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High knee loading in male adolescent pre-professional football players: Effects of a targeted training programme

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ABSTRACT

Objective: To assess whether targeted neuromuscular exercises can decrease knee loading of adolescent pre-professional footballers with high knee loading as identified with the field-based Drop Vertical Jump Test (DVJT).
Design: Prospective controlled trial, conducted between August and November 2016 at Erasmus Medical Centre, The Netherlands.
Methods: Pre-professional football players (aged 14–21 years) were evaluated at baseline and after 12 weeks follow-up with the field-based DVJT. The field-based DVJT is a standardised test in which a player drops from a box and jumps up immediately after landing; knee load is calculated based on five parameters. Players with high knee load (probability ≥ 0.75) from one club performed regular training(control group), and players with high knee load from another other club performed targeted neuromuscular exercises for 12 weeks (intervention group). The difference of change in knee load between both groups after 12 weeks was the primary outcome measure.
Results: Of 107 eligible players, 75 had a high knee loading. Knee loading decreased in both groups after 12 weeks of training, but change in probability of high knee load was not significantly different between both groups (95% Confidence Interval [−0.012–0.082], p = 0.139).
Conclusion: Targeted neuromuscular exercises had no additional effect in decreasing knee loading of adolescent male pre-professional football players compared to regular training.
Trial registration number: The Netherlands Trial Register (ID number: 6044).

1. Introduction

Young, pre-professional football players sustain 4.6 injuries per 1000 h of exposure.[1] Knee injuries account for 17% of all injuries.[1] Effective prevention is necessary to improve the athlete's health and performance.

A high risk of knee injury can be predicted with a screening test, such as the Drop Vertical Jump Test (DVJT). The DVJT was developed as a screening method for risk assessment of anterior cruciate ligament (ACL) injury.[2] The DVJT is a standardised test in which a player drops from a box and knee load is calculated based on five parameters. In general, a screening test should have the potential to classify a player at increased injury risk and there has to be an intervention with the ability to modify the outcome.[3] An abnormal DVJT test outcome was associated with 6.8% risk of ACL injury, which is 17 times higher than in football players with a normal test outcome.[4] The test was developed in young females, but is currently broadly deployed on men and women of all ages. A high probability of knee load (probability ≥ 0.75 as measured with the DVJT algorithm) has been associated with a higher risk of knee injury.[2] This algorithm includes knee valgisation and knee flexion range of motion as modifiable risk factors using neuromuscular training.

Prevention programmes focussed on these two factors have been shown to decrease knee injury risk.[5] Neuromuscular exercises from the Fédération Internationale de Football Association (FIFA) 11+ prevention programme aim to decrease the knee valgus motion and improve the knee flexion range of motion (ROM).[5] FIFA has developed the 11+ to reduce injuries among football players aged 14 years and older.[5,6] When the prevention programme is performed at least twice a week, it leads to 30–50% injury reduction per

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team.[5] However, implementation of this prevention programme in football players is not very successful yet. This implementation rate could improve through selection of players at risk, as it is known that a tailored prevention approach results in a higher compliance.[7] Furthermore, compliance rates could be improved if players can be provided with feedback on the efficacy of their neuromuscular training program.

One study evaluated the influence of neuromuscular training on the probability of high knee load.[8] The study showed a decrease in high knee load in high risk athletes. However, the study was conducted on a small sample size, and on adolescent females. Effects of targeted neuromuscular exercises on young male athletes are currently unknown. The main purpose of this study was to examine if a targeted prevention programme can decrease high knee loading of adolescent pre-professional footballers with a high probability of high knee load as identified with the field-based DVJT. As secondary aim, we evaluated the reliability of the field-based DVJT.

2. Methods

This prospective controlled trial was approved by the Medical Ethical Committee of the Erasmus University Medical Center Rotterdam, The Netherlands (MEC-2016-237). The trial is registered in the Dutch Trial Register (ID number: 6044).

Football players of the Under-16, Under-17 and Under-19 teams of two Dutch Premier League football clubs were asked to participate in the study in August 2016. The clubs played in the same football division. Eligibility criteria for inclusion were (1) football players aged 14–21 years, of (2) male gender and (3) free of musculoskeletal injuries at baseline during physical testing. Players were excluded if (1) the player or his parents did not give permission to participate, or if the player (2) was not available in the week of baseline testing. Informed consent was acquired from all players and parents (in case of underage players) before inclusion.

Football players from one club were assigned to the intervention group and the other club was assigned to the control group. Both clubs had the same amount of training days.

A baseline questionnaire was given to the participants to inquire about age and previous injuries. Body weight and height were measured. The field-based DVJT was performed one week after the start of the football season. There was no match or training day on the day before testing, to ensure all players were fit. The intervention group received their test results within one week and was given one week to get familiar with the exercises, to ensure good execution of the exercises. Test results were not given to the control group during the study period to prevent influencing their training habits as a consequence of the test results.

To perform the field-based DVJT, a player stands on a box, drops down, and jumps up as high as possible. The knee valgus motion and knee flexion range of motion (ROM) were calculated using video analyses.[2] Other elements of the algorithm are mass, tibia length and quadriceps-to-hamstring ratio. Online supplementary file 1 describes the methods in more detail.

Exercises of the FIFA 11+ program, aimed to decrease the knee valgus motion and improve the knee flexion ROM of the knee, were selected as intervention (online Supplementary file 3).[5] The difficulty of the exercises was gradually increased. Both intervention and control group followed regular training, while targeted exercises were advised for all players in the intervention group with a high knee load. We instructed to perform the exercises three times a week, after the completion of regular training.[9] One minute of rest between sets was advised. All exercises were explained and correct performance was controlled by one researcher (IL).

The primary outcome measure was the change in probability score of high knee load after 12 weeks of training. As no data is published reporting the cut-off probability for high knee loading, we estimated that a probability of ≥ 0.75 can be regarded as high risk for knee injuries. This was determined after personal correspondence with one of the developers of the original algorithm (Dr. G.D. Myer) and this value is also frequently used in daily clinical practice.

One researcher (IL) visited the club during every training to observe and register individual compliance of the football player to the exercises. The performed number of exercises divided by the number of prescribed exercises was calculated as percentage.

The club physiotherapist and one researcher (IL) had weekly meetings to register knee injuries. A knee injury was defined as a physical complaint of the ligaments, bone and muscle in or around the knee that leads to the athlete being unable to take part in training and/or competition.[10] Injuries were diagnosed by the club physiotherapist and confirmed by a sports physician or orthopaedic surgeon when the definition of a knee injury was met.

To evaluate the reliability of the field-based DVJT, intra-class correlation coefficient (ICC) for intra- and inter-observer reliability and minimal detectable change (MDC) were examined. The field-based DVJT, hamstring strength test and quadriceps strength test were performed by ten separate healthy male participants. The tests were instructed, measured and recorded by two researchers (RJdV, FG) individually.

Two researchers (RJdV, FG) independently calculated the probability of the field-based DVJT they instructed to evaluate the inter-observer reliability. One researcher (FG) repeated the field-based DVJT in the same players, one day after the first reliability tests. This was done to evaluate the intra-observer reliability and MDC. For the inter-observer reliability of the video analysis, one jump of every participant was analysed independently by two researchers (IL, RJdV). Knee valgus motion and knee flexion ROM were measured individually. The corresponding hamstring-to-quadriceps strength ratio and tibia length were used to calculate the probability scores.

ICC values for intra- and inter-observer reliability were interpreted as poor (<0.40), fair (0.40-0.59), good (0.60–0.75) and excellent (>0.75).[11] The standard error of measurement (SEM) was calculated as $SD * \sqrt{1 - ICC}$, where SD is the SD of all scores of the participants.[12] SEM was used for calculating the MDC with the formula $MDC = SEM \times 1.96 \times \sqrt{2}$.[12]

We performed statistical analyses using SPSS software (V.21.0; SPSS, Chicago, Illinois, USA). We excluded football players from the analyses if data from the field-based DVJT at 12 weeks were unavailable. We analysed the change in probability between the intervention and the control group with a linear regression analysis. For linear regression analysis, we first analysed if there was an association between baseline characteristics and the intervention group in an univariate model. Variables with a p-value < 0.10 were analysed in a multivariate stepwise regression. The change in probability for both the intervention group and control group over time was analysed using a paired sample t-test. The correlation between the difference in probability and compliance to the targeted training programme was calculated using a Pearson correlation test. We considered a p-value < 0.05 as statistically significant in the final analyses.

The probability of high knee loading is based on knee abduction moment (KAM).[8] As the probability of adolescent males is unknown, we used KAM for our power analysis. A study by Myer et al. showed a decrease in KAM score in female athletes after an intervention of 13% (39.9 + 15.8 Nm – 34.6 + 9.6 Nm).[8] We expect a higher baseline measure in our male population, but a comparable change in KAM score of 13%. With an estimated baseline KAM score in adolescent male soccer players of 80 Nm, we can expect a decrease to 70 Nm based on the above mentioned data. With a standard deviation of 12.5, a power of 0.80 and alpha of 0.05, we will need to include 25 players per study arm to detect this estimated improvement on KAM score.

3. Results

A total of 107 players were assessed for eligibility in July and August 2016, of which 36 were included in the intervention group, and 39 in the control group. Three players of the control group were not available for data collection at 12 weeks. We performed baseline measurements in August 2016. Two weeks after these baseline tests, the players in the intervention group with a high probability of high knee loading started the training programme. The progress of the players in this study is displayed in a flow chart in online Supplementary file 2. Baseline characteristics of 'players at increased risk' (probability of high knee load ≥ 0.75) are presented in Table 1.

The mean probability of high knee load ± standard deviation (SD) in the intervention group decreased from 0.90 ± 0.07–0.84 ± 0.12 (95%CI[0.020;0.087], $p = 0.002$). In the control group there was a decrease in mean probability ± SD from 0.92 ± 0.06 to 0.86 ± 0.11 (95%CI[0.030;0.093], $p < 0.001$). There was no difference in probability at baseline or at 12 weeks

Table 1
Baseline statistics of "players at increased risk".

	Intervention group (n = 36) (mean ± SD)	Control group (n = 36) (mean ± SD)	p-value
Age, years	16.5 ± 1.2	16.6 ± 1.3	0.683
Height, meters	1.78 ± 0.06	1.78 ± 0.08	0.949
Body weight, kg	65.5 ± 8.5	69.6 ± 9.0	0.056
BMI, kg/m^2	20.7 ± 2.0	21.9 ± 2.0	0.010*
Weekly training, hours	9.8 ± 2.5	9.5 ± 2.4	0.649
Experience in football, years	4.4 ± 2.7	6.6 ± 2.9	0.001*

* Statistically significant difference (p-value < 0.05). SD: Standard deviation. BMI = Body Mass Index.

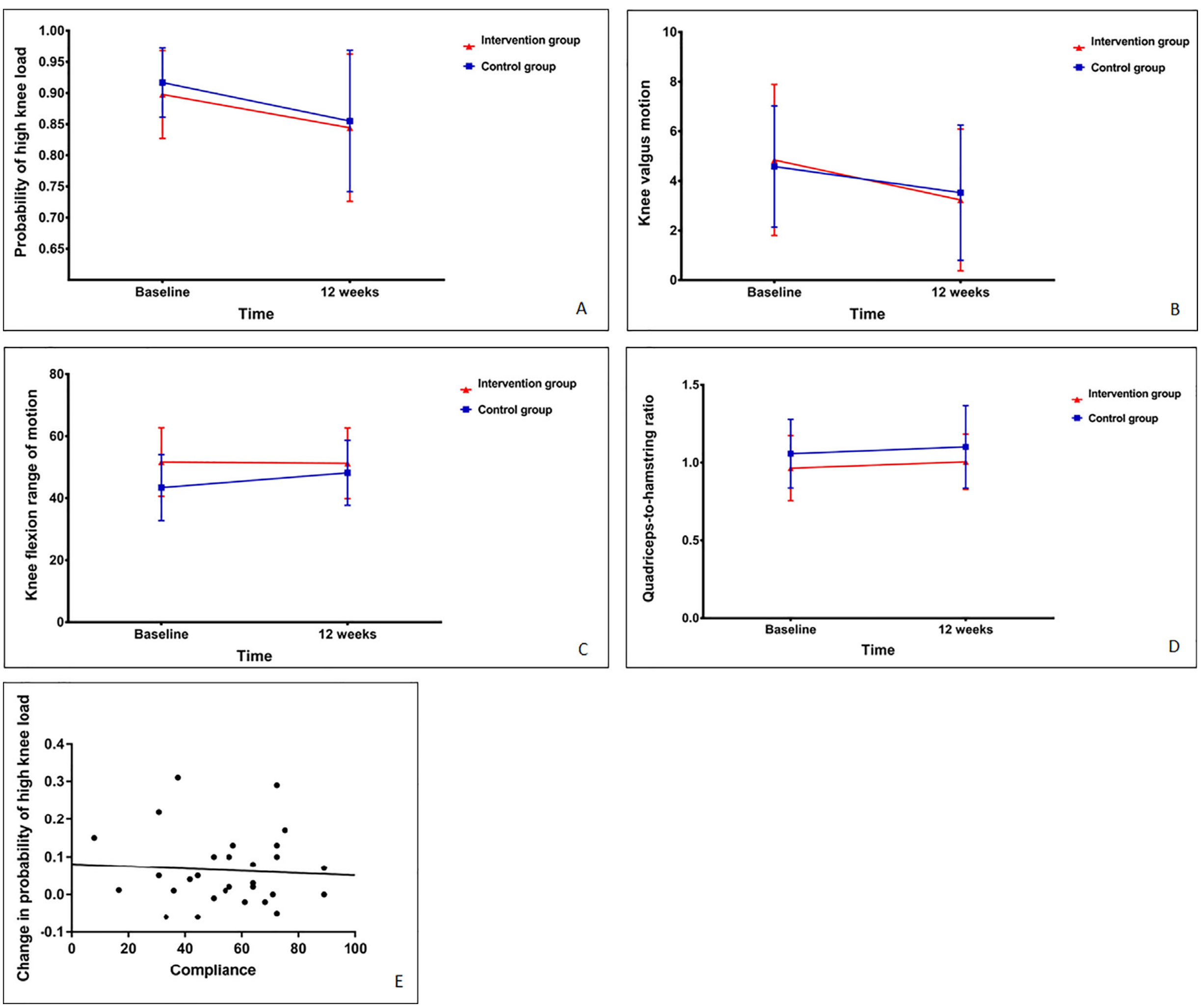

Fig. 1. Different elements of the algorithm for the intervention group (red) and the control group (blue) over time. Mean value is noted as a large dot between the error bars. Error bars denote the standard deviation. A) Change in probability of high knee load. Probability at baseline of the intervention group was 0.90 + 0.07 and of the control group 0.92 + 0.06 with mean difference of −0.02[−0.05;0.01]. Probability at 12 weeks for the intervention group was 0.84 + 0.12 and 0.86 + 0.11 with a mean difference of −0.01[−0.07;0.04]. B) Change in knee valgus motion. In the intervention group the mean knee valgus motion decreased from 4.85 + 3.05 cm to 3.23 + 2.86 cm after 12 weeks($p = 0.006$). Mean knee valgus motion of the control group decreased from 4.85 + 2.45 cm to 3.53 + 2.73 cm ($p = 0.014$). C) Change in knee flexion range of motion. The baseline knee flexion ROM of the intervention group and control group was 52° + 11° and 43° + 11°, respectively, ($p = 0.002$). The intervention group did not improve knee flexion ROM after 12 weeks ($p = 0.867$), whereas the control group improved after 12 weeks to 48° + 10° ($p = 0.021$). D) Change in quadriceps-to-hamstring ratio. No difference in quadriceps-to-hamstring-strength ratio was found between the intervention and the control group at baseline (0.96 + 0.21 and 1.06 + 0.22, respectively, $p = 0.070$) or after 12 weeks (1.00 + 0.18 and 1.10 + 0.27, respectively, $p = 0.073$). Neither intervention nor control group had improved ($p = 0.352$ and $p = 0.404$ respectively). E) Compliance to tailored exercises paired with change in probability score after 12 weeks of targeted exercises. The fitted line represents r^2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

($p = 0.205$ and $p = 0.693$ respectively) between the intervention group and control group (Fig. 1A).

Body weight, height and experience in pre-professional football had a negative influence on change in probability of high knee load. Taller, heavier and more experienced players had a smaller improvement in probability of high knee load (Table 2). The control group had a larger decrease of 0.035 in mean probability score compared to the intervention group. However, neither body weight ($p = 0.791$), height ($p = 0.149$), nor intervention ($p = 0.139$) were independent predictors of change in probability. Only experience in pre-professional football($p = 0.003$) was significantly associated with an increased change in probability.

There was no change between intervention group and control group in knee valgus motion ($p = 0.528$, Fig. 1B) and knee flexion ROM ($p = 0.106$, Fig. 1C). Quadriceps-to-hamstring strength ratio did not differ between both groups ($p = 0.744$, Fig. 1D).

Mean compliance to the exercise program was 56.9 ± 18.2%. The compliance of individual players did not significantly correlate with their corresponding change in probability score ($r = -0.033$, $p = 0.864$, Fig. 1E).

Six knee injuries occurred, of which three injuries occurred in the intervention group and three in the control group. Mean probability was 0.899 (SD ± 0.079) with an average recovery time of 12.4 (SD ± 5.2) days. The type of injury was diverse: three player sustained meniscus injuries, one player had Morbus Osgood-Schlatter disease, and two players suffered from patella tendinopathy. One meniscus injury required surgical intervention and was excluded for calculating recovery time, as he was not fully recovered at the last follow-up moment.

Intra-observer reliability of the probability score was 0.48 (95%CI[−0.30;0.80]). The inter-observer reliability was determined to be 0.48 (95%CI:−0.35;0.80]). Both can be defined as fair reliability.[11] The inter-observer reliability of the video analysis was 0.94 (95%CI[0.84;0.98]), which showed almost perfect agreement. The MDC of the probability score was 0.286.

4. Discussion

This is the first study in adolescent males that compared the effect of targeted neuromuscular exercises with regular training in a group with increased risk of high knee load. This study shows that targeted neuromuscular exercises do not decrease high knee loading more effectively than regular training in male adolescent pre-professional football players with a high knee loading. The high knee loading decreased in both groups after 12 weeks of training, but no difference in improvement was found.

The main purpose of screening for injury risk is to prevent injuries using a targeted intervention. Many steps should be taken before a screening test is developed: (1) risk factors need to be identified in prospective studies, (2) a cut-off value should be defined, (3) the cut-off value of the test should be validated in multiple cohorts and (4) the effect of combined screening and intervention should lead to a clinically relevant reduction in injury rate.[3] Based on a recent prospective study,[13] it is questionable whether the field-based DVJT could be regarded as a valuable screening tool.[3] We showed that this field-based DVJT cannot be used to explain the effect of intervention and furthermore, there is a high variability of test results given the relatively large MDC.

The field-based DVJT algorithm uses five parameters, of which tibia length and knee valgus motion have the largest impact on the probability score. As the field-based DVJT was developed in young females,[2] absence of adjusting for sex makes it questionable whether the algorithm can be extrapolated to male athletes. ACL injury incidence is three times lower for males than for females, but using tibia length and mass (males are generally taller and heavier), males receive more points for baseline statistics.[14,15] Therefore, further research is needed to validate the field-based DVJT algorithm for (adolescent) males as the field-based DVJT is frequently used in males in the daily clinical setting.

The field-based DVJT showed a 73% specificity and 78% sensitivity in a cohort study of female football players.[16] However, there was a substantial overlap in test results of healthy and injured players, resulting in a poor positive predictive value.[16] A recent cohort study with 782 females concluded that of none of the five variables in the algorithm were associated with an increased risk of ACL injury for players with no previous injury, and that it was a poor indicator for predicting ACL injury.[13] The conclusions of both studies question the validity of the field-based DVJT as a screening test. More research is needed to study the selected variables of the field-based DVJT algorithm to determine its validity as a screening test.

Studies have shown decreased knee loading after implementation of prevention exercises,[8,17] but none of these studies used a control group. We found a significant decrease in knee loading in both groups, but no difference in improvement between intervention and control group was found. When taking the presumptions about the algorithm (as stated previously) into account, we suspect the algorithm does not contain the correct modifiable factors to observe changes made in knee loading. Another explanation could be that the selected neuromuscular exercises have other effects, which are not related to decrease knee loading.

A strength of the study is that we included a sufficient number of football players to detect potentially significant and clinically relevant differences. This study has an adequate methodology with a previously defined and registered study protocol. The clear consensus between all researchers ensured the same instructions were given during test moments to all football players, to prevent accidental influence of data. We based our intervention on an effective exercise protocol.[5] Although changes after this intervention might take longer, we expected that the neuromuscular training was able to decrease knee loading within a time frame of three months.

There are some limitations to this study. First, we used two clusters to avoid "contamination" (one individual's changing behaviour might influence another individual within the same team). Our clusters were determined by the club at which a player was training, which makes different training regimes a possibility. Both clubs followed the regulations to not to alter their regular training, and not to perform extra prevention exercises. The baseline probability score and characteristics of both clusters did not show a clinically relevant difference. Therefore, we may assume that both clusters were at an equal physical level at baseline.

Another limitation could be the low compliance to the exercises. The FIFA 11+ programme specified that the intervention should be performed at least two times a week.[5] We made our intervention group perform the targeted neuromuscular exercises three times a week, thus making sure the included players reached the minimal advised exercises. Although, mean compliance rate was just above

Table 2
Linear regression analysis of change in probability after 12 weeks.

	Unstandardized beta [95%CI]	Significance (p-value)
Intervention	0.035 [−0.012;0.082]	0.139
Height (meters)	−0.309 [−0.731;0.114]	0.149
Body weight (kilograms)	0.000 [−0.004;0.003]	0.791
Experience in pre-professional football (years)	−0.011 [−0.019;−0.004]	0.003*

CI = Confidence Interval. $r^2 = 0.189$.
* Statistically significant difference (p-value < 0.05).

half of the prescribed number of exercises. Consequently, players might not have performed enough exercises to show a significant effect. However, there was no significant association between compliance rate and change in probability score for high knee load. We would like to emphasize that this is a reflection of daily clinical practice, where compliance rates are significantly lower than prescribed.

Last limitation is the reliability of the field-based DVJT; its intra- and inter-observer reliability are both of fair agreement, while the inter-observer reliability of the video analysis was excellent. These fair intra- and inter-observer reliability of the field-based DVJT suggest that two separate jumps of an individual cannot be compared, and this questions the reproducibility of the test. Another reason to question the reproducibility of the test is the high MDC of 0.286 on a scale of 0–1. This is probably due to the fact that the two separate landings of an individual change considerably. The noted change after 12 weeks in both groups lies far within the boarder of the MDC. A study by Rendler et al. showed similar results; they found an excellent inter-observer reliability (0.92 (95% CI 0.829–0.969, $p < 0.05$)) and a moderate intra-observer reliability (0.55 (95% CI 0.49–0.61, $p < 0.05$)).[18] However, they concluded that the moderate intra-observer reliability combined with the excellent inter-observer reliability is high enough to suggest that screening can be performed without significant training; they do not mention that their low intra-observer reliability might indicate that the landings of an individual change considerably. Based on these data, we presume that data analysis of the field-based DVJT is almost perfect,[11] but it questions the reproducibility of the field-based DVJT.

The outcome of this study questions whether this field-based DVJT should be used as a screening test and follow-up test. This study shows that there is a high variability of knee loading within one individual. Identifying new risk factors to improve the calculation of the probability of high knee load might be an interesting focus for future studies.

Another target for future research might be the validation of the field-based DVJT algorithm for males, as males are generally taller and heavier than females. We suggest correcting for the tibia length accordingly. No study has been conducted on the influence of tibia length on the knee injury risk of males. Future studies might evaluate the risk factors of ACL risk of males, and revise the algorithm for males accordingly.

5. Conclusion

A targeted training programme does not decrease high knee loading of male adolescent pre-professional football players more effectively than regular training. Based on this study, the effectiveness of a neuromuscular training programme cannot be explained by decreased knee loading.

Practical implications

- Both regular football training and targeted neuromuscular exercises decrease knee loading, but no difference is found between regular football training and targeted exercises.
- The modifiable risk factors knee valgus motion and knee flexion range of motion did not improve more effectively in the targeted exercise group compared to the regular football training group.
- Change in probability of high knee load and compliance rate to neuromuscular exercises were not correlated.
- The moderate inter-rater reliability of the field-based DVJT and high MDC question the reproducibility of the field-based DVJT.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.06.016.

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