ORIGINAL RESEARCH ARTICLE

The Effect of the FIFA 11 + with Added Neck Exercises on Maximal Isometric Neck Strength and Peak Head Impact Magnitude During Heading: A Pilot Study

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Abstract

Background Higher neck strength has been postulated to reduce head impact magnitude during purposeful heading in football.

Objectives This pilot trial explored the effect of a neck exercise programme on (1) neck strength and (2) head impact magnitude during heading in male and female adolescent football players.

Methods Boys and girls (aged 12–17 years) were randomised by team to the intervention (5 weeks of supervised neuromuscular neck exercises integrated into part 2 of the FIFA 11 +, completed three times per week) or the control group (usual part 2 of the FIFA 11 +, no neck exercises). Outcomes included isometric neck strength and head impact magnitude (peak linear acceleration and peak angular velocity) during standardised heading from a throw-in (at baseline and 6 weeks) plus completion of an evaluation survey by intervention players and coaches.

Results In total, 52 players ($n = 31$ intervention; $n = 21$ control) completed the study. Mixed-model analysis of variance (ANOVA) revealed significant differences in neck strength variables ($p < 0.001$), peak linear acceleration ($p = 0.04$) and peak angular velocity ($p = 0.04$) between the intervention and control groups over time. Intervention players demonstrated increases in mean composite neck strength (53.8% intervention vs 15.6% control) as well as decreases in mean peak linear head acceleration during heading (-11.8% vs -5.0%) from baseline to follow-up. Reduction in peak angular velocity was more pronounced in girls (-27.7%) than boys (-11.5%) in the intervention group. The addition of neck exercises into part 2 of the FIFA 11 + was feasible and accepted by players and coaches.

Conclusion On average, players who completed neck exercises demonstrated an increase in isometric neck strength and a decrease in head impact magnitude during heading. These exercises were easily incorporated into usual training.
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1 Introduction

While heading has always been an integral part of football, there is growing uncertainty surrounding the role repeated head impacts from football heading has on brain health [1]. A recent cohort study reported that Scottish male professional football players ($n = 7676$) were more likely (hazard ratio 3.66; 95% confidence interval [CI] 2.88–4.65; $p < 0.001$) to be identified with a neurodegenerative disease when compared with matched controls ($n = 23,028$) from the general population [2]. Any impact to the head has the potential to cause a transmission of force to the brain [3]. Whether this results in detrimental stress and strain to brain tissue is likely related to head impact magnitude [3–6]. Head impact magnitude (including peak linear acceleration and angular velocity of the head) is influenced by many factors, including ball properties (mass and pressure) [7–9] and player characteristics (sex, age and neck strength) [10, 11].

Despite scientific uncertainty regarding the effects of purposeful heading [12–14], some football organisations have prohibited or restricted heading in young players [15, 16]. For example, the influential Football Associations of England, Scotland and Northern Ireland released updated heading guidance in 2020 and again in 2021, which state

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Key Points

Findings: Male and female adolescent players who completed a 5-week neuromuscular neck exercise programme integrated into part 2 of the FIFA 11+ demonstrated an increase in isometric neck strength and a decrease in head impact magnitude during purposeful heading from a throw-in

Implications: Consideration should be given to adding neuromuscular neck exercises to part 2 of the FIFA 11+ for adolescent football players to reduce head impact magnitude during heading

Caution: The effect of heading technique, particularly the differences in technique adopted by boys and girls, should be considered when evaluating the magnitude of head impact during purposeful heading in football

that heading should not be introduced in training sessions for players under 11 years, with restricted heading practice now including professional players [16]. No restrictions on heading in matches are evident in these guidelines, with heading practice recommended to commence with lighter balls [16]. Although prohibiting heading in training for young players will reduce the accumulative number of headers per season, it will not reduce age of first exposure if players can still head the ball in matches [17]. In addition, there are no sex distinctions evident in these guidelines despite boys physically growing at a faster rate than girls during puberty. Thus, a more inclusive preventative approach, such as improving the strength and neuromusculature control of the neck muscles, may offer a more holistic strategy to reduce head impact magnitude and heading burden in young players.

Greater neck strength has been postulated to attenuate resultant head kinematics during purposeful heading [18]. Stronger muscles have a greater cross-sectional area, tensile stiffness and ability to generate torque [18]. Newtonian physics have been used to compute head acceleration during purposeful headers for a wide variety of game situations, including the ability of the player to increase the effective mass of the head-and-neck segment during a heading manoeuvre [19]. Increasing the effective mass of the head-and-neck segment is achieved through isometrically or concentrically contracting selected neck musculature that stiffens the neck column and enhances the coupling of the head to the torso. The contracted neck muscles are then better able to absorb and dissipate the applied force on the head down through the neck to the body thereby minimising the resultant acceleration of the head on ball impact [19].

Child, adolescent and women football players are reportedly at greater risk of sustaining a concussion [20], with young athletes taking longer to recover than adult male players [21]. They also typically exhibit lower absolute neck strength, which may contribute to a higher risk of injury during heading [19]. Women collegiate football (i.e. soccer) players exhibited significantly lower neck strength and greater head accelerations during purposeful heading than men [22]. These sex-specific differences in neck strength have been attributed to reduced muscle mass and lower neck girth of women [10, 18, 23, 24]. Players with reduced neck strength often demonstrate an inability to generate the necessary stiffness of the neck column to control the head's response during purposeful heading [18].

A recent systematic review reported that injury reduction programmes that include neck exercises can reduce the risk of sport-related head and neck injuries, including concussion [25]. This review included two studies which explored the effect of the 'Activate' injury reduction programme (which includes neck exercises) designed for rugby union players [26, 27]. The equivalent injury reduction programme in football is the FIFA 11+ [28], which currently does not contain neck exercises. The FIFA 11+ consists of three parts. Parts 1 and 3 contain running exercises, with part 2 consisting of strength, plyometric and balance exercises. The whole programme is recommended to be completed at every training session and takes approximately 20 min to complete (including 10 min to complete part 2) [28].

Despite evidence that higher neck strength is associated with lower head acceleration during heading [11, 29], very few studies have explored the effect of a neck exercise programme on head acceleration during heading in adolescent players [30], with none adding neck exercises to the current FIFA 11+ injury reduction programme. In addition, the feasibility and acceptability of a neck exercise programme is still to be explored.

1.1 Objectives

The primary objectives were to explore the effects of the FIFA 11+ with added neck exercises on:

1. Isometric neck flexor, extensor and side flexor strength
2. Head impact magnitude during purposeful heading in male and female adolescent football players.

A secondary objective was to explore the adoption and feasibility of the programme.

2 Methods

2.1 Study Design and Setting

This pilot trial was undertaken and reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines [31]. Approval for the research was granted by the University's Human Research Ethics Committee. This study was performed in accordance with the standards of ethics outlined in the Declaration of Helsinki and registered with the Australian New Zealand Clinical Trials Registry.

2.2 Participants

All players aged 12–17 years ($n = 88$) who were registered with one high-level youth football club in New South Wales (NSW), Australia, were invited to participate. The club has boys' and girls' teams registered to play in the National Premier League in NSW, with players considered to be of a high-skill level for their age. Club players train three times per week for 40 weeks of the year, with a competitive playing season lasting approximately 22 weeks. Players were excluded if they self-reported symptoms or showed signs of a current head or neck injury during screening. Written consent was obtained from both the player and their parent/legal guardian.

2.3 Randomisation, Allocation Concealment and Blinding

In accordance with coronavirus disease (COVID-19) pandemic restrictions, a limited number of research personnel were permitted at the club during data collection. This, in addition to the nature of the intervention, meant that blinding of the assessor and players was not possible. However, data from the respective devices (hand-held dynamometer and inertia measurement unit [IMU]) were extracted and analysed by a researcher blinded to group allocation. Teams, rather than players, were randomised to the intervention or control group. Players from eight teams (four boys' and four girls' teams) consented to participate. To limit large variations in player ages and sex allocated to each trial group, the club was split into junior (under-13 and under-14 boys' and girls' teams) and senior teams (under-15 boys' and girls' teams and under-16 boys' team and under-17 girls' team). A coin toss was then used to allocate one boys' and one girls' junior team to the intervention group (with the process repeated for the senior teams). This resulted in two boys' teams and two girls' teams being allocated to the intervention group (one junior and one senior team per sex) with the remaining four teams being allocated to the control group.

2.4 Data Collection

Data were collected between June and October 2020, with baseline assessment being conducted at the start of the resumption of training and competition following the easing of COVID-19 pandemic restrictions in community sport within NSW.

2.4.1 Intervention

The intervention consisted of players completing the FIFA 11 + injury reduction programme with the addition of three neck exercises, three times per week for 5 weeks. The neck exercises were designed to be football-specific based on prior clinical application of neck exercises within a sporting environment. For the first exercise, based on the Versteegh Roll and Tuck (VRT), players were instructed to sit on the ground and hold their knees before rolling backwards and forwards as fast as they could whilst keeping their chin tucked in and not allowing their head to touch the ground/floor (Fig. 1). Players completed the VRT for one set of the following (each lasting 30 s): VRT with the head (1) pointed straight ahead, (2) turned to the left and (3) turned to the right. These exercises were integrated into part 2 of the FIFA 11 + which all players at this club completed at the end of training (parts 1 and 3 were completed as pre-training warm-up for all players). The VRT exercises were taught to players and coaching staff in the intervention arm by the project lead (KP) once all baseline measures had been collected. Club coaching staff supervised exercise completion at training, with the project lead attending a sample of four training sessions unannounced to review team and player adherence to the intervention. The VRT added less than 2 min to part 2 of the FIFA 11 +. Players were instructed to continue these exercises during the pre-season trial period as well as during the entire playing season.

2.4.2 Control

The control arm continued to complete the FIFA 11 + as usual with part 2 at the end of training (which included strength, balance and plyometric exercises) [28, 32] but without the addition of neck exercises.

2.5 Measures

Screening The screening assessment included a questionnaire that collected demographic and sport experience information (e.g. age, sex, playing history, position, estimated number of headers per week [in training and match play]) in addition to previous head injury history (including concussion), as well as questions regarding any current head or neck pain or symptoms. Players then underwent a physical

Fig. 1 Example of the Versteegh Roll and Tuck (VRT) neck flexor exercise for players in the intervention arm

cervical spine assessment (including range of movement and palpation for posterior midline tenderness, which was defined as any player reporting tenderness on palpation greater than what may be typically expected when gently pressing on the skin over the back of the neck) to exclude any participants with current cervical spine issues.

Anthropometry Height (Seca 217®, Germany) and weight (BF-522 Tanita®, Japan) were collected with players in their standard training kit of light-weight shirt and shorts.

Muscle strength Maximal isometric muscle strength of the neck was defined as the maximal load in kilograms that could be applied to the player's head before deviation from a neutral testing position was observed. Assessment was undertaken using a previously reported 'break technique' protocol by the project lead using a Gatherer Systems™ hand-held dynamometer as used in earlier studies [33–35]. A head harness, with a load cell placed in series, was secured to the player's head. With the player's head in an anatomically neutral position, the same assessor applied manual incremental loading until a loss of test position occurred (i.e. to the point of head movement). The highest score from two repetitions was recorded. The test was repeated for each direction of movement (flexion, extension and left and right side flexion), with the same procedure and assessor measuring neck strength at baseline and follow-up [33, 34]. Prior to the assessment, players were advised of the assessment procedure and were given an opportunity to warm-up and practise. No adverse events were reported during muscle strength assessment. Figure 2 demonstrates the set-up for assessing maximal isometric muscle strength for the neck extensors.

Head impact magnitude All players completed heading trials using a size 5 Adidas® (Starlancer™) ball inflated to 5 pounds per square inch (psi).

Heading trials were supervised by the project lead using a standardised procedure described previously [9]. Players wore a close-fitting latex 'swim cap' that housed an IMU (AX6™, Axivity™, Newcastle, UK) to measure head impact magnitude: linear acceleration (tri-axial accelerometer) and angular velocity (tri-axial gyroscope). The swim cap was placed on the player's head with the IMU positioned centrally at the base of the occiput, similar to the procedure used in earlier research [36]. Prior to data collection, we pilot tested our methods for capturing head impact magnitude during heading by mounting both this IMU (Axivity™) and a hard-wired 25-g tri-axial accelerometer (Entran, EGA3-F-25™) to participants' heads using the same swim cap method. The average error between the two devices was 0.07 g, taken across 12 headers involving three participants.

A pro-licensed football coach (and ex-international player) delivered the balls from the sideline using an overhead throw-in using the following game scenario, familiar to the age group of players [37], which was provided to each player before the first throw-in: [9]

> "Imagine that you are in a game, the ball has gone out of play and your team-mate is about to throw the ball to you from the side-line. You are going to head the ball back to your team-mate's feet so that they can play on."

For each heading trial, players were asked to stand within a 1×1 m box positioned 5 m from the sideline on a standard outdoor football pitch. The validity assessment of headers was made subjectively by the same member of the research team for all headers at baseline and follow-up. For headers to be recorded as valid, players had to receive the ball on their forehead (as opposed to the top or side of the head), return the ball towards the coach delivering the throw-in, keep their feet grounded and be located inside the box when the header occurred. Otherwise, players could adopt any standing position or heading technique of their choosing. Invalid headers were repeated until at least two valid headers were recorded to a maximum of five headers to reduce heading burden. The intra-tester reliability of throw-ins was calculated from a sub-set of ten headers captured using slow motion video (120 frames per seconds) and using a process described previously [9].

Fig. 2 Dynamometry assessment position for neck extensors (image courtesy of Gatherer Systems)
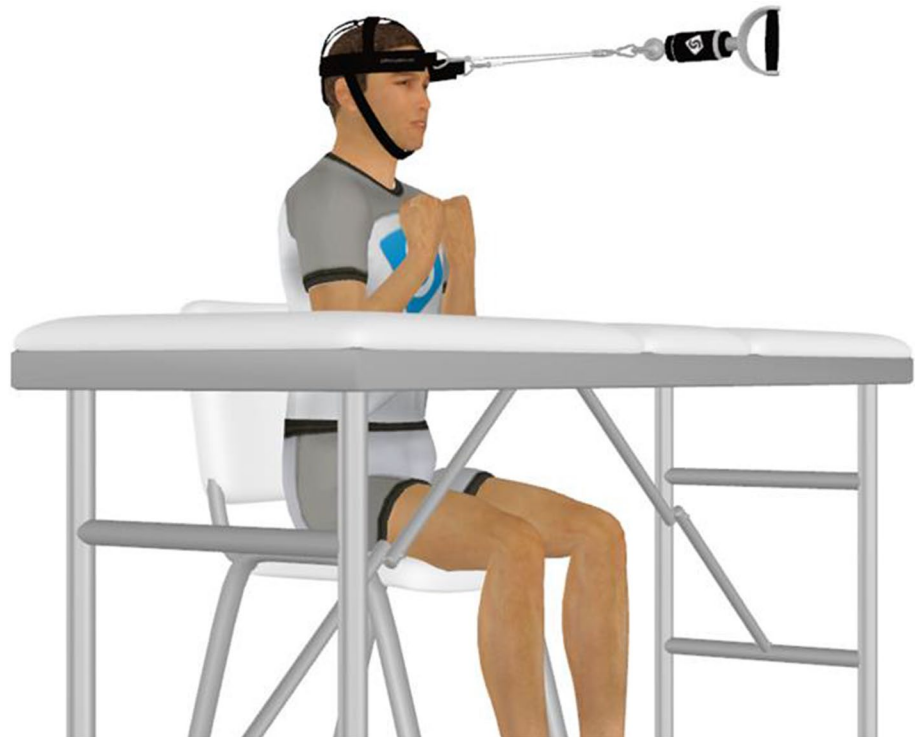
Data for linear acceleration (to a maximum of 16 g) and angular velocity (to a maximum of 1000°/s) were sampled along each orthogonal axis (i.e. x, y, z) at 800 Hz. Time series data were downloaded to the OmGui software (Axivity™, Newcastle, UK) as continuous wave accelerometer (*.cwa) files, which were converted into *.csv files. Resultant linear acceleration and angular velocity were calculated from the raw data using the Pythagorean equation ($r = \sqrt{x^2 + y^2 + z^2}$), and peak values were extracted from each heading trial to represent head impact magnitude [9] in MATLAB (R2018b, Mathworks Inc.™). As well as visually assessing whether each header was valid, the time each header occurred in the field during data collection was manually recorded (in hours:minutes:seconds). The time stamp of the data in the Axivity file (also recorded in hours:minutes:seconds) was then compared to the manual time recorded for each header. Figure 3 shows a typical time series of accelerometer data for two heading trials (see also Supplementary Appendix in the electronic supplementary material).

Isometric neck strength and IMU data were collected using the same standardised procedure at baseline and 6 weeks, following the 5-week intervention period.

Evaluation questionnaire The feasibility and acceptability of the trial's measures and intervention programme were evaluated using an anonymous questionnaire handed out to players at the end of the season. The questionnaire consisted of a number of statements, with players asked whether they agreed or disagreed with each statement based on a 5-point Likert scale (1 = completely disagree; 5 = completely agree). The coaches involved in supervising the neck exercise intervention were also requested to complete a similar questionnaire (see Supplementary Appendix In the electronic supplementary material).

2.6 Sample Size

An a priori sample size calculation was undertaken using G*Power 2019 (version 3.1.9.7, Dusseldorf, Germany). Using a mixed-model analysis of variance (ANOVA) with within-between group interaction ($f > 0.25$, power 0.90, $\alpha = 0.05$), a minimum group size of 46 participants was
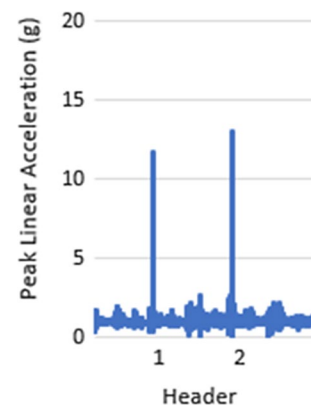
Fig. 3 Example of one player's peak linear acceleration for 2 headers

required, which was increased to 50 to account for a potential 10% dropout rate.

2.6.1 Statistical Methods

Analyses were performed using Stata (College Station, Texas, USA). The level of significance set a priori was $\alpha = 0.05$.

Descriptive data for participant demographics and the evaluation questionnaire are presented using counts, means and standard deviations. Baseline differences in group characteristic measures were analysed by t tests for continuous variables. Intra-tester reliability of the throw-ins as well as neck strength assessment were calculated using intra-class correlation coefficients (ICCs) (two-way mixed effects model using absolute agreement), with magnitudes interpreted as poor (less than 0.50), moderate (0.51–0.75), good (0.75–0.90) and excellent (more than 0.91) [38].

Neck strength variables are presented per direction of movement (flexion, extension, left and right side flexion) as well as a composite score (the sum of strength values for the four directions of movement divided by four). In addition, as participants were adolescent players at various stages of growth, each player's composite neck strength score was adjusted to their body mass index (BMI) [39]. BMI was calculated using the formula $BMI = kg/m^2$, where the player's mass in kilograms was divided by their height in metres squared.

For all outcome variables the minimal detectable change (MDC) was calculated. The MDC is the minimal amount of within-subject variability that a measurement can show that is not due to measurement error or chance [40]. The standard error of measurement (SEM) was used to calculate the MDC using the following formula: $MDC = SEM \times 1.96 \times \sqrt{2}$ [40].

Comparative analyses between groups were performed using an intention-to-treat approach, where every player who was randomised to either the intervention or control group was included in the analysis. Intention-to-treat analyses can assist in avoiding overoptimistic estimates of the efficacy of an intervention that result from the removal of non-adherers by accepting that non-adherence and protocol deviations are likely to occur in real life [41]. To analyse pre and post effects and group differences, the mixed-model ANOVA was applied with time (baseline and follow-up) as a within-player factor and group as a between-player factor. Separate mixed-model ANOVAs were performed with neck strength (in flexion, extension, left and right side flexion and composite neck strength) as well as peak linear head acceleration and peak angular velocity as the dependent variable. With each of these ANOVAs, the hypothesis of interest was the two-way interaction of group*time. Before completing the mixed-model ANOVA, the normality of data distribution ($p \geq 0.05$) of each dependent variable in each combination

was confirmed using the Shapiro–Wilk test, with homogeneity of variance ($p \geq 0.05$) tested with Levene's test. Calculation of effect size using partial eta squared (with 95% CI) was performed, with interpretations of no effect (< 0.01), small (0.02–0.05) medium (0.06–0.13) and large (> 0.14). Means (SD), f values and p values are reported.

3 Results

From a total number of 88 invited players, 59 players (67%) consented to participate. One player was excluded due to sustaining a recent concussion whilst playing school sport (badminton), leading to 58 players from eight teams being randomised into the intervention or control arm of the trial (Fig. 4). No other players were excluded following the screening assessment. Six players did not complete the baseline heading trials and were removed from the analysis. As players were randomised via their teams, this led to an unequal number of players in each group (intervention $n = 31$; control $n = 21$).

Table 1 reports the mean baseline characteristics of players. For combined boys' and girls' data, t tests revealed differences in baseline characteristics for hours trained per week and number of self-reported headers per week, with players in the control group completing more hours of training and more self-reported headers than players in the intervention group. There were no significant differences between groups for any of the girls' baseline characteristics, but significant between-group differences were observed for the boys, including age, height and weight, with players in the control group tending to be older, heavier and taller.

The ICC for throw-ins was calculated at 0.78 (95% CI 0.71–0.82), demonstrating good reliability. The ICC of neck strength assessment demonstrated good (flexion 0.80, right side flexion 0.84 and left side flexion 0.82) to excellent reliability (extension 0.92), similar to values reported in earlier studies [42, 43].

3.1 Intervention Effects on Neck Strength Variables and Head Impact Magnitude

Although within-group and between-group ($p \geq 0.05$) sex differences over time were not significant, we chose to perform separate mixed-model ANOVAs for boys' and girls' data as well as the combined data. This was done to further explore whether any sex differences in results were apparent given the variation in heading technique subjectively noted between the boys and girls during the heading trials (Table 2). The difference between composite neck strength and composite neck strength adjusted to BMI was non-significant ($p \geq 0.05$); therefore, only unadjusted scores are reported (Table 2).
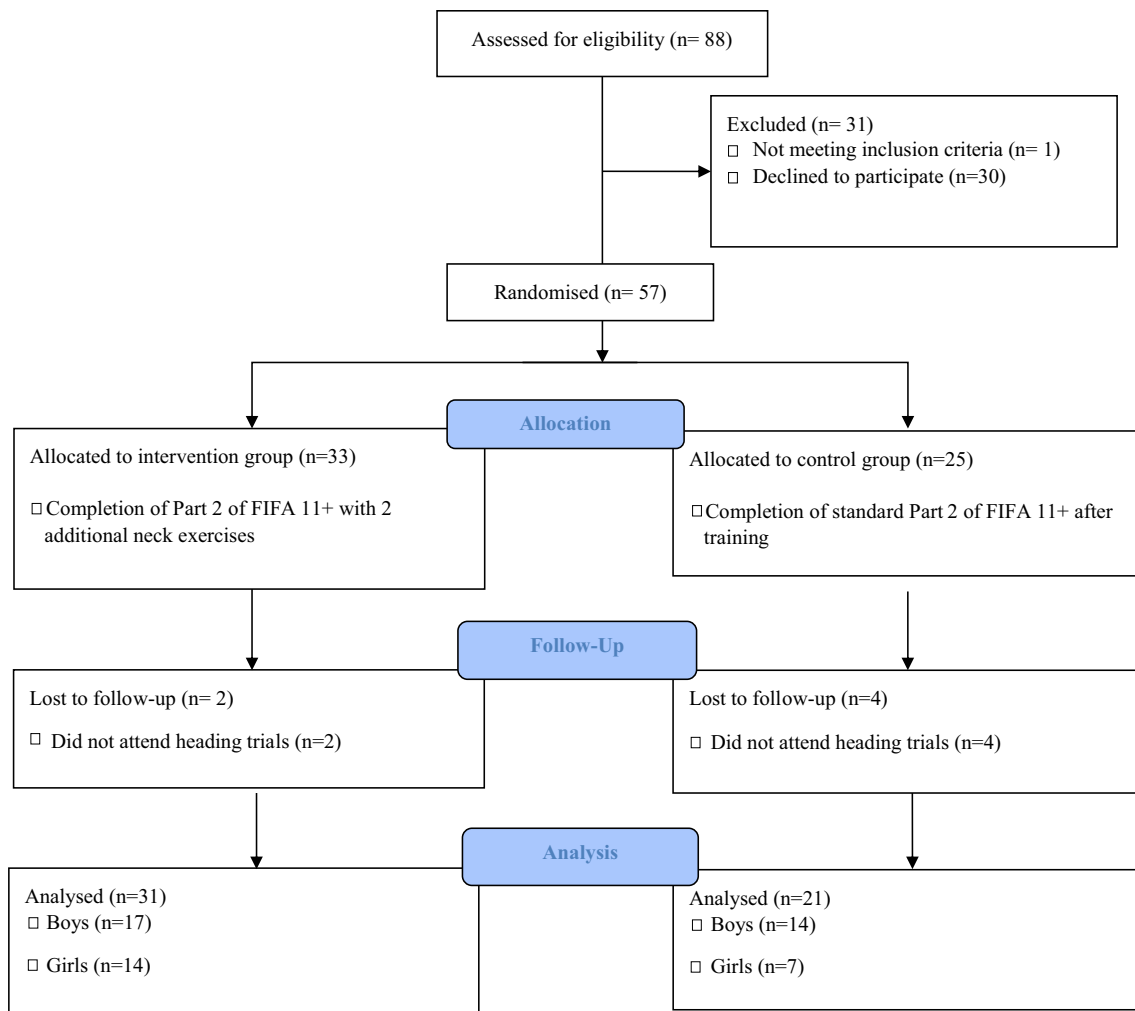
Fig. 4 CONSORT flow diagram of study protocol. *CONSORT* Consolidated Standards of Reporting Trials

For players in the intervention group, the change scores from pre to post test for all variables exceeded the MDC by more than 10% except for peak angular velocity, which exceeded the MDC by less than 10%. Mixed-model ANOVAs for the combined and girls' data revealed large effects for neck strength variables ($\eta^2 > 0.22$; $p < 0.001$), medium effects for peak linear acceleration ($\eta^2 > 0.08$; $p < 0.05$) and medium effects for peak angular velocity ($\eta^2 > 0.07$; $p < 0.05$) between the intervention and control groups over time. Boys' data demonstrated large effects for neck strength variables ($\eta^2 > 0.28$; $p \leq 0.001$), medium effects for peak linear acceleration (η^2 0.13; $p = 0.05$) and small effects for angular velocity (η^2 0.03; $p = 0.13$), although neither peak linear acceleration nor peak angular velocity were statistically significant due to the lower 95% CI crossing zero. Intervention players demonstrated greater increases in mean composite neck strength (53.8% intervention vs 15.6%

control) as well as greater decreases in mean peak linear head acceleration during heading (-11.8% vs -5.0%) from baseline to follow-up when compared with control players. Reduction in peak angular velocity was more pronounced in girls (-27.7%) than in boys (-11.5%) in the intervention group.

3.2 Acceptability and Feasibility of the Programme

The mean results for the player evaluation survey to assess the acceptability of the trial process can be seen in Table 3 (statements 1–5). All players reported a positive experience with neck strength testing (> 3.57), with no issues reported with neck strength testing (> 4.50) or heading trials (> 4.41). Players in both groups also reported feeling more confident heading a ball following involvement in the study (> 3.43).

Players involved in the intervention arm were given five additional statements (Table 3; statements 6–10) to assess the acceptability and feasibility of the neck exercise

Table 1 Baseline characteristics (mean [SD] for age, height, weight, body mass index, playing experience, training volume and self-reported number of headers per week for males and females and combined data

Characteristic	Intervention, mean (SD)			Control, mean (SD)		
	Combined ($n=31$)	Boys ($n=17$)	Girls ($n=14$)	Combined ($n=21$)	Boys ($n=14$)	Girls ($n=7$)
Age (years)	14.35 (0.29)	13.80* (0.24)	15.00 (0.55)	14.95 (0.21)	15.28* (0.26)	14.29 (1.88)
Height (metres)	1.64 (0.01)	1.64* (0.02)	1.63 (0.02)	1.69 (0.02)	1.73* (0.02)	1.59 (0.03)
Weight (kilograms)	53.06 (1.69)	51.52* (2.17)	54.93 (2.66)	55.90 (2.25)	60.14* (2.40)	47.42 (2.83)
Body mass index	19.63 (0.41)	19.01 (0.46)	20.40 (0.69)	19.39 (0.37)	19.84 (0.44)	18.48 (0.59)
Years played	8.51 (0.40)	8.41 (0.51)	8.64 (0.65)	9.67 (0.34)	9.57 (0.48)	9.87 (0.34)
Hours training per week	4.83* (0.27)	4.70* (0.28)	5.00 (0.50)	6.21* (0.56)	6.78* (0.79)	5.07 (0.38)
Headers per week (n)	5.80* (0.97)	5.94* (1.22)	5.64 (1.60)	13.00* (2.71)	16.92* (3.60)	5.14 (1.40)

SD standard deviation

*Difference in baseline characteristics $p < 0.05$

intervention. Intervention players all agreed or completely agreed that completing neck exercises was a positive experience (> 4.21), the exercises were easy to complete (> 4.44), did not take too long (> 4.42), provided personal benefit (> 4.05) as well as team benefit (> 4.00).

Coaches ($n=4$) involved in supervising the intervention agreed or completely agreed that the exercise programme was easy to schedule (mean 4.50 [SD 0.57]), did not take too long to complete (4.74 [SD 0.50]), benefitted the players (4.50 [SD 0.57]) and club (5.00 [SD 0.00]) and that intervention players appeared more confident heading a ball following the intervention (4.50 [SD 0.57]).

4 Discussion

This is one of the few studies to have explored the effects of a neck exercise programme on head impact magnitude during heading in adolescent male and female football players. Despite adding less than 2 min to part 2 of the FIFA 11 +, boys and girls in the intervention group were able to demonstrate large increases in neck strength in only 5 weeks (Table 2). In addition, players in the intervention group demonstrated a medium effect in reducing peak linear head acceleration ($\eta^2 = 0.08$; 95% CI 0.01–0.17) and a medium effect in reducing peak angular velocity ($\eta^2 = 0.07$; 95% CI 0.01–0.15) after the 5-week training programme. This effect was higher in girls than boys, which is possibly unsurprising given that girls in the intervention group generally exhibited weaker neck strength than boys at baseline, with slightly greater improvements in neck strength over the intervention period. Our results also demonstrated that adding neck exercises to part 2 of the FIFA 11 + was accepted by the players and coaches in this study.

An earlier study employing a twice weekly neck exercise programme for 14 weeks in 27 football players aged 15–18 years ($n = 14$ in the intervention group) [30] reported

a reduction in peak linear acceleration of the head during heading for players involved in the intervention group ($\eta^2 > 0.21$). This intervention effect was greater than the one seen in our study ($\eta^2 = 0.08$), possibly related to the longer intervention period (which was almost three times longer). In contrast, a 6-week strength training programme of the neck flexors and extensors in 33 male football players did not report a significant change in neck strength and little change in head impact magnitude during heading [44]. The difference in findings may be explained by the variations in study methodology and training intervention. In our study and the study by Müller and colleagues [30], the neck exercises predominantly emphasised neuromuscular control rather than muscle strengthening alone, plus the balls delivered in these studies replicated an accepted game scenario. A throw-in was used in our study, while the study by Müller and colleagues used a ball pitching machine to replicate a kicked ball delivery [30]. In contrast, the study by Becker and colleagues used strength based exercises with resistance bands or static resistance provided by another player, with the players asked to head a stationary pendular ball attached to the ceiling of the laboratory [44].

The notion that greater neck strength can reduce head acceleration during heading (and potentially reduce injury risk) is based on the premise that stronger, stiffer necks increase coupling of the head to the body and thus help stabilise the head on ball impact [19]. However, although absolute neck strength is an important factor, heading in football is a fast, dynamic action, placing importance not just on muscle strength but on the ability of players to recruit these muscles very quickly. Exercises that aim to enhance the neuromuscular responsiveness of the neck muscles are designed to help players generate the maximal amount of tension in the shortest amount of time. Thus, increasing the coupling of the head-neck-torso enables players to resist head acceleration on ball impact. Peak linear acceleration was shown to decrease in players who pre-tensed their neck

Table 2 Intervention effects of mean maximal isometric neck strength variables, mean peak linear head acceleration and mean peak angular velocity between intervention and control group from baseline to 5-week re-test for combined, male and female data

Combined boys and girls ($n=52$)	Minimal detectable change Pre; post	Intervention ($n=31$) Pre; post scores Change score (SD) %	Control ($n=21$) Pre; post scores Change score (SD) %	$F(1,102)$	p value	Effect size η^2 (95% CI)
Extensors (kg)	2.56↑	13.67; 20.89 7.21 (5.14) 52.8%	21.54; 23.54 2.00 (3.58) 9.3%	9.54	<0.001	0.22 (0.08–0.34)**
Flexors (kg)	1.39↑	8.44; 13.16 4.71 (2.79) 55.9%	13.66; 14.81 1.15 (2.84) 8.5%	10.99	<0.001	0.25 (0.10–0.36)**
Right side flexors (kg)	1.63↑	8.74; 13.70 4.96 (3.26) 56.8%	12.67; 16.15 3.48 (3.04) 8.4%	12.29	<0.001	0.27 (0.12–0.38)**
Left side flexors (kg)	1.65↑	9.02; 13.61 4.59 (3.30) 50.9%	13.37; 16.42 3.05 (3.52) 22.8%	11.62	<0.001	0.26 (0.11–0.37)**
Composite neck strength (kg)	1.67↑	10.37; 15.95 5.58 (3.34) 53.8%	15.94; 18.43 2.49 (3.97) 15.6%	12.47	<0.001	0.27 (0.12–0.39)**
Peak linear acceleration (g)	−1.30↑	12.85; 11.34 −1.51 (1.62) −11.8%	11.53; 10.95 −0.58 (2.83) −5.0%	2.77	0.04	0.08 (0.01–0.17)*
Peak angular velocity (dps)	−79.10↔	497.09; 415.31 −81.78 (202.76) −16.5%	399.09; 339.41 −59.68 (311.98) −15.0%	2.68	0.04	0.07 (0.01–0.15)*
Boys ($n=31$)	Minimal detectable change Pre; post	Intervention ($n=17$) Pre; post scores Change score (SD) %	Control ($n=14$) Pre; post scores Change score (SD) %	$F(1,60)$	p value	Effect size η^2 (95% CI)
Extensors (kg)	3.88↑	14.64; 22.07 7.44 (5.77) 50.8%	25.31; 26.89 1.58 (3.18) 6.2%	10.14	<0.001	0.34 (0.14–0.48)**
Flexors (kg)	2.19↑	9.26; 14.23 4.96 (3.25) 53.7%	16.17; 16.54 0.37 (2.49) 2.3%	7.45	<0.001	0.28 (0.08–0.41)**
Right side flexors (kg)	2.51↑	9.78; 15.28 5.50 (3.73) 56.2%	14.56; 18.35 3.79 (3.29) 26.0%	9.93	<0.001	0.34 (0.31–0.65)**
Left side flexors (kg)	2.41↑	9.87; 15.00 5.13 (3.58) 52.0%	15.50; 18.53 3.03 (3.58) 19.5%	9.35	<0.001	0.33 (0.13–0.47)**
Composite neck strength (kg)	2.53↑	11.32; 17.32 6.00 (3.76) 53.0%	18.60; 20.86 2.26 (4.15) 12.2%	10.62	<0.001	0.35 (0.14–0.49)**
Peak linear acceleration (g)	−0.71↑	13.74; 12.84 −0.89 (2.95) −6.6%	11.69; 11.21 −0.48 (2.87) −4.1%	2.42	0.05	0.13 (0.00–0.28)*
Peak angular velocity (dps)	−71.67↔	629.14; 556.83 −72.31 (103.78) −11.5%	441.18; 395.14 −45.85 (281.67) −10.5%	1.05	0.13	0.03 (0.00–0.09)

Table 2 (continued)

Girls (n=21)	Minimal detectable change Pre; post	Intervention (n=14) Pre; post scores Change score (SD) %	Control (n=7) Pre; post scores Change score (SD) %	F (1,40)	p value	Effect size η^2 (95% CI)
Extensors (kg)	3.03↑	12.52; 19.45 6.93 (4.46) 55.4%	14.00; 16.86 2.86 (3.98) 20.4%	5.61	0.003	0.30 (0.05–0.46)**
Flexors (kg)	1.62↑	7.44; 11.86 4.41 (2.19) 59.4%	8.68; 11.35 2.67 (3.19) 30.8%	4.84	0.006	0.28 (0.03–0.44)**
Right side flexors (kg)	1.90↑	7.48; 11.77 4.29 (2.51) 57.4%	8.89; 11.76 2.87 (2.79) 32.3%	4.84	0.006	0.28 (0.03–0.44)**
Left side flexors (kg)	2.16↑	7.98; 11.91 3.92 (2.91) 49.2%	9.10; 12.20 3.10 (3.48) 34.1%	4.66	0.007	0.33 (0.11–0.46)**
Composite neck strength (kg)	2.07↑	9.21; 14.28 5.07 (2.80) 55.0%	10.60; 13.60 3.00 (2.89) 28.3%	5.81	0.002	0.31 (0.06–0.47)**
Peak linear acceleration (g)	−1.54↑	11.78; 9.75 −2.03 (2.08) −17.2%	11.21; 10.44 −0.77 (2.80) −6.9%	3.25	0.03	0.14 (0.01–0.28)**
Peak angular velocity (dps)	−91.87↔	336.75; 243.48 −93.27 (210.43) −27.7%	314.91; 330.16 15.25 (314.49) 4.8%	5.34	0.002	0.21 (0.03–0.36)**

Effect size: * medium and ** large effect

CI confidence interval, *dps* degrees per second, *SD* standard deviation, ↑ exceeds minimal detectable change by > 10%, ↔ exceeds minimal detectable change by < 10%

Table 3 Player-reported evaluation results, mean (SD) (scored from 1 = completely disagree to 5 = completely agree)

Statement	Intervention, mean (SD)			Control, mean (SD)		
	Combined (n=31)	Boys (n=17)	Girls (n=14)	Combined (n=21)	Boys (n=14)	Girls (n=7)
1. Being involved with neck strength testing was a positive experience for me	4.21 (0.09)	4.04 (0.14)	4.39 (0.11)	3.78 (0.80)	3.57 (0.75)	4.00 (0.78)
2. The research team answered any questions or concerns that I had	4.24 (0.13)	4.26 (0.18)	4.22 (0.20)	4.29 (0.72)	3.85 (0.36)	4.71 (0.73)
3. I did not have any issues with the neck strength testing	4.54 (0.11)	4.57 (0.15)	4.50 (0.12)	4.78 (0.42)	4.71 (0.46)	4.85 (0.36)
4. I did not have any issues with the heading trials	4.41 (0.11)	4.52 (0.15)	4.27 (0.15)	4.71 (0.46)	4.71 (0.46)	4.71 (0.46)
5. I feel more confident heading a ball after being involved in this study	4.00 (0.13)	4.21 (0.20)	3.78 (0.17)	3.5 (1.01)	3.57 (10.08)	3.43 (0.93)
6. Being involved with neck strengthening exercises was a positive experience for me	4.27 (0.09)	4.21 (0.14)	4.33 (0.11)			
7. The neck exercise programme was easy to complete	4.48 (0.09)	4.52 (0.14)	4.44 (0.14)			
8. The neck exercise programme did not take too long for me to complete	4.45 (0.13)	4.42 (0.15)	4.5 (0.12)			
9. I feel that I benefitted from neck exercises	4.16 (0.13)	4.26 (0.20)	4.05 (0.17)			
10. I feel our team benefitted from completing neck exercises	4.14 (0.12)	4.26 (0.18)	4.00 (0.18)			

SD standard deviation

muscles compared with players who did not (relaxed condition) for low ball velocities (6 m/s) during a straight, standing header in an earlier study [45]. This result, although less pronounced, was replicated at higher ball velocities (8 m/s). During the pre-tensed condition, the right and left sternocleidomastoid muscles were active for a longer period of time when compared to the relaxed condition [45]. The smaller difference at the high ball velocity may indicate that at higher velocities, players need to recruit their muscles over a much shorter period of time. To this end, implementation of training stimuli specifically designed to enhance the neuromuscular responsiveness (e.g. rate of force development) of the neck musculature may be the most appropriate training method to minimise head acceleration during heading in football players. The neck exercises used in our study were deliberately chosen to focus more on neuromuscular control of the head rather than pure strength of the neck muscles.

One surprising finding in our study was that girls generally demonstrated lower peak linear acceleration and peak angular velocity when compared with boys despite generally having weaker isometric neck strength. This finding is inconsistent with findings from previous studies [11, 30, 46]. We suspect this was a result of the differences in standing position and heading technique observed between boys and girls. While the heading technique was not standardised, it was noted by both the pro-licence coach and project lead that boys tended to adopt a staggered lunge stance and were more actively engaged in their heading technique, leading to a shift in weight from their back to their front foot to meet and 'attack the ball'. In contrast, girls tended to stand with their feet shoulder-width apart and were more passive in their approach by waiting for the ball to reach them. Whether the boys and girls in our study were coached to head a ball differently or had varying levels of heading experience cannot be extrapolated from these results, although, boys did self-report more headers per week than girls, possibly indicating more opportunities to practise and develop heading technique proficiency. This interpretation is supported by previous research that more experienced players adopt different heading technique to less experienced players, with novices and amateur players demonstrating the largest variation in head impact magnitudes during heading when compared with elite players [36]. It was also reported in a study of 34 adult athletes ($n = 20$ men; $n = 14$ women) that despite women having lower neck muscle strength than men, women demonstrated increased activation of the sternocleidomastoid muscle to stabilise the head during laboratory-based head perturbations [47]. This finding possibly suggests that men and women use different strategies to stabilise the head during heading. Further, boys in our study tended to be more accurate in returning the ball to the feet of the coach delivering the throw-in (as instructed) than girls, who appeared to

have less control of the ball (although this was not captured objectively). Regardless of the heading technique adopted, both boys and girls in the intervention group reduced head impact magnitude (most notably peak linear acceleration for all players and peak angular velocity for predominantly girls) when compared with control players. Previous research [30, 36] has also shown that improved recruitment of neck muscles during heading resulted in decreased head acceleration on ball impact. A recommendation for future research is to analyse variations in heading technique between boys and girls from different age groups and experience levels as well as at different ball speeds using a much larger sample size of players. It is possible that the heading technique adopted by many girls in our study would result in different head impact magnitude data with higher velocity balls (replicating a kicked ball). In addition, accurately measuring head velocity as well as neck muscle activation, along with ball velocity prior to impact as well as the velocity and accuracy of the ball following a header would make important contributions to the literature [10].

4.1 Limitations

Players in both groups demonstrated improvements in isometric neck strength from baseline to follow-up, but the increase was much greater in players involved in the intervention group (53.8%) when compared with the control (15.6%). As the intervention period was only 5 weeks in duration, it is likely that some of this increase in both groups is attributable to players being more familiar and/or comfortable with the neck strength testing procedure. To account for this, we calculated the MDC to demonstrate the difference in change scores that could be attributed to a learning effect or measurement error. All outcome variables exceeded the MDC for the intervention group. It should also be noted that the mean baseline composite isometric neck strength of the players in the control arm (15.9 kg) was higher than the players in the intervention arm (10.4 kg), which was more pronounced in boys. This difference in strength is likely due to boys being older in the control arm (mean 15.3 years) when compared with the intervention arm (mean 13.8 years). It is likely that head impact magnitude during heading was influenced by these differences in age and strength for boys. Thus, it is plausible that the neck exercise programme used in our study provided greater benefit for younger players, but further research with a larger sample of age-matched players is required to elucidate this further. In addition, the result of our study in adolescent football players may not generalise to football players of different ages (i.e. young children or adult football players). It should also be noted that we only measured neck strength and not muscle activity, which would provide an important addition to a future study. When exploring sex differences, it should be noted that the

a priori sample size calculation did not account for separate analyses by sex. The decision to review the results for all players as well as for boys and girls separately was made following data collection when the different heading technique adopted by the boys and girls in our study was noted. Based on our a priori sample size calculation ($n = 46$), our study was sufficiently powered for combined data ($n = 52$), but underpowered for boys' ($n = 31$) and girls' ($n = 21$) data when analysed separately, which should be acknowledged when interpreting our results by sex. It is recommended that this trial is repeated using a larger sample size of male and female players to further explore the influence of sex on head impact magnitude during heading.

Previous research has indicated that poor coupling of head mounted IMUs may lead to an overestimation of peak head impact magnitude during heading when compared with an instrumented mouthguard under laboratory conditions [48]. Pilot testing of our measures revealed no detectable slippage of the 'swim cap' during heading when compared with video analysis. An instrumented mouthguard was also not used, as football players do not routinely wear mouthguards, making it possible that just wearing a mouthguard could have influenced head impact magnitude through teeth clenching, which has been shown to reduce head impact magnitudes during heading and with blows to the head [49, 50]. However, it should be acknowledged that the methodology for measuring head kinematics using the head mounted IMU was not validated against a gold standard measure (such as using a National Operating Committee on Standards for Athletic Equipment [NOCSAE] headform model). Further, it is also possible that the longer hair of many girls may have reduced the coupling of the head mounted IMU, which may also have dampened the head impact magnitude of girls, which in part, may explain the lower head impact magnitudes of girls (although this would not have influenced the effect of the intervention as testing conditions remained the same at baseline and follow-up for all participants). Finally, it should be noted that the ball pressure used in our study (5 psi) was lower than the ball pressure recommended for match balls by the International Football Association Board (8.5–15.6 psi). While the generalisability of our results may be limited to lower ball pressures, the differences between the intervention and control groups indicate a positive effect of neck exercises for reducing head accelerations during purposeful heading.

5 Conclusion

Male and female adolescent players who completed neuromuscular neck exercises demonstrated an increase in isometric neck strength and a decrease in head impact magnitude during heading. Given these exercises took less than 2 min

to complete and that they were perceived as feasible and acceptable by players and coaches involved in our study, the integration of neuromuscular neck exercises into part 2 of the FIFA 11 + for adolescent players warrants further investigation. It is also recommended that a larger trial is conducted to explore the effects of this neuromuscular neck exercise programme on the incidence of head and neck injuries (including concussion) in various age groups, female and male players and players with different experience levels.

Declarations

review from Andrew Gardner. All authors commented on versions of the manuscript, and all read and approved the final manuscript.

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