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Long-term neuromuscular training and ankle joint position sense

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Preventive effect of proprioceptive training is proven by decreasing injury incidence, but its proprioceptive mechanism is not. Major hypothesis: the training has a positive long-term effect on ankle joint position sense in athletes of a high-risk sport (handball). Ten elite-level female handball-players represented the intervention group (training-group), 10 healthy athletes of other sports formed the control-group. Proprioceptive training was incorporated into the regular training regimen of the training-group. Ankle joint position sense function was measured with the "slope-box" test, first described by Robbins et al. Testing was performed one day before the intervention and 20 months later. Mean absolute estimate errors were processed for statistical analysis. Proprioceptive sensory function improved regarding all four directions with a high significance ($p<0.0001$; avg. mean estimate error improvement: 1.77°). This was also highly significant ($p\leq0.0002$) in each single directions, with avg. mean estimate error improvement between 1.59° (posterior) and 2.03° (anterior). Mean absolute estimate errors at follow-up (2.24°±0.88°) were significantly lower than in uninjured controls (3.29°±1.15°) ($p<0.0001$). Long-term neuromuscular training has improved ankle joint position sense function in the investigated athletes. This joint position sense improvement can be one of the explanations for injury rate reduction effect of neuromuscular training.

Keywords: handball, ankle, joint position sense, proprioception, prevention, proprioceptive training, neuromuscular training

Ligamentous injuries of the ankle represent one of the most frequent sports injuries. In an analysis of 119 epidemiological articles from 1985 to 2002 – performed as epidemiological basis for one of our previous works – we found handball, as the sport representing the highest risk for ankle injuries, with an injury frequency rate (IFR) of 2.14 injuries in 1000 exposure hours. In fact, among the top five sports with the highest incidence for ankle injuries four are contact team sports (5). There is a very apparent need for the reduction of these high injury rates by different methods of prevention.

The mechanical stabilising effect of different braces and stirrups, and thus their preventive effect, is well known and described. A special neuromuscular training programme, often referred to as "proprioceptive training", was also proved to be effective in reducing the incidence of lower limb injuries (2, 17, 20). There are numerous studies, supporting the positive effect of the proprioceptive training on balance (1, 4, 7, 16, 23–25), but little is known about its effect on joint position sense, particularly as an injury-preventing mechanism, when the programme is incorporated in the training regimens of athletes.

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In our hypothesis, the above-mentioned training does improve the proprioceptive sensory function of the ankle, when applied long-term as part of the regular trainings and contributes to its preventive effect. Additionally we aimed to compare the results of the investigated athletes with a control-group of previously uninjured athletes. To measure the proprioception sensory function, we carried out these evaluations in the possible outermost two time points. The first evaluation took place at the start of the preseason, when we knew which players had a long term contract with the club. Twenty months later, as the transfer period approached we carried out the second evaluation not to lose players from the sample because of club transfers.

Methods

Similar to other comparable biomechanical outcome studies a relatively small number of subjects, a total of twenty people representing 40 ankle joints participated in this study.

The handball team consisted of 19 players. After the exclusion, ten of them, aged an average 23.7±4.4 years, could be followed-up after 20 months – they formed our training-group. Exclusion criteria for the training-group were previously applied preventive training in one player's career and ankle surgery or major ankle injury (absent from sport>1 month) one year before the intervention, which could considerably influence the proprioceptive sensory function of the ankle. Another excluding circumstance was, when an athlete was traded, or finished his other playing career.

At the beginning of the season, coaches of the intervention team were educated in the use of the prescribed proprioceptive training program by a physical therapist. The team was provided with wobble boards, soft mats and an instructional DVD. During the season the intervention team was visited three times by a sports physician and a physical therapist to check compliance and ensure proper use of the training program. The training programme was designed in collaboration with sports physicians of the Department of Sports Surgery and Department of Rehabilitation. The main focus of the exercises was to improve awareness and control of knees and ankles during standing, cutting, jumping, and landing. The training program modified from Olsen et al (17) consisted of 24 basic exercises (Box 1) (18, 19). They performed the prevention training twice times a week for 30 minutes, as a special warming up under the supervision of the assistant coach (Fig. 1).

Fig. 1. Handball-specific proprioceptive drills

Ten athletes, representing 20 ankle joints (5 men and 5 women, mean age 23.0±5.8 years) served as control-group. This was intentionally the same control-group, already featured in our previous two studies in these series of investigations on ankle proprioception. They were chosen from competitive- and elite-level athletes participating in different kinds of high-risk sports (regarding ankle injuries) coming to our institute for regular checkups. Criteria for selection and inclusion were 16–40 years of age, negative medical history and physical status of the lower extremities, equal numbers of males and females. None of them had any previous supination injuries, nor did they undergo any interventions, which might theoretically influence the joint position sense of their ankles.

All participating players of the training-group were first measured one day before the start of the implementation of the special neuromuscular physical therapy programme into their regular training regimen and were followed-up 20 months later. In the control-group measurements were performed only once on each subject with the exception of the first three. They were examined twice within 24 hours to test the reliability of the method (6).

Box 1. Programme of proprioception training

(30 seconds and one repetition each)
Warm up
- Jogging end to end
- Sideways running with crossovers
- Forward running in a zigzag line
- Backward running in a zigzag line

Static balance
(10 repetitions each bare footed)
- Squats (one or two-leg stance) with or without side steps
- Wobble board
  - Squats (two-leg stance)
  - Passing the ball (two-leg stance knee flexion 60º)
  - One leg stance
  - One leg stance other leg crossing over
  - Pushing each other off balance
  - One leg stance giving the ball to the teammate with trunk rotation

Dynamic balance
(10 repetitions each bare footed)
- Sport specific drills
  - Two-leg jump from a small box to a soft mat into two-leg stance knee bended
  - Passing the ball during the previous exercise
  - Two-leg jump from a small box to a soft mat into two leg stance while trunk rotated 90°
  - Passing the ball during the previous exercise
  - One leg jump from a small box to a soft mat
  - The wobble boards and soft mats are placed next to each other. Step along the wobble boards and jump along the soft mats

Exercises in shoes
  - Vertical jumps while the teammate pushes the player's trunk in the air

There were no significant differences between the two groups (training vs. control) with respect to baseline data (in terms of age, body height and weight) (Table I). Lower extremity dominance of the subjects was determined using a ball-kicking test. This test is regularly used to determine lower extremity dominance. The subjects have to kick a ball passed to them, but the choice of the leg is optional. Subjects usually pass the ball back with their more skilful, dominant lower extremity.

Table I. Baseline data of the two study-groups

		Training-group n=10	Control-group n=10
Age (years)	Mean±SD	23.7±4.4	23.0±5.8
	Min.–max.	18.2–30.7	16.2–31.6
Height (cm)	Mean±SD	176.1±7.3	172.8±8.1
	Min.–max.	165–190	163–185
Weight (kg)	Mean±SD	69.7±6.7	66.5±11.3
	Min.–max.	60–81	56–85
BMI (kg/m^2)	Mean±SD	22.5±1.3	22.1±1.8
	Min.–max.	20.5–24.1	20.2–25.4
Male/Female		0/10	5/5
Lower extremity dominance Right/Left		9/1	7/3

None of the anthropometric data differ significantly between the training and the control group.

For the assessment of ankle joint position sense we used the slope-box test, first applied and described by Robbins et al. (21). It has a reliability of 0.91–0.92 (6, 22). The test was acknowledged by numerous biomechanical experts ever since (8, 12, 21). Circumstances of the test were identical in both groups (training and controls).

A total of 11 wooden platforms with a basal area of 30×30 cm inclined at various angles every 2.5 degrees between 0 and 25 degrees were constructed. Their top surface was covered with slip-proof rubber material. Rotating them in four different directions enabled a total of 4×11 different testing positions.

A total of 44 tests on each ankle were thus performed. Before starting the investigation, we designed a random order of boxes with different amplitudes and slope-directions, which was followed in all measurements. In order to eliminate the effects of learning, subjects did not see the platforms (before, during or after testing), did not know the degrees of inclination, did not receive any feedback on the accuracy of their guesses, but were shown references of 3 different slopes (0, 12.5 and 25 degrees) in four directions, in front of random sets of 11 boxes. Subjects were asked to tell the direction and the amplitude of the slope they were stepping on from a small stool, putting once full weight on the slope-box, barefoot, with their knees in full extension on a single leg. Subjects had no visual information on the horizontal plane for they had to wear glasses darkened on the bottom, but had the possibility of supporting themselves on a wall in front of them should they lose their balance (Fig. 2).

Amplitudes had to be estimated on a scale between 0 (horizontal) and 15 (35 degrees), enabling a possible over-estimation of the slope-angle. Slope-directions had to be defined as “outward”, “inward”, “forward” or “backward”. All tested subjects were informed that a certain testing position (direction and amplitude) could be provided more than once. Actually, with the exception of the horizontal plane, no testing positions were repeated.

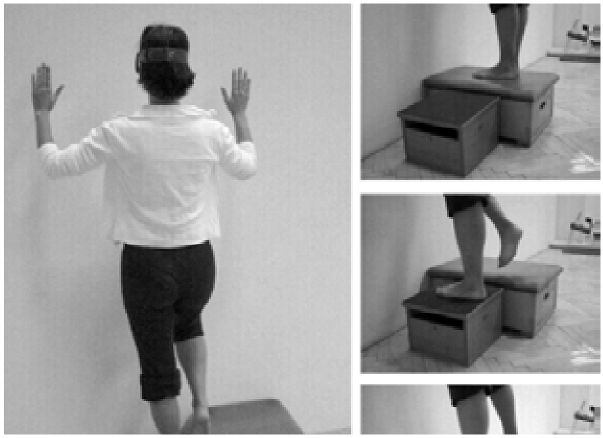

Fig. 2. The “slope-box” test

This way one testing session produced 88 estimates, making a total of 1760 estimates from the training-group, and further 880 (+264 for reliability testing) from the control-group available for statistical analysis. However, as one person’s different estimations could not be observed as individual and unrelated events, statistic calculations were performed with mean absolute estimate errors deriving from a participant’s absolute estimate errors recorded in one direction. The absolute estimate error, which is the measure used to characterise the accuracy of inclination estimates, is simply the absolute value of the difference between the estimated and actual slope-amplitudes (in degrees). The mean absolute estimate error also has the advantage of providing opportunity to compare results with the work of other researchers on joint position sense testing. Based on our previously published conclusions regarding the control-group (6), calculations were made with mean absolute estimate errors from all estimates of slopes with an amplitude of 7.5 degrees or above.

All research data were recorded on Microsoft Excel sheets while statistical analysis was performed using the STATISTICA 6.0 software. For comparisons between two dependent sets of data (thus longitudinal changes in mean absolute estimate errors) we used the non-parametric Wilcoxon’s matched pairs test. For comparisons between two independent samples the non-parametric Mann-Whitney U-test was applied. Comparisons between more than two sets of mean absolute estimate errors were computed with Kruskal-Wallis’ non-parametric analysis of variance (Kruskal-Wallis ANOVA). Statistical significance was assumed at p levels of 0.05 or below.

The study was designed to comply with the Declaration of Helsinki and was approved by the local ethics committee. All participants gave informed consents before joining the study.

Results

The training exposure for the intervention group was 8840 hours, the prevention training exposure was 780 hours.

In the statistical analysis’ range-of-interest of slope-amplitudes there were no direction-misjudgements. In the control-group, no differences of ankle joint position sense function could be observed in relation to side-dominance and gender (6). Due to these results we used further the mean absolute estimate error of the tests performed on the total of twenty healthy ankles in the control-group as a baseline value for later comparisons. Furthermore, as reported in one of our previous papers, we found similarly high reliability rates (avg. 0.92, ranging 0.90–0.93) for the applied method of joint position sense testing as the original authors of the applied measurement method did (6, 22).

When comparing longitudinal changes of ankle joint position sense function in the training-group there is an overall improvement of the mean absolute estimate error of 4.01° before training to 2.24° after training (Wilcoxon matched pairs test: $p<0.0001$ (T=0.00, Z=7.62)). We also see significant changes in all single directions, with p values ranging from 0.0001 to 0.0002. However, we could not observe any significant differences between the improvements of different single directions (Kruskal-Wallis ANOVA: p=0.5764; (H(3, N=80)=1.980672)) (Table II).

Table II. Changes in joint position sense function before implementation of the special neuromuscular training and 20 months later at follow-up (Inclination range: 7.5°–25°)

Direction	Mean absolute estimate error		Improvement	Significance
	Before	At follow-up		
Anterior	4.22°±1.57°	2.19°±1.04°	2.03°	p=0.0001*
Posterior	4.00°±1.50°	2.41°±0.75°	1.59°	p=0.0002*
Lateral	3.64°±1.01°	1.81°±0.71°	1.63°	p=0.0001*
Medial	4.18°±1.32°	2.55°±0.86°	1.63°	p=0.0001*

* Marked changes are significant (Wilcoxon matched pairs test).

The training-group had higher mean absolute estimate errors at the start of the investigation than the controls (Mann-Whitney U-tests: $p_{anterior}=0.0062$; $p_{posterior}=0.4310$; $p_{lateral}=0.1466$; $p_{medial}=0.0402$). However, at follow-up the training-group fared in every single direction – with the slight exception of the anterior direction – significantly better, than the control-group (Mann-Whitney U-tests: $p_{anterior}=0.0602$; $p_{posterior}=0.0004$; $p_{lateral}=0.0001$; $p_{medial}=0.0171$). When examining overall results of all directions, these above tendencies and significant differences became apparent (Table III and Fig. 3).

Table III. Changes in joint position sense function before and after training (Inclination range: 7.5°–25°)

Direction	Mean absolute estimate error		Significance
	Before	At follow-up	
All directions	4.01°±1.36°	2.24°±0.88°	p<0.0001*
Controls	3.29°±1.15°		
Significance	p<0.0001**	p<0.0001**	

* Marked changes are significant at the intervention group before and after the intervention (Wilcoxon matched pairs test).

** Marked differences are significant between the intervention group and the control group (Mann-Whitney U-test)

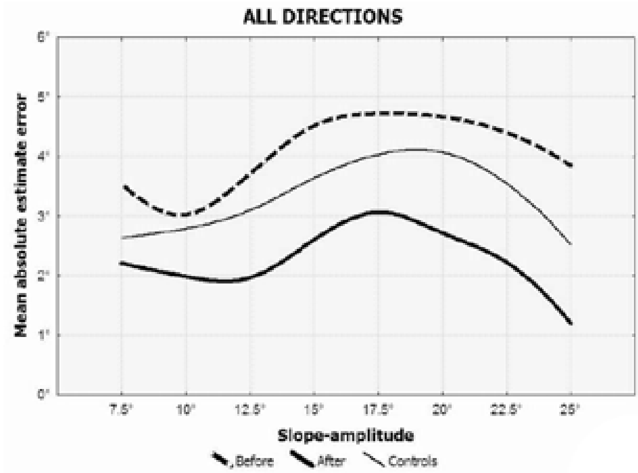

Fig. 3. Mean absolute estimate errors of the training-group before the start of the special training programme [dashed bold lines], at follow-up 20 months later [continuous bold lines] and results of the control-group [continuous thin lines]. Comparison of all four directions combined

Discussion

Mann et at. (14) and Konradsen and (11, 12) both on their researches stated based, that temporary or permanent failure of the proprioceptive function would play a main role in the development of acute ligament-injuries of the lower limb. According to this statement, any training method that improves the proprioceptive function must theoretically reduce the incidence of injuries.

Caraffa and his co-workers implemented more than a decade ago special agility drills for over 600 players of 40 soccer teams, which lead to a significant reduction of the incidence of ACL-injuries (2). Myklebust et al. observed the same positive effect of a similar further developed neuromuscular training programme in over 800 players of more than 50 Norwegian female handball teams (16.). Petersen et al. investigated not only the positive effect on ACL-injuries but also on other injuries of the lower limb. They found the incidence of ankle injuries in their intervention group of 134 female handball players 42% lower, than in the control-group (N=142) (19). These large and very important epidemiological studies have actually proved the positive preventive effect of this neuromuscular training, but they did not investigate the mechanism of the effect.

Previous biomechanical studies observed the effects of rather intensive neuromuscular trainings with durations between 4 and 6 weeks. Most of them did well prove the positive effect of this training method on balance, but they did not investigate the effect on joint position sense (16, 23–25). Similar to one of our previous studies, where we applied the training over 6 weeks (3×45mins/week) (14). Eils and Rosenbaum examined the proprioceptive effect of a 6-week exercise programme applied to subjects with chronic talocrural instability. They found a significant improvement in joint position sense, postural sway and muscle reaction times (3). However, we did not find any previous studies investigating the proprioceptive effect of this special physiotherapy programme applied as an injury-preventing method long-term with a lower intensity as part of the regular training regimen in a group of athletes in a high-risk sport.

Applying any physical therapy or training method over a long period of time of course raises the question of compliance. However, the neuromuscular training integrated into the regular training regimen provided a change for the athletes, so that they always performed it with good motivation. On the other hand, trainers, who actually define the actual exercises for the athletes, were fond of the already known positive injury-preventing effect of the training, so that they never discussed the possibility of stopping the intervention.

As the main result of our study we found highly significant improvements in every single as well as in all directions combined, without differences in improvement between directions. Also, at follow-up, the proprioceptive sensory function of the investigated handball-players was significantly better, than that of the control-group – with the exception of the anterior slopes, where the difference was just not significant. The control-group included previously uninjured competitive- and elite-level athletes of other high-risk sports, who never performed any similar special training for the improvement of the proprioceptive function.

However, pre-training results of the training-group indicated a significantly worse proprioceptive function than measured on the control-group's ankles. This of course raises the question about the role of previous injuries on ankle proprioception in the training-group, for elite handball players suffer significantly more ankle injuries – as several studies proved in the literature (9, 10) – than athletes in other sports. In our previous study of this series of investigations (14) pre-training results of the intervention group of athletes with chronic functional talocrural instability were comparable to those of the training-group in this study, giving evidence on the negative role of previous injuries on ankle proprioception.

Thus, it would have been obligatory to retrospectively record all participating athlete's history on ankle injuries. However, reliability of retrospective medical history has a time limit of only one year (26). It was also the reason why we decided not to choose another handball team as a control-group. In fact, if had done so, there could have been the paradox situation featuring a control-group with already significantly worse ankle proprioception than the intervention team before intervention.

We have also recorded the injury rates in the investigated team, and defined retrospectively a pre-investigation incidence of ankle injuries for the previous season. Here we also found an apparent reduction of injuries from 0.88 to 0.34 injuries per 1000 playing hours, indicating the preventive effect of the applied proprioceptive drills. However, we believe that on such a small group of athletes, and especially within the frames of a primarily biomechanical study we cannot draw general conclusions regarding the epidemiological effect. In this point-of-view we must rely on the above-mentioned large epidemiological studies, which already called this preventive method "proprioceptive training", without proving its true proprioceptive effect.

Conclusion

We believe our study provides an important complement to the previously known epidemiological result, proving that this neuromuscular training method is truly worthy the name "proprioceptive training". Agreeing to these previous studies we can only recommend its incorporation into training regimens of athletes participating in high-risk sports, such as contact team sports.

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