PEER REVIEW HISTORY

This paper was submitted to the BJSM but declined for publication following peer review. The authors addressed the reviewers' comments and submitted the revised paper to BMJ Open where it was re-reviewed and accepted.

ARTICLE DETAILS

TITLE (PROVISIONAL)	Comparative cervical profiles of adult and under-18 front row rugby players: implications for playing policy.
AUTHORS	Hamilton, David; Gatherer, Don; Robson, James; Graham, Neil; Rennie, Nick; MacLean, James; Simpson, Hamish

VERSION 1 - REVIEW

REVIEWER	Hendricks, Sharief NRF Innovation Post-Doctoral Research Fellow UCT/MRC Research Unit for Exercise Science and Sports Medicine, Sport Science Institute of South Africa, Boundary Road, Newlands
REVIEW RETURNED	13-Nov-2013

GENERAL COMMENTS	Thank you for the opportunity to review this paper. The main purpose of the study was to compare cervical isometric strength and fatigue endurance between elite school aged players (under 18) and amateur adult club players' front row players in rugby union. The secondary aims of this study were to identify correlates of isometric neck strength, and also predictors of isometric neck strength using multivariate predictive modelling. The paper adds to growing literature on the importance of neck strength on reducing the risk of injury during the scrum. In a number of countries, junior/school players are allowed to compete at an adult level if demonstrate the necessary requirements to compete at that level. For the scrum, specific approval by the relevant authority is even needed. This paper highlights that even though some junior players may qualify to compete at the adult level, there are still marked differences in the cervical neck strength, which is cause for concern. With that said, I have made a number of comments and suggestions for the authors to consider before accepting the manuscript for publication. Introduction Page 3 From the objectives of the study, "…to assess the cervical isometric strength and fatigue endurance of both adult and senior school-aged rugby players…" "…to assess the relationship between isometric strength, and various other physical parameters previously shown to predict this. " I feel the authors have not adequately discussed or presented their argument for these objectives. The first paragraph introduces rugby union and the scrum, the second paragraph discusses the risk of injury in the scrum, the 3rd highlights the physical mismatch and

	attempts to reduce this mismatch, and the 4th paragraph touches on the importance of the cervical strength for scrumming. Fatigue endurance and various other physical parameters (what are these physical parameters) are mentioned for the first time in the objectives. I think the authors need to discuss the importance and how fatigue endurance and the physical parameters relate to scrumming and injury risk. Also, further discussion on the importance of cervical isometric strength is needed. Some specific comments for the Introduction are… Line 5 - 'Rugby' – I suggest stating Rugby Union and then perhaps follow with henceforth rugby in brackets. Line 5 – 'collision, sport…' comma after sport. Line 10 – Not sure why there is reference after tissue injury only, and not after structural failure?Is structural failure an assumption then? Perhaps include a reference after structural failure too? Line 13-14 – "Around 8% of all injuries in professional rugby are thought to result from the scrum [3,4], and rates in amateur youth are thought to be similarly proportioned." There seems to be a lot of doubt expressed in this sentence with use of 'around' and 'thought' twice). I suggest the authors state the findings as reported. For example, 'In professional rugby union, 8% of injuries are reported to occur during the scrum'. "…and rates in amateur youth are thought to be similarly proportioned" is this a deduction or can it be referenced? Also the authors mention a percentage of injuries in the first part of the sentence (which I presume is injury proportion) and in the second part of the sentence the authors mention rates. This needs to clarified. Line 15 – 'Though this number is comparatively small, these injuries are likely…" I suggest 'Though this injury proportion is relatively small compared to the tackle event (60% of all injuries), …" Line 19 – " This is though…' Suggest "The force generated from the scrum engagement is thought to be… Line 23 – "front rows has been standardised in an attempt to reduce…" include 'an' Line 24 – Change "Collapsing of the scrum" to scrum collapse. Line 31 – "to be associated to injury" – Suggest 'to be associated with injury' Line 34 – Comma after 'However' Line 35 – 'no such segregation' – Suggest '…and the banding rule no longer applies'. Line 35 – Full stop after place. New sentence, "Indeed, rugby…" Include reference after sentence. Line 39-42 – Either split into 2 sentences, "leagues. However, there" or leagues, however, there… Methods Page 4 Line 5 – Change subheading 'population' to 'sample' because

	technically speaking, the authors are using sample. Line 7 – Change ’30 senior’ to Thirty senior… Line 8-9 – Where the 22 adult players also assessed during a training day? What is a training day in this case? A day where the SRU invites the top junior and top adult amateur players (on separate occasions) for testing and skills development? Line 12-17 ‘The adults were a representative sample of amateur players, drawn from 6 clubs reflecting the top 5 playing levels in Scottish club rugby (as defined by the position of their first XV in the Scottish national leagues). Players were assessed from Dunfermline, Heriots, Murrayfield Wanderers, Musselburgh, Royal High Corstorphine, and Watsonian rugby clubs, comprising players from 1st, 2nd and 3rd teams.’ These two sentences are a bit unclear. The players were drawn from 6 clubs, reflecting the top 5 playing levels as defined by the position of their first XV – Does ‘playing level’ mean log position here? If it reflects the top 5, why 6 clubs? Then, when the clubs are mentioned, I count 7 clubs, and all 3 levels within each club? Are these not the playing levels? Please clarify this. Line 32- ‘…applied and data were recorded at…’ Line 34 – ‘…3 tests are reported’. Line 47 – Change ‘.3 readings’ to . Three readings Line 49-51 – Suggest revising sentence to ‘Prior to the physical assessment, the player’s rugby playing history and detail of neck specific training and injuries were determined using a self-reported questionnaire.’ Line 4 – Delete repeated sentence. ‘Pearson…correations’. Line 6-8 – ‘Predictive variables were selected with a significance of $p < 0.1$ to accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables were controlled.’ Can this sentence be made clearer? Is $p<0.1$ correct? What is meant by to ‘accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables were controlled.’ Results Page 5 Line 13 – I suggest removing ‘As expected’. ‘As expected’ indicates attitude and, although appropriate for the Introduction section or Discussion section, should be avoided in the Results section. Line 19 – ‘Substantial’ is a bit vague for the results section. Were the differences significant or not? Line 21-24 – ‘This may be due to the selection bias of elite players in the younger age group, which may have somewhat homogenised

	this data. Despite this potential positive skew in the under-18 data,' I think this reasoning can be moved to the Discussion section. Line 33 – 39 'Isometric neck strength was most associated with the experience of playing in the front row (r=0.5) (Figure 2), followed by weight (r=0.4) and player age (r=0.4). In contrast, grip strength correlated relatively poorly (r=0.2) (figure 3). Cervical fatigue endurance was associated with peak isometric extension strength but correlated poorly (r=0.30). Player weight (r=0.6) was the factor most associated with fatigue, again grip strength correlated poorly (r=0.1).' This paragraph and figure is a bit misleading as the authors are referring to different things when reporting the data. In the first sentence, the authors report the factors most associated isometric neck strength, whereas in the subsequent paragraph, the strength of the relationship is being reported. The 3rd sentence seems contradictory in saying cervical fatigue endurance was associated with peak isometric extensions strength but correlated poorly? The same issue of referring to most associated and then strength of association in the final sentence too. Figure 2 reads 'strong relationship between cervical strength and playing experience, but the r value is 0.5, which is not strong. Also, r values should be reported in Figures. Table legends could be more descriptive. Discussion Line 51 – Suggest change '…than their adult equivalents' to '…than adult players' Line 51 – Recommend Remove 'highly' Line 51 – Suggest change 'in' to 'when' Line 52 – Recommend 'of such players' to 'of junior players' Line 56-57 – ' A particular concern…age-grade players'. The purpose of this sentence is not clear, and does not add to the point being made. I suggest deleting this sentence, and starting the next sentence with… 'The under 18 players in this study were the top front row players in Scotland, and this sample of players are most likely to be considered appropriate to play in the adult leagues as they may seem physically stronger and bigger. Based on this, it may then be speculated that the difference in neck strength between the general under 18 playing population and adults may be even greater.' Line-18.-19. Forgive me if I may have missed something, but how the link between the findings stated here and players lack of neck specific training is not clear to me at this stage. Line 18-19 I suggest revising to 'Only 12 of the 64 players reported to have performed neck specific exercises. This may suggest that

	the current neck strength of the players in this study were developed from either general strength training and for from scrumming over the years.' Line 23-26 I suggest removing this sentence. Page 6 Line 47- Page 7 line 7– The link between these paragraphs and the findings in this study needs to be clearer. Line 14 – 'characteristics were poor'.

VERSION 1 – AUTHOR RESPONSE

Thank you for the opportunity to review this paper. The main purpose of the study was to compare cervical isometric strength and fatigue endurance between elite school aged players (under 18) and amateur adult club players' front row players in rugby union. The secondary aims of this study were to identify correlates of isometric neck strength, and also predictors of isometric neck strength using multivariate predictive modelling.

The paper adds to growing literature on the importance of neck strength on reducing the risk of injury during the scrum. In a number of countries, junior/school players are allowed to compete at an adult level if demonstrate the necessary requirements to compete at that level. For the scrum, specific approval by the relevant authority is even needed. This paper highlights that even though some junior players may qualify to compete at the adult level, there are still marked differences in the cervical neck strength, which is cause for concern. With that said, I have made a number of comments and suggestions for the authors to consider before accepting the manuscript for publication.

Introduction Page 3
From the objectives of the study,
"…to assess the cervical isometric strength and fatigue endurance of both adult and senior school-aged rugby players…"
"…to assess the relationship between isometric strength, and various other physical parameters previously shown to predict this. "

I feel the authors have not adequately discussed or presented their argument for these objectives. The first paragraph introduces rugby union and the scrum, the second paragraph discusses the risk of injury in the scrum, the 3rd highlights the physical mismatch and attempts to reduce this mismatch, and the 4th paragraph touches on the importance of the cervical strength for scrumming. Fatigue endurance and various other physical parameters (what are these physical parameters) are mentioned for the first time in the objectives. I think the authors need to discuss the importance and how fatigue endurance and the physical parameters relate to scrumming and injury risk. Also, further discussion on the importance of cervical isometric strength is needed.

Yes the reviewer is quite correct. We have not adequately set the scene and explained the direct reasoning for our stated research questions in the introduction. This has been addressed by further considering the direct relevance of cervical strength and fatigue endurance in a lengthened paragraph 4.

Some specific comments for the Introduction are… Line 5 - 'Rugby' – I suggest stating Rugby Union and then perhaps follow with henceforth rugby in brackets.

This suggested change has been made.

Line 5 – ‘collision, sport…’ comma after sport.

This suggested change has been made.

Line 10 – Not sure why there is reference after tissue injury only, and not after structural failure? Is structural failure an assumption then? Perhaps include a reference after structural failure too?

Yes this reference was poorly formatted and reflects the entire sentence. This is now corrected.

Line 13-14 – “Around 8% of all injuries in professional rugby are thought to result from the scrum [3,4], and rates in amateur youth are thought to be similarly proportioned.”

There seems to be a lot of doubt expressed in this sentence with use of ‘around’ and ‘thought’ twice). I suggest the authors state the findings as reported. For example, ‘In professional rugby union, 8% of injuries are reported to occur during the scrum’. “…and rates in amateur youth are thought to be similarly proportioned” is this a deduction or can it be referenced? Also the authors mention a percentage of injuries in the first part of the sentence (which I presume is injury proportion) and in the second part of the sentence the authors mention rates. This needs to clarified.

The purpose of this paragraph is to highlight the injury events linked to scrummaging. Though the percentage of injuries (8%) is comparatively low, these are typically more serious injuries, often involving the spine. We have reworded the paragraph to better reflect this intention. We have also corrected the confusing use of percentages and ‘rates’.

Line 15 – ‘Though this number is comparatively small, these injuries are likely…” I suggest ‘Though this injury proportion is relatively small compared to the tackle event (60% of all injuries), …”

Hopefully this point has been adequately addressed by the rewording of the paragraph (above).

Line 19 – “ This is though…’ Suggest “The force generated from the scrum engagement is thought to be…

This suggested change has been made.

Line 23 – “front rows has been standardised in an attempt to reduce…” include ‘an’

This suggested change has been made.

Line 24 – Change “Collapsing of the scrum” to scrum collapse.

This suggested change has been made.

Line 31 – "to be associated to injury" – Suggest 'to be associated with injury'

This suggested change has been made.

Line 34 – Comma after 'However'

This suggested change has been made.

Line 35 – 'no such segregation' – Suggest '…and the banding rule no longer applies'.

This suggested change has been made.

Line 35 – Full stop after place. New sentence, "Indeed, rugby…" Include reference after sentence.

This suggested change has been made.

Line 39-42 – Either split into 2 sentences, "leagues. However, there" or leagues, however, there

We have updated the manuscript with the later.

Methods Page 4
Line 5 – Change subheading 'population' to 'sample' because technically speaking, the authors are using sample.

This suggested change has been made.

Line 7 – Change '30 senior' to Thirty senior…

This suggested change has been made.

Line 8-9 – Where the 22 adult players also assessed during a training day? What is a training day in this case? A day where the SRU invites the top junior and top adult amateur players (on separate occasions) for testing and skills development?

Testing sessions were arranged in conjunction with the SRU, and in the case of the youth players tied into a coaching session. We have clarified this in the manuscript.

Line 12-17 - 'The adults were a representative sample of amateur players, drawn from 6 clubs reflecting the top 5 playing levels in Scottish club rugby (as defined by the position of their first XV in the Scottish national leagues). Players were assessed from Dunfermline, Heriots, Murrayfield

Wanderers, Musselburgh, Royal High Corstorphine, and Watsonian rugby clubs, comprising players from 1st, 2nd and 3rd teams.'

These two sentences are a bit unclear. The players were drawn from 6 clubs, reflecting the top 5 playing levels as defined by the position of their first XV – Does 'playing level' mean log position here? If it reflects the top 5, why 6 clubs? Then, when the clubs are mentioned, I count 7 clubs, and all 3 levels within each club? Are these not the playing levels? Please clarify this.

We state that we have defined the playing level by the position of the club first team in the Scottish national leagues. This sentence was included to delineate the range of players tested and highlight the representative sample of the amateur playing population, against which the under 18's may play. 6 clubs accepted our invitation and sent players for testing. We stipulated that these individuals did not need to be regular first team players, but could also be drawn from the second or third teams – again to reflect the opposition that a youth player may face. Players were drawn from the 6 stated clubs, not 7. The confusion here may be that Royal High Corstorphine is a single club. The grammar is clearly important to reflect this accurately. We have included an additional sentence to clarify the range of clubs from which the senior players were drawn.

Line 32- '…applied and data were recorded at…'

This suggested change has been made.

Line 34 – '…3 tests are reported'.

We believe that our original sentence is correct in this case, but will happily accept any such changes that the editorial or production team feel necessary.

Line 47 – Change '.3 readings' to . Three readings

This suggested change has been made.

Line 49-51 – Suggest revising sentence to 'Prior to the physical assessment, the player's rugby playing history and detail of neck specific training and injuries were determined using a self-reported questionnaire.'

This suggested change has been made.

Line 4 – Delete repeated sentence. 'Pearson…correations'.

This suggested change has been made.

Line 6-8 – 'Predictive variables were selected with a significance of $p < 0.1$ to accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables were controlled.'

Can this sentence be made clearer? Is p<0.1 correct? What is meant by to 'accommodate the possibility of variables achieving statistical significance once the confounding influence of additional variables were controlled.'

This is fairly standard reporting of the stepwise modelling parameters, though we have further explained the entry criteria. .

Results Page 5
Line 13 – I suggest removing 'As expected'. 'As expected' indicates attitude and, although appropriate for the Introduction section or Discussion section, should be avoided in the Results section.

This suggested change has been made.

Line 19 – 'Substantial' is a bit vague for the results section. Were the differences significant or not?

We think that substantial is an appropriate term in this situation as we are summarising the overall strength characteristics. It also reflects the large differences in strength which were observed - irrespective of the various specific significance levels attached to individual test parameters. The reader is directed to the tables for a detailed report of all tested parameters and statistical significance of between group comparisons.

Line 21-24 – 'This may be due to the selection bias of elite players in the younger age group, which may have somewhat homogenised this data. Despite this potential positive skew in the under-18 data,' I think this reasoning can be moved to the Discussion section.

As this sentence specifically relates to the interpretation of the data, we believe a comment as to the homogeneity of the under 18 group is relevant here. We further expand on this point in the discussion.

Line 33 – 39 - 'Isometric neck strength was most associated with the experience of playing in the front row (r=0.5) (Figure 2), followed by weight (r=0.4) and player age (r=0.4). In contrast, grip strength correlated relatively poorly (r=0.2) (figure 3). Cervical fatigue endurance was associated with peak isometric extension strength but correlated poorly (r=0.30). Player weight (r=0.6) was the factor most associated with fatigue, again grip strength correlated poorly (r=0.1).'

This paragraph and figure is a bit misleading as the authors are referring to different things when reporting the data. In the first sentence, the authors report the factors most associated isometric neck strength, whereas in the subsequent paragraph, the strength of the relationship is being reported. The 3rd sentence seems contradictory in saying cervical fatigue endurance was associated with peak isometric extensions strength but correlated poorly? The same issue of referring to most associated and then strength of association in the final sentence too.

We believe it is quite reasonable to state that an association between variables was apparent and then to quantify the strength of it using the appropriate correlation statistic. This paragraph reflects that the variables assessed were associated, though few were strongly correlated.

To simplify this paragraph, and better relate it to the predictive modelling, we have changed to format of our reporting in response to the 2nd reviewer. This hopefully adequately addresses the points raised here.

Figure 2 reads 'strong relationship between cervical strength and playing experience, but the r value is 0.5, which is not strong. Also, r values should be reported in Figures.

As is typically done, we interpret the correlation magnitude as defined by Cohen's classification. As per Cohen, 0.5 is described as a strong correlation.

Table legends could be more descriptive.

We have added further description to the legends.

Discussion
Line 51 – Suggest change '…than their adult equivalents' to '…than adult players'

This suggested change has been made.

Line 51 – Recommend Remove 'highly'

This suggested change has been made.

Line 51 – Suggest change 'in' to 'when'

This suggested change has been made.

Line 52 – Recommend 'of such players' to 'of junior players'

This suggested change has been made.

Line 56-57 – ' A particular concern…age-grade players'. The purpose of this sentence is not clear, and does not add to the point being made. I suggest deleting this sentence, and starting the next sentence with…

'The under 18 players in this study were the top front row players in Scotland, and this sample of players are most likely to be considered appropriate to play in the adult leagues as they may seem physically stronger and bigger. Based on this, it may then be speculated that the difference in neck strength between the general under 18 playing population and adults may be even greater.'

This is a better sentence and has been incorporated into the text. Many thanks.

Line-18.-19. Forgive me if I may have missed something, but how the link between the findings stated here and players lack of neck specific training is not clear to me at this stage. I suggest revising to 'Only 12 of the 64 players reported to have performed neck specific exercises. This may suggest that

the current neck strength of the players in this study were developed from either general strength training and for from scrumming over the years.'

Thank you, we have reworded along the lines suggested above.

Line 23-26 I suggest removing this sentence.

We would like to defend this sentence. This is our impression form the testing and interaction with the players. We think it reasonable and relevant to state this in the discussion.

Page 6 Line 47- Page 7 line 7– The link between these paragraphs and the findings in this study needs to be clearer.

This point was also raised by the other reviewer and has been addressed in the previous response

Line 14 – 'characteristics were poor'.

This suggested change has been made.

VERSION 2 – REVIEW

REVIEWER	Grant Trewartha University of Bath, UK
REVIEW RETURNED	03-Mar-2014

GENERAL COMMENTS	5. Was parental consent obtained from U18 players? 7. More detail required in the description and reporting of the correlation analyses. 12. The authors should acknowledge more fully the role of factors other than isometric strength which will play a role in scrummaging performance / stability / injury risk. General Comments: Overall, the study uses a nice simple design to provide some important information to the community on cervical strength profiles of rugby players, which will, with some caveats, be able to be used as a benchmark into the future, . The data also has a real-world context in terms of being used to guide age-grade policy and this adds to its importance. I do have a number of comments regarding the description of the work. Specific Comments: Article Summary: p.3, 15-17: Statement is too strong, appropriate neck strength is one important factor amongst many others to prevent scrum collapse. Introduction:

	p.4, 13-14: could reference Roberts et al (2014), BJSM, doi: 10.1136/bjsports-2013-092988 to support this point. p.4, 23-24: could reference Roberts et al (2014), BJSM, doi: 10.1136/bjsports-2013-092988 to support this point. p.4, 44: amend player's to players' Methods: p.5, 8: What is the justification for using such a range of playing levels within the adult group? There could be a good rationale, e.g. U18 players could potentially play across a number of senior levels, but it should be articulated. p.5, 19-20: Was parental consent obtained for under 18 participants? p.5, 30: Would be worth considering in the Discussion whether the neutral anatomical position is the most appropriate testing position. Likewise for the fatigue endurance test, since the position of the seated participant does not resemble body orientation during scrummaging. A comment on the ecological validity of the testing protocol for both maximum testing and fatigue testing is warranted. p.5, 33: Time interval between test attempts? p.5, 58: Correction for multiple tests is applied to reduce possibility of type I errors rather than type II errors. p.5, 56: Significance testing was completed to assess differences between the two groups, which is fine but doesn't really give an indication of the magnitude of the difference. Given the aims of the study were to assess the ability of the groups to play together then it could be worth considering some magnitude based statistics (effect sizes) and also confidence intervals. p.6, 5: Authors need to consider whether the term 'Multivariate stepwise regression…' is appropriate for the statistical tests they carried out. Were there multiple outcome variables or just one outcome variable? It is not clear to me what the outcome variable of the regression analysis was from the text although caption for Table 3 suggests it was one outcome variable (isometric neck extension). If so, this sounds like 'Univariate stepwise multiple regression…' is a more appropriate descriptor. Results: p.6, 13-18: Inclusion of some key values in the text would help the description of the results. p.6, 17: Change 'under-18 group had a greater range of cervical flexion and rotation' to 'under-18 group had a greater range of cervical flexion and side flexion' p.6, 34-39: Correlation results also need significance (p) values reported. p.7, 27-28: As far as I can tell Figure 1 shows load values not fatigue values so reference to Figure 1 is incorrect? Also the 'fatigue' variable calculates the area under a load-time curve and therefore

	represents a measure of 'Impulse' not 'Work'; it is an isometric action with no displacement so no mechanical work is being done. I would suggest removal of the term 'Work' from the description of the analysis. p.7, 34-45: Were both groups combined into one for the correlation and regression analyses? Why was this done? There is a chance that the more homogeneous U18 group will create a clustering effect (seems possible from visualising the scatter plots). This should be examined and discounted before proceeding with the combined analysis. Discussion: p.7, 7-25: The usefulness of the discussion regarding factors associated with neck strength depends a little on the utility of including all participants together as one group for the correlation analysis. Would similar results have been obtained if U18 and adult groups were considered separately? Overall, more clarity is required in the description of correlations/regression analyses to justify the approach. p.7, 43-45: The 'scrum-specific' values for magnitude and direction may well be sensible but it would be preferable for the authors to either include a reference for stating these values or to tone the statement down slightly in terms of the 'better reflects' aspect. p.7, 47-54: It would be beneficial for the authors to attempt to relate the discussion in this section to their present results so that the section includes interpretation of the present data rather than an overview of previous research. p.7, 56-p.8, 7: Similarly to comment above, more reference to the presented data and how it aligns with the discussion point in this section is required. p.7, 57: change 'bucking' to 'buckling'. Overall, it may be worth the authors providing some interpretation with regard to which phases of the scrum they believe maximum isometric force of cervical musculature might be more or less important from an injury minimisation point of view, possibly in the context of higher influence in the sustained push phases versus perhaps less influence during any engagement phase; and also refer to the recent transition to a de-emphasised engagement (crouch-bind-set) and re-emphasis on the scrum as a pushing contest. It seems sensible that isometric force capability of the cervical spine should play a role in scrum performance/stability and for minimising the risk of injury and the authors make this connection well, but for balance it also seems appropriate to provide some mention / consideration of other factors that will indubitably also have an influence on injury risk during scrummaging such as: applied external load, point of force application, direction of force, specific orientation of the head-neck complex when external load is applied. These factors are not part of the analysis so only limited mention can be made of their influence but, to my mind, the link being made by the authors with regards to the association of cervical isometric strength to injury risk in scrummaging is a bit strong given the numerous other contributing factors which are present in the real situation.

	Table 2: The units provided for Total Fatigue appear wrong and should be ‘kg·sec’ (integral, area under the curve) rather than ‘kg/sec’ (derivative, kg per sec). Table 2: Could consider including confidence intervals for the measured strength variables rather than SD to give an indication of the range of the likely true value in each group – this should be a more informative measure than SD when highlighting any differences between groups. Table 3: Would be useful to indicate the amount of explained variance for each version of the stepwise model. Figure 1: This figure should be redundant as data are presented in Table 2, particularly if confidence intervals are also presented in Table 2.

VERSION 2 – AUTHOR RESPONSE

Reviewer(s) Reports:

Was parental consent obtained from U18 players?

This was not required for this study – detailed description follows below.

More detail required in the description and reporting of the correlation analyses.

This concern has been addressed – detailed description follows below.

The authors should acknowledge more fully the role of factors other than isometric strength which will play a role in scrummaging performance / stability / injury risk.

The reviewer is of course quite correct, and this was acknowledged in our original submission. We have added further qualification as to the limitation of describing the role of cervical strength in isolation.

Comments to Author:
General Comments:
Overall, the study uses a nice simple design to provide some important information to the community on cervical strength profiles of rugby players, which will, with some caveats, be able to be used as a benchmark into the future, . The data also has a real-world context in terms of being used to guide age-grade policy and this adds to its importance. I do have a number of comments regarding the description of the work.

Specific Comments:

Article Summary:
p.3, 15-17: Statement is too strong, appropriate neck strength is one important factor amongst many others to prevent scrum collapse.

We have qualified this statement in the summary box

Introduction:
p.4, 13-14: could reference Roberts et al (2014), BJSM, doi: 10.1136/bjsports-2013-092988 to support this point.

p.4, 23-24: could reference Roberts et al (2014), BJSM, doi: 10.1136/bjsports-2013-092988 to support this point.

Thank you for highlighting this paper, which we were not aware of at the time of article submission. It is now included as a helpful reference.

p.4, 44: amend player's to players'

Thank you, this typo has been corrected.

Methods:
p.5, 8: What is the justification for using such a range of playing levels within the adult group? There could be a good rationale, e.g. U18 players could potentially play across a number of senior levels, but it should be articulated.

Yes the reviewer is quite correct in his assumption that we wanted to try to ensure that a fair comparison was made between the under 18's and the players they were likely to meet in competition. The top 5 amateur leagues were thus chosen. Additional descriptive text has been included to the revised manuscript.

p.5, 19-20: Was parental consent obtained for under 18 participants?

No. Scottish statute makes legal provision for young people to consent to medical procedures or treatment where they are considered to be competent. Young people aged 16 and above are presumed to be competent to give consent until proven otherwise. The MRC data toolkit on research consent for children notes that in the absence of law dealing specifically with research, the principles of Scottish law relating to consent procedures and treatment might reasonably be applied to research. At the same time, the threshold for understanding will vary according to the complexity of the research being undertaken.

Our ethics guidance from NRES relating to our school-aged rugby player physical assessments determined parental consent was applicable up until the age of 16, and that boys could consent themselves above this age.

p.5, 30: Would be worth considering in the Discussion whether the neutral anatomical position is the most appropriate testing position. Likewise for the fatigue endurance test, since the position of the seated participant does not resemble body orientation during scrummaging. A comment on the

ecological validity of the testing protocol for both maximum testing and fatigue testing is warranted.

Yes the reviewer is quite correct here and a sentence has been added to the discussion addressing this. Quite simply we chose the neutral anatomic position from a safety perspective due to the lack of published data. As with the loading profiles employed, scrum specific test positioning should clearly be a focus of further research.

p.5, 33: Time interval between test attempts?

A 60 second rest interval between tests was enforced as we have previously employed. This is now stated in the methods.

p.5, 58: Correction for multiple tests is applied to reduce possibility of type I errors rather than type II errors.

Thank you, a somewhat embarrassing typo, now corrected.

p.5, 56: Significance testing was completed to assess differences between the two groups, which is fine but doesn't really give an indication of the magnitude of the difference. Given the aims of the study were to assess the ability of the groups to play together then it could be worth considering some magnitude based statistics (effect sizes) and also confidence intervals.

Thank you, this is a very reasonable suggestion, and 95% confidence intervals are now used for the neck strength variables reported in table 2.

p.6, 5: Authors need to consider whether the term 'Multivariate stepwise regression…' is appropriate for the statistical tests they carried out. Were there multiple outcome variables or just one outcome variable? It is not clear to me what the outcome variable of the regression analysis was from the text although caption for Table 3 suggests it was one outcome variable (isometric neck extension). If so, this sounds like 'Univariate stepwise multiple regression…' is a more appropriate descriptor.

The reviewer is correct; this is a descriptive error on our part. We performed stepwise regression modelling using all assessed parameters (that achieved bivariate significance) to predict global neck strength which we define as isometric extension. A revised and more accurate description is now included in the methods.

Results:
p.6, 13-18: Inclusion of some key values in the text would help the description of the results.

Some values have been included to aid the readability of the results section.

p.6, 17: Change 'under-18 group had a greater range of cervical flexion and rotation' to 'under-18 group had a greater range of cervical flexion and side flexion'

Thank you, this error has been corrected.

p.6, 34-39: Correlation results also need significance (p) values reported.

These have been added as suggested

p.7, 27-28: As far as I can tell Figure 1 shows load values not fatigue values so reference to Figure 1 is incorrect? Also the ‘fatigue’ variable calculates the area under a load-time curve and therefore represents a measure of ‘Impulse’ not ‘Work’; it is an isometric action with no displacement so no mechanical work is being done. I would suggest removal of the term ‘Work’ from the description of the analysis.

Yes this is a typo; the reference should be to table 2.

Yes we agree with the reviewer that impulse is the more accurate term and this has been amended in the text.

p.7, 34-45: Were both groups combined into one for the correlation and regression analyses? Why was this done? There is a chance that the more homogeneous U18 group will create a clustering effect (seems possible from visualising the scatter plots). This should be examined and discounted before proceeding with the combined analysis.

Yes the groups were combined for the correlation and regression analyses. While we accept that there may be some clustering evident on the scatter plot as a result of the homogeneity of the under 18 data, we do not believe this meaningfully impacts the results of the combined group analysis.

We suggested in the original submission that there may be a homogenising effect by the nature of these boys being at the elite end of the spectrum of under-18 rugby. The correlation analysis however was performed to address our second stated research question as to describing the relationship between isometric strength and the various other physical parameters previously shown to predict this for schoolboys of all ages and playing position. The assumption was that the specific demands of the front row would not be reflected in the previously described population model. In terms of the real world application of this data, any of the under 18 boys assessed in this study could play for adult clubs in the front row. Thus for the second research question, for predicting neck strength of front row players, we considered the group as a single cohort – and believe this is appropriate. Linear relationships were determined and we highlight the under 18s to be at the lower end of the scale in the muscle performance data. The distinct lack of specific neck strengthening exercises this group conducted was interesting in that it suggests that the differences here will be due to anthropologic variation and experience of playing in the front row - as a surrogate for muscle strengthening. The particular relevance of this is that it suggests that specific neck strength training could enhance the values achieved by the younger players.

Separate analysis of the adult data in isolation demonstrates the same general relationships with the predictor variables as the combined analysis and the same predictors of isometric extension are derived in the regression modelling. The specific correlations coefficients are slightly weaker, perhaps also reflecting the loss of half the data volume. This lends credibility to the combined analysis, which we believe is the correct way to address the second research question. However we do certainly appreciate the potential of clustering to influence the results and are very happy to include some discussion of this in the methods section. Ultimately a much larger population study would be the best way to address these concerns, and the work presented here can perhaps be seen as the pilot study to drive future investigations.

Discussion:
p.7, 7-25: The usefulness of the discussion regarding factors associated with neck strength depends a little on the utility of including all participants together as one group for the correlation analysis. Would similar results have been obtained if U18 and adult groups were considered separately? Overall, more clarity is required in the description of correlations/regression analyses to justify the approach.

As described above, we believe that combining all the data as a single cohort is the correct methodology in answering our second research question. Further description has now been included to clarify the specific investigations as suggested.

p.7, 43-45: The ‘scrum-specific’ values for magnitude and direction may well be sensible but it would be preferable for the authors to either include a reference for stating these values or to tone the statement down slightly in terms of the ‘better reflects’ aspect.

This sentence is merely a suggestion for future work that we believe would be relevant and helpful in determining the required neck strength parameters for the front row. We have added further qualification as suggested.

p.7, 47-54: It would be beneficial for the authors to attempt to relate the discussion in this section to their present results so that the section includes interpretation of the present data rather than an overview of previous research.

We found this a somewhat surprising comment; it is quite typical for a discussion section to put the current work into the context of previous relevant research. A single paragraph is included that highlights another relevant study looking more broadly at the forced generated in the scum across different playing levels. These authors described potentially injurious forces that need to be modulated by the cervical spine complex and its musculature, which is critical to our assertion that there may be parameters that younger players should meet prior to playing with more experienced players. We have though added a further comment to this paragraph to articulate the relevance to the results we present.

p.7, 56-p.8, 7: Similarly to comment above, more reference to the presented data and how it aligns with the discussion point in this section is required.

Again, this is a highly relevant couple of sentences where we highlight the potential importance of the cervical musculature in moderating scrum collapse. We have been explicit that cervical strength is not causative in the relationship with cervical injury, thus applying some context as to where we see the link is clearly relevant and appropriate in the discussion. We have though considerably lengthened this discussion incorporating some of the relevant points the reviewer raises in the following comments, and thank him for his insight here.

p.7, 57: change ‘bucking’ to ‘buckling’.

Yes thank you, this was a Typo, now corrected

Overall, it may be worth the authors providing some interpretation with regard to which phases of the scrum they believe maximum isometric force of cervical musculature might be more or less important from an injury minimisation point of view, possibly in the context of higher influence in the sustained push phases versus perhaps less influence during any engagement phase; and also refer to the recent transition to a de-emphasised engagement (crouch-bind-set) and re-emphasis on the scrum as a pushing contest.

Yes we agree that this is quite relevant and further discussion has been added surrounding these points.

It seems sensible that isometric force capability of the cervical spine should play a role in scrum performance/stability and for minimising the risk of injury and the authors make this connection well, but for balance it also seems appropriate to provide some mention / consideration of other factors that will indubitably also have an influence on injury risk during scrummaging such as: applied external load, point of force application, direction of force, specific orientation of the head-neck complex when external load is applied. These factors are not part of the analysis so only limited mention can be made of their influence but, to my mind, the link being made by the authors with regards to the association of cervical isometric strength to injury risk in scrummaging is a bit strong given the numerous other contributing factors which are present in the real situation.

Yes, we are very happy to highlight the various other factors that can be speculated as having an influence. We are keen to provide a balanced argument and are acutely conscious as to the limitations of considering muscle strength in isolation. Further discussion has been included in the revised manuscript.

Table 2: The units provided for Total Fatigue appear wrong and should be ‘kg·sec’ (integral, area under the curve) rather than ‘kg/sec’ (derivative, kg per sec).

This change has been made.

Table 2: Could consider including confidence intervals for the measured strength variables rather than SD to give an indication of the range of the likely true value in each group – this should be a more informative measure than SD when highlighting any differences between groups.

Yes, this is a helpful suggestion and the table has been amended to report 95% CIs of the mean.

Table 3: Would be useful to indicate the amount of explained variance for each version of the stepwise model.

The number of years playing experience in the front row variable explained the greatest variation at around 22%, adding the weight variable increased this to 31%. Adding age as an independent variable marginally enhanced the model by around 0.5%, but the Mallows Cp statistic was worse and it was felt that the 2-variable model was the best fit. This is a bit clunky to add to the text, but some further description is now provided in the results section and table legend to aid interpretation.

Figure 1: This figure should be redundant as data are presented in Table 2, particularly if confidence

intervals are also presented in Table 2.

We take the point that there is some repetition of data here, however we do think it is useful to display a visual representation of the differences found between groups. Though the confidence intervals added to reflect the range the true mean in likely to be found are very useful, they don't describe the range of data surrounding individual performance that can be gleaned from the boxplots. We believe that focusing on a single measurement (to reflect global strength) highlights the issue well. We would be happy to let the editorial team make the final decision as to the inclusion or removal of this figure.