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Original research

Neck strength and concussion prevalence in football and rugby athletes

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ABSTRACT

Objectives: To determine the maximal isometric neck strength of male and female rugby and football (soccer) athletes, and to investigate the relationship between neck strength and sport played, sex, age, anthropometric measurements and concussion history.
Design: Cross-sectional observational study.
Methods: In total, 358 (70% male) healthy football and rugby playing adolescents and adults participated. Isometric neck strength and anthropometry measurements were collected, as well as completion of a sociodemographic survey. The mean (standard deviation) of all measurements for each age group was calculated and compared between sports and sexes, with correlation analyses performed to determine associations between all variables.
Results: In general, rugby athletes had stronger neck musculature compared to football athletes, and males had stronger neck musculature compared to age-matched females, with these strength differences becoming increasingly significant with age ($p < 0.05$). The athletes with stronger neck muscles were older, taller, heavier, had higher bilateral grip strength and larger neck girth compared to those with weaker neck muscles ($p < 0.05$). Male rugby athletes who self-reported higher rates of a previous concussion had lower neck flexor/extensor strength ratio ($p < 0.01$). In 11–12-year-old male footballers, increased heading was associated with increased self-reported previous concussion ($p < 0.01$).
Conclusions: These normative neck strength data can form important reference values for rugby and football athletes from adolescence into adulthood. Male rugby athletes with a previous history of concussion demonstrated strength imbalances of their neck musculature (lower flexor/extensor ratio), with this finding having potentially important implications for training protocols and injury prevention initiatives.

Practical implications

- These neck strength reference values may be useful for coaches, medical and performance staff involved with football and rugby when assessing players' concussion risk.
- We suggest that concussion prevention initiatives and programmes should be focused on increasing the strength of the neck muscles, particularly the neck flexors to gain a higher flexor/extensor ratio and the concurrent stabilisation of the head on contact.
- We suggest that in football, particularly in the younger athletes, teaching correct football heading technique is imperative for concussion prevention.

1. Introduction

Rugby (union and league) and football (soccer) are popular contact sports played around the world. In Australia, 48% of children aged 14 years and younger, and 83% of females and 79% of males aged over 15 years participate in organised sport at least once per week.[1] Playing contact sport comes with a risk of injury, including sustaining a sports-related concussion, defined as a traumatic brain injury that results from biomechanical forces to the body including the head and neck.[2]

It has been proposed that higher neck strength may reduce the risk of sustaining a sports-related concussion.[3,4] Stronger neck muscles, when activated, may increase the ability to absorb the impact forces during head or body contact, mitigating the transfer of energy from the head to the brain.[4] A strong, stiff, activated neck can increase the 'effective mass' of the athlete, resulting in reduced head acceleration and potentially the risk of concussion.[5,6] Research by Collins et al.[3] concluded that for every one-pound increase in neck strength, risk of concussion decreased by 5%. Obtaining normative values of neck strength is a critical first step in exploring the possible protective role of neck muscles to assist with the development of tailored injury prevention strategies, however there is limited data for adolescent rugby and football playing populations.[6,7]

The cervical flexor/extensor ratio can be determined from neck strength measurements and has been proposed as a potential indicator of concussion risk.[8] This ratio documents the strength between reciprocal muscle groups in the neck which play an important role in stabilising

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the cervical spine, however this relationship needs further exploration. The effect of a previous concussion on neck strength (including the flexor/extensor ratio) has also not been explored, which is an important consideration given the high prevalence of repeated sports-related concussions from participation in contact sport.

Anthropometric measurements, used to assess the composition of the body, also have associations with neck strength.[3,10] When a muscle undergoes hypertrophy, the cross-sectional area of the muscle fibre increases. Hypertrophy of the neck muscles would therefore be expected to increase neck girth, indicating that this non-invasive measure may be a good indicator of neck strength. However, there is currently no consensus for this amongst current literature.[3,10] Grip strength is a biomarker representing outcomes such as overall strength and upper limb function, however the correlations reported between neck and grip strength are highly variable between studies.[10,14] The influence weight, height and body mass index (BMI) have on neck strength values also currently has no consensus[3,10,14] and therefore warrants further investigation particularly within an adolescent cohort.

The aims of this cross-sectional study were to explore the:

1) maximal isometric neck strength of male and female rugby and football athletes, and
2) relationship between neck strength and sport played, sex, age, anthropometric measurements, and concussion history.

2. Methods

Ethical approval was granted from the Human Research Ethics Committee of The University of Sydney (2019/655) and the procedure was carried out according to the National Statement on Ethical Conduct in Human Research (2007).

This cross-sectional comparative observational study included high school students (aged 11–16 years) and adults (aged 17 years and over) who played football or rugby (league and/or union). Eligibility criteria for participation included male and female students who were enrolled in a selective sport development programme for football, rugby union or league within one of two sports high schools within New South Wales (NSW) or were an adult male athlete from a rugby or football development academy, or an adult female football or rugby athlete from a high-level University club. Athletes and their parents/guardians (if <18 years) were given a Participant Information Statement and consent form from the research team *via* their school or academy/club.

Data were collected between February 2020 and April 2021. All consenting, eligible athletes completed a screening assessment with an experienced physiotherapist (MM or KP) involving questions about current neck pain/symptoms, previous concussions and head and neck injury history. A physical assessment of the cervical spine was completed, including range of motion and posterior midline tenderness. Any athlete who reported current neck pain or had sustained a concussion or neck injury within the last 28 days was excluded. Measures for each athlete were collected at one time-point during the pre-season period for their sport and included: A face-to-face sociodemographic survey completed with a member of the research team regarding age, sport, position, number of years they had played the sport, current completion of neck strengthening exercises, hours per week spent training, number of football headers per week, history of diagnosed concussions and potential concussive events (defined as a blow to an athlete's head or body whilst playing their chosen sport that left them with a headache, feeling dizzy, sick or unwell).

Anthropometry assessment included weight (Tanita Solar Scale, Model No: 1631) and height (Seca Portable Stadiometer, Model No: 213), neck girth (measured with a cloth tape held superior to the thyroid cartilage, and perpendicular to the long axis of the neck, with their head in neutral),[9] grip strength and neck strength. Grip strength was measured using a Jamar™ (USA) hydraulic hand dynamometer in sitting with the elbow at 90 degree flexion, and the highest value from two maximal efforts on each hand was recorded. Neck strength measurements were assessed using a hand-held dynamometer (GSA Analyser™, Gatherer Systems, UK) and were completed for all athletes by the same experienced assessor (KP) following a standardised testing protocol with established reliability.[10–12] In sitting, a head harness with a load cell placed in series was secured to the athlete's head. Maximal isometric neck muscle contraction was tested using a 'break technique' where incremental manual loading of the head harness occurred until the athlete's head moved out of the neutral position. Verbal informed consent was provided before testing and the athlete completed a warm-up and practice prior to assessment.[10–12] The highest value from two maximal isometric contractions of neck flexors, extensors and lateral flexors was recorded.[10–12]

An *a priori* sample size calculation using g* power (version 3.1.9.7, Dusseldorf, Germany) estimated that a minimum total sample size of 214 athletes was required ($n = 107$ per sport for rugby and football) based on two independent Pearson's r tests with moderate correlation between variables ($r = 0.50$, $\alpha = 0.05$ and $\beta = 0.95$). To account for a likely recruitment of more males than females it was estimated that a minimum of 161 males and 81 females (total $n = 242$) was needed based on two independent Pearson's r tests with moderate correlation between variables ($r = 0.50$, $\alpha = 0.05$ and $\beta = 0.95$). All statistical analyses were performed using SPSS Version 27 (IBM Statistics, Armonk, NY). Statistical significance was assessed at two levels, $p < 0.01$ and $p < 0.05$.

For descriptive and inferential analyses, athletes were categorised according to their age on the day of testing. Anthropometric and neck strength measurements are reported as means and standard deviations (SDs). Neck strength results are expressed as absolute values and values adjusted for height, weight and BMI.[6,7] The neck flexor/extensor strength ratio was calculated by dividing the neck flexor score by the neck extensor score. A flexor/extensor score below 0.6 was considered low, based on earlier research.[7] Self-reported heading and prevalence of concussions or potential concussive events are also reported using a percentage of the total athletes in each group who self-reported a prior history of these events. Independent sample *t*-tests (2-tailed) were then conducted for all values to determine the significance between sports and sexes.

A bivariate Pearson correlation analysis was conducted to determine associations between continuous variables with a point-biserial Pearson correlation analysis for dichotomous and continuous variables. Analyses were conducted within subgroups (sport type, age and sex). Self-reported concussion history was used to determine the correlation with anthropometric and neck strength measurements for athletes with/without a history of concussion. A strong correlation was defined as $r > 0.700$, moderate $r = 0.500$–0.699, fair $r = 0.250$–0.499 and little to no relationship $r < 0.249$.[13]

3. Results

In total, 358 athletes (30% female and 70% male) including 231 football athletes and 127 rugby athletes with a mean age of 14.56 years (SD 2.90) participated from two sports high schools and three sports academies/clubs. No athletes declined to participate, and none were excluded from the study following the screening assessment. The only missing data included left grip strength of one 14-year-old male due to a current thumb injury. The female rugby athletes, aged 17+ years, were the only group who self-reported completing specific neck muscle strengthening exercises (which included isometric neck holds and range of movement neck rolls). Descriptive data, including the mean (SD) of athlete anthropometric variables, prevalence of self-reported concussions, potential concussive events and football headers per week are presented in Table 1.

The means (SDs) of the raw isometric neck strength values and neck strength adjusted for weight are presented in Table 2. Male rugby athletes demonstrated higher neck strength values with increasing age when compared with male footballers. For females, rugby athletes in the oldest age group (17+ years) were significantly stronger than

Table 1
Player demographics and anthropometrics.

	Total sample	11–12 years				13 years				14 years				15–16 years				17+ years			
		Males		Females		Males		Females		Males		Females		Males		Females		Males		Females	
		Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby
No.	358	45	21	15	2	41	10	17	2	31	19	15	5	20	26	18	7	13	23	16	12
Age (years)	14.56	11.91	11.90	11.93	12.00	13.00	13.00	13.00	13.00	14.00	14.00	14.00	14.00	15.00	15.04	15.22	15.00	18.69	18.74	19.75	22.75
	(2.90)	(0.20)	(0.30)	(0.26)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.20)	(0.43)	(0.00)	(0.75)	(0.62)	(3.26)	(3.93)
Height (cm)	166.02	153.36	160.33	153.80	164.50	159.27	172.70	158.53	164.00	171.47	173.29	159.60	166.00	172.32	176.02	161.24	166.86	180.39	185.72	166.69	170.25
	(11.87)	(8.34)[a]	(8.17)[d]	(4.20)[a]	(0.71)	(8.84)[a]	(5.52)	(5.69)	(4.24)	(9.33)[c]	(7.21)[c]	(6.31)[a]	(2.92)	(8.57)[c]	(7.42)[c]	(5.12)	(6.44)	(5.91)[b,c]	(6.35)[c]	(5.91)	(7.79)
Weight (kg)	59.96	42.53	52.17	43.27	59.00	49.86	64.45	46.29	59.00	62.01	73.68	55.67	57.80	61.82	74.59	57.82	61.49	73.46	94.65	61.94	73.17
	(16.91)	(7.16)[a]	(11.23)	(4.08)[b]	(2.83)	(10.53)[a]	(11.34)	(6.70)[b]	(2.83)	(8.78)[b,d]	(17.49)[c]	(8.75)	(3.77)	(9.39)[a]	(15.26)[c]	(7.10)	(5.53)	(6.70)[a,c]	(8.83)[c]	(8.87)[a]	(10.29)
BMI (kg/m^2)	21.35	18.00	20.10	18.31	21.81	19.51	21.49	18.38	21.93	21.04	24.36	21.88	20.95	20.73	23.87	22.22	22.07	22.57	27.44	22.24	25.23
	(3.67)	(2.09)[a]	(2.85)	(1.77)	(1.23)	(3.01)	(2.87)	(2.18)[a]	(0.08)	(2.00)[a]	(4.71)[c]	(3.52)	(0.78)	(2.12)[a,d]	(3.35)[d]	(2.33)	(1.38)	(1.62)[a]	(2.18)[d]	(2.37)[b]	(3.14)
Neck girth (cm)	33.36	30.63	33.02	28.94	32.50	31.70	33.90	31.38	32.50	33.13	35.53	31.60	32.80	32.85	36.98	31.00	33.21	37.77	41.63	32.31	35.00
	(3.52)	(1.74)[a,c]	(2.65)	(1.09)[b]	(0.71)	(1.38)[b]	(2.18)	(1.60)	(0.71)	(1.34)[a,c]	(2.70)[d]	(1.59)	(1.48)	(1.81)[a,c]	(2.38)[c]	(1.24)[a]	(1.47)	(2.17)[a,c]	(1.89)[c]	(1.58)[a]	(2.00)
Left grip strength (kg)	33.39	24.82	28.95	24.33	27.00	29.63	33.00	26.88	30.00	35.83	36.58	25.13	26.60	35.80	41.08	30.72	33.57	44.38	59.91	30.75	34.50
	(10.64)	(4.40)[a]	(3.93)	(4.35)	(1.41)	(4.77)[b,d]	(3.65)	(4.01)	(2.83)	(6.34)[c]	(9.16)[c]	(3.54)	(1.95)	(7.35)[b,d]	(10.24)[d]	(4.11)	(7.00)	(8.00)[a,c]	(7.69)[c]	(5.96)	(4.60)
Right grip strength (kg)	35.54	25.69	30.43	24.60	29.00	31.80	34.90	29.41	33.00	38.00	39.11	27.60	30.20	39.00	43.96	31.78	34.57	48.69	62.70	34.88	35.67
	(11.20)	(4.68)[a]	(4.38)	(4.47)[b]	(1.41)	(4.99)[d]	(4.95)	(2.62)	(2.83)	(6.60)[c]	(9.55)[c]	(4.03)	(1.92)	(7.35)[c]	(10.56)[c]	(4.97)	(6.16)	(7.06)[a,c]	(8.17)[c]	(7.20)	(4.74)
Years played (years)	8.20	7.64	7.12	7.30	2.00	8.36	7.00	7.53	3.00	9.29	8.58	7.20	2.60	8.75	8.81	7.61	1.79	13.77	10.61	12.00	3.29
	(3.04)	(1.27)	(1.48)[c]	(2.09)[a]	(0.00)	(1.50)[b]	(1.63)[c]	(1.94)[a]	(0.00)	(1.68)[c]	(2.32)[c]	(1.57)[a]	(0.55)	(2.17)	(2.37)[c]	(2.59)[a]	(0.39)	(1.24)[a]	(2.33)[c]	(5.35)[a]	(1.84)
Training time per week	9.09	9.21	5.78	9.23	5.00	9.68	5.75	9.68	6.50	9.76	7.89	8.90	8.00	8.48	9.42	9.17	6.71	6.23	14.57	8.59	11.50
(h)	(3.22)	(2.55)[a]	(1.90)	(1.62)[a]	(0.00)	(1.54)	(1.65)	(1.54)	(2.12)	(1.75)[b,d]	(2.66)	(0.87)	(1.22)	(1.40)	(5.04)[d]	(2.92)[b]	(1.60)	(1.67)[a,d]	(4.30)[d]	(3.52)	(3.85)
Self-reported concussion n = 349	83	5	3	2	0	5	1	1	1	5[b]	9	1	1	3[b]	12	4	2	5	14	4	5
Percent of total (%)	23.20	11.10	14.30	13.30	0.00	12.20	10.00	5.90	50.00	16.10	47.40	6.70	20.00	15.00	46.20	22.20	28.60	38.50	60.90	25.00	41.70
Self-reported potential concussive event n = 356	127	18[b]	15[c]	5[b]	0	15	4	7	1	11	8	2	1	3	7	7	2	5	5	7	4
Percent of total (%)	35.50	40.00	71.40	33.30	0.00	36.60	40.00	41.20	50.00	35.50	42.10	13.30	20.00	15.00	26.90	38.90	28.60	38.50	21.70	43.80	33.30
Self-reported heading no. per week		37	–	15	–	38	–	16	–	30	–	15	–	19	–	14	–	13	–	16	–
Mean		18.78		13.93		16.76		12.00		7.00		4.73		7.32		4.00		9.69		5.88	
		(17.23)		(14.78)		(16.30)		(16.03)		(6.91)		(4.08)		(6.92)		(4.64)		(5.57)		(4.18)	
Range		0–60		1–50		0–65		0–50		0–30		0–15		0–25		0–15		5–25		0–13	

[a] Significant sport differences $p < 0.01$.
[b] Significant sport differences $p < 0.05$.
[c] Significant sex differences $p < 0.01$.
[d] Significant sex differences $p < 0.05$.

Table 2
Maximal isometric neck strength of male and female rugby and football athletes.

	Total sample	11–12 years				13 years				14 years				15–16 years				17+ years			
		Males		Females		Males		Females		Males		Females		Males		Females		Males		Females	
		Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby	Football	Rugby
No.	358	45	21	15	2	41	10	17	2	31	19	15	5	20	26	18	7	13	23	16	12
Maximal neck flexion (kg)	15.75 (5.80)	13.23 (3.02)	14.73 (3.11)[c]	11.96 (2.27)[a]	9.38 (0.23)	15.27 (4.33)[a,c]	21.70 (4.64)	11.91 (3.72)	12.83 (5.64)	18.60 (4.74)[c]	17.50 (6.79)[d]	9.11 (2.99)	10.99 (3.37)	15.99 (4.79)[c]	19.79 (8.35)[c]	12.21 (3.48)	12.58\ (4.18)	18.58 (7.29)	22.47\ (4.75)[d]	15.23 (5.30)	18.17 (4.08)
Adjusted for weight		0.32 (0.08)	0.29 (0.07)[c]	0.28 (0.07)[a]	0.16 (0.00)	0.31 (0.09)	0.34 (0.09)	0.27 (0.11)	0.22 (0.11)	0.30 (0.08)[b,c]	0.25 (0.10)	0.16 (0.05)	0.19 (0.07)	0.26 (0.07)[d]	0.26 (0.08)	0.21 (0.07)	0.20 (0.07)	0.25 (0.08)	0.24 (0.04)	0.24 (0.06)	0.25 (0.04)
Maximal neck extension (kg)	24.12 (9.12)	16.92 (3.53)	18.48 (3.77)	16.34 (2.83)	16.74 (5.97)	23.06 (5.12)[d]	27.70 (7.08)	19.98 (4.89)	18.48 (6.94)	28.13 (6.44)[c]	29.42 (10.30)[c]	16.06 (4.90)	18.59 (4.69)	23.55 (4.87)[a]	33.10 (8.85)	16.99 (4.54)	17.79 (4.41)	30.29 (7.29)[a,d]	41.01((7.97)[c]	24.33 (4.42)[b]	29.54 (7.23)
Adjusted for weight		0.40 (0.08)	0.36 (0.08)	0.38 (0.07)	0.28 (0.08)	0.47 (0.10)	0.43 (0.10)	0.44 (0.14)	0.32 (0.13)	0.46 (0.12)[c]	0.40 (0.11)	0.29 (0.08)	0.32 (0.10)	0.38 (0.06)[a]	0.44 (0.08)	0.30 (0.08)	0.29 (0.06)	0.41 (0.08)	0.43 (0.07)	0.40 (0.08)	0.40 (0.08)
Flexor/extensor ratio	0.68 (0.18)	0.79 (0.16)	0.81 (0.15)	0.74 (0.12)	0.60 (0.20)	0.66 (0.13)[b]	0.81 (0.16)	0.61 (0.15)	0.69 (0.05)	0.68 (0.16)[d]	0.61 (0.18)	0.58 (0.11)	0.59 (0.13)	0.69 (0.19)	0.59 (0.13)	0.76((0.32)	0.72 (0.24)	0.60 (0.14)	0.55 (0.10)	0.63 (0.17)	0.64 (0.16)
Maximal neck left lateral flexion (kg)	17.60 (6.21)	14.31 (3.43)	15.47 (2.55)	13.75 (2.74)	12.67 (3.71)	17.57 (4.48)[d]	19.16 (4.50)	14.63 (3.62)	12.40 (5.88)	19.15 (3.24)[c]	18.27 (5.49)[d]	11.55 (3.89)	12.63 (3.80)	16.73 (4.15)[a]	22.46 (8.01)	13.14 (3.22)	14.90 (4.17)	20.84 (6.65)[a]	28.90 (6.73)[c]	17.25 (4.44)[b]	22.08 (6.20)
Adjusted for weight		0.34 (0.09)	0.31 (0.07)	0.32 (0.08)	0.22 (0.05)	0.36 (0.09)	0.30 (0.08)	0.33 (0.11)	0.22 (0.11)	0.31 (0.06)[c]	0.26 (0.08)	0.21 (0.07)	0.22 (0.08)	0.27 (0.06)[d]	0.30 (0.08)	0.23 (0.06)	0.24 (0.07)	0.28 (0.08)[a]	0.30 (0.06)	0.28 (0.06)	0.30 (0.07)
Maximal neck right lateral flexion (kg)	17.55 (6.25)	14.25 (3.59)	15.45 (2.56)	13.37 (2.67)	12.87 (3.63)	17.74 (4.37)[d]	20.54 (4.25)	14.92 (3.92)	14.10 (5.83)	18.61 (3.46)[c]	18.22 (4.91)[d]	11.51 (3.54)	12.07 (3.54)	16.57 (3.70)[a]	23.48 (9.23)	13.09 (2.90)	13.24 (3.15)	21.34 (6.32)[a,d]	28.12 (7.21)[c]	16.99 (3.99)[b]	21.27 (4.66)
Adjusted for weight		0.34 (0.09)	0.31 (0.07)	0.31((0.07)	0.22 (0.05)	0.36 (0.09)	0.32 (0.06)	0.34 (0.13)	0.24 (0.11)	0.31 (0.07)[b,c]	0.25 (0.07)	0.21 (0.07)	0.21 (0.07)	0.27 (0.06)[d]	0.31 (0.08)	0.23 (0.05)	0.21 (0.05)	0.29 (0.08)	0.30 (0.06)	0.28 (0.06)	0.29 (0.05)
Total neck strength (kg)	75.01 (25.53)	58.70 (11.79)[b]	64.13 (8.66)	55.42 (8.76)	51.66 (13.53)	73.64 (16.33)[b,c]	89.10 (18.24)	61.44 (14.71)	57.81 (24.28)	84.49 (15.12)[c]	83.41 (24.44)[c]	48.22 (14.33)	54.28 (11.27)	72.84 (14.26)[a]	98.83 (32.88)	55.43 (11.98)	58.52 (14.09)	91.06 (25.16)[a,d]	120.49 (24.41)[c]	73.80 (15.77)[b]	91.07 (19.85)
Adjusted for weight		1.40 (0.30)	1.27 (0.24)	1.29((0.25)	0.87 (0.18)	1.51 (0.33)	1.40 (0.31)	1.38 (0.47)	1.00 (0.46)	1.39 (0.28)[b,c]	1.16 (0.32)	0.87 (0.24)	0.95 (0.25)	1.19 (0.19)	1.31 (0.29)	0.96 (0.22)	0.95 (0.21)	1.23 (0.28)	1.27 (0.20)	1.19 (0.20)	1.24 (0.20)

[a] Significant sport differences $p < 0.01$.
[b] Significant sport differences $p < 0.05$.
[c] Significant sex differences $p < 0.01$.
[d] Significant sex differences $p < 0.05$.

similarly aged footballers ($p < 0.05$). However, when adjusted for weight the values were no longer significant (Appendix A). Female rugby and football athletes demonstrated significantly weaker neck strength profiles than aged-matched male rugby and football athletes for all age groups except the youngest athletes aged 11–12 and 13 years.

When football and rugby data were combined, there was a fair correlation between maximal isometric neck strength and age with neck strength increasing for all directions of movement as athletes got older ($r = 0.287–0.453$, $p < 0.001$), an exception being the neck flexor/extensor ratio which decreased with age ($r = -0.407$, $p < 0.001$) (Appendix B). Athletes with stronger neck strength in all directions of movement were correlated with being taller, heavier, had stronger bilateral grip strength and larger neck girth compared to those with weaker neck strength. Neck extensor strength showed the strongest correlation with grip strength (Right; $r = 0.772$, $p < 0.001$ Left; $r = 0.760$, $p < 0.001$) and neck girth ($r = 0.738$, $p < 0.001$); however neck flexor strength was only moderately correlated with grip strength (Right; $r = 0.629$, $p < 0.001$ Left; $r = 0.637$, $p < 0.001$) and neck girth ($r = 0.552$, $p < 0.001$). Those with stronger neck muscles correlated with more hours of training per week and had played the sport for more years when compared to those with weaker neck muscles.

The above findings were also found in the rugby athletes (Appendix C). Male rugby athletes with stronger neck extensors were strongly correlated with stronger right grip strength ($r = 0.795$, $p < 0.001$) and larger neck girth measurements ($r = 0.739$, $p < 0.001$) (Appendix D). In female rugby athletes, higher neck strength was correlated with increasing age, weight, neck girth and training hours in the 17+ age group only (Appendix E). In footballers, those with stronger neck extensor muscles were strongly correlated with being taller ($r = 0.559$, $p < 0.001$), heavier ($r = 0.538$, $p < 0.001$), had stronger grip strength (Right; $r = 0.664$, $p < 0.001$ and Left; $r = 0.645$, $p < 0.001$) and larger neck girth ($r = 0.584$, $p < 0.001$) (Appendix F). For female footballers, only athletes in the 17+ age group demonstrated a correlation of stronger overall neck strength with being taller ($r = 0.658$, $p = 0.006$), heavier ($r = 0.586$, $p = 0.017$), stronger grip strength (R: $r = 0.755$, $r = 0.001$ and L: 0.784, $p < 0.001$) and higher number of training hours ($r = 0.510$, $p = 0.043$).

In male rugby athletes, higher rates of self-reported previous concussion were reported in athletes who had a lower neck flexor/extensor strength ratio ($r = -0.338$, $p = 0.001$) (Appendix D). Self-reported concussion prevalence in 11–12-year-old male footballers demonstrated a fair correlation with the increasing number of years the sport had been played for ($r = 0.381$, $p = 0.001$). The number of self-reported headers was lower with increasing age particularly for males ($r = -0.307$, $p < 0.001$) (Appendix F). Players who self-reported higher numbers of headers were more likely to self-report a history of concussion in male 11–12 footballers ($r = 0.447$, $p = 0.006$).

4. Discussion

Our findings showed that rugby athletes had stronger neck musculature compared to footballers, and males had stronger neck musculature compared to females, which supports earlier studies.[6,14] The differences in neck strength between sexes became increasingly significant in the older age groups which is likely attributed to the increased muscular development particularly in boys during puberty.[15] The differences between the sports is likely due to the different physical demands of rugby resulting in stronger muscles, as well as the athlete's natural physique potentially influencing their chosen sport. Disparities with athlete maturation, muscle development and mass due to genetic and hormonal differences may also have contributed to the differences between the sports and sexes, however, these data were not collected as part of our study.[16]

Athlete neck strength in all directions was correlated with increased age, a finding which supports earlier studies,[7,10,14] and likely attributable to pubertal development, as well as the sports high schools commencing strength and conditioning training from 14 to 15 years of age. In addition, as athletes got older they trained for more hours per week, potentially leading to the development of increased neck muscle strength through actions involved in contact training (such as scrum practice) or heading. Specific neck muscle training, however, was only reported in the 17+-year-old female rugby athletes. The association between increased neck strength with age was strongest in male athletes, with a weaker association found in female athletes. Previous evidence of neck strength development during adolescence within a sporting population is largely based on boys and men,[10,14,17] and should not be applied to girls and women due to anatomical and physiological differences, therefore further research focusing solely on girls and women is needed.

Overall, neck extensor strength (when compared with neck flexor strength) was more strongly correlated to neck girth and grip strength. This finding highlights the need to assess both the neck flexors and extensors in contact sport athletes to gain a more informed neck strength profile and that a proxy measure of neck strength (such as grip strength or neck girth) should not be used. Our study also found that neck extensor strength was moderately–strongly correlated to athletes' height, weight and BMI overall, supporting earlier research.[7,10,17]

Rugby athletes reported a significantly higher number of previous concussion prevalence compared to footballers, which aligns with an earlier study.[18] Overall, males reported higher concussion prevalence compared to females, in contrast to previous literature reporting that females sustain higher rates of concussion.[19,20] This difference may be due to the selected sports schools having a higher number of males enrolled in rugby, as female athletes typically start playing rugby at an older age.[21] Our results show that male rugby athletes of all ages had played the sport for significantly more years compared to females, and consequentially had increased opportunity to sustain a concussion.

Athletes in both sports and sexes reported a similar number of self-reported previous potential concussive events, which is not widely reported in the literature. In rugby most concussive and potential concussive events occur during tackles or collisions,[22] whereas in football the most common mechanism is from elbow-to-head and head-to-head contact usually during a heading duel.[23] Interestingly, higher numbers of self-reported headers per week were associated with increased reported history of concussions in male footballers aged 11–12 years. An earlier study of heading incidence in a similar cohort of footballers reported that athletes aged 9 years and older regularly head the ball in competitive matches.[24] Furthermore, head acceleration during heading in professional footballers has been shown to be lower compared to adolescent footballers, likely due to improved technique, larger overall body mass and stronger neck muscles.[25] These results may indicate a need to reduce heading exposure for young footballers to decrease their risk of concussion, as well as ensuring that they are taught good heading technique, including body positioning for heading duels, before they start to head the ball in matches.

Male rugby athletes with a lower neck flexor/extensor ratio were correlated with a higher history of concussion prevalence, however the cross-sectional design of our study means that it is not possible to infer causality or longitudinal trends. Further research is needed to determine if a lower flexor/extensor ratio contributed to the athlete sustaining a concussion, or if sustaining a concussion resulted in a lower flexor/extensor ratio. A sports-related concussion can occur through a whiplash-type movement, where the neck hyperextends followed by hyperflexion.[26] This mechanism is potentially facilitated by weaker neck flexors in relation to the neck extensors (*i.e.* lower flexor/extensor strength ratio). The relationship between the neck flexor/extensor ratio and head acceleration was reported in a study by Dezman et al., which concluded a lower flexor/extensor ratio resulted in higher head acceleration.[8] These findings may indicate that increasing the strength of the neck flexor muscles, thereby increasing the flexor/extensor strength ratio, is key in reducing head acceleration and stabilising the head–neck–torso during impacts to the head or body.[4,12]

Earlier research reported that lower neck strength results in increased concussion incidence.[3,4] Intervention programmes that include neck strengthening exercises can decrease the number of head/neck injuries, including concussion.[27,28,29] In footballers, addition of neuromuscular neck exercises to the FIFA 11+ programme was also found to reduce head impact magnitude in adolescents.[12] However, such studies and interventions have focused on increasing neck strength as a whole, not the flexor/extensor strength ratio. Our findings are clinically important as they indicate a need for specific neck training programmes to focus on increasing the neck flexor/extensor strength ratio and subsequent stabilisation of the head on contact. Further research is recommended which focuses on specific neck strength interventions aimed at increasing the flexor/extensor strength ratio and the potential protective effect on concussion risk.

Furthermore, as athletes got older, their neck flexor/extensor ratio decreased. This may be due a natural increase in neck extensor dominance that occurs with maturation or as a result of sport participation, and/or strength and conditioning exercises. It is also possible that strengthening exercises involving the upper limbs, especially the upper trapezius, increase the strength of the neck extensors but not the neck flexors.[4] The demands of these sports may also promote neck extensor dominance, therefore the older and longer athletes have played their sport, the lower the flexor/extensor ratio becomes. The flexor/extensor ratio was highest in the 11–12-year-old athletes, therefore injury prevention interventions aimed at maintaining this higher ratio may have their greatest impact if implemented from a young age.

Athletes in this study played at a high-level which may affect the generalisability of the results to athletes with a lower skill level in these sports. Although the assessment of neck strength is not routinely collected in many contact sport athletes,[10] there is potential to add this assessment to the battery of physical outcome measures collected during the pre-season period. The neck assessment protocol used in this study took 4–5 min to complete per athlete with established reliability used across a number of earlier studies in both football and rugby.[10–12] There's a growing awareness of concussion in contact sports, which along with recall bias may have caused athletes to under or over-report the number of previous concussions and/or potential concussive events. However self-reporting was used consistently across all age groups with the percentage of athletes reporting a history of concussion in our study (23%) being of a similar value to earlier self-reported concussion rates in high-school American football (30%), football (soccer) (21%), lacrosse (30%) and basketball athletes (23%).[30] In addition, self-report was the only means for us to collect these data as there is no standardised reporting system used in Australian sport. It is acknowledged that the smaller sample size of females may have influenced the results, due to the lower number of females enrolled within sport development programmes at the two sports high schools, especially rugby, and this recruitment bias towards males was expected and thus accounted for in the *a priori* sample size calculation. Finally, female rugby athletes aged 17+ years reported completing limited neck exercises which may have influenced the results in this cohort.

5. Conclusion

This study provides important normative neck strength data of adolescent and adult, male and female, football and rugby athletes. These reference values may be useful for coaches, medical and performance staff involved with football and rugby when assessing athletes' concussion risk. Male rugby athletes with a previous history of concussion demonstrated strength imbalances of their neck musculature (lower flexor/extensor ratio), with this finding having potentially important implications for injury prevention programmes aimed at increasing the strength of the neck muscles, in particular the flexor/extensor ratio, and the subsequent stabilisation of the head on contact.

Data availability

The datasets (deidentified participant data) generated during and/or analysed are available from the corresponding author on request.

CRediT authorship contribution statement

Kerry Peek developed the initial concept and design of this study. Kerry Peek, Marnee McKay, Shannon Nutt and Lachlan Gillies collected the data. Shannon Nutt inserted, cleaned and analysed the data. The first draft of the manuscript was written by Shannon Nutt with initial review from Kerry Peek and Marnee McKay. All authors commented on versions of the manuscript and all read and approved the final manuscript.

Consent to participate and publish

All participants and their parent/carer/guardian provided written consent to participate and for the results to be published prior to study commencement.

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Declaration of interest statement

Shannon Nutt, Marnee McKay, Lachlan Gillies and Kerry Peek declare that they have no competing interests or conflicts of interest.

Confirmation of ethical compliance

Ethical approval was granted from the Human Research Ethics Committee of The University of Sydney (2019/655) and the procedure was carried out according to the National Statement on Ethical Conduct in Human Research (2007).

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Appendix A. Supplementary data

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