Cervical Range of Motion, Cervical and Shoulder Strength in Senior versus Age-grade Rugby Union International Front-Row Forwards

Keywords: normative strength, rugby, neck injury, upper limb

Abstract

Objectives: To provide normative values for cervical range of motion (CROM), isometric cervical and shoulder strength for; International Senior professional, and International Age-grade Rugby Union front-row forwards.

Design: Cross-sectional population study

Setting: All international level front-row players within a Rugby Union Tier 1 Nation.

Participants: Nineteen Senior and 21 Age-grade front-row forwards underwent CROM, cervical and shoulder strength testing.

Main outcome measures: CROM was measured using the CROM device and the Gatherer System was used to measure multi-directional isometric cervical and shoulder strength.

Results: The Age-grade players had significantly lower; cervical strength (26 - 57% deficits), cervical flexion to extension strength ratios (0.5 vs. 0.6), and shoulder strength (2 – 36% deficits) than the Senior players. However, there were no differences between front-row positions within each age group. Additionally, there were no differences between age groups or front-row positions in the CROM measurements.

Conclusions: Senior Rugby Union front-row forwards have greater cervical and shoulder strength than Age-grade players, with the biggest differences being in cervical strength, highlighting the need for position specific normative values. Importantly, Age-grade players should be evaluated to ensure they have developed sufficient cervical strength prior to entering professional level Rugby Union.

Introduction

Cervical (neck) injury rates are high in both Senior (Fuller, Sheerin, & Targett, 2013) and Age-grade (under18 or under 20) (Bleakley, Tully, & O'Connor, 2011; Palmer-Green et al., 2013) Rugby Union players. These injuries often involve long absences from the game and can affect long-term health (Fuller et al., 2013). Cervical injuries typically occur during contact events, such as scrums, rucks and mauls, competing for the ball at a ruck and tackles. Consequently, Front-row Forwards, who have relatively high exposure to contact with the opposition (Brown et al., 2014; Duthie, Pyne, & Hooper, 2003), are particularly vulnerable (Brooks & Kemp, 2011; Usman & McIntosh, 2012).

The scrum is an important component of Rugby Union and has a high injury propensity (Fuller, Brooks, Cancea, Hall, & Kemp, 2007). It involves a pack of eight players, termed 'Forwards'. Three play in the front-row (Loose-head Prop, Hooker and Tight-head Prop), two 'locks' in the second-row, and three 'back row' players. They scrummage aggressively against an opposing Forward pack to secure the ball when restarting play following an infringement or stoppage (IRB, 2014). Effective scrummaging requires coordinated pushing by the eight players (Trewartha, Preatoni, England, & Stokes, 2014), which produces forces greater than the sum of each forward's individual scrummaging force (Quarrie & Wilson, 2000). Unsurprisingly, scrum engagement forces are positively related to the total body mass of the opposing pack (Du Toit, Olivier, & Buys, 2005; Milburn, 1990). Rugby players' size has increased markedly over the last 25 years (Sedeaud et al., 2012) and therefore, engagement forces have doubled since 1990 (8000 N vs. 16500 N) (Milburn, 1990; Preatoni, Stokes, England, & Trewartha, 2013). Front-row players

bare the brunt of this engagement force, absorbing a greater proportion of the load than the other forwards (Milburn, 1990; Quarrie & Wilson, 2000).

Increased Rugby Union player cervical muscle strength following specific neck muscle training has been demonstrated (Geary, Green, & Delahunt, 2014), and it is proposed that greater cervical strength could protect against injury (Brooks, Fuller, Kemp, & Reddin, 2005; Brooks & Kemp, 2011; Peek & Gatherer, 2005), as a stronger neck should have higher capability to withstand extreme forces applied during Rugby contact events, such as the scrum and tackle. This is supported by a recent study that associated strength improvements following a short-term exercise intervention, with lower rates of Rugby Union related neck injuries (Naish, Burnett, Burrows, Andrews, & Appleby, 2013). Whilst some isometric cervical strength data for generic groups of professional Rugby Union players is available, specific normative cervical strength values for the very best players, in the most high risk positions, are required to provide player rehabilitation, conditioning and selection benchmarks.

Some normative cervical strength values have been reported for adult amateur and school-aged players (Hamilton et al., 2012; Hamilton et al., 2014) although not all cervical movements were assessed. Further, establishing normative upper limb strength values (as myotomal shoulder strength deficit is a common sequeale to cervical injury) for players at high-risk of cervical injury would be useful in informing injury prevention and return to play programmes. Normative values would not only inform preparation of elite young front-row players for professional Senior rugby, but could also help distinguish between injured and uninjured individuals

(Cagnie, Cools, De Loose, Cambier, & Danneels, 2007), thus informing rehabilitation programmes and return to play criteria.

Not all cervical injuries in Rugby Union stem from one-off traumatic incidents, others, such as gradual onset disc and facet joint degeneration may result from the cumulative demands of rugby contact events. It has been hypothesised that the cumulative effect of Rugby's physical demands may be the cause of reduced cervical range of motion (CROM) identified in rugby players (Lark & McCarthy, 2007). Indeed, Rugby Union players have been reported to have similar CROM profiles to whiplash sufferers (Dall'Alba, Sterling, Treleaven, Edwards, & Jull, 2001; Lark & McCarthy, 2007) and greater rugby experience is associated with reduced CROM (Lark & McCarthy, 2007). Previous studies have measured CROM for semi-professional Rugby Union players (Lark & McCarthy, 2007, 2009, 2010b), but not professional players and have not compared top-level Senior and Age-grade players. Therefore, it is not known whether Age-grade players, with less playing experience, exhibit greater CROM than Senior players.

Therefore, the aim of this project is to establish and compare normative values for CROM, cervical strength and shoulder strength for Senior International Rugby Union front-row forwards, and International Age-grade Rugby Union front-row forwards.

Methods

Participants

The participants were split into two groups based on their age and playing level. The 'Age-grade' group consisted of 21 front-row players who had represented their

country at under 18 or under 20 level, and the 'Senior' group that consisted of 19 front-row players who were all current or former Internationals currently playing professional rugby. All participants were deemed neck injury free and fit for Rugby selection by their team medical staff. These cohorts effectively consisted of the entire population of international level front-row forwards within a single Tier 1 Rugby Union Nation. Each player's front-row position (Loose-head, Hooker or Tight-head), body mass and height were recorded and descriptive data for each position, within each age group, are shown in Table 1. Ethical approval was granted by the Cardiff Metropolitan University, Cardiff School of Sport Ethics Committee and written informed consent was obtained from all participants.

Procedures

Each participant's CROM, cervical strength and shoulder strength were tested on the same day with one tester collecting all Senior participant data whilst another collected all the Age-grade participant data. CROM was assessed prior to strength testing.

The testing procedure followed the methods described by Lark and McCarthy (Lark & McCarthy, 2007). Prior to the CROM device (Orthopedic Physical Therapy Products, Minneapolis, USA) being fitted, the player was seated in an upright position and practised each of the cervical movements to be tested. This pre-stretched the muscles and familiarised them with the testing protocol (Lark & McCarthy, 2007). The CROM device was then secured on the player's head. Additionally a magnetic collar was placed on the shoulders of the player to take into account any trunk rotation (Audette, Dumas, Cote, & De Serres, 2010). This device has previously been shown to be both valid and reliable at measuring CROM

(Audette et al., 2010). Participants CROM was then measured when they attained the maximum active range of motion during a single repetition in each of the movement directions tested (flexion, extension, bilateral rotation and bilateral side flexion).

Prior to the cervical and shoulder strength testing participants undertook a standardised warm-up of self-resistance exercises, supervised by the tester. First, one isometric repetition at a self-perceived 50% maximum force was held for four seconds in each testing position. This was followed by a second repetition at self-perceived maximal (100%) force. Resistance was provided by either; the palm of the hand for cervical strength testing positions; or the opposite limb for shoulder strength testing positions. The sequence of positions used in the warm-up was identical to the sequence of positions used for the strength tests.

Cervical and shoulder strength was tested using the Gatherer System (Gatherer Systems Ltd, Aylesbury, UK), which has previously been used to test cervical and upper limb strength in Rugby Union players (Hamilton et al., 2014; Peek & Gatherer, 2005). This is an isometric dynamometer that uses a 300 kg load cell and bespoke software system to accurately measure the forces exerted during each maximal contraction. It has been shown to be a reliable tool for measuring cervical strength (Hamilton et al., 2012; Hamilton, Simpson, & Gatherer, 2010) and can distinguish variability in maximal strength between age groups (Hamilton et al., 2012).

During Cervical testing the tester subjected the player's neck to manually controlled incremental loading using the neck harness. The player resisted the load and held their head in the neutral anatomic position. Peak isometric force was recorded when the player could no longer resist the load and their head moved out of neutral (D. F

Hamilton et al., 2012). To reduce inter-player variability during testing, player body and seating position were standardised. A 3-section hydraulic plinth (Plinth 2000) was used for all testing, set at chair height (90cm) for each of the cervical strength tests. The cervical spine directions of movement tested were as follows; flexion (Figure 1), extension, bilateral side flexion, flexion in 45° rotation (bilateral), and extension in 45° rotation (bilateral). Bilateral shoulder strength of flexion and extension in neutral, internal and external rotation in neutral, adduction at 90°, and abduction at 90° was also assessed. For all the strength tests the mean of three repetitions was recorded with a rest period of 15 seconds provided between each maximal strength effort.

Insert Figure 1 near here

Figure 1. Isometric strength testing of cervical flexion

Statistical Analyses

The mean and standard deviation values for each front-row position, for all CROM, cervical and shoulder strength tests were calculated. Data were tested for normality using Sharipo-Wilk tests, for variables where normality was not present, equivalent non-parametric tests were used. To analyse strength differences between the age groups (regardless of front-row position) independent T-tests or Mann-Whitney U tests were employed. To analyse strength differences between front-row positions (regardless of age) a one-way ANOVA or Kruskal-Wallis test was utilised. Post-hoc tests were conducted when these analyses were significant, and Bonferroni corrections were applied. Due to the number of participants in each position within an age group, only descriptive data are presented for comparisons between positions

and age groups. CROM and strength deficits were defined as the mean difference between Senior and Age-grade players in each front-row position. For all strength measures where both left and right sides, or flexion and extension movements, were tested a mean of the two deficits was calculated to give the overall deficit for a particular movement. All statistical tests were performed using SPSS version 20 (SPSS Inc., Chicago, Illinois) with significance set at $p \leq 0.05$.

Results

The Senior players were significantly taller ($p = 0.04$) and heavier ($p = 0.007$) than the Age-grade players. With regards to position, the Loose-heads ($p < 0.001$) and Tight-heads ($p < 0.001$) were heavier than the Hookers, but were similar to each other ($p = 0.267$) (Table 1).

Table 1. Age group profiles [mean (SD)] for each front row position

Age group	Players (n)	Age (y)	Height (cm)	Mass (kg)
Loose-head				
Age-grade	8	18 (1)	184 (3)	113 (6)
Senior	6	28 (5)	186 (5)	117 (5)
Total	14	23 (6)	185 (4)	115 (5)∝
Hooker				
Age-grade	9	19 (1)	180 (4)	102 (4)
Senior	7	28 (4)	185 (3)	109 (3)
Total	16	23 (5)	182 (4)	105 (5)
Tight-head				
Age-grade	4	18 (1)	185 (8)	115 (4)
Senior	6	25 (4)	185 (5)	120 (4)
Total	10	22 (5)	185 (6)	118 (4)∝
All front-row positions				
Age-grade	21	19 (1)	182 (5)	109 (7)
Senior	19	27 (5)**	185 (4)*	114 (6)*

∝ indicates significantly heavier than Hookers ($p \leq 0.05$). * indicates Senior significantly greater than Age-grade players ($p \leq 0.05$). ** indicates Senior significantly greater than Age-grade players ($p < 0.001$).

There were no significant differences in CROM measurements between any positions or age groups (Table 2). Whilst there was little difference in CROM between the Senior and Age-grade Loose-heads and hookers, the Senior Tight-heads had noticeably less range of motion (29% deficit), across all cervical movement directions (Figure 2 and Table 2).

Table 2. Cervical range of motions (degrees) [mean (SD)] for Senior and Age-grade players.

Age group	Cervical		Side flexion		Rotation	
	Flexion	Extension	Left	Right	Left	Right
Loose-head						
Age-grade	53 (10)	54 (7)	38 (5)	36 (6)	56 (6)	54 (6)
Senior	48 (17)	61 (11)	41 (9)	39 (11)	57 (6)	58 (10)
Hooker						
Age-grade	49 (7)	60 (10)	43 (8)	40 (6)	60 (6)	61 (8)
Senior	48 (15)	66 (15)	44 (7)	38 (10)	56 (5)	58 (8)
Tight-head						
Age-grade	58 (16)	70 (9)	52 (8)	47 (8)	58 (10)	58 (10)
Senior	46 (15)	56 (20)	33 (4)	28 (8)	49 (5)	48 (6)
All front-row positions						
Age-grade	52 (10)	59 (10)	42 (8)	40 (7)	58 (7)	58 (8)
Senior	48 (15)	61 (16)	40 (9)	35 (10)	54 (7)	55 (9)

When comparing the cervical range of motion between positions within age groups, the Senior Tight-heads had less range of motion compared to the Senior Loose-heads and Hookers. For the Age-grade players, the Loose-heads had the least range of motion.

The Senior players exhibited significantly greater cervical strength than the Age-grade players across all tests ($p < 0.001$) (Table 3), in addition to a significantly higher ($p = 0.018$) cervical flexion to extension ratio of 0.6 (0.2) vs. 0.5 (0.1), for the Senior and Age-grade groups respectively. However, there were no significant differences found for any of the cervical strength variables or flexion to extension ratios between front-row positions. The Age-grade player neck strength tests were at least 33% weaker than the Senior players, except for neck flexion/extension within

Hookers (26%). In five of the neck strength tests the Age-grade players exhibited a 50% strength deficit in comparison to the Senior players (Figure 3a).

Table 3. Cervical strength norms (kg) [mean (SD)] for Senior and Age-grade players.

Age group	Neck flexion/ extension		Neck side flexion		Neck flexion in 45° rotation		Neck extension in 45° rotation	
	Flex	Ext	Left	Right	Left	Right	Left	Right
Loose-head								
Age-grade	26 (9)	52 (7)	36 (10)	42 (13)	20 (5)	18 (6)	35 (9)	39 (11)
Senior	47 (9)	76 (7)	63 (7)	62 (9)	42 (7)	43 (8)	69 (6)	72 (9)
Hooker								
Age-grade	28 (8)	50 (6)	35 (9)	39 (10)	24 (3)	23 (6)	39 (10)	39 (12)
Senior	38 (11)	67 (9)	54 (14)	56 (13)	37 (8)	37 (14)	63 (10)	64 (13)
Tight-head								
Age-grade	23 (5)	54 (6)	32 (2)	31 (7)	22 (3)	19 (4)	40 (4)	40 (5)
Senior	48 (14)	72 (10)	63 (9)	68 (11)	43 (9)	43 (10)	69 (11)	71 (6)
All front-row positions								
Age-grade	26 (8)	52 (6)	35 (8)	38 (10)	22 (4)	20 (6)	38 (9)	39 (10)
Senior	44 (12)**	71 (9)**	59 (11)**	61 (11)**	40 (8)**	41 (11)**	66 (9)**	68 (11)**

** indicates Senior significantly greater than Age-grade players ($p < 0.001$).

When comparing the positions across age groups, Hookers had the smallest overall difference across all strength assessments (33%), compared to Loose-heads (46%) and Tight-heads (48%) (Figure 3a). The biggest difference between the Senior players and Age-grade players was seen in the Loose-heads and their flexion in 45° rotation strength (left deficit: 54%; right deficit: 59%).

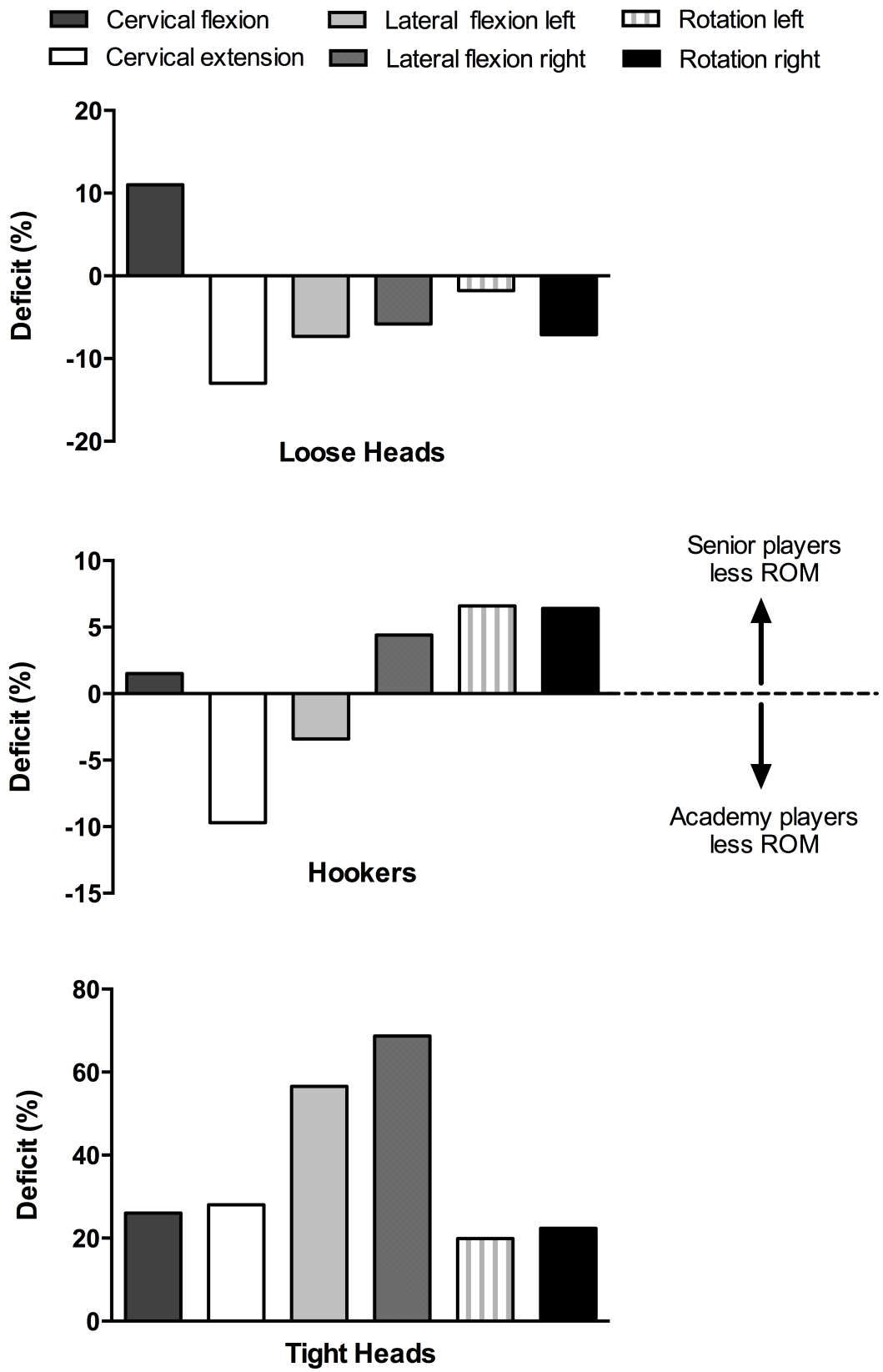

Figure 2. Cervical range of motion deficits for Senior and Age-grade players for each position. Positive deficit = Senior players had less range of motion (ROM). Negative deficit = Age-grade players had less ROM.

The Senior players had significantly greater shoulder strengths across all tests (all $p < 0.01$), except left shoulder flexion ($p = 0.069$) and bilateral shoulder abduction at 90° ($p = 0.114$ and $p = 0.078$, left and right respectively) (Table 4). However, similar to neck strength, there were no significant differences in shoulder strength between front-row positions. Whilst the Age-grade players were weaker than the Senior players in every shoulder assessment, the deficits (range: 2 – 36%) were much smaller than the neck strength assessments (Figure 3a-c). When comparing positions across age groups, all front-row positions produced similar overall strength deficits (Loose-head, 25%; Hooker, 23%; Tight-head, 22%). Shoulder internal and external rotation strength consistently demonstrated large deficits between the Senior and Age-grade players (at least 18 and 25%, respectively) (Figure 3c).

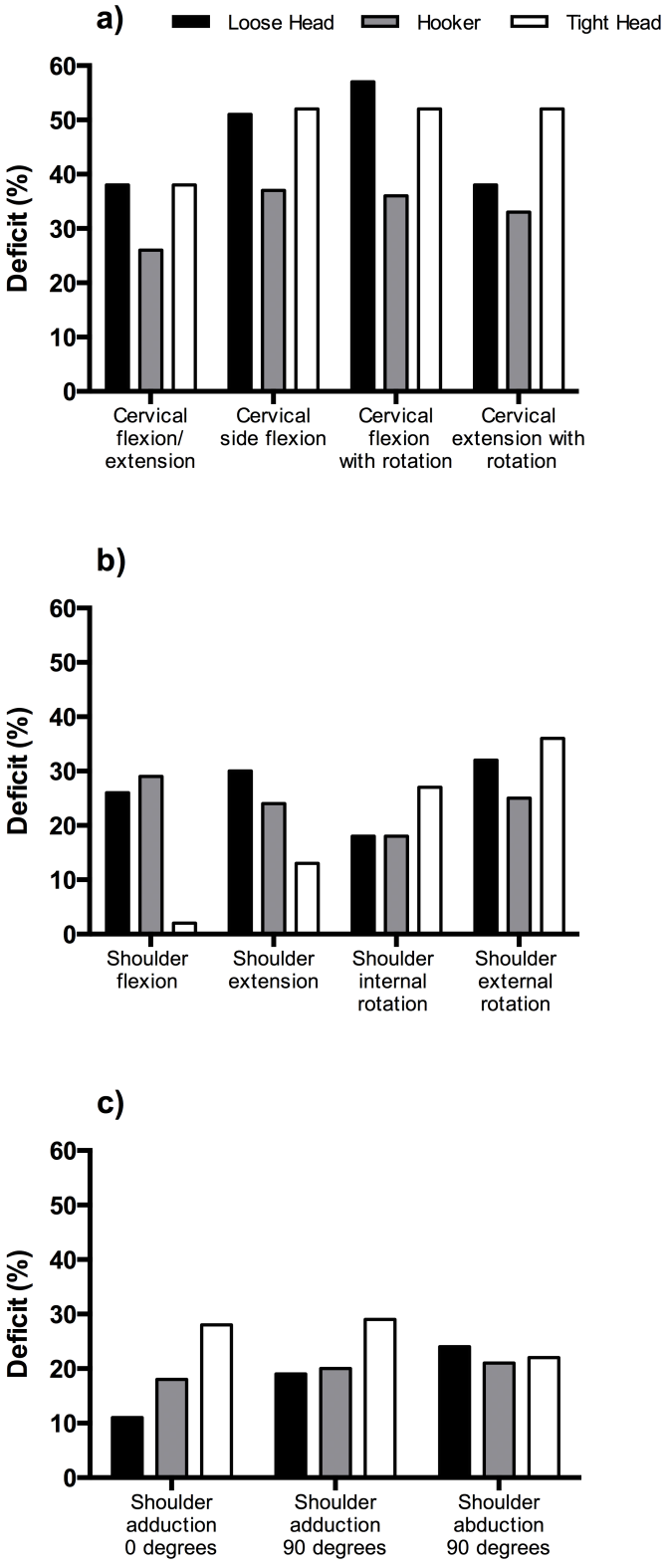

Figure 3. Strength deficits between Senior and Age-grade players in a) cervical strength; b) shoulder flexion-extension and rotation strength and; c) shoulder adduction-abduction strength.

Table 4. Isometric shoulder flexion/extension, internal/external rotation and adduction/abduction (at 90° abduction) strength norms (kg) [mean (SD)] for Senior and Age-grade players

Age group	Flexion		Extension		Internal Rotation		External Rotation		Adduction		Abduction	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Loose-head												
Age-grade	28 (11)	22 (10)	28 (5)	29 (9)	37 (7)	38 (9)	26 (7)	25 (7)	33 (9)	35 (6)	22 (2)	25 (6)
Senior	32 (5)	37 (9)	36 (8)	34 (7)	48 (13)	47 (10)	38 (5)	37 (8)	34 (7)	39 (9)	30 (5)	34 (5)
Hooker												
Age-grade	24 (7)	22 (5)	26 (4)	29 (3)	37 (8)	38 (7)	25 (3)	26 (5)	26 (6)	31 (6)	21 (3)	23 (4)
Senior	30 (7)	34 (6)	26 (7)	33 (5)	48 (10)	44 (10)	34 (7)	35 (6)	32 (11)	37 (9)	27 (8)	28 (7)
Tight-head												
Age-grade	31 (6)	32 (12)	27 (10)	25 (6)	30 (11)	34 (9)	23 (5)	25 (4)	39 (9)	28 (9)	20 (6)	24 (7)
Senior	32 (6)	32 (8)	36 (4)	35 (3)	43 (11)	49 (17)	36 (7)	40 (7)	34 (5)	36 (8)	30 (4)	27 (5)
All front-row positions												
Age-grade	27 (9)	24 (9)	27 (5)	27 (64)	36 (8)	37 (8)	25 (5)	26 (6)	29 (8)	32 (7)	21 (3)	24 (5)
Senior	31 (6)	34 (8)**	33 (7)*	34 (5)**	46 (11)*	46 (12)*	35 (6)**	37 (7)**	33 (8)	38 (8)	29 (6)**	29 (6)*

* indicates Senior significantly greater than Age-grade players ($p \leq 0.05$). ** indicates Senior significantly greater than Age-grade players ($p \leq 0.001$).

Discussion

The aim of this study was to assess differences in CROM, cervical and shoulder strength in Senior and Age-grade International Rugby Union players. The Senior players were significantly stronger in all cervical strength assessments and the majority of the shoulder assessments. However, there were no significant differences in CROM. The strength deficits between the Senior and Age-grade players were much higher for the cervical assessments than for the shoulder, highlighting the need for normative values for each age group.

Similar to previous findings, and as would be expected; the props (both Loose and Tight-heads) were significantly heavier than the Hookers (Durandt et al., 2006; Duthie et al., 2003; Quarrie, Handcock, Toomey, & Waller, 1996). Additionally, the Senior players were significantly heavier than the Age-grade players and given that scrum engagement forces are high, the relatively low body mass of the Hookers may be a contributory factor in them being at the highest risk of scrum related cervical injury (Bohu et al., 2009; Quarrie, Cantu, & Chalmers, 2002; Wetzler, Akpata, Laughlin, & Levy, 1998). Other factors that may predispose Hookers are that during scrum engagement they wrap both of their arms around the adjacent players (Loose-head and Tight-head) making them reliant on these players for support, and limiting their ability to adjust their body position to reduce cervical stress (Trewartha et al., 2014).

All CROM values, except left and right rotation, exhibited by both the Senior and Age-grade players were similar to those previously reported for semi-professional players (Lark & McCarthy, 2007, 2010b). The left and right rotation CROM was more restricted and was more closely matched to individuals who had suffered

whiplash or orthopaedic disorders (Dall'Alba et al., 2001; Youdas, Carey, & Garrett, 1991). The elite Age-grade rotation CROM values were also 12° lower than those reported for similar aged, schoolboy players (Hamilton et al., 2012), who have had less high-level rugby exposure. All CROM values were similar between the Senior and Age-grade players. Collectively, these results suggest that exposure to high-level rugby could be a significant, contributory factor to CROM deficits. Furthermore, the observed reduction in left and right rotation range of motion may have the potential to negatively impact performance, as a player may have a narrower field of view whilst on the pitch, thereby limiting their ability to read the play.

Although there were no significant age and positional differences in CROM, the Age-grade Tight-heads had 29% more CROM than the Senior Tight-heads. Lark and McCarthy (2009, 2010b) reported that decreased CROM after a full rugby season, and after just one rugby match, with specific positional-related changes. The finding within forwards that the greatest loss of CROM were in extension and side flexion direction (Lark & McCarthy, 2009) is supported by the current study which showed side flexion deficits in the Senior Tight-head players. Additionally, reduced cervical side flexion range of motion has been associated with greater number of years playing rugby, but not with players being older (Lark & McCarthy, 2007). Therefore, it is conceivable that the deficits observed in the Senior players were due to greater rugby playing exposure. Whilst the demands of rugby matches, such as scrummaging and tackling may contribute to reductions in CROM, shorter modern off-seasons that limit recovery and rehabilitation time, may also be a contributing factor (Lark & McCarthy, 2010a).

The Age-grade players in this study weighed less than their Senior international counterparts, in addition their cervical, and to a lesser extent shoulder strength was also less developed. Age-grade players may thereby be at increased risk of injury when playing within their own age group where pack weights are still high but cervical strength has not fully developed. Furthermore, whilst the cervical strength for the Age-grade players was similar to those of amateur adult players (Hamilton et al., 2014), the Senior International players had much higher values. Greater senior player exposure to elite-level rugby matches, training and preparation methods is likely to account for this.

Age-grade front-row forwards selected or transitioning to Senior professional Rugby may also be vulnerable when playing against older, heavier counterparts with comparatively stronger necks and shoulders. Whilst the World Rugby law 3.5 (b) states "each player in the front row and any potential replacement(s) must be suitably trained or experienced" (IRB, 2014), there are no quantifiable descriptors to distinguish between trained-untrained and experienced-inexperienced. It is therefore advisable that coaches provide Age-grade players with specific cervical and shoulder conditioning programmes aimed at bridging age related neck and shoulder strength deficits. Further, benchmark cervical and shoulder strength testing using methods detailed in this paper is advised for all elite (Age-grade and Senior) front-row forwards. This will provide benchmarks important for determining when players have fully recovered from cervical injury and deciding when they are sufficiently physically conditioned to transition to higher levels of Rugby.

The cervical flexion-extension strength ratios are similar to previous reports using healthy populations (Garces, Medina, Milutinovic, Garavote, & Guerado, 2002;

Jordan, Mehlsen, Bulow, Ostergaard, & Danneskiold-Samsoe, 1999). However, the Age-grade players had a much greater cervical flexion strength deficit (41%) than extension strength deficit (27%) when compared to their Senior counterparts leading to a lower cervical flexion-extension strength ratio. This suggests that particular attention should be given to training cervical flexor strength. There was also greater positional disparity in neck strength than shoulder strength between Senior and Age-grade players, particularly when contrasting Age-grade and Senior International props. This might be a reflection of current rugby strength and conditioning practice that may emphasise shoulder strength development in elite Age-grade players, but may not sufficiently or specifically include cervical strength training.

As is often the case when studying elite sporting populations, although the participants formed a relatively homogenous cohort and effectively represented the entire population of top-level front-row forward playing within this Nation, the actual participant numbers are relatively small and therefore the power of statistical comparisons is limited.

Conclusion

Senior International Rugby Union players have higher cervical and shoulder strength than International Age-grade players, with the biggest differences being found in cervical strength. However, CROM was similar between Senior and Age-grade players and there were no differences in neck strength, shoulder strength or CROM between the front-row positions. The normative values determined in this study can be used to inform future preparation and rehabilitation programmes. Importantly, Age-grade players should be evaluated to ensure they have developed sufficient

cervical strength, particularly of the neck flexors, prior to entering professional Senior rugby.

REFERENCES

Audette, I., Dumas, J. P., Cote, J. N., & De Serres, S. J. (2010). Validity and between-day reliability of the cervical range of motion (CROM) device. *Journal of Orthopaedic and Sports Physical Therapy, 40*(5), 318-323. doi: 10.2519/jospt.2010.3180

Bleakley, C., Tully, M., & O'Connor, S. (2011). Epidemiology of adolescent rugby injuries: a systematic review. *Journal of Athletic Training, 46*(5), 555-565.

Bohu, Y., Julia, M., Bagate, C., Peyrin, J. C., Colonna, J. P., Thoreux, P., & Pascal-Moussellard, H. (2009). Declining incidence of catastrophic cervical spine injuries in French rugby: 1996-2006. *American Journal of Sports Medicine, 37*(2), 319-323. doi: 10.1177/0363546508325926

Brooks, J. H. M., Fuller, C. W., Kemp, S. P. T., & Reddin, D. B. (2005). Epidemiology of injuries in English professional rugby union: part 1 match injuries. *British Journal of Sports Medicine, 39*(10), 757-766. doi: 10.1136/bjsm.2005.018135

Brooks, J. H. M., & Kemp, S. P. T. (2011). Injury-prevention priorities according to playing position in professional rugby union players. *British Journal of Sports Medicine, 45*(10), 765-775. doi: 10.1136/bjsm.2009.066985

Brown, J. C., Lambert, M. I., Hendricks, S., Readhead, C., Verhagen, E., Burger, N., & Viljoen, W. (2014). Are we currently underestimating the risk of scrum-related neck injuries in rugby union front-row players? *British Journal of Sports Medicine, 48*(14), 1127-1129. doi: 10.1136/bjsports-2013-092869

Cagnie, B., Cools, A., De Loose, V., Cambier, D., & Danneels, L. (2007). Differences in isometric neck muscle strength between healthy controls and women with chronic neck pain: the use of a reliable measurement. *Archives of Physical Medicine and Rehabilitation, 88*(11), 1441-1445. doi: 10.1016/j.apmr.2007.06.776

Dall'Alba, P. T., Sterling, M. M., Treleaven, J. M., Edwards, S. L., & Jull, G. A. (2001). Cervical range of motion discriminates between asymptomatic persons and those with whiplash. *Spine, 26*(19), 2090-2094.

Du Toit, D. E., Olivier, P.E., & Buys, F. J. (2005). Kinetics of full scrum and staggered scrum engagement in under 19 schoolboy rugby union players. *South African Journal for Research in Sport, Physical Education and Recreation, 27*(2), 15 - 28.

Durandt, J., du Toit, S., Borresen, J., Hew-Butler, T., Masimla, H., Jokoet, I., & Lambert, M. (2006). Fitness and body composition profiling of elite junior South African rugby players. *South African Journal of Sports Medicine, 18*(2), 38-45.

Duthie, G., Pyne, D., & Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Medicine, 33*(13), 973-991.

Fuller, C. W., Brooks, J. H., Cancea, R. J., Hall, J., & Kemp, S. P. (2007). Contact events in rugby union and their propensity to cause injury. *British Journal of Sports Medicine, 41*(12), 862-867; discussion 867. doi: 10.1136/bjsm.2007.037499

Fuller, C. W., Sheerin, K., & Targett, S. (2013). Rugby World Cup 2011: International Rugby Board injury surveillance study. *British Journal of Sports Medicine, 47*(18), 1184-1191. doi: 10.1136/bjsports-2012-091155

Garces, G. L., Medina, D., Milutinovic, L., Garavote, P., & Guerado, E. (2002). Normative database of isometric cervical strength in a healthy population. *Medicine and Science in Sports and Exercise, 34*(3), 464-470.

Geary, Kevin, Green, Brian S., & Delahunt, Eamonn. (2014). Effects of Neck Strength Training on Isometric Neck Strength in Rugby Union Players. *Clinical Journal of Sport Medicine, Publish Ahead of Print*, 10.1097/JSM.0000000000000071.

Hamilton, D. F, Gatherer, D, Jenkins, P. J, Maclean, J. G, Hutchison, J. D, Nutton, R. W, & Simpson, A. H. (2012). Age-related differences in the neck strength of adolescent rugby players: A cross-sectional cohort study of Scottish schoolchildren. *Bone and Joint Research, 1*(7), 152-157. doi: 10.1302/2046-3758.17.2000079

Hamilton, D. F, Simpson, H. R, & Gatherer, D. (2010). *Repeatability and inter-tester reliability of a new tool to assess isometric neck strength in adolescents*. Paper presented at the Physiotherapy Research Society, Middlesborough, UK.

Hamilton, D. F., Gatherer, D., Robson, J., Graham, N., Rennie, N., MacLean, J. G. B., & Simpson, A. H. R. W. (2014). Comparative cervical profiles of adult and under-18 front-row rugby players: implications for playing policy. *British Medical Journal Open, 4*(5), e004975. doi: 10.1136/bmjopen-2014-004975

IRB. (2014). Retrieved 14/2/14, from http://www.irblaws.com/index.php?law=20

Jordan, A., Mehlsen, J., Bulow, P. M., Ostergaard, K., & Danneskiold-Samsoe, B. (1999). Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine, 24*(13), 1343-1348.

Lark, S. D., & McCarthy, P. W. (2007). Cervical range of motion and proprioception in rugby players versus non-rugby players. *Journal of Sports Sciences, 25*(8), 887-894. doi: 10.1080/02640410600944543

Lark, S. D., & McCarthy, P. W. (2009). The effects of a single game of rugby on active cervical range of motion. *Journal of Sports Sciences, 27*(5), 491-497. doi: 10.1080/02640410802632136

Lark, S. D., & McCarthy, P. W. (2010a). Active cervical range of motion recovery following the rugby off-season. *Journal of Sports Medicine and Physical Fitness, 50*(3), 318-325.

Lark, S. D., & McCarthy, P. W. (2010b). The effects of a rugby playing season on cervical range of motion. *Journal of Sports Sciences, 28*(6), 649-655. doi: 10.1080/02640411003631968

Milburn, P. D. (1990). The kinetics of rugby union scrummaging. *Journal of Sports Sciences, 8*(1), 47-60. doi: 10.1080/02640419008732130

Naish, R., Burnett, A., Burrows, S., Andrews, W., & Appleby, B. (2013). Can a Specific Neck Strengthening Program Decrease Cervical Spine Injuries in a Men's Professional Rugby Union Team? A Retrospective Analysis. *Journal of Sports Science and Medicine, 12*(3), 542-550.

Palmer-Green, D. S., Stokes, K. A., Fuller, C. W., England, M., Kemp, S. P., & Trewartha, G. (2013). Match injuries in English youth academy and schools rugby union: an epidemiological study. *American Journal of Sports Medicine, 41*(4), 749-755. doi: 10.1177/0363546512473818

Peek, G., & Gatherer, D. (2005). The rehabilitation of a professional Rugby Union player following a C7/T1 posterior microdiscectomy. *Physical Therapy in Sport, 6*(4), 195 - 200.

Preatoni, E., Stokes, K. A., England, M. E., & Trewartha, G. (2013). The influence of playing level on the biomechanical demands experienced by rugby union forwards during machine scrummaging. *Scandinavian Journal of Medicine and Science in Sports, 23*(3), e178-184. doi: 10.1111/sms.12048

Quarrie, K. L., Cantu, R. C., & Chalmers, D. J. (2002). Rugby union injuries to the cervical spine and spinal cord. *Sports Medicine, 32*(10), 633-653.

Quarrie, K. L., Handcock, P., Toomey, M. J., & Waller, A. E. (1996). The New Zealand rugby injury and performance project. IV. Anthropometric and physical performance comparisons between positional categories of senior A rugby players. *British Journal of Sports Medicine, 30*(1), 53-56.

Quarrie, K. L., & Wilson, B. D. (2000). Force production in the rugby union scrum. *Journal of Sports Sciences, 18*(4), 237-246. doi: 10.1080/026404100364974

Sedeaud, A., Marc, A., Schipman, J., Tafflet, M., Hager, J. P., & Toussaint, J. F. (2012). How they won Rugby World Cup through height, mass and collective experience. *British Journal of Sports Medicine, 46*(8), 580-584. doi: 10.1136/bjsports-2011-090506

Trewartha, G., Preatoni, E., England, M. E., & Stokes, K. A. (2014). Injury and biomechanical perspectives on the rugby scrum: a review of the literature. *British Journal of Sports Medicine*. doi: 10.1136/bjsports-2013-092972

Usman, J., & McIntosh, A. S. (2012). Upper limb injury in rugby union football: results of a cohort study. *British Journal of Sports Medicine*. doi: 10.1136/bjsports-2012-091224

Wetzler, M. J., Akpata, T., Laughlin, W., & Levy, A. S. (1998). Occurrence of cervical spine injuries during the rugby scrum. *American Journal of Sports Medicine, 26*(2), 177-180.

Youdas, J. W., Carey, J. R., & Garrett, T. R. (1991). Reliability of measurements of cervical spine range of motion--comparison of three methods. *Physical Therapy, 71*(2), 98-104.