Preventing ankle sprain recurrences in sports

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Effect of sensorimotor training on morphological, neurophysiological, and functional characteristics of the ankle: a critical review

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ABSTRACT

Background Sensorimotor training is effective in preventing ankle sprain recurrences, but the pathway through which this effect occurs is unknown. Biomechanical and neurophysiological analyses of sensorimotor training leading to functional changes of the ankle are needed to establish this pathway.

Objectives This article reviews the effect of sensorimotor training on morphological, neurophysiological and functional characteristics of the ankle.

Methods A MEDLINE and CINAHL computerized literature search was conducted to search for relevant articles. A study was included if (i) the study contained research questions regarding the effect of sensorimotor training on mechanical, neurophysiological, and/or functional ankle functioning; and (ii) the study dealt with subjects with a history of ankle sprain; and (iii) the study contained a control group; and (iv) the results contained measures of mechanical, neurophysiological, or functional insufficiencies as study outcome; and (v) the study met a pre-defined cut-off score set for methodological quality.

Results Results on joint position sense and muscle reaction times showed a learning effect of repeated measures and not a training effect. Decrements of postural sway after sensorimotor training were mainly attributable to a learning effect as well. Effects on muscle strength were not found.

Conclusions Evidence for an effect of sensorimotor training on neurophysiological, morphological, and functional characteristics is limited, if present at all. Thus, the pathway of sensorimotor training remains unclear. Future studies need to focus on (i) differentiating between morphological, physiological, and functional changes, (ii) larger sample sizes with a priori sample size calculations, (iii) correspondence between training and test method, (iv) using other measures than postural sway more closely linked to functional stability, and (v) using a longer follow-up period than six weeks.

INTRODUCTION

With an incidence of about 25% of all injuries across all sports, the most common injury is the ankle injury.[1-5] Of all ankle injuries up to 95% involve the lateral ankle ligaments, i.e. acute lateral ankle sprain, causing a partial or complete rupture of the anterior talofibular ligament and in some cases also the calcaneofibular ligament.[6]

It has been well documented that athletes who suffer an ankle sprain have a higher risk of re-injury within one year post-injury.[7-10] This increased injury risk after an initial ankle sprain is generally thought to be caused by a proprioceptive impairment in the ankle due to trauma to mechanoreceptors of the ankle ligaments after an ankle sprain.[11] Partly based on this rationale sensorimotor training is widely used for the rehabilitation after an ankle sprain, and is thought to improve proprioception by re-establishing and strengthening the protective reflexes of the ankle.[12,13] As stated by Ashton Miller et al.[14] and Taube et al.[15], multiple terms are used to summarize balance exercises aimed at improving balance. Although the term proprioceptive training is widely used, by definition, proprioception is a purely afferent sensory modality, discarding adaptations on the motor side.[15] The exercises described in the literature, and therefore also in this review, are primarily motor (efferent) tasks. Another term such as neuromuscular training[16], or preferably sensorimotor training[17,18], has been used extensively in the literature to describe the afferent and efferent aspects of these processes.

In a variety of sports, multiple studies[19-29] have looked at the effectiveness of sensorimotor training for the prevention of ankle sprains. A common finding in these studies is that sensorimotor training reduces the increased injury risk for ankle sprains in athletes with a previous injury to the same level as athletes without any history of ankle sprains.[24,27] Athletes without a previous injury do not seem to benefit from sensorimotor training.[30] Thereby, these studies provide indirect evidence that sensorimotor training indeed improves ankle proprioception after an initial ankle sprain.

However, a ‘true’ effect on ankle proprioception due to sensorimotor balance board training can only be established through biomechanical and neurophysiological analyses, looking at the pathway of morphological (changes in ankle form and structure) and neurophysiological changes (changes in nervous system function) of the ankle, leading to functional effects (changes in physiological activity of the ankle; e.g. postural sway). Although impaired proprioception, impaired neuromuscular control, strength deficits, and impaired postural control are all denominated ‘functional insufficiencies’[31], logically changes in morphology and physiology cause a change in function of the ankle, which in turn will show up in a decrease in for instance postural sway. Hertel’s[31] interpretation of all above mentioned changes as ‘functional insufficiencies’ is widely used[27,32-39], while only postural sway can be considered a true functional measure of proprioception.

In contrast to the epidemiological studies on the preventive effect of sensorimotor training, which are characterised by large cohorts and prospective study design with a long follow-up, most biomechanical and neurophysiological studies rely on small sample sizes and mixed study designs. Therefore, it is not surprising that the number of these studies reporting changes in ankle functioning due to a sensorimotor training programme matches the number of studies failing to show such changes.[40]

Thereby, despite an abundance of epidemiological evidence on the secondary preventive effect of sensorimotor training, the biomechanical and/or neurophysiological pathway through which such a training program affects injury risk remains unclear. For this reason, a critical review of the literature was performed to answer the following two questions: (1) ‘What is the effect of sensorimotor training on morphological and neurophysiological characteristics in subjects with a previous ankle sprain?’ and (2) ‘What is the effect on measurable functional properties such as postural sway?’

LITERATURE SEARCH

Study selection

A MEDLINE and CINAHL computerized literature search was conducted for published studies relating to sensorimotor training and mechanical, neurophysiological, and functional insufficiencies of the ankle. The search period ranged from January 1980 to December 2007. The following keywords were used in the search: 'sensorimotor training', 'balance training', 'neuromuscular training', 'proprioceptive training', or 'proprioception training' in combination with 'ankle sprain' or 'ankle instability', and 'functional' or 'mechanical'. A search for relevant articles was also performed in reference lists of thus identified studies.

A study was included in the review if:

(1) the study contained research questions regarding the effect of sensorimotor training on biomechanical, neurophysiological, and/or functional ankle functioning; and

(2) the study dealt with subjects with a history of ankle sprain; and

(3) the study contained a control group; and

(4) the results contained measures of biomechanical, neurophysiological, or functional insufficiencies as study outcome; and

(5) the study met a pre-defined cut-off score set for methodological quality.

Criteria 1 to 4 were used as a pre-selection measure, whereas criterion 5 was used as a quality assessment of eligible studies.

The initial search yielded a total of 58 studies, of which 24 were relevant and of potential interest. None of these studies dealt with mechanical ankle functioning. Twelve out of 24 studies met criteria 1 through 4, and were considered relevant for this review (Table 1).

Table 1 Score for pre-selection criteria 1 to 4 (1 = positive score, 0 = negative score).

Reference	Training	History	Control	Relevant outcome measure
Akhbari[41] (2007)	1	1	0	1; postural sway; muscle reaction time
Bernier[32] (1998)	1	1	1	1; postural sway, joint position sense
Docherty[42] (2006)	0	1	1	1; postural sway
Eils[33] (2001)	1	1	1	1; postural sway, joint position sense, muscle reaction time
Gauffin[43] (1988)	1	1	0	1; postural sway
Hale[44] (2007)	1	1	1	1; postural sway
Hess[34] (2001)	1	1	1	1; postural sway
Høiness[35] (2003)	1	1	1	1; postural sway, strength
Holme[27] (1999)	1	1	1	1; postural sway, joint position sense, strength
Kaminski[45] (1999)	0	1	1	1; strength
Kaminski[36] (2003)	1	1	1	1; strength
Kidgell[37] (2007)	1	1	1	1; postural sway
Matsusaka[46] (2001)	1	1	0	1; postural sway
Michell[47] (2006)	1	1	0	1; postural sway
Osborne[48] (2001)	1	1	0	1; muscle reaction time
Pintsaar[49] (1996)	1	1	0	1; postural sway
Powers[38] (2004)	1	1	1	1; postural sway

Table 1 cont. Score for pre-selection criteria 1 to 4

Ross[50] (2006)	1	1	1	1; postural sway
Ross[51] (2007)	1	1	1	1; postural sway
Rozzi[52] (1999)	1	1	0	1; postural sway
Sekir[53] (2007)	0	1	1	1; postural sway, joint position sense, strength
Sheth[54] (1997)	1	0	1	1; muscle reaction time
Verhagen[39] (2005)	1	1	1	1; postural sway
Willems[55] (2002)	0	1	1	1; joint position sense, strength

Quality assessment

A total of 11 predefined criteria were used in order to assess the quality of studies (Table 2). These criteria were adapted from Verhagen et al.[56] and customized to cover the topic of this review.

The twelve relevant studies were reviewed on design and methodology independently by two reviewers (EALMV and MDWH). Each item of a selected study that met a criterion was assigned a value of '1' (positive), if the item did not meet a criterion or was not described at all a '0' was assigned. This made the highest possible score '11'. In case of difference in opinion on items, both reviewers tried to reach consensus. If no consensus was reached, a third reviewer (WvM) should make the final decision. This latter, however, did not occur. In order to establish the reliability and proper use of this set of predefined criteria the interrater agreement, expressed as Cohen's Kappa, was calculated.

Studies scoring 60% or more ('7' or more) of the maximum possible score were considered to be of sufficient methodological quality and were taken into further analysis. The choice for this cut-off score is in agreement with

Table 2 Quality assessment: criteria list for the assessment of the methodological score of studies on effects of sensorimotor training on functional and mechanical insufficiencies.

Criterion
(A) Is a randomization procedure mentioned?
(B) Are the intervention and control groups homogenous with regards to the subject characteristics?
(C) Is a definition for 'history of injury' given?
(D) Are testing procedures described and performed in sufficient detail?
1- test procedure
2- standardized measurement
(E) Are intervention procedures described and performed in sufficient detail?
1- applied training procedure
2- time span of intervention
3- control of compliance to the intervention
(F) Are the research design and statistical analysis sufficient?
1- statistical analysis is consistent with the research design
2- corrected for accurate variables
3- are all relevant statistical outcomes presented (e.g. mean, SD, p-value)

Verhagen et al.[56] and Borghouts et al.[57], who used a similar arbitrary choice of cut-off score and stated this to be the best way to make a discrimination between 'high quality' and 'low quality' studies. The results of the methodological quality score of the individual studies are presented in Table 3. After both reviewers had scored the studies, there was disagreement on 3 (2.3%) of the 132 criteria scored. This made the interrater agreement high (κ = 0.89). All studies met the predefined cut-off score of 60%.

Overview of selected studies

Characteristics of the reviewed studies are presented in table 4. The next section will present the effect of sensorimotor training on neurophysiological changes (i.e. joint position sense), morphological changes (i.e. strength), or a combination measure of both entities (i.e. muscle reaction time). Next, changes in postural sway as a measurable functional effect of sensorimotor training will be presented.

Although limited on several points, all studies scored high on methodological quality. All, but two[33,35], studies scored negative on homogeneity of subject characteristics. In four studies[32,36,38,50] a description of subject characteristics was missing. In other studies a significant difference in mean body height[34,37], mean age[34], total number of positive anterior drawer signs[27], or gender[39] was found between groups. The lack of definition of history of injury[35,38], an insufficiently detailed description of the compliance to the programme[32,37,38,50,51] or randomization procedure[33,50] led to negative scores as well.

EFFECTS OF SENSORIMOTOR TRAINING

Neurophysiological changes

Holme et al.[27] looked at the influence of sensorimotor training on the ability to reproduce joint angles. They compared a group of subjects given general instructions on ankle sprain rehabilitation to a group given the same instruction and a 4 months sensorimotor training. Since subjects were included five days post injury, no postural sway baseline measurements could be determined. No improved position sense was found in the training group compared to the control group after six weeks and four months. Furthermore, no differences in position sense were found between injured and non-injured ankles. From these findings the conclusion can be drawn that sensorimotor training was not effective in improving joint position sense. However, it is impossible to assess whether or not progress was achieved through the training programme, because baseline data are missing. Baseline position sense of the ankle could well have been different between both groups, because of the significantly greater number of positive anterior drawer signs in the training group compared to the control group at baseline.

Bernier and Perrin[32] found an improvement in joint position sense after six weeks of sensorimotor training for subjects in the training group compared to baseline. A similar improvement was found for the control group as well, which indicates a learning effect of repeated testing. No significant differences between groups were found at six weeks, which can have different causes; e.g. the specificity of the training compared to the testing method (the coordination and strength exercises were carried out standing up, whereas the test was performed lying down, bearing no body weight). A second reason could be that a training period of six weeks, three times ten minutes a week, is too short to bring about physiological changes at central nervous system level.

Eils and Rosenbaum[33] found an improved position sense in a group of athletes with chronic ankle instability undergoing sensorimotor training, whereas the control group showed no improvement. It was not clear if significant position sense differences between groups existed at baseline, but baseline mean error scores differed visually between groups (mean degrees of error ± SD at pretest: 2.0 ± 0.6 and 1.5 ± 0.5, respectively). Eils and Rosenbaum[33] concluded that position sense improved significantly after a six-week sensorimotor training. Strikingly, the intervention group improved to the same level as the control group. It is possible that subjects in the control group performed at best at pretest and no improvement was possible, whereas the intervention group left room for improvement after a poor performance at baseline. It is unknown if this result is due to a training effect or due to a learning effect.

From these studies can be concluded that subjects' improvements in angle reproduction after balance training is more likely attributable to a learning effect than to the effect of sensorimotor training. This conclusion also applies to subjects with a recent ankle sprain as well as for subjects with ankle instability.

Morphological changes

Three studies have looked into the effect of sensorimotor training on strength.[27,35,36] Peak torques were measured by means of an isokinetic dynamometer. Kaminski et al.[36] evaluated eversion to inversion ratios (E/I ratios), which were calculated from average torque and peak torque measures. Given that the strength of the evertor muscles in individuals with chronic ankle instability had declined, a combination of sensorimotor training and strength exercises could be beneficial in preventing recurrent ankle sprains.[35,36]

Holme et al.[27] chose another type of training with recently injured subjects. At six weeks and after four months Holme et al.[27] found no significant differences in strength between training and control group. There was a strength difference between the injured and the uninjured side 6 weeks after ankle injury. After four months ankle strength was normalized. It is plausible that strength increase in the injured ankle was caused by natural recovery and was not evoked by sensorimotor training. Furthermore, pain in the ankle could be apparent in persons recovering from an ankle sprain, which could influence the maximal force deliverance during test. This could lead to a distorted impression of the amount of muscular force applied.

Kaminski et al.[36] randomly assigned subjects to one of four groups (sensorimotor training, strength training, strength and sensorimotor training, and control). Baseline strength differences between groups were not described in detail. Results showed no significant increase in isokinetic E/I ratios and showed no significant differences between the four groups for E/I ratios at the end of the training protocol. Torque values in both directions were not presented, which makes it possible that strength increased proportionally in the eversion direction as well in the inversion direction. Kaminski et al.[36] stated that the method of testing was not specific enough to detect differences. The strength training protocol involved isotonic strength training exercises, but the tests were performed on an isokinetic dynamometer. Another theory is that the applied strength training was not vigorous enough and did not offer enough resistance to bring about changes in effect measures.

Results of the study by Høiness et al.[35] revealed that in 19 subjects with chronic ankle instability the injured ankle was 11.5% weaker than the non-injured ankle. In contrast to Holme et al.[27], pain did not hinder subjects' performance. After sensorimotor training, subjects in the intervention group increased their peak eversion torque, whereas the control group showed no increase. At baseline testing no significant differences were found between the groups with respect to eversion torque. In contrast to Kaminski et al.[36] and Holme et al.[27], Høiness et al.[35] found an increase in peak eversion torque. A possible shortcoming in the studies by Holme et al.[27] and Høiness et al.[35] is that average torque was not measured during subjects' efforts. It is highly possible that not only the peak torques changed, but the average torque as well.

The described results indicate that the effects of sensorimotor training and strength training on muscle torques are minimal, if present at all. The intensity of training needs to be high, either in frequency or in resistance of training, and the method of testing needs to be highly specific with the training method in order to demonstrate increases in strength. The question that rises is whether isokinetic measurement of muscle torques gives a realistic view of the strength that can be applied during sudden inversion, which probably does not elapse in a fully isokinetic way.

Combination of neurophysiological and morphological changes

Eils and Rosenbaum[33] studied the effect of sensorimotor training on muscle reaction time after ankle inversion perturbations. The interpretation of study results is limited, because a thorough analysis of baseline muscle reaction time differences between groups was not carried out. Muscle reaction times for peroneus longus and peroneus brevis were significantly prolonged after six weeks in both groups. As a result of this prolonged reaction, the activity of the peroneus muscles will synchronize with the activity pattern of the tibialis anterior muscle. Through this co-contraction a higher joint stiffness could be established, which may have led to an increased ability to resist movements. Prolongation of reaction time is counterintuitive to an increased ability to resist movements. However, it is possible that other strategies for an optimized reaction were utilized. Differences between pre- and posttests for the Integrated Electromyography were not found[33], which might imply that no increase in muscular strength was present directly after sudden inversion.

The question is raised whether the minimal reaction times changes in the study by Eils and Rosenbaum[33] make any difference during the reflex reaction of muscles after sudden inversion. From previous research[58,59] can be concluded that a sudden inversion lasts between 40 to 45 msec. Reaction times measured in the study by Eils and Rosenbaum[33] are too long to sort effect on the degree of inversion, even after the training period (reaction times between 60 and 70 msec).

Functional changes

The majority of studies[27,32-35,37-39,44,51] focused on the effects of sensorimotor training on static postural sway, whereas one study[50] measured dynamic postural stability. Postural sway was determined as a measure of balance on a force platform[27,32,33,37-39,44,50,51] or a balance system[34,35] in one-legged stance.

Two studies investigated the effect of a sensorimotor training programme on postural sway in subjects with an ankle sprain in the previous year.[27,39] Holme et al.[27] found no significant differences in postural sway between both groups after six weeks and four months. After six weeks there were no differences between affected and non-affected ankles in both groups. Whereas after four months a difference was found. This would suggest that balance improvements were due to natural recovery and not due to sensorimotor training. Although a difference in the number of positive anterior drawer signs was reported, it is unlikely that this affected results.
Verhagen et al.[39] randomly assigned twenty-two subjects to either an intervention or a control group. An additional eight subjects were participants in an organized volleyball competition and were assigned to a convenience volleyball group. All subjects of the intervention group and the volleyball group received a five and a half week sensorimotor training programme, whereas subjects of the control group received no training. At baseline no significant postural sway differences were found between all groups. Postural sway improved equally in all three groups after five and a half weeks. This improvement was thought to be due to a learning effect and not to sensorimotor training.
Other studies reported on the effect of sensorimotor training on postural sway in subjects with ankle instability.[32-35,37,38,43,44,47] Bernier and Perrin[32] focused primarily on sensorimotor training, where others offered a combination of both sensorimotor training and strength exercises.[33-35,37,38,44,50,51] Bernier and Perrin[32] tested subjects on a moving platform as well as on a static one, both with eyes open and closed. Results indicated an improvement in proprioception, since the training group had a significant postural sway and balance improvement in the stable platform condition (eyes closed) and the moving platform condition (eyes open). The condition in which subjects' postural sway and balance was assessed on a stable platform with eyes open showed a trend in improvement of the experimental group. Improvements in the eyes closed condition might be

attributable to an enhanced proprioception, since subjects cannot rely on their visual system in that situation. However a learning effect of repeated testing is more likely, because after six weeks the control group showed reduced postural sway in both eyes open and closed conditions compared to baseline.

Powers et al.[38] used the same strength and training protocol as Kaminski et al.[36] Powers et al.[38] showed no differences in static balance in all groups after the training period. The fact that only one trial was used to measure balance at pretest and at posttest makes it difficult to interpret results. Although this choice was made to rule out a learning or practice effect and the effect of fatigue[38], it is recommended to use multiple trials because of susceptibility to faulty measurements.

Whereas a study duration of six weeks is considered to be a gold standard among various studies[32-35,37,38,50,51], Hess and colleagues[34] prescribed an exercise programme of only four weeks. They found no significant differences on sway in any direction between groups after four weeks. The reason for this could be that the duration of the training programme was too short to bring about functional changes. Another reason is that with the chosen type of training (emphasis on agility) the dynamic balance was improved, which may not show in a static balance test. The fact that differences were found in subject characteristics at baseline will not alter the conclusion drawn from the study.

Hale et al.[44] randomly assigned twenty-nine subjects with chronic ankle instability to either an intervention or a control group. Another nineteen subjects without chronic instability were assigned to a healthy group, but are not of interest in this review. Subjects of the intervention group received a four-week sensorimotor training programme, whereas subjects of the control group received no training. At baseline and at four weeks follow-up no significant postural sway differences were found between groups. Possible reasons for not finding an improved postural control were (1) discarding and repeating trials at baseline and (2) the intensity and focus of the training programme.[44] Hale et al.[44] also measured functional improvements through the Star Excursion Balance Test (SEBT) and self reported function through the Foot and Ankle Disability Index (FADI and FADI-Sport). At baseline there were no differences in SEBT and FADI between intervention and control group. Intervention group's mean reach distance of the SEBT improved significantly after sensorimotor training compared to control. This change was apparent in the posteromedial, posterolateral, and lateral directions, as well as in the mean of all eight reach directions. The intervention group showed more improvement in FADI scores at follow-up compared to the control group. As discussed by Hale et al.[44] this improvement could possibly be attributed to a placebo effect, since the control group did not participate in any rehabilitation programme.

In the study by Høiness et al.[35] both groups improved in single legged stance after training. Compared to baseline testing the control group showed more improvement than the training group did after six weeks. However, there was already a difference in postural sway between groups at baseline. A missing definition for history of injury hampers comparability with other relevant studies, but took no effect on the conclusion that the sensorimotor training was not effective. It is more likely that the improved single legged stance was due to a learning effect.

The majority of studies[32-34,37,38,50] lack a clear analysis of postural sway differences between training and control group at baseline testing. Baseline outcome measures data was presented as means and standard deviations only. This made it difficult to assess whether statistical analyses had been undertaken and to interpret the impact of possible significant differences between groups at the end of a training programme.

Eils and Rosenbaum[33] showed an improvement for all postural sway parameters in both the intervention group and the control group after six weeks. Furthermore, the intervention group improved on static balance in medio-lateral direction[33], while the control group showed no improvement.

However, the control group showed an improvement in static balance in the antero-posterior direction. A non-significant reduction of sway in that direction was found in the training group. Eils and Rosenbaum[33] attributed these results to a short term adaptation by a learning process in the control group. A long term adaptation might apply for the intervention group as a result of the exercise programme. This conclusion needs to be put in the right perspective, since it is partly based on statistically non-significant findings.

Kidgell et al.[37] found an effect of a balance training programme on postural stability. After six weeks the training groups (dura disc and mini-trampoline) showed a significant improvement in postural sway compared to the control group. However, these results need to be looked at with caution because of the small observed power (0,233). This small power was due to the small sample size that was chosen (namely n=20).[37] The mentioned difference in body height between groups might have influenced results, but this is not probable.

Ross and Guskiewicz[50] studied the effects of a six-week sensorimotor training with and without stochastic resonance (SR) stimulation on dynamic postural stability in subjects with functional ankle instability by measuring time-to-stabilization (TTS). Thirty subjects were assigned to a conventional training group (CCT), SR stimulation training group (SCT), or a control group. The training programme led to an improved anterior/posterior and medial/lateral TTS compared to baseline for both training groups. However, compared to the control group, this improvement was not significant. It is striking that pretest scores of anterior/posterior TTS differed visually between CCT and control (pretest mean TTS ± SD: 2.2 ± 0.8 and 1.6 ± 0.4, respectively).

Ross et al.[51] used the same training protocol as Ross and Guskiewicz.[50] Thirty subjects with functional ankle instability were assigned to the same three groups: CCT, SCT, or control group. Whereas Ross and Guskiewicz[50] focused on dynamic postural stability, Ross et al.[51] measured static postural stability. Group differences were not present at baseline. After six weeks no difference in postural sway was found between CCT and control, but the SCT group had reduced posttest means compared to pooled posttest means of CCT and control. From these findings can be concluded that sensorimotor training alone did not result in significantly better postural stability than subjects who did not participate in sensorimotor training. SR stimulation might be used as an alternative therapy to improve postural stability deficits associated with functional ankle instability.

From these studies the conclusion can be drawn that an effect of sensorimotor training on postural sway was masked by a learning effect of repeated measures. Whether sensorimotor training led to a short term improvement in postural sway is not shown in these studies. A follow-up period longer than six weeks seems necessary to address long term effects of sensorimotor training on postural regulation.

TRAINING VERSUS LEARNING EFFECTS

The goal of this critical review was to determine the effects of sensorimotor training on morphological and neurophysiological properties of the previously sprained ankle on the one hand, and functional characteristics on the other hand. Based on the discussed studies no effect of sensorimotor training on ankle characteristics was found. This applies to morphological and neurophysiological ankle properties, as well as for functional characteristics.

In our opinion changes in morphology and neurophysiology (e.g. improved joint position sense, decreased muscle reaction times, and increased strength) induced by sensorimotor training lead to functional improvements of the ankle which, subsequently lead to reduced re-injury risk (see Figure 1). Possible neurophysiological adaptations are changes in physiological processes such as the sensory threshold of specific peripheral mechanoreceptors, nerve conduction velocity, sensorimotor integration at the spinal and/or suprispinal level, alpha motoneuron pool excitability, and/or gamma-motor neuron/muscle spindle function. Potential changes in morphology are changes in muscle cross-sectional area, myofibril size, and/or ligament structure. Hertel[31] validates our conceptual model in stating that postural control deficits are likely due to a combination of impaired proprioception and neuromuscular control. Hertel's use of the term 'functional insufficiencies' was developed to show that individual authors were using several different sensorimotor constructs (proprioception, postural control, strength, and neuromuscular responses to inversion perturbation) to indentify the condition of functional ankle instability. Although it was not meant to state that proprioceptive measures were truly functional, multiple studies on this topic have blindly copied Hertel's view in determining effects of sensorimotor training, without making a distinction between properties, which in our opinion is wrong.

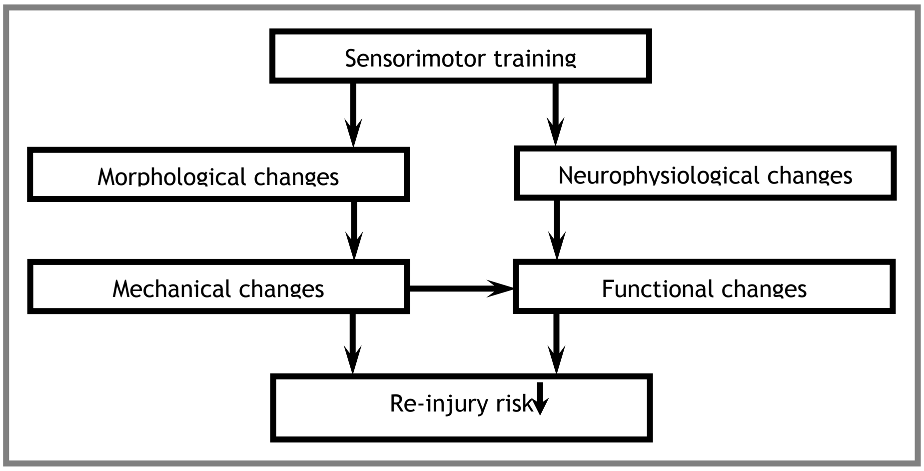

Figure 1 Conceptual model of the pathway of proprioceptive training leading to a reduced re-injury risk of the ankle.

The first aim in defining the underlying mechanisms responsible for the preventive effect of sensorimotor training in subjects with previous ankle sprains, is establishing the effects on morphological and neurophysiological characteristics of the ankle (e.g. joint position sense, muscle reaction times, and strength). From the literature reviewed, it can be concluded that improvements in position sense and reaction times are merely caused by a learning process of repeated testing and are not a training effect. This might imply a validity problem, while no change was to be expected in control. As mentioned by Ashton-Miller et al.[14] postural sway measurements are skills in motor tasks and are no true measures of proprioception. As direct measurement of proprioception is impossible, these skills in motor tasks are the closest mean to measuring proprioception. Future focus needs to be on establishing methods more closely linked to proprioception. A new potential workable method is 'time-to-stabilization', which is a functional measure of stability. This measure of dynamic stability forces subjects to maintain balance through a transition from a dynamic to a static state.[60] Effects on strength seem to be not apparent. An important observation by Holme et al.[27] was that at twelve month follow-up there was a significant group difference in re-injury rate. Despite finding no significant improvements in postural sway, joint position sense, and strength after training, a secondary preventive effect was found.

In general, a relatively low number of on topic and relevant studies were found. In addition, a differentiation had to be made between studies examining interventions in patients after acute ankle sprains compared to patients with ankle instability. Furthermore, an important factor is the details of the rehabilitation protocols. An adequate training stimulus was not always provided to subjects, which could have influenced results. The majority of studies scored negative on homogeneity of the intervention and control group with regards to subject characteristics. Likely this is due to the low number of subjects, which is typical for this type of laboratory based studies. Study populations of studies discussed here ranged from 19 to 92 subjects. Studies must rely on larger sample sizes for higher statistical power, to be able to detect smaller differences in outcome measures. A multidisciplinary approach, combining biomechanics and epidemiology, preferably using a randomized controlled trial design, is recommended to obviate this small sample size issue.

To date no study has been conducted on the effect of sensorimotor training on the mechanical aspects of recurrent ankle sprains. Mechanical instability of the ankle complex occurs as a result of morphological changes after an initial ankle sprain. These changes may include pathologic laxity, impaired arthrokinematics, synovial changes, and the development of degenerative joint disease, which all may occur in combination or isolation.[31] Chronic ankle instability, increasing re-injury risk, in subjects may not only be caused by mechanical instability or functional instability alone, but by a combination of these two entities.[61,62] It could be that sensorimotor training affects those morphological factors closely linked to mechanical stability. However, this has never been studied, while functional changes induced by sensorimotor training seem more plausible.

CONCLUSION

The pathway through which sensorimotor training reduces re-injury risk remains unclear. The black box on the 'true' effect of sensorimotor training remains unopened. Using enhanced measurement techniques, which equate to specific physiological processes that are inside the black box would be beneficial for future research. To create more insight in the pathway reducing re-injury risk, studies should (i) differentiate between morphological, physiological, and functional changes, (ii) use larger sample sizes with a priori sample size calculations, (iii) ensure correspondence between training and test method, (iv) use other measures than postural sway more closely linked to functional stability, and (v) use a longer follow-up period than six weeks.

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REFERENCES

1. Garrick JG, Requa RK. Role of external support in the prevention of ankle sprains. Med Sci Sports 1973; 5: 200-3
2. Rovere GD, Clarke TJ, Yates CS, et al. Retrospective comparison of taping and ankle stabilizers in preventing ankle injuries. Am J Sports Med 1998; 16: 228-33
3. Sitler M, Ryan J, Wheeler B, et al. The efficacy of a semi rigid ankle stabilizer to reduce acute ankle injuries in basketball a randomized clinical study at West Point. Am J Sports Med 1994; 22: 454-61
4. Surve I, Schwellnuss MP, Noakes T, et al. A fivefold reduction in the incidence of recurrent ankle sprains in soccer players using the sport-stirrup orthosis. Am J Sports Med 1994; 22: 601-6
5. Wexler FK. The injured ankle. AmFamPhys 1998; 57: 474-80
6. Tropp H, Ekstrand J, Gilquist J. Factors affecting stabilometry recordings of single limb stance. Am J Sports Med 1984; 12 (3): 185-8
7. Bahr R, Bahr IA. Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. Scand J Med Sci Sports 1997; 7: 166-71
8. Ekstrand J, Tropp H. The incidence of ankle sprains in soccer. Foot Ankle 1990; 11: 41-4
9. Milgrom C, Shlamkovitch N, Finestone A, et al. Risk factors for lateral ankle sprains: a prospective study among military recruits. Foot Ankle 1991; 12: 26-30
10. Verhagen EALM, van der Beek AJ, Bouter LM, et al. A one-season prospective cohort study of volleyball injuries. Br J Sports Med 2004; 38 (4): 477-81
11. Freeman MAR. Instability to the foot after injuries to the lateral ligament of the ankle. J Bone Joint Surg Br 1965; 47: 669-77
12. Karlsson J, Lansinger O. Chronic lateral instability of the ankle in athletes. Sports Med 1993; 16 (5): 355-65

13. Lephart SM, Conley K. The role of proprioception in chronic ankle instability. In: Schmidt R, Benesch S, Lipke K, editors. Chronic ankle instability: manuscripts of the International Ankle Symposium. Ulm: Libri Verlag, 2000: 254-67
14. Ashton-Miller JA, Wojtys EM, Huston LJ, et al. Can proprioception really be improved by exercises? Knee Surg Sports Traumatol Arthrosc 2001; 9: 128-36
15. Taube W, Gruber M, Gollhofer A. Spinal and supraspinal adaptations associated with balance training and their functional relevance. Acta Physiol 2008; 193 (2): 101-16
16. Paterno MV, Myer GD, Ford KR, et al. Neuromuscular training improves single-limb stability in young female athletes. J Orthop Sports Phys Ther 2004; 34: 305-16
17. Banaschewski T, Besmens F, Zieger H, et al. Evaluation of sensorimotor training in children with ADHD. Percept Mot Skills 2001; 92: 137-49
18. Gruber M, Gollhofer A. Impact of sensorimotor training on the rate of force development and neural activation. Eur J Appl Physiol 2004; 92: 98-105
19. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. Am J Sports Med 1985; 13 (4): 259-62
20. Olsen OE, Myklebust G, Engebretsen L, et al. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. Br Med J 2005; 330: 449-52
21. Petersen W, Hohmann G, Pufe T, et al. A controlled prospective case control study of a prevention training program in female team handball players: the German experience. Arch Orthop Trauma Surg 2005; 125 (9): 614-21
22. Wedderkopp N, Kaltoft M, Lundgaard B, et al. Prevention of injuries in young female players in European team handball: a prospective intervention study. Scand J Med Sci Sports 1999; 9 (1): 41-7

23. Wedderkopp N, Kaltoft M, Holm R, et al. Comparison of two intervention programmes in young female players in European team handball – with and without ankle disc. Scand J Med Sci Sports 2003; 13 (6): 371-5
24. Bahr R, Lian O, Bahr IA. A twofold reduction in the incidence of acute ankle sprains in volleyball after the introduction of an injury prevention program: a prospective cohort study. Scand J Med Sci Sports 1997; 7 (3): 172-7
25. Stasinopoulos D. Comparison of three preventive methods in order to reduce the incidence of ankle inversion sprains among female volleyball players. Br J Sports Med 2004; 38 (2): 182-5
26. Verhagen E, van der Beek AJ, Bouter LM, et al. The effect of a proprioceptive balance board training program for the prevention of ankle sprains: a prospective controlled trial. Am J Sports Med 2004; 32 (6): 1385-93
27. Holme E, Magnusson SP, Becher K, et al. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. Scand J Med Sci Sports 1999; 9 (2): 104-9
28. McGuine TA, Keene JS. The effect of a balance training programon the risk of ankle sprains in high school athletes. Am J Sports Med 2006; 34 (7): 1103-11
29. Mohammadi F. Comparison of 3 preventive methods to reduce the recurrence of ankle inversion sprains in male soccer players. Am J Sports Med 2007; 35 (6): 922-6
30. Eils E. The role of proprioception in the primary prevention of ankle sprains in athletes: a review. Int Sports Med J 2003; 4: 1-9
31. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. J Athlet Train 2002; 37 (4): 364-75

32. Bernier JN, Perrin DH. Effect of coordination training on proprioception of the functionally unstable ankle. J Orthop Sports Phys Ther 1998; 27 (4): 264-75
33. Eils E, Rosenbaum D. A multi-station proprioceptive exercise program in patients with ankle instability. Med Sci Sports Exerc 2001; 33 (12): 1991-8
34. Hess DM, Joyce CJ, Arnold BL, et al. Effect of a 4-week agility training program on postural sway in the functionally unstable ankle. J Sports Rehab 2001; 10: 24-35
35. Høiness P, Glott T, Ingjer F. High-intensity training with a bi-directional bicycle pedal improves performance in mechanically unstable ankles: a prospective randomized study of 19 subjects. Scand J Med Sci Sports 2003; 13 (4): 266-71
36. Kaminski TW, Buckley BD, Powers ME, et al. Effect of strength and proprioceptive training on eversion and inversion strength ratios in subjects with unilateral functional ankle instability. Br J Sports Med 2003; 37 (5): 410-5
37. Kidgell DJ, Horvath DM, Jackson BM, et al. Effect of six weeks of dura disc and mini-trampoline balance training on postural sway in athletes with functional ankle instability. J Strength Cond Res 2007; 21 (2): 466-9
38. Powers ME, Buckley BD, Kaminski TW, et al. Six weeks of strength and proprioception training does not affect muscle fatigue and static balance in functional ankle instability. J Sport Rehabil 2004; 13: 201-27
39. Verhagen E, Bobbert M, Inklaar M, et al. The effect of a balance training programme on centre of pressure excursion in one-leg stance. Clin Biomech 2005; 20 (10): 1094-100
40. Riemann BL. Is there a link between chronic ankle instability and postural instability? J Athlet Train 2002; 37 (4): 386-93
41. Akhbari B, Ebrahimi Takamjani I, Salavati M, et al. Ankle musculature latency measurement to varying angles of sudden external oblique

perturbation in normal functionally unstable ankles. Med J Islamic Rep Iran 2007; 20: 166-74

42. Docherty CL, Valovich McLeod TC, Shultz SJ. Postural control deficits in participants with functional ankle instability as measured by the balance error scoring system. Clin J Sport Med 2006; 16: 203-8
43. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. Int J Sport Med 1988; 9: 141-4
44. Hale SA, Hertel J, Olmsted-Kramer LC. The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. J Orthop Sports Phys Ther 2007; 37 (6): 303-11
45. Kaminski TW, Perrin DH, Gansneder BM. Eversion strength analysis of uninjured and functionally unstable ankles. J Athl Train 1999; 34: 239-45
46. Matsusaka N, Yokoyama S, Tsurusaki T, et al. Effect of ankle disk training combined with tactile stimulation to the leg and foot on functional instability of the ankle. Am J Sports Med 2001; 29: 25-30
47. Michell TB, Ross SE, Blackburn JT, et al. Functional balance training, with or without exercise sandals, for subjects with stable or unstable ankles. J Athl Train 2006; 41: 393-8
48. Osborne MD, Chou LS, Laskowski ER, et al. The effect of ankle disk training on muscle reaction time in subjects with a history of ankle sprain. Am J Sports Med 2001; 29: 627-32
49. Pintsaar A, Brynhildsen J, Tropp H. Postural corrections after standardised perturbations of single limb stance: effect of training and orthotic devices in patients with ankle instability. Br J Sports Med 1996; 30: 151-5
50. Ross SE, Guskiewicz KM. Effect of coordination training with and without stochastic resonance stimulation on dynamic postural stability

of subjects with functional ankle instability and subjects with stable ankles. Clin J Sport Med 2006; 16 (4): 323-8

51. Ross SE, Arnold BL, Blackburn JT, et al. Enhanced balance associated with coordination training with stochastic resonance stimulation in subjects with functional ankle instability: an experimental trial. J Neuroeng Rehabil 2007 Dec 17; 4: 47
52. Rozzi SL, Lephart SM, Sterner R, et al. Balance training for persons with functionally unstable ankles. J Orthop Sports Phys Ther 1999; 29: 478-86
53. Sekir U, Yildiz Y, Hazneci B, et al. Effect of isokinetic training on strength, functionality and proprioception in athletes with functional ankle instability. Knee Surg Sports Traumatol Athrosc 2007; 15: 654-64
54. Sheth P, Yu B, Laskowski ER, et al. Ankle disk training influences reaction times of selected muscles in a simulated ankle sprain. Am J Sports Med 1997; 25: 538-43
55. Willems T, Witvrouw E, Verstuyft J, et al. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. J Athl Train 2002; 37: 487-93
56. Verhagen EA, van Mechelen W, de Vente W. The effect of preventive measures on the incidence of ankle sprains. Clin J Sports Med 2000; 10 (4); 291-6
57. Borghouts JAJ, Koes BW, Bouter LM. The clinical factors of non-specific neck-pain: a systematic review. Pain 1998; 77: 1-13
58. Ashton-Miller JA, Ottaviani RA, Hutchinson C, et al. What best protects the inverted weightbearing ankle against further inversions? Am J Sports Med 1996; 24: 800-9
59. Gruneberg C, Nieuwenhuijzen PHJA, Duysens J. Reflex responses in the lower leg following landing impact on an inverting and non-inverting platform. J Physiol 2003; 550: 985-93

60. Goldie P, Bach T, Evans O. Force platform measures for evaluating postural control: reliability and validity. Arch Phys Med Rehabil 1989; 70: 510-7
61. Tropp H, Odenrick P, Gillquist J. Stabilometry recordings in functional and mechanical instability of the ankle joint. Int J Sports Med 1985; 6: 180-2
62. Wilkerson GB, Nitz AJ. Dynamic ankle stability: mechanical and neuromuscular interrelationships. J Sport Rehabil 1994; 3: 43-57

Table 3 Methodological quality score of relevant studies for the criteria A to F listed in Table 2.

Reference	A	B	C	D1	D2	E1	E2	E3	F1	F2	F3	Total score	% of total
Bernier[32] (1998)	1	0/u	1	1	1	1	1	0/u	1	1	1	9	82%
Eils[33] (2001)	0	1	1	1	1	1	1	1	1	1	1	10	91%
Hale[44] (2007)	1	1	1	1	1	1	1	1	1	1	1	11	100%
Hess[34] (2001)	1	0	1	1	1	1	1	1	1	1	1	10	91%
Høiness[35] (2003)	1	1	0	1	1	1	1	1	1	1	1	10	91%
Holme[27] (1999)	1	0	1	1	1	1	1	1	1	1	1	10	91%
Kaminski[36] (2003)	1	0/u	1	1	1	1	1	1	1	1	1	10	91%
Kidgell[37] (2007)	1	0	1	1	1	1	1	0	1	1	1	9	82%
Powers[38] (2004)	1	0/u	0	1	1	1	1	0	1	1	1	8	73%
Ross[50] (2006)	0	0/u	1	1	1	1	1	0/u	1	1	1	8	73%
Ross[51] (2007)	1	1	1	1	1	1	1	0/u	1	1	1	10	91%
Verhagen[39] (2005)	1	0	1	1	1	1	1	1	1	1	1	10	91%

1 = positive score, 0 = negative score, u = unknown

Table 4 Characteristics of relevant and methodological adequate studies.

Author	Subjects	Training	Tests	Outcome
Bernier[32] (1998)	Functional Instability 14 control 14 sham 17 experimental	6 weeks; 3 times a week. sensorimotor training	**Postural sway**: single-leg stance on static and moving force plate. **Joint position sense**: angle reproduction test on ankle footplate.	**Postural sway**: main effect on sway index and equilibrium score for test in all groups ($F_{(1,42)}$ = 11.07, p = .002 and $F_{(1,42)}$ = 6.63, p = .014, resp.). Training group significantly improved on postural sway and balance in the stable platform condition (eyes closed; p < .05) and the moving platform condition (eyes open; p < .05). **Joint position sense**: No significant differences between groups at baseline and after training. All subjects performed better on the test after six weeks ($F_{(1,42)}$ = 5.46, p = .024).
Eils[33] (2001)	Chronic Instability 10 control 20 experimental	6 weeks; once a week. sensorimotor training	**Postural sway**: single-leg stance on force plate. **Joint position sense**: angle reproduction test on footplate. **Muscle reaction time**: reaction after simulated ankle sprain on trap door.	**Postural sway**: sway of centre of gravity and sway distance improved significantly in the intervention group and the control group. The intervention group improved significantly on static balance in medio-lateral direction (pre mean ± SD: 22.3 ± 4.8 mm; post 20.4 ± 2.8, p < .01). The control group improved significantly on static balance in antero-posterior direction (pre mean ± SD: 30.3 ± 7.9 mm; post 27.8 ± 7.8, p < .05). **Joint position sense**: training group improved significantly after six weeks (pre mean error ± SD 2.0 ° ± 0.6° ; post 1.5 ± 0.4, p < .01). **Muscle reaction time**: significant prolongation of reaction time after six weeks for peroneus longus (pre mean ± SD: 61.6 ± 6.5 ms; post 64.8 ± 6.2, p < .001) and brevis muscles pre mean ± SD: 66.9 ± 6.8 ms; post 70.4 ± 6.0, p < .001).
Hess[34] (2001)	Functional Instability 10 control 10 experimental	4 weeks; 3 times a week. Agility training	**Postural sway**: single-leg stance on balance system.	**Postural sway**: no effect of agility training on balance was found.
Hale[44] (2007)	Chronic Instability 29 subjects randomly divided over: -intervention -control	4 weeks; variable intensity. Strength and sensorimotor training	**Postural sway:** single-leg stance on force plate. **Star Excursion Balance Test** (SEBT) **Foot and Ankle Disability Index** (FADI and FADI-Sport)	**Postural sway:** At baseline and at four weeks no significant postural sway differences were found. **SEBT**: no differences between groups at baseline. At follow-up, the intervention group showed significant improvements compared to control in the posteromedial (p = .013), posterolateral (p = .011), and lateral directions (p = .018), as well as in the mean of all eight reach directions (p = .019). **FADI**: no differences between groups at baseline. At follow-up the intervention group showed more improvement compared to baseline (FADI: p = .003, FADI-Sport: p = .009).

Table 4 cont. Characteristics of relevant and methodological sufficient studies.

Høiness[35] (2003)	Mechanical Instability 9 control 10 experimental	6 weeks; 3 times a week. High intensity aerobic training	**Postural sway**: single-leg stance on balance system. **Strength**: peak eversion torque on isokinetic dynamometer.	Difference in postural sway at baseline (mean ± SD: int 72.5 ± 10.7 % of max; con 56.1 ± 32.0, p = data missing). No significant differences in strength at baseline. **Postural sway**: after training both groups kept balance at a significantly higher speed of the moving platform (int: p = .005 CI 2.5 – 12.5; con: p = .018 CI 2.3 – 21.0). **Strength**: eversion torque increased peak inversion torque significantly after bi-directional pedal training. Traditional pedal showed no increase. Difference between groups was not significant (p = .264 and p = .239, resp.).
Holme[27] (1999)	Recent ankle sprain 46 control 46 experimental	4 months; 2 times a week. Balance training as part of supervised rehabilitation	**Postural sway**: single-leg stance on force plate. **Joint position sense**: angle reproduction test on footplate. **Strength**: peak eversion torque on isokinetic dynamometer.	No baseline measurements were executed. **Postural sway**: no significant differences between groups after six weeks and four months. Significant difference between affected and non-affected side in both groups at six weeks (mean ± SD: int 219 ± 15 cm and 197 ± 11, p < .001; con 237 ± 13 and 196 ± 9, p < .001), not after four months. **Joint position sense**: no significant difference after six weeks and four months. **Strength**: no significant differences between both groups after six weeks and four months.
Kaminski[36] (2003)	Functional Instability 38 subjects randomly divided over: control strength sensorimotor combination	6 weeks; 3 times a week. Strength and sensorimotor training	**Strength**: peak torques for dorsiflexion, plantar flexion, inversion, and eversion on isokinetic dynamometer.	**Strength**: no significant increase in E/I ratios (at 30°/s: $F_{(3,34)}$ = 1.434. p = .250; at 120 °/s: $F_{(3,34)}$ = 2.123, p = .116) and no significant differences between the four groups at the end of the training protocol (at 30°/s: $F_{(3,34)}$ = 0.098. p = .961; at 120 °/s: $F_{(3,34)}$ = 1.434, p = .929).
Kidgell[37] (2007)	Functional Instability 7 control 7 dura disc 6 mini-trampoline	6 weeks; 3 times a week. Balance training	**Postural sway**: single-leg stance on force plate.	**Postural sway**: significant improvement in postural sway after six weeks for both training groups compared to the control group (pre mean ± SD: con 36.9 ± 9.9 mm; post 36.7 ± 8.2, MT 56.8 ± 20.5 resp. 33.3 ± 8.5, p = .003, DT 41.3 ± 2.6 resp. 27.2 ± 4.8, p = .003).

Table 4 cont. Characteristics of relevant and methodological sufficient studies.

Powers[38] (2004)	Functional Instability 38 subjects randomly divided over: -control -strength - sensorimotor -combination	6 weeks; 3 times a week. Strength and sensorimotor training	**Postural sway**: single-leg stance on force plate.	**Postural sway**: after six week of training there were no significant differences between groups with respect to centre of pressure excursion (Group x Test: p = .737. Pre mean ± SD: con 9.11 ± 1.14 cm; post 8.96 ± 2.25, str 8.42 ± 1.15 resp. 8.28 ± 0.74, prop 8.82 ± 4.37 resp. 7.92 ± 1.80; comb 8.23 ± 0.90 resp. 8.72 ± 0.88).
Ross[50] (2006)	Functional Instability 30 subjects assigned to - conventional -stimulus -control	6 weeks; 5 times a week. Coordination training with or without stochastic resonance stimulation.	**Postural sway:** dynamic through time to stabilization.	**Postural sway:** after six weeks both training groups significantly improved TTS compared to baseline. Compared to the control group there was no significant improvement.
Ross[51] (2007)	Functional Instability 30 subjects assigned to - conventional -stimulus -control	6 weeks; 5 times a week. Coordination training with or without stochastic resonance stimulation.	**Postural sway:** single-leg stance on force plate.	**Postural sway**: no group differences at baseline. After six weeks no difference in postural sway between conventional training group and control. The stimulation group had reduced posttest means compared to pooled conventional and control.
Verhagen[39] (2005)	Previous ankle sprain 11 control 11 experimental 8 volleyball	5.5 weeks; 2 times a week. sensorimotor training	**Postural sway**: single-leg stance on force plate.	No significant differences between groups at baseline. **Postural sway**: no significant differences between groups in centre of pressure excursion and no differences between the groups after the training period.

comb = combination training group; con = control group; DT = dura disc training group; dura disc = sensorimotor training tool; E/I = eversion to inversion; FADI = Foot and Ankle Disability Index; int = intervention group; MT= mini-trampoline group; prop = proprioceptive training group; resp. = respectively; SEBT = Star Excursion Balance Test; str = strength training group; TTS = time-to-stabilization