

# Does load management using the acute:chronic workload ratio prevent health problems? A cluster randomised trial of 482 elite youth footballers of both sexes

Dalen-Lorentsen, Torstein<sup>1</sup>; Bjørneboe, John Andreas<sup>1</sup>; Clarsen, Benjamin Matthew<sup>1,2</sup>; Vagle, Markus<sup>1,3</sup>; Fagerland, Morten<sup>1</sup>; Andersen, Thor Einar<sup>1</sup>

<sup>1</sup>Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sports Sciences, Oslo, Norway

<sup>2</sup>Department of Health Promotion, Norwegian Institute of Public Health, Bergen, Norway

<sup>3</sup>Department of Sports, Physical Education and Outdoor Studies, University of South-Eastern Norway Horten, Norway

Dalen-Lorentsen, T., Bjørneboe, J., Clarsen, B., Vagle, M., Fagerland, M. W., & Andersen, T. E. (2020). Does load management using the acute: chronic workload ratio prevent health problems? A cluster randomised trial of 482 elite youth footballers of both sexes. *British Journal of Sports Medicine*, 55(2), 108-114.  
<https://doi.org/10.1136/bjsports-2020-103003>

This is the accepted version of an article published in:  
*British Journal of Sports Medicine*

Publisher's version: DOI: <https://doi.org/10.1136/bjsports-2020-103003>

# Does load management using the Acute:Chronic Workload Ratio prevent health problems? A cluster-randomised trial of 482 elite youth footballers of both sexes

Torstein Dalen-Lorentsen,<sup>1</sup> John Bjørneboe,<sup>1</sup> Benjamin Clarsen,<sup>1,2</sup> Markus Vagle,<sup>1,3</sup> Morten Wang Fagerland,<sup>1</sup> Thor Einar Andersen,<sup>1</sup>

1 Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sports Sciences, Oslo, Norway

2 Department of Health Promotion, Norwegian Institute of Public Health, Bergen, Norway

3 Department of Sports, Physical Education and Outdoor Studies, University of South-Eastern Norway Horten, Norway

Corresponding author: Torstein Dalen-Lorentsen, [Torstein.dalen@nih.no](mailto:Torstein.dalen@nih.no), +4793841844

Word count: 3749

Keywords: Workload, youth, football, soccer, RCT, prevention

## ABSTRACT

**Background:** The Acute:Chronic Workload Ratio (ACWR) is commonly used to manage training load in sports, particularly to reduce injury risk. However, despite its extensive application as a prevention intervention, the effectiveness of load management using ACWR has never been evaluated in an experimental study.

**Aim:** To evaluate the effectiveness of a load management intervention designed to reduce the prevalence of health problems among elite youth football players of both sexes.

**Methods:** We cluster-randomised 34 elite youth football teams (16 female, 18 male) to an intervention group (18 teams) and a control group (16 teams). Intervention group coaches planned all training based on published ACWR load management principles using a commercially available athlete management system (AMS) for a complete 10-month season. Control group coaches continued to plan training as normal. The prevalence of health problems was measured monthly in both groups using the Oslo Sports Trauma Research Centre Questionnaire on Health Problems (OSTRC- H2).

**Results:** The between-group difference in health problem prevalence (primary outcome) was 1.8 %-points (-4.1 to 7.7 %-points;  $P=0.55$ ) with no reduction in the likelihood of reporting a health problem in the intervention group (Relative Risk, RR 1.01 [95% CI 0.91 to 1.12 ];  $P=0.84$ ) compared to the control group.

**Conclusions:** We observed no between-group difference, suggesting that this specific load management intervention was not successful in preventing health problems in elite youth footballers.

**Trial registration number:** ISRCTN18177140

## INTRODUCTION

Health problems are common among elite youth footballers, who experience similar injury and illness patterns and burden as senior professional players.<sup>1-3</sup>

Previous studies in elite youth football have found that at any given time of the season, the prevalence of health problems is over 40%.<sup>3</sup> Loss of participation due to health problems can negatively affect the players' performance,<sup>4</sup> their health later in their career,<sup>5,6</sup> and ultimately, their long-term development.<sup>7</sup> Therefore, preventive measures are important.

A range of general and specific exercise-based interventions have shown substantial efficacy.<sup>8-15</sup> In most cases, these interventions have been tested among elite adult male players<sup>8-10,13,15</sup> and recreational youth players;<sup>12,14,16</sup> only one study has been performed on elite youth players.<sup>17</sup>

Recently, researchers and practitioners have increased their interest in training load as a risk factor for health problems in football,<sup>18</sup> with numerous studies reporting an association between training load and injury.<sup>19-22</sup> Consequently, training load monitoring and management has gained widespread popularity as a preventive measure in professional and elite youth football.<sup>18,23</sup> There is currently no consensus on which training load parameters should be monitored, how their cut off values should be set and how load progression should be evaluated. Moreover, load management is performed in numerous ways, is often dictated by the philosophy of the club staff or manager, and has no consensus scientifically.<sup>18,23</sup> In 2014, Hulin et al. proposed the concept of the Acute:Chronic Workload Ratio (ACWR), whereby an athlete's recent training load (acute workload) is divided by their training load over a longer period of time (chronic workload).<sup>24</sup> This metric is suggested to aid practitioners in managing training load within certain ranges.<sup>25,26</sup> The initial concept was based on avoiding sudden spikes in training load, trying to keep ACWR within an arbitrary "optimal range" of 0.8 to 1.5.<sup>25,26</sup>

Observational evidence supporting an association between ACWR and injury is inconsistent and controversial,<sup>27-30</sup> and there are no experimental studies to determine whether using ACWR to manage training loads actually prevents injury or illness. Therefore, the aim of this cluster-randomised controlled trial was to assess the effect of an ACWR-based load management intervention on health problem risk among elite youth footballers of both sexes.

## **METHODS**

This study involved 482 Norwegian elite U-19 football players (178 females, 278 males), conducted during a complete season from February through November 2018.

### **Recruitment**

We identified 78 teams from the vicinity of members in our research group and their participation in one of the top two tiers of Norwegian youth football. Of these, 15 teams that already used a training load management system were not invited, as this was likely to affect their adherence with the intervention. Sixty-three teams were invited and 27 declined to participate, 10 due to time constraints and 17 teams did not respond to the invitation or give any specific reason for why they declined (Figure 3). Players who were permanent squad members were invited to participate in the study, with the exception of players who were likely to be absent from football training and match play for the study period due to severe health problems at baseline.

### **Participants**

Thirty-six teams (15 female and 21 male) accepted the invitation to participate and all players (or their guardian) on these teams gave their written consent to take part in the study (Figure 3). The trial started for each team after all players had provided written consent and the team had completed their introductory course to either the intervention group or the control group routines. Data collection was closed as each team finished their season.

### **Randomisation**

We randomised on a team level to minimize the risk of contamination bias between players within the teams. A statistician, blinded to the study protocol, computer-generated blocks of 4 and 6 teams in random order. After a team and their players agreed to participate, the principal investigator opened a sealed envelope revealing the team's group assignment.

### **Blinding**

It was impossible to blind players, coaches, or the principal investigator to group allocation. However, a research assistant decoded the outcome measures during the data collection period,

and outcome measures were not available to any of the members of the study group until all data had been collected.

## **Intervention**

The intervention consisted of individualised load management of every player in the intervention group. Intervention group-coaches planned the weekly training plan (micro-cycle) based on each player's training load history. A commercially-available athlete monitoring system (AMS; Athlete Monitoring, Fitstats Inc., New Brunswick, Canada) assisted coaches in planning player micro-cycles, based on ACWR theory.<sup>24</sup> ACWR was calculated as the coupled 7- to 28-day ratio using a rolling average. We instructed the intervention group-coaches on training load management theory and how to use the AMS to plan training content, duration and intensity. Each coach received a one-hour introductory session and a follow-up session two weeks later if necessary. Coaches were instructed to follow a periodization model based on the "optimal range" concept described by Hulin et al.,<sup>24,31</sup> where the aim was to progress or maintain player load while ensuring they remained within the desired ACWR range of 0.8 to 1.5.

All training load data reported by the players were instantly available on the coach dashboard in the AMS (Figure 1). After finishing all weekly football activity every Sunday evening, coaches reviewed and arranged the individual training plans for the following week. The coaches were expected to have detailed insight into all their players' planned training and match activities (including activities outside the club team, i.e. high-school training, regional team, national team). The AMS combined the subsequent week's (7-days) planned training load with the training load from the past 21-days (a rolling average of 28-days) and calculated the planned ACWR for the subsequent week.

If the planned training activity in the subsequent week led to players having an ACWR below 0.8, the AMS alerted the coach with a suggestion to increase the load accordingly. Conversely, if the planned activity led to an ACWR above 1.5 for, the AMS alerted the coach (Figure 2), and suggested that they decrease the planned load. Additionally, during the week, coaches were expected to ensure that players completed their training as planned and, if necessary, adjust the program to keep them within the ACWR "optimal range" (i.e. if a player reported much higher loads than planned in the start of the week, the remainder of the weekly load could be reduced, or vice versa).

We regularly contacted the coaches and sent supportive email each month to encourage them to continuing their training planning based on the intervention.

## **Insert figure 1 here**

*Figure 1 Coaches dashboard in the AMS after next weeks training load is planned*

## **Insert figure 2 here**

*Figure 2 Coaches dashboard in ASM suggesting a revision of planned load*

### **Collection of training load data**

Intervention group players recorded the duration and their overall perceived rate of physical exertion (RPE) using the modified Borg CR-10 scale<sup>32</sup> after all footballing activity, including non-organized football play. Players were familiarized with the collection method as well as the Borg scale before study start. We calculated an arbitrary training load unit (AU) by multiplying the duration with the session RPE (sRPE)<sup>32</sup> for all football activities. Ten minutes after each training session was planned to be completed, a link to a questionnaire in the AMS smartphone app was sent to the players via an automated short message service (SMS; see supplementary #3 for details). If players had not replied to the questionnaire 12 h post activity, they received a second SMS, reminding them to complete the questionnaire. If players failed to complete the session questionnaire, the AMS treated the player as not being a part of the training and leaving a session-value of nil in the calculations (and falsely decreasing the load of the player). The control group did not record any training load data.

### **Collection of health data**

We used the OSTRC-H2 questionnaire (Supplementary file #1)<sup>33</sup> to record health data. Players responded to the questionnaire in the last week of each month and were instructed to report health problems for the previous 7-days only, giving us weekly prevalence of 10 intervals at approximately 1-month apart.

The questionnaire was distributed using an online survey software (Briteback AB, version 2.5.3.1; Norrköping, Sweden) via SMS Sunday at 9 PM. Non-responders received an SMS-reminder the following morning at 8 AM. Players were asked to report all complaints, irrespective of their consequences on football participation or their need to seek medical attention, including illness and injury.<sup>34</sup> If players answered anything but the lowest score (i.e. “no problem”) on either of the questions, a health problem was registered. If a player registered alternative two or higher (i.e., moderate or severe reduction, or inability to participate) in question 2 (training volume) or 3 (performance), the health problem was registered as substantial. Each month, we calculated prevalence of both outcomes by dividing the number of players reporting either a health problem

or a substantial health problem to the total number of respondents in each group. To ensure consistent reporting of all health problems, we familiarised players with the definitions in the pre-study meeting, and repeatedly emphasized the importance of reporting all health problems during the study period, irrespective of their consequences. We informed the players that the coaches and other club staff members did not have access to any health data.

## **Outcome measures**

The primary outcome measure was the occurrence of all health problems over the course of the season. The secondary outcome measure was occurrence of substantial health problems over the course of the season.

## **Statistical methods**

The primary effect measure was the between-group difference in prevalence (intervention – control). The secondary effect measure was relative risk ratio (intervention/control). To evaluate the effectiveness of the intervention, we fitted generalized estimating equations (GEE) panel-data models to the two outcomes: all health problems and substantial health problems. The models were defined with a binomial family, a log-link function, and an exchangeable correlation matrix. The estimated standard errors were adjusted for clustering, and a Kauermann and Carroll bias-corrected variance estimator,<sup>35</sup> which is specifically recommended for cluster randomized trials, was used. The models included terms for group (intervention vs. control) and time, and we report the results for group as the relative risk of intervention vs. control. Initial models also included a term for group x time interaction; however, this term did not impact the models (P=0.44 for all health problems; P=0.34 for substantial health problems), and we removed the interaction term to obtain a simple and easily-interpretable estimate of the intervention effect. We used the `xtgeebcv` command<sup>36</sup> in Stata (version 15.3 StataCorp LLC, College Station, TX; see supplementary file #2 for script and results). No attempt to impute missing training or health data was performed. All analyses were performed according to the intention-to-treat principle, using a full analysis set-definition; that is, we included all available data and analysed the teams as randomised. Teams that withdrew from the study directly after randomisation were excluded, as were players who did not record any outcome data.



## Sample size

The sample size calculation was based on an average prevalence of health problems among elite youth footballers of 40%.<sup>3</sup> Based on an analysis of variance of within-subject and within-team prevalence, an inflation factor (DE) of 1.65 (to account for randomization at the cluster level), a cluster size of 20 players, a power of 80% and a 5% significance level ( $\alpha$ ), we estimated that a sample of 2 x 380 players would be needed to detect a 40% reduction in prevalence. This was based on previous studies with a similar design,<sup>8,37</sup> and on our estimation of what coaches would consider a worthwhile meaningful difference. To find the inflation factor, the following formula was used  $DE = 1 + (n-1)p$ , where  $n$  is the number of individuals and  $p$  is the intra-cluster correlation coefficient.<sup>38</sup>

## Ethics

The study was reviewed by the South-Eastern Norway Regional Committee for Medical and Health Research Ethics (2017/2232) and approved by the ethics board of The Norwegian School of Sports Sciences (39-191217) and the Norwegian Center for Research Data (56935). The study was registered in the International Standard Randomised Controlled Trial Number Registry (ISRCTN18177140).

# RESULTS

## Participants

A total of 34 teams were enrolled in the study; nine teams withdrew shortly after randomisation, and 88 players did not respond to any of the health problems questionnaires. Eleven teams in the intervention group and 14 teams in the control group completed the study and the total number of players analysed was 394 (Table 1).

Insert table 1 here

*Table 1 Baseline characteristics of players included in the analyses*

The flow of the teams and the number of players is shown in Figure 3. Of the nine teams that withdrew after randomisation, seven teams were randomised to the intervention group and two teams to the control group. The reasons stated for withdrawal from the intervention group were: wanted to be in the control group ( $n=4$ ), wanted to implement a different load management

routine (n=2), and change of coaching staff (n=1). The two teams that withdrew from the control group indicated that they would rather be in the intervention group.

### **Insert figure 3 here**

*Figure 3 Flow of the teams and the players throughout the intervention*

### **Questionnaire response rate**

We recorded a total of 2 475 health problems questionnaires. The compliance to the OSTRC-H2 questionnaire was 62% (range 10 to 100%) in the intervention group, and 76% (range 10 to 100%) in the control group, which amounts to an average of 69%. The intervention group coaches planned a total of 25 004 player sessions and received 15 253 player responses, which amounts to an overall response of 74% (range 0% to 100.0%) to the post-training questionnaire.

### **Training data**

The intervention group players' median weekly sRPE was 1 470 (Interquartile range 750) AU.

### **Adherence with the intervention**

In a post-study survey the intervention group-coaches replied to the following question describing their compliance with the intervention: Did you use the AMS to plan training every week throughout the season? Eight out of eleven coaches responded and five replied "yes, every week", two replied "no, every other week" and one, "no, every month".

### **Primary outcome: all health problems**

The average prevalence of health problems was 65.7% [61.1% to 70.2%] in the intervention group and 63.8% [60.0% to 67.7%] in the control group (Figure 4). The prevalence was 1.8%-points [-4.1 to 7.7%-points; P=0.55] higher in the intervention group, and there was no reduction in the likelihood of reporting a health problem in the intervention group (Relative Risk, RR 1.01 [95% CI 0.91 to 1.12 ]; P=0.84) compared to the control group.

### **Insert figure 4 here**

*Figure 4 Prevalence of health problems in the control group and the intervention group throughout the season.*

## Secondary outcome: substantial health problems

The average prevalence of substantial health problems was 31.1% [26.7% to 35.5%] in the intervention group and 35.3% [31.6% to 39.1%] in the control group (Figure 5). The prevalence was 4.1%-points [-1.6 to 9.9; P=0.15] higher in the control group, and there was no reduction in the likelihood of reporting a substantial health problem (RR 0.88 [0.72 to 1.06]; P=0.17) in the intervention group compared to the control group.

### Insert figure 5 here

*Figure 5 Prevalence of substantial health problems in the control group and the intervention group throughout the season.*

## DISCUSSION

This is the first randomized controlled trial investigating the effect of individual management of training loads on the risk of health problems in any sport. We did not identify any significant differences in either outcome between the intervention groups and the control group.

### Intervention

When planning this study, choosing the exact mode of intervention represented a major challenge. We were guided by the literature at the time, as well as the recommendations from the group that developed the ACWR approach.<sup>24 26 39</sup> Also, we considered what was commonly used in the field, and therefore had the most practical relevance.

Since then, there has been increased scrutiny of the ACWR concept, with several papers highlighting methodological challenges,<sup>30 40-45</sup> and some authors questioning the validity of the entire concept.<sup>27-29</sup> Despite many studies showing an association, no study has yet managed to predict health problems based on ACWR,<sup>20</sup> indicating that a meaningful and pronounced relationship between ACWR and health problems is unlikely.

We tested the preventive effect on health problems by using one particular approach of load management. However, there is no consensus on which load management concept should be used, or, if using ACWR, how it should be calculated.<sup>30</sup> Our intervention was a one-size-fits-all approach, as we considered it to be the most feasible method for the coaches and because a structured individual protocol remains in a conceptual phase.<sup>46</sup> Moreover, at the time we planned the study, the available literature recommended that a similar threshold should be used for all players.<sup>24</sup> This one-size-fits-all approach has recently been challenged by both scientists and

practitioners, as the relationship between ACWR and health problems is affected by a large number of individual moderating factors.<sup>46</sup>

Our training load parameter was sRPE. We chose sRPE as it is considered a valid method for measuring training load across various sports,<sup>47</sup> and for elite youth footballers specifically.<sup>48</sup> Moreover, sRPE was the most practical way to quantify load in 25 non-professional youth football teams, and the majority of previous ACWR studies have used sRPE as their primary measure of load.<sup>19 20 22 49-67</sup>

## **Methodological considerations**

This study involved an intervention that was arguably more technically demanding and time-consuming for coaches and players than previous prevention studies in sports.<sup>8 37</sup> These challenges may have led to reduced adherence to the intervention by the coaches, and to reduced questionnaire response rates by the players.

A major limitation of the study is the method used to assess the coaches' adherence to the intervention. Ideally, we would have logs or questionnaires describing the extent to which their training planning was influenced by the ACWR, and how often they intervened in their players' training plan based on feedback from the AMS. However, we asked the coaches in a post-study questionnaire where they indicated that, to a large extent, the intervention had been followed.

Another problem we faced was the health problem questionnaire average response rate of 69%, and specifically the intervention group response rate of 62%. One reason that the intervention group had lower response rate might be questionnaire fatigue, as they also reported training load after every football session. Moreover, as the AMS could not be used to collect the OSTRC-H2 at the time, the intervention group had to use two different systems to record training and health data, which is not optimal. Contrary to the health problem questionnaire, the training load questionnaire had a reasonably good response rate of 74%, which might indicate that the AMS collected data in a more feasible way. Non-responders and non-compliances will introduce selection and measurement bias in our analyses and should be taken into consideration when interpreting our results. Despite some of the challenges with this method, using athlete-recorded health problems allowed us to use a broad health problem definition, and thereby gain a more complete understanding of the range of health problems affecting the players.<sup>68 69</sup> In particular, this broader approach was specifically designed to record overuse injuries, which are presumably the most preventable type of injury from a load management intervention. Nevertheless, this approach also has limitations.<sup>70</sup> Health problems were not confirmed by a sports medicine

practitioner or by diagnostic imaging, making our data less secure and detailed. Moreover, our approach includes illness as a health problem without knowing more specifically whether or to what extent the illness is caused by training load. If illness is not affected by training load, it might result a bias towards the null in our analyses. On the other hand, including illness is also a strength of the study as illness prevention is a favourable potential outcome of load management.<sup>71</sup>

The average prevalence of both health problems and substantial health problems are higher in our study than in previous studies.<sup>38</sup> The reason for this is unknown. However, as this finding was the same in both groups, we believe a between-group comparison is appropriate.

Choosing a suitable population is key when performing experimental research; elite youth players have previously been targeted in injury prevention research.<sup>17</sup> We chose this cohort of athletes since many elite youth players in Norway train with and play for several different teams, making their load management challenging. Furthermore, this was deemed one of few cohorts where coaches systematically plan their training, and at the same time, where we would be allowed to influence their training content.

The modified intention to treat (ITT) analysis could introduce selection bias due to the withdrawals post randomisation and should be acknowledged as a limitation of the study.

We were unable to identify statistically significant differences between groups, a larger study with higher statistical powered might have found otherwise. In this case, and based on our confidence intervals, the effect of the intervention would nonetheless be small- to moderate.

## **Perspectives**

Although many practitioners, researchers, and players consider training load to be an important risk factor for health problems in football, supporting evidence is currently conflicting. To date, studies examining the relationship between training load and health problems have largely been descriptive studies.

This trial - the first randomized study in the field – demonstrates that, although difficult to conduct, it is not impossible. We hope, despite this study's methodological limitations, it will pave the way for future training load studies using a similar design.

In elite football, sports medicine and performance practitioners meticulously and continuously assess each player's training load together with numerous other factors, such as history of

previous injuries, injuries, player age, wellness, non-sporting load, communication with player, screening and strength test and the importance of next match. This is done to inform subjective decisions that aim to increase performance and reduce risk of health problems. Providing coaches with a one-size-fits-all metric does not seem to add much value to this process. We believe that, given the results of this study and the current state of knowledge in the field, load management remains just as much an art as a science.

## **Conclusion**

We provided coaches of teams in the intervention group with tools and knowledge to manage their players' training load using a common form of ACWR. This did not lead to a reduction in the prevalence of health problems, compared to teams in the control group. Managing training loads using ACWR does not appear to represent an effective prevention intervention in elite youth football.

## **What are the findings?**

- Load management using ACWR in a one-size-fits-all approach does not appear to prevent health problems among elite youth football players of both sexes.

## **How might it impact on clinical practice in the future?**

- The lack of a clear relationship between training load and health problems does not mean practitioners should abandon training load management. Its primary role has always been performance enhancement, and not health problem prediction or prevention.
- With a lack of models linking training load and health problems, practitioners should follow the general training principles such as the principle of progressive overload.
- Alternative models of load management should be developed, and their preventative effect tested.

## **COI statement**

The Oslo Sports Trauma Research Centre (OSTRC) has a research partnership together with Fitstats Inc. This partnership is based on the development of injury surveillance tools, which

were not used in this study. Fitstats provided the use of AMS free for this study. However, we are not involved in their load management products, and have no financial interest of any kind in Fitstats.

### **Patient and Public Involvement statement**

Coaches were involved in the design of the intervention and recruitment of teams and players to the study. Coaches and players were not involved in the design of the research questions, the outcome measures or the analyses. The results from the study will be disseminated to all teams that were included in the project.

### **Data sharing**

All data are available as supplementary files.

### **Patient consent**

Not required

### **Ethics approval**

The study was reviewed by the South-Eastern Norway Regional Committee for Medical and Health Research Ethics (2017/2232) and approved by the ethics board of The Norwegian School of Sports Sciences (39-191217) and the Norwegian Center for Research Data (56935). The study was registered in the International Standard Randomised Controlled Trial Number Registry (ISRCTN18177140).

### **Acknowledgments**

The authors are grateful to all the players and coaches who participated in the study. The authors would like to thank Rikke Kommedahl, Astrid Grøttå Ree, Gunvor Halmøy, Margareta Endresen, Michael Kleppen, Andreas Ranvik, Peder Lindsetmo, Margareta Endresen for participating in the data collection, as well as Roald Bahr, Lena Bache-Mathiesen and Eirik Halvorsen Wik for valuable feedback on the draft manuscript.

## Funding

The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the International Olympic Committee, the Norwegian Olympic Committee and Confederation of Sport, and Norsk Tipping AS.

## Authors contribution

TD, BC, TEA, JB, and MWF planned the study. The data collection was done by TD and MV. All authors have been involved in the data analyses, drafting, and revision of the manuscript, and all have approved the final version.

1. Jones S, Almousa S, Gibb A, et al. Injury Incidence, Prevalence and Severity in High-Level Male Youth Football: A Systematic Review. *Sports Medicine* 2019;49(12):1879-99. doi: 10.1007/s40279-019-01169-8
2. Ekstrand J, Hagglund M, Walden M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med* 2011;45(7):553-8. doi: 10.1136/bjsm.2009.060582 [published Online First: 2009/06/26]
3. Moseid CH, Myklebust G, Fagerland MW, et al. The prevalence and severity of health problems in youth elite sports: A 6-month prospective cohort study of 320 athletes. *Scandinavian Journal of Medicine & Science in Sports* 2018;28(4):1412-23. doi: 10.1111/sms.13047
4. Røksund OD, Kristoffersen M, Bogen BE, et al. Higher Drop in Speed during a Repeated Sprint Test in Soccer Players Reporting Former Hamstring Strain Injury. *Frontiers in physiology* 2017;8:25-25. doi: 10.3389/fphys.2017.00025
5. Maffulli N, Longo UG, Gougoulas N, et al. Long-term health outcomes of youth sports injuries. *British Journal of Sports Medicine* 2010;44(1):21. doi: 10.1136/bjsm.2009.069526
6. Fyfe JJ, Opar DA, Williams MD, et al. The role of neuromuscular inhibition in hamstring strain injury recurrence. *J Electromyogr Kinesiol* 2013;23(3):523-30. doi: 10.1016/j.jelekin.2012.12.006 [published Online First: 2013/02/09]
7. Ward P, Hodges NJ, Starkes JL, et al. The road to excellence: deliberate practice and the development of expertise. *High Ability Studies* 2007;18(2):119-53. doi: 10.1080/13598130701709715
8. Harøy J, Clarsen B, Wiger EG, et al. The Adductor Strengthening Programme prevents groin problems among male football players: a cluster-randomised controlled trial. *British Journal of Sports Medicine* 2019;53(3):150. doi: 10.1136/bjsports-2017-098937



9. van der Horst N, Smits DW, Petersen J, et al. The preventive effect of the nordic hamstring exercise on hamstring injuries in amateur soccer players: a randomized controlled trial. *Am J Sports Med* 2015;43(6):1316-23. doi: 10.1177/0363546515574057 [published Online First: 2015/03/22]
10. Arnason A, Andersen TE, Holme I, et al. Prevention of hamstring strains in elite soccer: an intervention study. *Scandinavian Journal of Medicine & Science in Sports* 2008;18(1):40-48. doi: 10.1111/j.1600-0838.2006.00634.x
11. van Dyk N, Behan FP, Whiteley R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: a systematic review and meta-analysis of 8459 athletes. *British Journal of Sports Medicine* 2019;53(21):1362. doi: 10.1136/bjsports-2018-100045
12. Soligard T, Myklebust G, Steffen K, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. *BMJ* 2008;337:a2469. doi: 10.1136/bmj.a2469
13. Whalan M, Lovell R, Steele JR, et al. Rescheduling Part 2 of the 11+ reduces injury burden and increases compliance in semi-professional football. *Scand J Med Sci Sports* 2019;29(12):1941-51. doi: 10.1111/sms.13532 [published Online First: 2019/08/04]
14. Waldén M, Atroshi I, Magnusson H, et al. Prevention of acute knee injuries in adolescent female football players: cluster randomised controlled trial. *BMJ : British Medical Journal* 2012;344:e3042. doi: 10.1136/bmj.e3042
15. Mohammadi F. Comparison of 3 preventive methods to reduce the recurrence of ankle inversion sprains in male soccer players. *The American Journal of Sports Medicine* 2007;35(6):922-26. doi: 10.1177/0363546507299259
16. Steffen K, Emery CA, Romiti M, et al. High adherence to a neuromuscular injury prevention programme (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth female football players: a cluster randomised trial. *British Journal of Sports Medicine* 2013;47(12):794. doi: 10.1136/bjsports-2012-091886
17. Owøye OBA, Akinbo SRA, Tella BA, et al. Efficacy of the FIFA 11+ Warm-Up Programme in Male Youth Football: A Cluster Randomised Controlled Trial. *J Sports Sci Med* 2014;13(2):321-28.
18. Akenhead R, Nassis GP. Training Load and Player Monitoring in High-Level Football: Current Practice and Perceptions. *International journal of sports physiology and performance* 2016;11(5):587-93. doi: 10.1123/ijsp.2015-0331
19. Delecroix B, McCall A. Workload and non-contact injury incidence in elite football players competing in European leagues. *Taylor & Francis* 2019 doi: 10.1080/17461391.2018.1477994
20. Fanchini M, Rampinini E, Riggio M, et al. Despite association, the acute:chronic work load ratio does not predict non-contact injury in elite footballers. *Science and Medicine in Football* 2018;2(2):108-14. doi: 10.1080/24733938.2018.1429014
21. Jaspers A, Kuyvenhoven JP, Staes F, et al. Examination of the external and internal load indicators' association with overuse injuries in professional soccer players. *Journal of Science and Medicine in Sport* 2017:1-7. doi: 10.1016/j.jsams.2017.10.005

22. Malone S, Owen A, Newton M, et al. The acute:chronic workload ratio in relation to injury risk in professional soccer. *J Sci Med Sport* 2017;20(6):561-65. doi: 10.1016/j.jsams.2016.10.014 [published Online First: 2016/11/20]
23. Weston M. Training load monitoring in elite English soccer: a comparison of practices and perceptions between coaches and practitioners. *Science and Medicine in Football* 2018;2(3):216-24. doi: 10.1080/24733938.2018.1427883
24. Hulin BT, Gabbett TJ, Blanch P, et al. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med* 2014;48(8):708-12. doi: 10.1136/bjsports-2013-092524 [published Online First: 2013/08/22]
25. Blanch P, Gabbett HT. Has the athlete trained enough to return to play safely? The acute:chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury. *British journal of sports medicine* 2016;50(8):471-75. doi: 10.1136/bjsports-2015-095445
26. Gabbett HT. The training-injury prevention paradox: should athletes be training smarter and harder? *British journal of sports medicine* 2016;50(5):273-80. doi: 10.1136/bjsports-2015-095788
27. Impellizzeri FM, Tenan M, Kempton T, et al. Acute:Chronic Workload Ratio: Conceptual Issues and Fundamental Pitfalls. *International Journal of Sports Physiology and Performance* 2020:1-7. doi: 10.1123/ijsp.2019-0864
28. Impellizzeri FM, Woodcock S, Coutts AJ, et al. Acute to random workload ratio is 'as' associated with injury as acute to actual chronic workload ratio: time to dismiss ACWR and its components. *SportRxiv Preprints* 2020 doi: 10.31236/osf.io/e8kt4
29. Impellizzeri FM, Woodcock S, McCall A, et al. The acute-chronic workload ratio-injury figure and its 'sweet spot' are flawed. 2019 doi: <https://doi.org/10.31236/osf.io/g8yu>
30. Dalen-Loretsen T, Andersen TE, Bjørneboe J, et al. A cherry tree ripe for picking: The relationship between the acute:chronic workload ratio and health problems. *SportRxiv Preprints* 2020 doi: <https://doi.org/10.31236/osf.io/nhgbx>
31. Hulin BT, Gabbett HT, Lawson DW, et al. The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. *British journal of sports medicine* 2016;50(4):231-36. doi: 10.1136/bjsports-2015-094817
32. Foster C, Florhaug JA, Franklin J, et al. A New Approach to Monitoring Exercise Training. *Journal of Strength and Conditioning Research* 2001;15(1):109-15. doi: 10.1519/00124278-200102000-00019
33. Clarsen B, Ronsen O, Myklebust G, et al. The Oslo Sports Trauma Research Center questionnaire on health problems: a new approach to prospective monitoring of illness and injury in elite athletes. *Br J Sports Med* 2014;48(9):754-60. doi: 10.1136/bjsports-2012-092087 [published Online First: 2013/02/23]
34. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med*

2006;40(3):193-201. doi: 10.1136/bjism.2005.025270 [published Online First: 2006/03/01]

35. Kauermann G, Carroll RJ. A Note on the Efficiency of Sandwich Covariance Matrix Estimation. *Journal of the American Statistical Association* 2001;96(456):1387-96. doi: 10.1198/016214501753382309
36. Gallis JA, Li F, Turner EL. xtgeebcv: A command for bias-corrected sandwich variance estimation for GEE analyses of cluster randomized trials. *The Stata Journal* 2020;20(2):363-81. doi: 10.1177/1536867X20931001
37. Andersson SH, Bahr R, Clarsen B, et al. Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. *British Journal of Sports Medicine* 2017;51(14):1073. doi: 10.1136/bjsports-2016-096226
38. Rutterford C, Copas A, Eldridge S. Methods for sample size determination in cluster randomized trials. *International Journal of Epidemiology* 2015;44(3):1051-67. doi: 10.1093/ije/dyv113
39. Soligard T, Schwelnus M, Alonso JM, et al. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med* 2016;50(17):1030-41. doi: 10.1136/bjsports-2016-096581 [published Online First: 2016/08/19]
40. Lolli L, Batterham AM, Hawkins R, et al. Mathematical coupling causes spurious correlation within the conventional acute-to-chronic workload ratio calculations. *British Journal of Sports Medicine* 2019;53(15):921. doi: 10.1136/bjsports-2017-098110
41. Lolli L, Batterham AM, Hawkins R, et al. The acute-to-chronic workload ratio: an inaccurate scaling index for an unnecessary normalisation process? *British Journal of Sports Medicine* 2018:bjsports-2017-098884. doi: 10.1136/bjsports-2017-098884
42. Sampson JA, Fullagar HH, Murray A. Evidence is needed to determine if there is a better way to determine the acute:chronic workload. *Br J Sports Med* 2017;51(7):621-22. doi: 10.1136/bjsports-2016-097085 [published Online First: 2016/11/18]
43. Williams S, West S, Cross MJ, et al. Better way to determine the acute:chronic workload ratio? *British journal of sports medicine* 2016:bjsports-2016-096589-3. doi: 10.1136/bjsports-2016-096589
44. Andrade R, Wik EH, Rebelo-Marques A, et al. Is the Acute: Chronic Workload Ratio (ACWR) Associated with Risk of Time-Loss Injury in Professional Team Sports? A Systematic Review of Methodology, Variables and Injury Risk in Practical Situations. *Sports Medicine* 2020 doi: 10.1007/s40279-020-01308-6
45. Wang C, Vargas JT, Stokes T, et al. Analyzing Activity and Injury: Lessons Learned from the Acute:Chronic Workload Ratio. *Sports Med* 2020;50(7):1243-54. doi: 10.1007/s40279-020-01280-1 [published Online First: 2020/03/04]
46. Bittencourt NFN, Meeuwisse WH, Mendonca LD, et al. Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition-

- narrative review and new concept. *Br J Sports Med* 2016;50(21):1309-14. doi: 10.1136/bjsports-2015-095850 [published Online First: 2016/07/23]
47. Haddad M, Stylianides G, Djaoui L, et al. Session-RPE Method for Training Load Monitoring: Validity, Ecological Usefulness, and Influencing Factors. *Frontiers in Neuroscience* 2017;11(612) doi: 10.3389/fnins.2017.00612
  48. Impellizzeri FM, Rampinini E, Coutts AJ. Use of RPE-based training load in soccer. *Medicine and science ...* 2004 doi: 10.1249/01.MSS.0000128199.23901.2F
  49. Ahmun R, McCaig S, Tallent J, et al. Association of Daily Workload, Wellness, and Injury and Illness During Tours in International Cricketers. *International Journal of Sports Physiology and Performance*;14(3):369-77. doi: 10.1123/ijsp.2018-0315
  50. Carey DL, Blanch P, Ong K-L, et al. Training loads and injury risk in Australian football—differing acute: chronic workload ratios influence match injury risk. *British journal of sports medicine* 2016:bjsports-2016-096309. doi: 10.1136/bjsports-2016-096309
  51. Colby MJ, Dawson B, Peeling P, et al. Multivariate modelling of subjective and objective monitoring data improve the detection of non-contact injury risk in elite Australian footballers. *Journal of Science and Medicine in Sport* 2017;20(12):1068-74. doi: <https://doi.org/10.1016/j.jsams.2017.05.010>
  52. Cross MJ, Williams S, Trewartha G, et al. The Influence of In-Season Training Loads on Injury Risk in Professional Rugby Union. *Int J Sports Physiol Perform* 2016;11(3):350-5. doi: 10.1123/ijsp.2015-0187 [published Online First: 2015/08/27]
  53. Esmaeili A, Hopkins WG, Stewart AM, et al. The Individual and Combined Effects of Multiple Factors on the Risk of Soft Tissue Non-contact Injuries in Elite Team Sport Athletes. *Frontiers in Physiology* 2018;9(1280) doi: 10.3389/fphys.2018.01280
  54. Harrison PW, Johnston RD. Relationship Between Training Load, Fitness, and Injury Over an Australian Rules Football Preseason. *The Journal of Strength & Conditioning Research* 2017;31(10):2686-93. doi: 10.1519/jsc.0000000000001829
  55. Jaspers A, Brink MS, Probst SGM, et al. Relationships Between Training Load Indicators and Training Outcomes in Professional Soccer. *Sports Medicine* 2016:1-12. doi: 10.1007/s40279-016-0591-0
  56. Johnston R, Cahalan R, Bonnett L, et al. Training Load and Baseline Characteristics Associated With New Injury/Pain Within an Endurance Sporting Population: A Prospective Study. *International Journal of Sports Physiology and Performance* 2019;14(5):590-97. doi: 10.1123/ijsp.2018-0644
  57. Lathlean T, Gatin P, Newstead S, et al. Absolute and Relative Load and Injury in Elite Junior Australian Football Players Over 1 Season. *International Journal of Sports Physiology and Performance* 2019:1-9. doi: 10.1123/ijsp.2019-0100
  58. Lu D, Howle K, Waterson A, et al. Workload profiles prior to injury in professional soccer players. *Science and Medicine in Football* 2017;1(3):237-43. doi: 10.1080/24733938.2017.1339120
  59. Malone S, Roe M, Doran DA, et al. Protection Against Spikes in Workload With Aerobic Fitness and Playing Experience: The Role of the Acute:Chronic Workload Ratio on

- Injury Risk in Elite Gaelic Football. *Int J Sports Physiol Perform* 2017;12(3):393-401. doi: 10.1123/ijsp.2016-0090 [published Online First: 2016/07/12]
60. McCall A, Dupont G, Ekstrand J. Internal workload and non-contact injury: a one-season study of five teams from the UEFA Elite Club Injury Study. *Br J Sports Med* 2018;52(23):1517-22. doi: 10.1136/bjsports-2017-098473 [published Online First: 2018/04/08]
  61. O'Keeffe S, O'Connor S, Ní Chéilleachair N. Are internal load measures associated with injuries in male adolescent Gaelic football players? *European Journal of Sport Science* 2019:1-12. doi: 10.1080/17461391.2019.1621950
  62. Pote L, Christie CJ. Workloads placed on adolescent cricket players: A pilot study. *International Journal of Sports Science & Coaching* 2019;14(1):107-13. doi: 10.1177/1747954118810505
  63. Raya-González J, Nakamura F, Castillo F, et al. Determining the Relationship Between Internal Load Markers and Noncontact Injuries in Young Elite Soccer Players. *International Journal of Sports Physiology and Performance* 2019;14(4):421-25. doi: 10.1123/ijsp.2018-0466
  64. Stares J, Dawson B, Peeling P, et al. Identifying high risk loading conditions for in-season injury in elite Australian football players. *J Sci Med Sport* 2018;21(1):46-51. doi: 10.1016/j.jsams.2017.05.012 [published Online First: 2017/06/12]
  65. Thornton HR, Delaney JA, Duthie GM, et al. Importance of Various Training-Load Measures in Injury Incidence of Professional Rugby League Athletes. *International Journal of Sports Physiology and Performance* 2017;12(6):819-24. doi: 10.1123/ijsp.2016-0326
  66. Weiss KJ, Allen SV, McGuigan MR, et al. The Relationship Between Training Load and Injury in Men's Professional Basketball Players. *International Journal of Sports Physiology and Performance* 2017:1-20. doi: 10.1123/ijsp.2016-0726
  67. Watson A, Brickson S, Brooks A, et al. Subjective well-being and training load predict in-season injury and illness risk in female youth soccer players. *Br J Sports Med* 2017;51(3):194-99. doi: 10.1136/bjsports-2016-096584 [published Online First: 2016/12/07]
  68. Clarsen B. Current severity measures are insufficient for overuse injuries. *Science and Medicine in Football* 2016;1(1):91-92. doi: 10.1080/24733938.2016.1256579
  69. Clarsen B, Bahr R. Matching the choice of injury/illness definition to study setting, purpose and design: one size does not fit all! *British Journal of Sports Medicine* 2014;48(7):510. doi: 10.1136/bjsports-2013-093297
  70. Orchard J, Hoskins W. For Debate: Consensus Injury Definitions in Team Sports Should Focus on Missed Playing Time. *Clinical Journal of Sport Medicine* 2007;17(3):192-96. doi: 10.1097/JSM.0b013e3180547527
  71. Schwellnus M, Soligard T, Alonso JM, et al. How much is too much? (Part 2) International Olympic Committee consensus statement on load in sport and risk of illness. *Br J Sports Med* 2016;50(17):1043-52. doi: 10.1136/bjsports-2016-096572 [published Online First: 2016/08/19]

# Tables

Table 2 Baseline characteristics of players included in the analyses

|       | Intervention group | Control group |
|-------|--------------------|---------------|
| N     | 177                | 217           |
| Girls | 57                 | 107           |
| Boys  | 120                | 110           |
| Age   | 17.2 (1.2)         | 17.4 (1.1)    |

# FIGURES

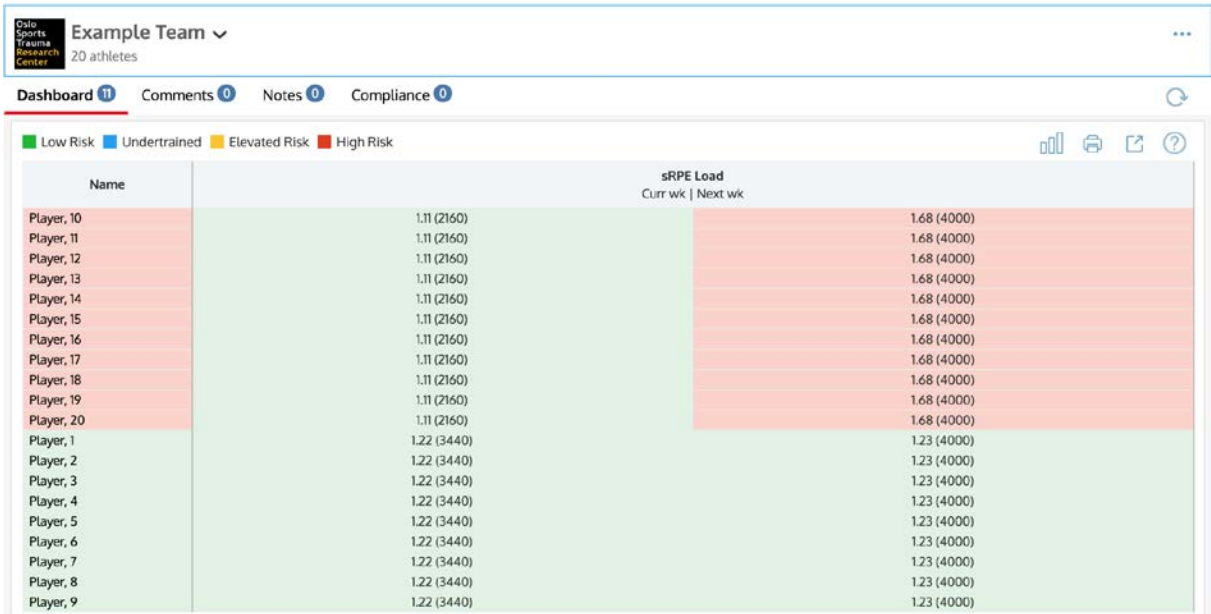


Figure 6 Coaches dashboard in the AMS after next weeks training load is planned

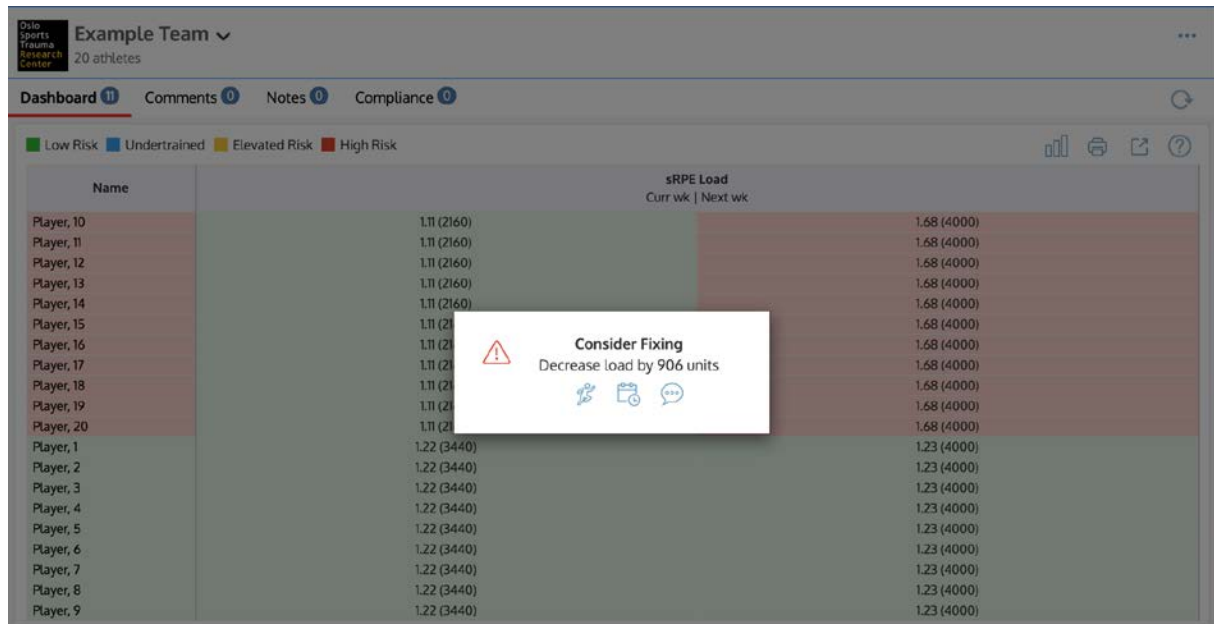


Figure 7 Coaches dashboard in ASM suggesting a revision of planned load

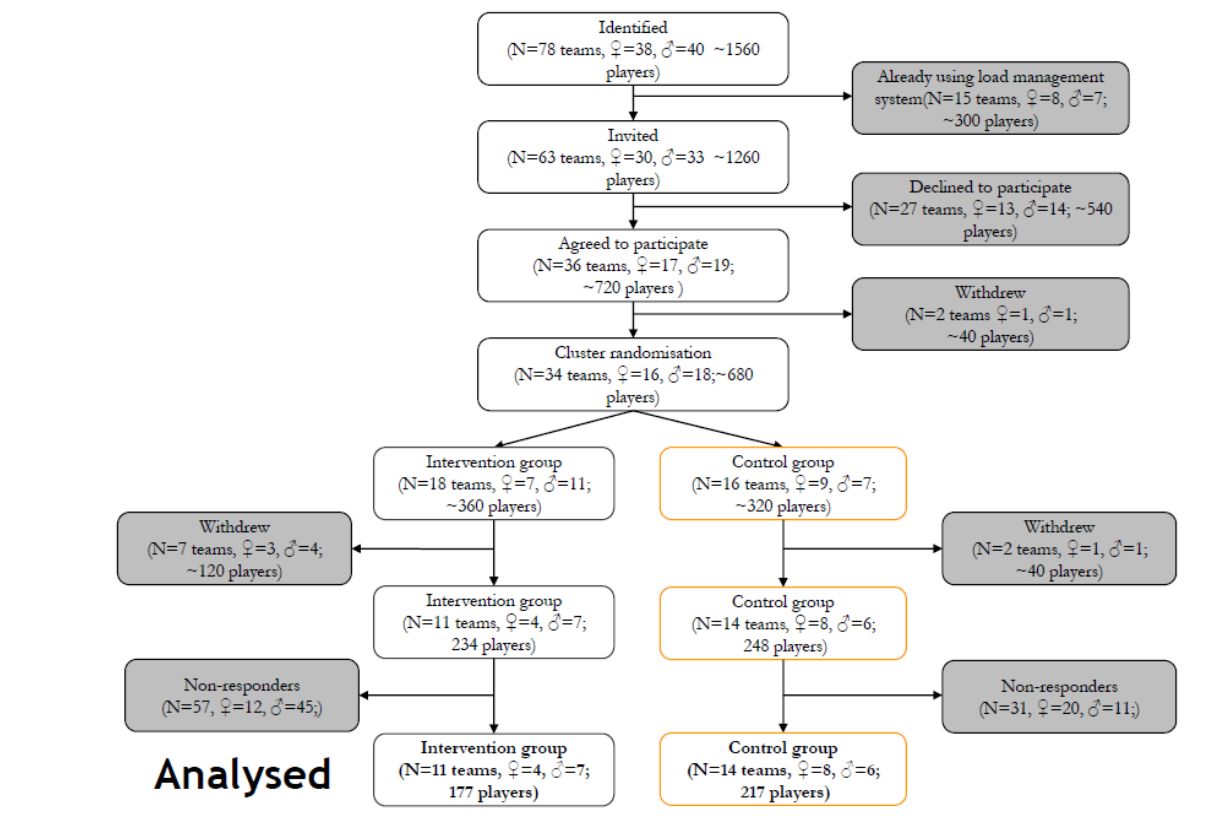


Figure 8 Flow of the teams and the players throughout the intervention

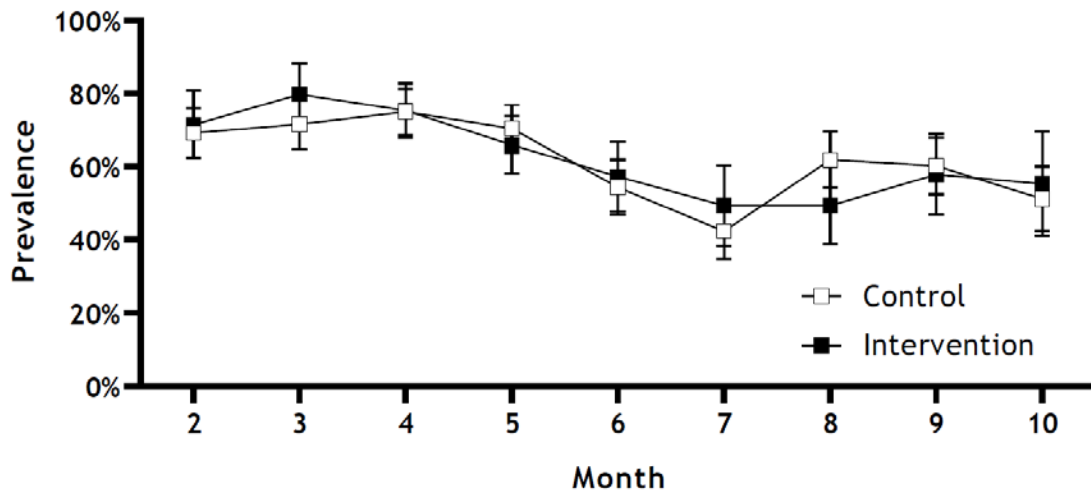


Figure 9 Prevalence of health problems in the control group and the intervention group throughout the season.

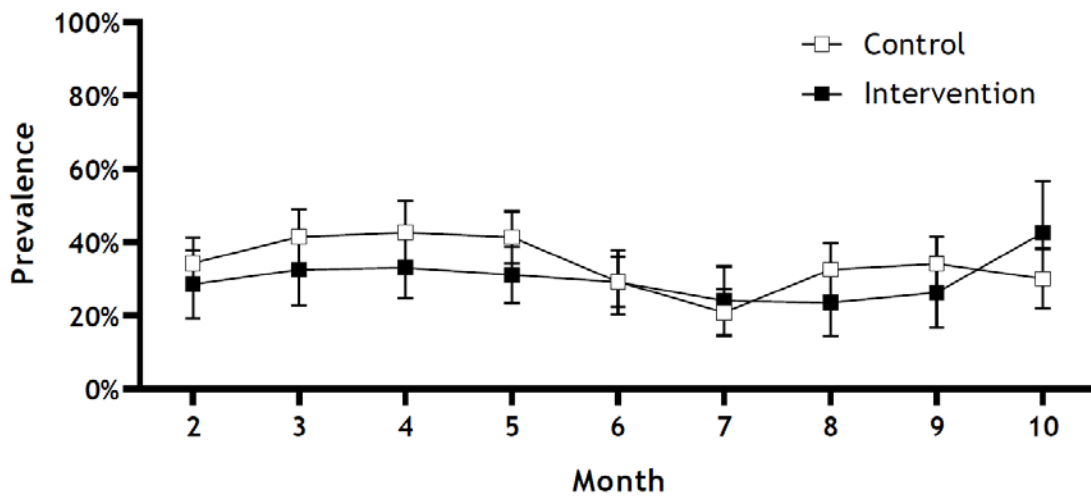


Figure 10 Prevalence of substantial health problems in the control group and the intervention group throughout the season.