magnitude of sustained compression forces was approximately 50% of the magnitude of the peak compression forces during engagement. This is a larger difference between peak engagement forces and sustained forces than has been found in previous research [11], where sustained forces were approximately 75% of engagement forces, this difference due mainly to relatively higher peak forces in the current data.

Lateral force patterns were more inconsistent between trials and teams and lower in intensity than in the compression and vertical directions. Even with a progressive increase of values from School to International, all categories tended to produce a sustained lateral push with positive values, which were directed to the right (tight-head prop side). This outcome is in opposition with Milburn [11] who studied a University team and found forces directed to the left and with greater magnitudes than the average of our teams in the same category. One proposed reason for forward packs to be applying slight forces towards the tight-head side rather than pushing directly forward would be to try and promote the tight-head prop forward via rotation of the scrum on a team's attacking put-in in order to take the opposition back row away from the direction of play and to offer more security to the scrum half of the team in possession. However, the development of high lateral forces may be counter-productive for scrummaging (takes away from compression forces) and may be a risk factor for chronic degeneration of the spine [18] because shear forces introduce a moment of force which is not present during pure compression which would tend to induce undesirable rotation and/or bending of the spine.

Vertical force showed a negative (downwards) peak soon after engagement of the forward pack with the machine, which occurred approximately at the same time of the peak compression force. The results of the current study are different from findings of previous authors, who measured forces in the region of -1 kN [11],[17] for all categories except International [11] who at that time produced a substantial upwards force.

Whilst most recent studies [12],[17] have noted a downward force during engagement which is reinforced by the orientation of the front row players at engagement it is speculated that the actual magnitude of vertical forces may be more influenced than the forces in other directions by the design of the scrum machine used in any particular study since generation of vertical force likely depends on whether the position of the head is constrained or not and on the degrees of freedom available in the pusher arms. Magnitudes of both negative peak and sustained vertical force appeared to differentiate the International and Elite categories from the others, even though this observation is not fully supported by statistical evidence, due to the high variability in the datasets. It may be argued that if the production of downward forces at engagement transfers to live scrummaging and both packs behave similarly, the risk of scrum collapse would increase. However, it should also be observed that at this stage of the research the forward packs involved in the testing knew they were engaging with a static object and might have adjusted their engagement strategy relying on the stable opposition exerted by the scrum machine. International and Elite levels generally showed a tendency to generate greater vertical upward forces than the other groups during the sustained push, for whom the vertical component was about zero. Having higher vertical forces during sustained shove may mean increasing the risk of disrupting the scrum, by creating a rotational (upward) momentum on the front row opponents, with the consequent risk, in actual scrummaging conditions, of disrupting the scrum. However, similar to what was observed for the initial downward peak, the tendency to push up in the late phase might have been induced by the machine scrummaging context, where the pusher arms of the scrum machine react with a steady opposition to the players' action.

Bearing in mind that machine scrummaging may have different characteristics from actual contested scrummaging, the magnitude of the engagement and sustained forces, in combination with (i) the presence of vertical and lateral shear forces, (ii) the geometric misalignment of body segment that may be observed by video recordings, (iii) the constrained head and body segment motions, and (iv) the repeated loading to which players are subjected during training and matches, places the rugby forward in a situation which studies on cadaveric specimens have indicated has the potential to produce the repetitive sub-critical injuries that might lead to chronic pain and early degenerative changes to the cervical and lumbar spine [19],[20],[21],[22],[23]. However, it should be remarked that this observation is speculative and based on a transfer of general injury-mechanism literature to the specific rugby scrum situation. Further investigations that also include a quantitative measurement of body alignment are needed to give a better evaluation of potential injury risks.

V. CONCLUSIONS

The present study described the forces generated by rugby forward packs during machine scrummaging and discussed the differences that occur across different playing levels. Machine scrummaging offers the opportunity to evaluate magnitude and characteristics of forces in a controllable environment, but it also introduces a set of differences from live scrummaging. Therefore, the extent to which interpretation can be made on injury mechanisms and injury risk for contested scrummaging from the current data still has to be verified. Nevertheless, it is apparent that rugby scrummaging generates substantial magnitude of forces. The forces measured across all playing levels were higher, and sometimes considerably higher, in all directions than the most commonly cited previous research [11] although the force values produced by the forward packs in the current study are very much in line with more recent data [12],[17] collected on a smaller number of forward packs when cross-referencing the magnitudes of peak forces with the level of team being studied. Differences in the absolute force values were very obvious between different playing levels with elite male packs producing almost twice the magnitude of peak forces of School level or Women's forward packs. However, normalizing force values to take into account the mass of the pack eradicated some of the differences in the outcome measures between playing levels, suggesting that higher forces in the elite male groups (International and Elite) were both partly a result of greater physical size and partly better scrummaging technique. Further studies are needed and have been programmed to gain more insight into the biomechanics of the rugby scrum during live contested situations.

VI. ACKNOWLEDGEMENT

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