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A kinematic analysis of the spine during rugby scrummaging on natural and synthetic turfs

Ramesh Swaminathan [a], Jonathan M. Williams [b], Michael D. Jones [a] and Peter S. Theobald [a]

[a] Bioengineering Research Group, School of Engineering, Cardiff University, Cardiff, UK; [b] Faculty of Health and Social Sciences, Bournemouth University, Bournemouth, UK

ABSTRACT
Artificial surfaces are now an established alternative to grass (natural) surfaces in rugby union. Little is known, however, about their potential to reduce injury. This study characterises the spinal kinematics of rugby union hookers during scrummaging on third-generation synthetic (3G) and natural pitches. The spine was sectioned into five segments, with inertial sensors providing three-dimensional kinematic data sampled at 40 Hz/sensor. Twenty-two adult, male community club and university-level hookers were recruited. An equal number were analysed whilst scrummaging on natural or synthetic turf. Players scrummaging on synthetic turf demonstrated less angular velocity in the lower thoracic spine for right and left lateral bending and right rotation. The general reduction in the range of motion and velocities, extrapolated over a prolonged playing career, may mean that the synthetic turf could result in fewer degenerative injuries. It should be noted, however, that this conclusion considers only the scrummaging scenario.

ARTICLE HISTORY
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KEYWORDS
Rugby; scrum; spine; playing surface; kinematic

Introduction

There is an increasing rise in the popularity of rugby union worldwide. In parallel, World Rugby, formerly known as the International Rugby Board (IRB), continually reviews the laws to ensure player safety and spectator enjoyment. One area of the game that has come under particular scrutiny is the scrum. A drive to improve player safety and facilitate a quick, safe and fair restart following minor infringements (IRB, 2013) has resulted in significant rule changes. The complex interaction of the 16 players, combined with the desire to regain ball possession by being a superior scrummaging team, means that the scrum is a demanding physical environment. Consequently, whilst the scrum typically forms a relatively small period of game-time, this environment is associated with a disproportionality high percentage of injuries (6–13%) (Brooks, Fuller, Kemp, & Reddin, 2005; Fuller, Brooks, Cancea, Hall, & Kemp, 2007; Schick, Molloy, & Wiley, 2008; Taylor, Fuller, & Molloy, 2011). The lower leg and shoulder musculature are frequently injured in front-row players as a result of scrummaging and account for up to 54% and 66% of these two types of injury, respectively (Brooks, Fuller, & Kemp, 2005; Brooks & Kemp, 2011). Scrummaging also causes a significant proportion of all rugby spinal injuries (Bohu et al., 2009; Quarrie, Cantu, & Chalmers, 2002; Secin, Poggi, Luzuriaga, & Laffaye, 1999; Wetzler, Akpata, Laughlin, & Levy, 1998). Furthermore, the scrum is associated with a relatively high injury risk compared with other contact events (Fuller, Brooks, Cancea, et al., 2007; Taylor, Kemp, Trewartha, & Stokes, 2014) and collapsed scrums are associated with an even greater injury risk (Roberts, Trewartha, England, & Stokes, 2014). The most common and well-documented injuries are to the cervical spine, both chronic and acute (Bohu et al., 2009; Dunn & van der Spuy, 2010; Secin et al., 1999; Wetzler et al., 1998), but injuries to the lumbar region as a result of scrummaging have also been reported, which include lumbar disc injury or radiological abnormalities (Fuller, Brooks, & Kemp, 2007; Iwamoto, Abe, Tsukimura, & Wakano, 2005). Front-row players represent as high as 78% of all cervical spine injuries in the scrum (Bohu et al., 2009; Brooks, Fuller, Kemp, 2005) with the "hooker" position at the greatest statistical risk ($P < 0.01$) (Bohu et al., 2009; Secin et al., 1999; Wetzler, Akpata, Albert, Foster, & Levy, 1996; Wetzler et al., 1998).

Scrum stability is an integral part of player safety, as an unstable scrum may expose front-row forwards to scenarios that are potentially dangerous (Williams & McKibbin, 1987). Greater vertical and lateral forces may be generated (Milburn & O'Shea, 1994) and greater excursion of range of motion (ROM) means players must make more postural adjustments and are thus themselves less stable (Cazzola, Preatoni, Stokes, England, & Trewartha, 2015).

World Rugby has also focussed on improving game quality by permitting synthetic turf for use at all playing levels, ensuring a consistent playing surface standard and so encouraging high-quality and faster paced rugby. In the UK, elite teams including Cardiff Blues, London Saracens and Newcastle Falcons have adopted such surfaces now using a "3rd generation" (3G) synthetic turf that comprises a stone base, shock pad, carpet and rubber infill. Such surfaces are specifically designed to more accurately replicate the mechanical response of natural turf (IRB, 2003), thereby eradicating the extenuated ball bounce and high injury prevalence associated

CONTACT Peter S. Theobald TheobaldPS@Cardiff.ac.uk

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with earlier generations. The injury prevalence on synthetic turfs is perceived to be higher than on natural turf; however, no significant differences have been recorded in the literature (Ekstrand, Timpka, & Hägglund, 2006; Fuller, Clarke, & Molloy, 2010; Steffen, Andersen, & Bahr, 2007; Williams, Trewartha, Kemp, Michell, & Stokes, 2015). Ekstrand et al. (2006) reported only insignificant differences relating to ankle sprain incidence, whilst foot, ankle and knee injuries all had a greater, though statistically insignificant, prevalence during synthetic turf gameplay (Fuller et al., 2010). Indeed, no researcher has yet been able to identify a definitive cause and effect relationship relating to play on synthetic turf (Ekstrand et al., 2006; Fuller, Dick, Corlette, & Schmalz, 2007; Steffen et al., 2007).

A high prevalence of injury within the scrum has already prompted other studies to focus on quantifying force production during "machine-based" scrummaging (Milburn, 1990; Preatoni, Stokes, England, & Trewartha, 2013; Quarrie & Wilson, 2000) and, most recently, "live" scrummaging (Cazzola et al., 2015) environments. The presented study therefore addresses an important gap within the literature of a comprehensive analysis of player spinal kinematics during scrummaging on natural versus synthetic turf. This study aimed to quantify spinal kinematics during live scrummaging on two different playing surfaces with specific focus on the hooker as a result of the distribution of injuries throughout the scrum. Given that there is no significant change in injury incidence between the two types of turf, this study hypothesises that no significant changes will occur in spinal kinematics during scrummaging of the playing position investigated.

Methodology

Participants

Twenty-two participants were recruited from a convenience sample of local community club and university teams. The participants were divided equally into two groups, with the playing surface composition (i.e. natural or synthetic/3G turf) dictated by the surface available to a particular team. Teams only had access to either natural or synthetic turfs, and thus the study was unmatched as a result of the availability of the playing surface. All participants played in the hooker position and had been appropriately trained to play in the front row according to the discretion of the team's qualified coach (IRB, 2013). Exclusion criteria included those players with inadequate front-row playing experience according to the coach based on World Rugby guidelines (IRB, 2013), a history of any major spinal injury or any indication of current neuromusculoskeletal neck problems (e.g. pain). The World Rugby laws do not specifically state what inadequate experience is; this is at the discretion of the qualified coach. Recordings were undertaken of age, height, body mass, neck, shoulder and chest circumference (anthropometric data), number of training sessions per week, years of playing experience and number of scrummages per week (background data). No significant differences ($P > 0.05$) were found for any of the anthropometric or background information collected between the two groups. The study was approved by the Cardiff School of Engineering Ethics Committee, with all volunteers providing written consent.

Procedures

Data acquisition

Six landmarks were identified (forehead and the spinous processes of C7, T7, T12, L3 and S1) to create five spinal segments defined as the cervical (C), upper thoracic (UTx), lower thoracic (LTx), upper lumbar (ULx) and lower lumbar (LLx) regions. All landmarks were identified through palpation with the exception of the forehead, where a consistent position was identified across all players using a specially modified scrum cup. C7 was palpated by identifying the bony prominences of C6 and C7 and getting the participants to extend their neck. By doing this, C6 glides away and C7 remains prominent (Middleditch & Oliver, 2005). T7 was found by identifying the inferior borders of the scapulae and finding a midpoint of a line drawn in the transverse plane connecting these points (Willems, Jull, & Ng, 1996). T12 was identified by counting up from L4. L4 was identified by a line bisecting in the transverse plane at the most superior point of the iliac crests (Burton, 1986). L3 was found in a similar manner by counting up from L4. S1 was found by finding the midpoint of a line in the transverse plane created by the posterior superior iliac spines (Chakraverty, Pynsent, & Isaacs, 2007). Three-dimensional kinematic data describing these five spinal segments were measured using a string of six inertial sensors (ThetaMetrix, Waterlooville, UK). The sensors sampled at 40 Hz/sensor, with data recorded via USB to a laptop computer for retrospective analysis. The sensors were attached to the skin using hypoallergenic double-sided tape, with all trailing wires secured using Hypafix tape (BSN Medical, Hamburg, Germany).

Experimental procedure

All trials were conducted outdoors and were part of their team's training session. All participants completed their club's warm-up routine, before being instrumented with the six inertial sensors. All participants first took part in a series of ROM trials to quantify their normal, active spinal ROM. This was performed in a predefined order for the full spine, the cervical spine in a standing position and the cervical spine in a position of hip flexion similar to that of scrummaging. During each stage of the ROM trials, each movement was repeated three times in the order of flexion, extension, right and left lateral bending and finally right and left rotation. Between each movement, the participant resumed a neutral position. For each of these motions, the peak ROM was calculated for each motion and each segment and collated for the two groups.

Having performed the ROM trials, the participant was then joined by another seven players to comprise a complete "pack". An opposing pack was drawn from other suitably experienced players from within the same club. Each scrum was performed using the current engagement sequence of "crouch-bind-set" (CBS), dictated by the trainer leading the session. This scrum engagement sequence was introduced worldwide in the 2013–2014 playing season. On the "crouch" call, the front row must bend at the hips and be ready to engage. On the "bind" call, the props must take a grip of their opponent's jersey. On the "set" call, the scrums are permitted to engage through the interlocking of the heads of the front row (IRB, 2013). Three live scrums were performed, with players being given adequate rest between each trial. Data recording commenced when the players adopted the scrum position and were ready to engage with the opposing pack. Players were instructed to scrummage as per typical "live" training sessions, and to wear appropriate attire (including boots, shorts and a shirt). After each trial the sensors were checked to ensure proper adhesion to the skin and, if needed, realigned to counteract any problems with movement. Any trial where the sensors had moved or become detached was deleted.

Having collected the data of absolute orientation, described as Euler angles, this was converted into rotation matrices and the resultant angles between two adjacent sensors were calculated through matrix multiplication to determine the motion of each individual spinal segment, through a custom written code in Matlab (Lee, Laprade, & Fung, 2003; Williams, Haq, & Lee, 2013a). The rotation order corresponded to rotation describing flexion/extension, lateral bending and then rotation. This yielded six different motions for each segment, which were defined as flexion, extension, left lateral bending, right lateral bending, left rotation and right rotation. Peak ROM values were extracted over the full duration of the scrum. Specific time periods of the scrum were not identified. ROM data was filtered using a low-pass, bidirectional Butterworth filter with a cut-off frequency of 6 Hz to remove high-frequency noise (Fioretti, 1996). The neutral position was defined as the standing position adopted at the start of the ROM trials, serving as the reference plane for all subsequent data; hence, a position of 30° upper lumbar flexion is 30° relative to the standing position. A five-point differentiation method was used to yield the angular velocity of each individual segment for the six different motions.

Statistical analysis

Mean and standard deviations of peak kinematic variables were calculated for each condition (synthetic vs. natural turf) and these pooled data were used to determine the existence of any significant differences. An analysis of the data was performed (SPSS 18, SPSS Inc., Chicago, USA) to test for normality. A Pearson's correlation test was used to determine whether any correlation existed between peak ROM of the groups and the anthropometric and background data collected. A two-tailed, independent *t*-test (with Bonferroni correction) was performed across every motion of every segment, considering the ROM and angular velocity ($P < 0.05$). Furthermore, Cohen's effect size (d) was calculated to determine the magnitude of differences between conditions and $d > 0.8$ was considered to be a "large" effect.

Results

Anthropometry

Table 1 shows the participant's height, mass and BMI.

No significant difference was determined between the groups for the anthropometric or background data ($P > 0.05$).

Table 1. Anthropometric data for both natural (n = 11) and synthetic turf (n = 11) groups.

	Natural turf group	Synthetic turf group
Age (years)	24.73 (4.49)	22.08 (3.78)
Height (m)	1.78 (0.04)	1.76 (0.05)
Mass (kg)	99.63 (8.57)	98.00 (13.37)
BMI (kg · m^{-2})	31.52 (2.65)	31.51 (4.38)

Note: Mean data are presented with standard deviation in parentheses.

ROM

The mean ROM data for the natural and synthetic turf groups are presented in Table 2. No significant differences were identified across the peak motion of any segment between the two groups. Furthermore, there was no correlation between the peak ROM, anthropometric data and playing history.

Hooker spinal kinematics during live scrummaging

Mean peak ROM and angular velocity magnitudes were calculated for each group and all 30 movements (i.e. six motions for each of the five segments). Figure 1 displays mean, peak cervical ROM for all six motions on natural (dark grey shading) and synthetic (diagonal lines) turfs, respectively. This data indicates a reduction in right rotation, when comparing the mean peak ROM when scrummaging on natural versus synthetic turfs. This, however, was not statistically significant ($P > 0.01$), but the size of the effect was moderate ($d > 0.5$).

Table 3 displays mean peak percentage ROM relative to maximum mean peak ROM for all 11 participants of each group on natural and synthetic turf, respectively. Peak percentage ROM was calculated from the mean peak ROM experienced during scrummaging for the group and the mean peak ROM of the group demonstrated during the ROM trials. No significant differences were present in the ROM between the two groups ($P > 0.05$) for any segment during the live scrummaging trials.

Regardless of surface, it is apparent that scrummaging utilises almost all the available ROM in the upper lumbar spine for flexion. Similarly, almost all available right rotation of the upper lumbar segment was utilised and a large amount of both right lateral bending and right rotation of the lower lumbar segment. These percentages, however, are for the peak values of ROM and thus these segments are only periodical in such a position.

Figure 2 shows an example of the dynamic time history of motion for the upper lumbar segment during live scrummaging (CBS) on (a) synthetic and (b) natural surfaces. Owing to the dynamic and unpredictable nature of scrummaging, the peaks extracted from the ROM graphs for the analysis did not always appear at the same time points in the data. This particular segment was always in a position of flexion throughout the trials.

For angular velocity, the lower thoracic segment demonstrated a reduction from scrums on natural turf to scrums on synthetic turf. These differences were in left and right lateral bending and left rotation, but none of these were significant after Bonferroni correction. When considering the size of the effect, however, Cohen's *d*-value was above 0.8 for all three of

Table 2. Mean peak ROM for the natural (n = 11) and synthetic (n = 11) turf trials.

	Flexion (°)		Extension (°)		Right lateral bending (°)		Left lateral bending (°)		Right rotation (°)		Left rotation (°)	
	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural
Cervical (Scrummaging position)	36.2 (6.6)	42.4 (7.4)	23.6 (10.0)	27.7 (8.6)	28.1 (10.1)	30.4 (9.5)	27.3 (8.2)	30.4 (8.3)	42.2 (10.0)	45.2 (6.5)	45.1 (11.6)	43.4 (5.8)
Cervical	46.1 (9.8)	43.2 (7.2)	33.6 (9.4)	33.0 (7.8)	35.5 (4.6)	34.9 (4.3)	30.2 (4.9)	34.4 (7.0)	42.1 (11.3)	42.9 (6.1)	41.9 (8.2)	44.9 (7.1)
Upper thoracic	17.7 (12.7)	23.7 (10.4)	10.8 (11.9)	1.5 (1.6)	9.4 (3.1)	10.4 (4.0)	8.1 (4.6)	9.6 (4.2)	26.9 (12.9)	23.3 (11.01)	20.5 (9.4)	24.8 (10.2)
Lower thoracic	16.3 (9.1)	19.27 (7.4)	7.3 (6.0)	6.3 (5.3)	15.5 (9.1)	15.8 (3.2)	16.1 (7.6)	16.0 (2.7)	27.8 (14.4)	33.3 (7.9)	28.9 (14.2)	31.0 (8.2)
Upper lumbar	34.1 (11.9)	33.4 (7.9)	12.9 (5.9)	13.6 (7.5)	13.9 (4.2)	14.5 (4.3)	12.3 (4.4)	15.1 (7.4)	9.4 (5.9)	12.9 (8.8)	10.7 (6.6)	13.3 (7.6)
Lower lumbar	24.4 (13.2)	23.4 (10.1)	20.1 (13.9)	22.3 (9.6)	8.3 (4.5)	9.2 (4.4)	7.1 (2.6)	9.8 (5.3)	9.7 (5.3)	9.2 (2.7)	7.3 (3.3)	11.9 (3.2)

Note: Mean data (degrees) are presented with standard deviation in parentheses.

the aforementioned variables, indicating that the size of the effect was large.

Discussion

The high injury prevalence of the rugby scrum has ensured this fundamental component of the game – and specifically force generation – has long remained a research focus (Cazzola et al., 2015; Milburn, 1987; Quarrie & Wilson, 2000). The current study reflects the sport's evolutionary nature, and is the first to compare the hooker's spinal kinematics in scrums on natural versus synthetic turf.

Hooker peak ROM during the scrum did not change significantly with respect to the playing surface; however, the synthetic surface produced a more conservative ROM in nearly 80% of the 30 variables. The natural surface produced greater angular velocities in right lateral bending and left rotation, and left lateral bending, in the lower thoracic segment. Although these differences were not statistically significant after Bonferroni correction, the size of the effect was large ($d > 0.8$).

Whilst no injury data was collected during this study, the results suggest that there may be a trend towards a slightly reduced injury risk when scrummaging on synthetic surfaces due to greater stability. Spinal angular velocity has a direct relationship to trunk muscle activity with increased angular velocities resulting in much increased paraspinal muscle activity (Fan, Liu, & Ni, 2014; Mawston & Boocock, 2012; Williams, Haq, & Lee, 2013b). Increased paraspinal muscle activity has been shown to cause spinal compression in both cervical (Skrzypiec, Pollintine, Przybyla, Dolan, & Adams, 2007) and lumbar (Adams & Hutton, 1982, 1985a) regions. Similarly, in the thoracic spine, increased paraspinal muscle activity has been suggested to cause greater compressive loading (Caneiro et al., 2010). Compressive loading of the thoracic spine significantly loads the cortical shell with 45% of the load being borne by this structure (Kilincer et al., 2007). In the lumbar region, compressive loading has been shown to be at a high risk of endplate fracture and, when combined with bending, may cause injury to the intervertebral disc (Adams & Hutton, 1982, 1985a). Furthermore, there is a relatively high prevalence of thoracic spine injuries reported in rugby forwards from T8-T12 (Hind, Birrell, & Beck, 2014). In the cervical spine, compression causes the loss of intervertebral disc height and resultant increased load bearing on the neural arch and uncovertebral joints (Skrzypiec et al., 2007). Over a prolonged time, this may lead to the development of degenerative changes in the spine such as the formation of osteophytes (Kumaresan, Yoganandan, Pintar, Maiman, & Goel, 2001). These degenerative changes have been observed previously in front-row players in the cervical spine (Berge, Marque, Vital, Senegas, & Caille, 1999; Scher, 1990). Whilst it is not known whether similar pathologies occur in the thoracic spine, it appears likely that owing to the responses shown to similar increases in muscle activity of other regions of the spine, similarity can be predicted for the effects on the thoracic spine.

As this was one of the first studies to investigate spinal kinematics during live scrummaging, the measured ROM

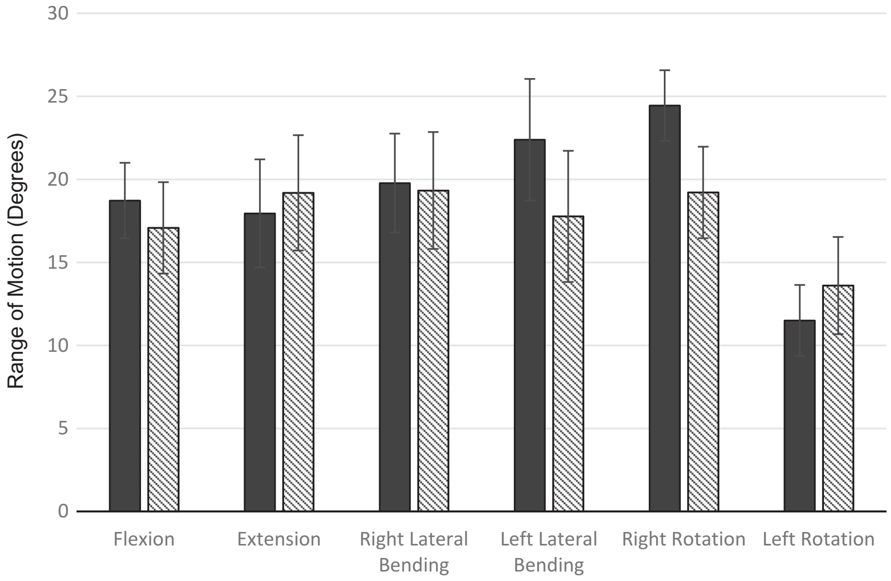

Figure 1. Mean peak cervical ROM during live scrummaging (CBS engagement) on natural (dark grey shading) and synthetic (diagonal lines) turf for all 11 players of each group.

Table 3. Mean peak percentage ROM during live scrummaging (CBS) for the synthetic (n = 11) and natural (n = 11) turf trials.

	Flexion		Extension		Right lateral bending		Left lateral bending		Right rotation		Left rotation	
	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural
Cervical	47.2	44.5	81.4	64.8	68.7	65.0	65.2	73.6	45.5	54.1	30.2	26.5
Upper thoracic	46.4	37.1	40.4	46.0	79.7	77.1	70.9	77.3	40.7	62.2	94.6	71.6
Lower thoracic	50.7	23.8	65.3	36.4	32.1	47.3	74.6	47.5	38.6	39.9	29.5	42.4
Upper lumbar	88.4	98.0	1.3	3.8	58.9	66.2	55.6	72.3	97.2	95.7	68.1	67.2
Lower lumbar	42.6	78.5	56.5	42.7	80.8	91.9	75.2	93.6	79.1	20.7	57.1	72.9

merits further discussion. Stand-alone ROM values can be difficult to interpret and hence these values were converted to a percentage of maximum ROM. It is well documented that the strength of the spine is compromised at the end of the range; therefore, loading the spine at, or close to, the end of range significantly increases the risk of spinal failure. The results illustrate a very high percentage of total range was used during scrummaging for specific segments. Over 95% and 90% of the total range of upper lumbar flexion and rotation was observed, respectively, a position shown to result in significant motion segment weakness (Gallagher, Marras, Litsky, & Burr, 2006), be associated with reduced paraspinal muscle activity and a transfer of loads from active to passive tissues (McGill & Kippers, 1994). The lower lumbar spine also appears to utilise a significant amount of its available range, ~85% of lateral bending, a position known to compromise the pars interarticularis (Stokes, 1988). Therefore, it appears that scrummaging may place the spine in a position that results in its compromised osteoligamentous strength and may be one factor associated with the high spinal injury prevalence relating to scrummaging.

Although there is evidence to suggest that loading the spine towards the end of its range has a significant risk of injury, as mentioned above, there is also evidence that suggests that more constrained kinematic conditions, as seen on synthetic turf, may lead to repeated stresses on the same vertebral structures (Adams & Hutton, 1985b; Adams, McNally, Chinn, & Dolan, 1994; Adams, McNally, & Dolan, 1996). Therefore, the link between more constrained kinematic conditions (i.e. synthetic turf) and reduced injury risk is not quite as straightforward as it may initially seem. For example, flexion reduces stress in the apophyseal joints and posterior half of the annulus fibrosus, but it also increases stress on the anterior annulus (Adams & Hutton, 1985b). Thus, the suggestion that scrummaging on a synthetic surface may reduce injury risk must be interpreted with caution owing to the aforementioned reasons.

The cervical spine is widely reported in the literature to suffer from the greatest number of injuries during scrummaging (Quarrie et al., 2002; Scher, 1982; Wetzler et al., 1998) and front-row players are well documented to suffer from premature chronic degeneration of the cervical vertebrae (Berge et al., 1999; Broughton, 1993; O'Brien, 1996; Scher, 1990). The data presented relating to angular velocities (Table 4) of the cervical spine is relevant to this as it may provide some information as to why these chronic injuries are so prevalent. From the data, it can be seen that mean peak cervical spine angular velocity was greater on natural turf than on synthetic turf. For flexion, left lateral bending and right rotation, there was a medium effect size ($d > 0.5$). Greater angular velocities

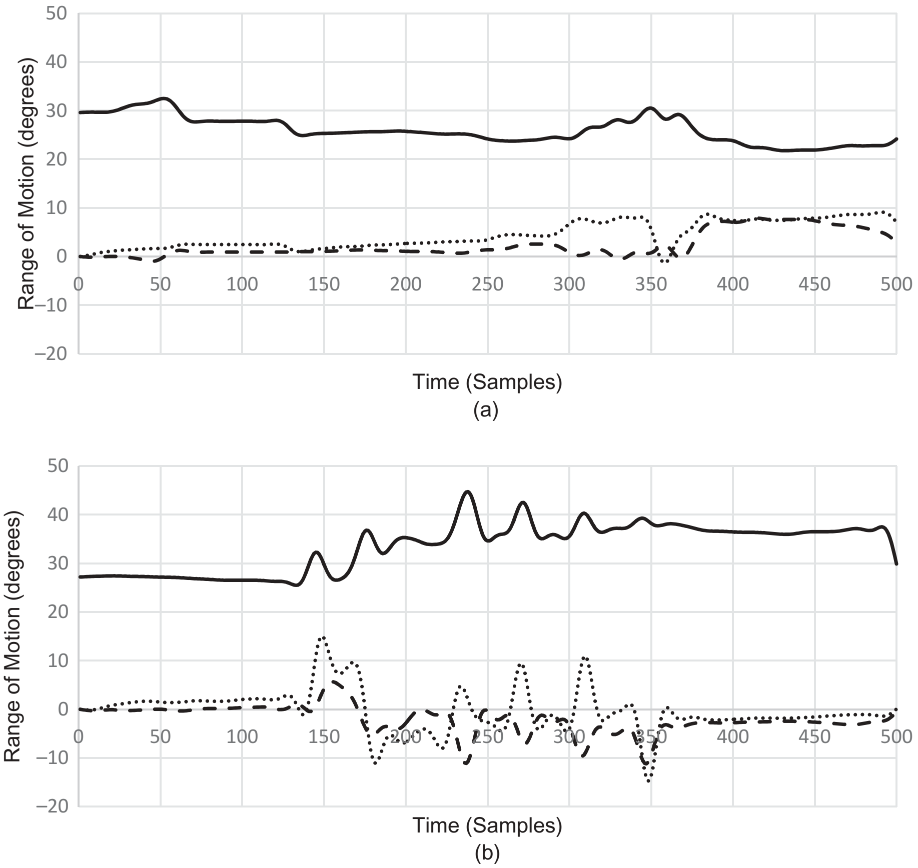

Figure 2. Example of dynamic upper lumbar ROM during live scrummaging (CBS) on (a) synthetic and (b) natural turfs. Solid line – flexion-extension; dashed line – lateral bending; dotted line – rotation.

Table 4. Mean peak angular velocity during live scrummaging (CBS) on 3G and natural surfaces.

	Flexion ($^\circ \cdot s^{-1}$)		Extension ($^\circ \cdot s^{-1}$)		Right lateral bending ($^\circ \cdot s^{-1}$)		Left lateral bending ($^\circ \cdot s^{-1}$)		Right rotation ($^\circ \cdot s^{-1}$)		Left rotation ($^\circ \cdot s^{-1}$)	
	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic	Natural
Cervical	8.5 (4.3)	10.3 (4.2)	9.4 (4.2)	10.9 (6.7)	8.2 (3.7)	14.9 (13.0)	7.6 (2.0)	7.1 (1.9)	7.1 (1.9)	10.5 (6.4)	8.2 (4.0)	9.2 (5.1)
Upper thoracic	6.6 (2.2)	10.1 (6.9)	6.9 (3.7)	6.1 (1.4)	6.0 (1.3)	8.0 (4.7)	6.7 (3.8)	9.4 (5.0)	7.6 (5.1)	10.6 (9.7)	7.6 (2.1)	12.0 (12.8)
Lower thoracic	3.0 (1.6)	4.4 (2.3)	2.8 (1.8)	4.5 (2.8)	***3.8 (2.6)***	***7.1 (3.5)***	***3.3 (1.8)***	***6.0 (1.9)***	4.8 (3.5)	7.5 (4.9)	***4.4 (2.1)***	***9.8 (5.9)***
Upper lumbar	4.1 (2.3)	5.4 (2.7)	3.0 (1.6)	4.6 (2.4)	4.1 (1.8)	5.0 (2.2)	3.4 (2.1)	5.9 (4.4)	4.2 (3.2)	6.0 (5.3)	5.0 (4.6)	7.8 (4.3)
Lower lumbar	4.3 (3.5)	5.7 (6.5)	4.2 (2.4)	9.2 (8.7)	3.9 (2.7)	6.0 (5.4)	3.7 (1.9)	5.7 (4.1)	4.8 (4.6)	8.7 (5.5)	3.9 (2.2)	9.2 (7.8)

Note: Mean peak data ($^\circ \cdot s^{-1}$) are presented with standard deviations in parentheses. Large effect sizes ($d > 0.8$) are highlighted in bold italics.

mean greater loading/force of the structure in question (Yoganandan & Pintar, 1997; Yoganandan, Pintar, Cusick, & Hollowell, 1999; Yoganandan, Pintar, Sances Jr, Reinartz, & Larson, 1991). The repetitive loading experienced during scrummaging (Scher, 1990), with forces, (Nightingale, McElhaney, Camacho, Winkelstein, & Myers, 1997; Nightingale, Richardson, & Myers, 1997; Yoganandan et al., 1991) velocities and accelerations (Portero, Quaine, Cahouet, Thoumie, & Portero, 2013; Yoganandan et al., 1991) that are comparable to the current data and other published data on scrummaging (Cazzola et al., 2015; Milburn, 1993; Preatoni et al., 2013; Preatoni, Stokes, England, & Trewartha, 2015; Quarrie & Wilson, 2000) may, with time, lead to chronic degenerative changes and neck pain (Berge et al., 1999; Lark & McCarthy, 2010; Pinsault, Anxionnaz, & Vuillerme, 2010; Scher, 1990). Thus, a reduction in angular velocity is likely to be a positive outcome for the playing position considered as it may delay the onset of chronic degenerative changes that are often seen in these players.

Scrum stability is extremely important to try and reduce the number of collapses and therefore reduce the risk of catastrophic spinal injury. Stability was estimated by considering the magnitude of kinematic variables where lower magnitudes were taken to mean more stability for the player being investigated. This approach is similar to that adopted by Cazzola et al. (2015), where lower excursions/ROM were considered to mean greater stability, since players made less postural adjustments. There has been some anecdotal evidence to suggest that scrums are more stable on synthetic surfaces, as there was an observed decrease in the number of collapsed scrums (BBC, 2013), but this is the first study to provide empirical evidence to suggest that scrummaging on a synthetic surface does have a potentially positive effect on stability for the player that was investigated.

Strengths and limitations

This was the first study to investigate spinal kinematics of multiple segments during rugby scrummaging on different turfs. To the best of the authors ability, as many variables as possible were controlled to make the statistical tests as robust as possible. Variables that were controlled included the hooker always being on the attacking side, the same coach was used to call the engagement sequence and the same scrum-half was used.

Ideally, the groups in this study would not have been unmatched. It would have been preferable to have a group of players who had access to training on both synthetic and natural turf pitches so that each player was exposed to both conditions, meaning a more robust statistical test could have been used. Owing to the availability of pitches to different teams, it was not possible to do this and this limitation is acknowledged by the authors.

Conclusions

A study was conducted to assess the differences in spinal kinematics of the rugby union hooker when scrummaging on two different playing surfaces: synthetic and natural. A general trend was observed of a reduction in the magnitude of kinematic variables for hookers in both ROM and angular velocity, but no significant differences were observed. Only lower thoracic angular velocity, of left and right lateral bending and left rotation proved to have a large effect size ($d > 0.8$). These reductions suggest that there is more stability when scrummaging on synthetic pitches compared to natural turf, as players have lower excursions and therefore fewer postural adjustments. Given the fact that research suggests there to be no difference in traction on synthetic and natural surfaces, the authors suggest that it is the consistency in the properties of synthetic turf in a variety of weather conditions that give rise to this increased spinal stability of the hooker. No significant differences ($P > 0.05$) were found between normal ROM values and anthropometric and background data, between the two groups, and no correlation between ROM and anthropometric and background data were observed. Although separate groups were used, the lack of significant differences of anthropometric and background data observed between the two suggest similarity between the groups. Finally, the observed reduction in peak kinematic variable magnitudes suggests that scrummaging on synthetic pitches may potentially be safer, in the long term, as a result of the increased stability that this data suggests.

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Disclosure statement

The authors would like to declare that there is no conflict of interest.

ORCID

Ramesh Swaminathan http://orcid.org/0000-0003-2871-4016
Peter S. Theobald http://orcid.org/0000-0002-3227-7130

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