Neuromuscular Training for Rehabilitation of Sports Injuries: A Systematic Review

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ABSTRACT

ZECH, A., M. HÜBSCHER, L. VOGT, W. BANZER, F. HÄNSEL, and K. PFEIFER. Neuromuscular Training for Rehabilitation of Sports Injuries: A Systematic Review. *Med. Sci. Sports Exerc.*, Vol. 41, No. 10, pp. 1831–1841, 2009. **Purpose**: Although proprioceptive and neuromuscular exercises are considered to be part and parcel of rehabilitation programs after sport injuries, there is an uncertainty regarding the effectiveness of corresponding training interventions. The objective of this review was to evaluate the effectiveness of proprioceptive and neuromuscular training (PT/NT) for the treatment of ankle, knee, and shoulder joint injuries. **Methods**: Two independent reviewers performed a literature search in various databases and reference lists of articles. Data of included trials were then extracted, and methodological quality was assessed by using predetermined forms. **Results**: Fifteen trials met the inclusion criteria. PT/NT was effective at increasing functionality as well as at decreasing the incidence of recurrent injuries and "giving way" episodes after ankle sprains and in conservative treatment of anterior cruciate ligament injuries. However, conflicting results or no efficacy of training were reported for static postural control, joint position sense, neuromuscular control, joint laxity, and lower extremity strength. No study that examined PT/NT after shoulder injuries was found. **Conclusions**: From this review, it can be concluded that proprioceptive and neuromuscular interventions after ankle and knee joint injuries can be effective for the prevention of recurrent injuries and the improvement of joint functionality. **Key Words:** ANKLE SPRAIN, ANTERIOR CRUCIATE LIGAMENT RUPTURE, PROPRIOCEPTIVE TRAINING, METHODOLOGICAL QUALITY ASSESSMENT

Sport-related injuries of the knee, ankle, or shoulder joint tend to result in severe and long-term alterations in proprioceptive and neuromuscular functions. They are often caused by a partial or complete destruction of the joint and/or ligament receptors because of the injury itself or reconstructive surgery (12,40). It is also likely that the joint receptors that remain intact relay altered afferent information for the prevention of further injury or aggravation of existing symptoms (12). Both physiological changes, the loss of information from mechanoreceptors and the induced changes of remaining receptor inputs, are considered to be responsible for persisting functional deficits such as limited postural control, decreased maximal strength, or prolonged muscle reaction time (15,48). Thus, with the aim of improving and optimizing sensorimotor control, rehabilitation after surgical or nonsurgical treatment of sports injuries focuses on the restoration and enhancement of proprioceptive and neuromuscular abilities (12). However, the implementation of evidence-based practice into rehabilitation care is complicated because of the following reasons. First, recent studies examining proprioceptive and neuromuscular training (PT/NT) interventions for rehabilitation of orthopedic lower limb and upper limb injuries show a large variety of exercises. Whereas in most studies balance exercises on stable or unstable platforms with and without perturbations of postural control are used, some authors describe neuromuscular training as multi-intervention programs with a combination of balance, weight, plyometric, agility, and sport-specific exercises (36,41). Second, comparability of results obtained in different studies is also impeded by the large number of outcome variables including measures of postural control, scores for joint function (10), maximal strength (19), pain (47), or neuromuscular fatigue (35). And third, the methodological quality of published studies reveals substantial differences in key criteria concerned predominantly with internal validity. These methodical limitations

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Submitted for publication January 2009.
Accepted for publication March 2009.

0195-9131/09/4110-1831/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e3181a3cf0d

might explain the inconsistencies in reported findings and produce controversy regarding the effectiveness of PT/NT. Thus, systematic reviews using methodical quality assessment are needed to determine the evidence of effectiveness of NT/PT. The lack of reviews on exercise therapy after knee and shoulder joint injuries in general may be partly due to the low number of previously published studies in this field. For sport-related injuries of the ankle joint, several reviews reported positive training effects for the reduction of recurrent injury risk after acute ankle sprains (30,44) and giving way episodes in patients with chronic ankle instability (28). However, because of the inconsistent findings between these reviews regarding changes in other outcomes (e.g., postural control, proprioception), the impact of NT/PT on recovery or improvements in functional performance that might help the athlete to return early to sport participation is still unclear.

Therefore, a systematic review of randomized controlled trials (RCT) and controlled clinical trials (CCT) without randomization was performed to determine the effectiveness of proprioceptive and neuromuscular rehabilitation programs for the posttraumatic or postsurgical treatment of knee, ankle, or shoulder joint injuries.

METHODS

Literature search strategy. Two independent researchers (A.Z. and M.H.) performed a search for articles published between 1966 and October 2007 in the following databases: Cochrane Bone, Joint and Muscle Trauma Group Register and Cochrane Controlled Trials Register, MEDLINE, EMBASE, PEDro, and SCOPUS. The used keyword phrases in different combinations were the following: neuromuscular, sensorimotor, kinesthetic, proprioceptive, training, therapy, exercise, rehabilitation, program, wobble board, plyometric, balance, balance board, proprioception, coordination, jump, jumping, postural control, and perturbation. References listed in papers and cited references were also examined for the identification of additional studies. Both English and German trials were considered for this review.

Selection criteria. Title, abstract, and keywords of identified studies were examined by the two independent reviewers to determine whether they met the following inclusion criteria: randomized controlled trial (RCT) or controlled clinical trial without randomization (CCT), PT/NT (balancing, plyometric, and perturbation exercises) of the intervention group, no PT/NT interventions for controls, subjects up to 65 yr with an acute sport-related injury (within the last 6 months) or chronic instability (more than one "giving way" or sprain within the last 2 yr) of the ankle, knee, or shoulder joint in posttraumatic or postsurgery condition. The outcomes of interest were as follows: recurrent injury rate, postural control, proprioception, pain, "giving way" episodes, joint laxity, active and passive knee range of motion (ROM), function scores, swelling, muscle strength, and neuromuscular activity (EMG). Papers with imprecise abstracts were considered for full-text analyses. Disagreements between the reviewers regarding the eligibility of studies were solved by consensus. Persisting disagreements were discussed in the monthly consensus meetings of all coauthors.

Data extraction. Relevant information of the selected studies was extracted by the two independent reviewers (A.Z. and M.H.) using predetermined extraction forms. Data of interest were as follows: research question, methodological assessment, subjects, training intervention, outcome, timing of the outcome assessment, and results. To ensure an agreement in selecting study characteristics between the two reviewers, the extraction form was pilot-tested on five unrelated articles before data extraction. Discrepancies in data extraction were solved by discussion. The final data reports were based on consensus of the two reviewers.

Data analysis. For analyses of continuous outcome measures, we calculated standardized mean differences (SMD = difference between the posttest treatment and control means divided by the pooled SD) and 95% confidence intervals (CI) for each trial when sufficient data were available (24). As a measure of association for dichotomous outcomes (recurrent injuries), the odds ratio (OR) and 95% CI were calculated. If several variables were available for one outcome (e.g., various angles for joint position sense), the SMD were pooled. Because of the high variety of treatment dose and data analysis methods for measured outcomes, we refrained from doing a comprehensive meta-analysis (with global effect sizes). For single-trial data analysis, we used the Review Manager 5.

Methodological quality. The methodological quality of all eligible studies was independently examined by the two

TABLE 1. List of excluded studies and reason for exclusion.

Excluded Studies			
Ankle Joint	**Knee Joint**	**Shoulder Joint**	**Reason for Exclusion**
Kynsburg et al. (26); Matsusaka et al. (29); Michell et al. (31); Pintsaar et al. (34); Rozzi et al. (39)	Ageberg et al. (1); Chmielewski et al. (6); Jerosch et al. (20); von Porat et al. (46)	Naughton et al. (32)	Inadequate controls
Freeman et al. (11)	Liu-Ambrose et al. (27); Vengust et al. (45)		Inadequate report of intervention
Akhbari et al. (2); Gauffin et al. (13); Osborne et al. (33)	Shelbourne and Davis (41); Strojnik et al. (42)	Jerosch and Wüstner (21)	Noncontrolled design
Hoiness et al. (18)	Zätterström et al. (49); Zätterström et al. (50)		Inadequate intervention
	Risberg et al. (37)		PT/NT exercises in controls

TABLE 2. Description of included studies examining the effectiveness of PT/NT in therapy for sport injuries.

Eligible Studies	Patient Group	Subjects (Age in yr)	Gender (Female/Male)	Design	Quality Score
Beard et al. (3)	ACL rupture	*n* = 50 (16–49)	8/42	RCT	6
Bernier and Perrin (4)	Chronic ankle instability	*n* = 45 (22.5 ± 3.9)	Mixed	RCT	3
Chaiwanichsiri et al. (5)	Acute ankle sprain	*n* = 32 (18.0 ± 1.6)	—/32	RCT	4
Clark and Burden (7)	Functional ankle instability	*n* = 19 (29.7 ± 4.9)	—/19	RCT	3
Cooper et al. (8)	ACL reconstruction	*n* = 29 (16–50)	9/20	RCT	7
Eils and Rosenbaum (9)	Chronic ankle instability	*n* = 30 (27.0 ± 7.7)	18/12	CCT	3
Fitzgerald et al. (10)	ACL injury or rupture	*n* = 26 (29.2 ± 11.5)	6/20	RCT	5
Hale et al. (14)	Chronic ankle instability	*n* = 29 (21.0 ± 3.1)	19/10	RCT	2
Hess et al. (16)	Functional ankle instability	*n* = 20 (20.9 ± 3.0)	13/7	RCT	2
Holme et al. (19)	Acute ankle sprain	*n* = 71 (25.5 ± 3.8)	27/44	RCT	3
Kaminski et al. (22)	Functional ankle instability	*n* = 38 (21.6 ± 2.9)	16/22	RCT	2
Kidgell et al. (25)	Functional ankle instability	*n* = 20 (25.4 ± 4.2)	9/11	RCT	2
Powers et al. (35)	Functional ankle instability	*n* = 38 (21.6 ± 2.9)	16/22	RCT	3
Ross and Guskiewicz (38)	Functional ankle instability	*n* = 30 (20 ± 2)	16/14	CCT	4
Wester et al. (47)	Acute ankle sprain	*n* = 48 (25 ± 7.2)	19/29	RCT	3

reviewers. For this approach, the van Tulder scale for the assessment of internal study validity (43) was used. Neglecting the criteria of patient and therapist blinding, the original van Tulder scale was shortened by 2 of the 11 criteria. Consequently, the modified van Tulder scale in this review included the following items: (a) acceptable method of randomization, (b) concealed treatment allocation, (c) similar group values at baseline, (d) blinded assessor, (e) avoided or similar cointerventions, (f) acceptable compliance, (g) acceptable dropout rate, (h) similar timing of the outcome assessment in all groups, and (i) intention-to-treat analysis. Adequate methods of randomization were computer-generated random-number table and use of sealed opaque envelopes. Methods of allocation using date of birth, date of admission, hospital numbers, or alternation were not accepted as appropriate (43). Compliance to the interventions, determined by training diaries or monitoring, should not have been less than 75%. The drop out rate was considered acceptable up to 25% for follow-up <6 months and up to 30% for follow-up >6 months. The nine criteria for assessment of methodological quality were scored with "yes," "no," or (in case of inadequate reports) "unclear." A criterion was given 1 point on the van Tulder scale for each "yes" score. On the summary quality score (maximum, 9 points), at least 50% "yes" scores were needed to get a high-quality status. The methodological quality assessment was pilot-tested by the reviewers for agreement on a common interpretation of the items and their operationalization. Consensus method was used to discuss and solve the disagreements between the reviewers.

Levels of evidence. The evaluation of effectiveness of PT/NT was based on the evidence-level grading of van Tulder et al. (43), taking into account the methodological quality score, injury pattern, control interventions, and outcomes. The grades of evidence were as follows: strong (consistent findings among multiple high-quality RCT), moderate (consistent findings among multiple low-quality RCT and/or CCT and/or one high-quality RCT), limited (one low-quality RCT and/or CCT), conflicting (inconsistent findings among multiple trials—RCT and/or CCT), and no evidence from trials (no RCT or CCT).

RESULTS

Literature Search

The literature search and reference searching identified 38 relevant trials (25 for ankle injuries, 11 for knee injuries, and 2 for shoulder injuries), of which 32 where RCT or CCT. Fifteen (13 RCT and 2 CCT) of these studies met the selection criteria and were accepted for inclusion in this review. Excluded trials and specific reasons for exclusion are listed in Table 1.

A total of 525 patients participated in the included trials (*n* = 35 ± 14; 63% male; mean age between minimal 18.0 ± 1.6 and maximal 29.7 ± 4.9 yr; mean height between 170.6 ± 11.8 and 178.3 ± 7.1 cm; mean weight between 71.7 ± 15.7 and 83.6 ± 16.1 kg). They were categorized into subgroups according to the affected joint. Relevant patient groups for this review were knee and ankle joint injuries. No valid trial was found for shoulder injuries. Within the 12 ankle joint-related trials, the primary diagnosis was chronic or functional ankle instability (9 trials). The three trials regarding knee joint injuries examined subjects after

TABLE 3. Methodological quality scores of included trials.

		Items of the Modified van Tulder Scale								
Included Trials	Quality Score	a	b	c	d	e	f	g	h	i
Beard et al. (3)	6	x	x		x			x	x	x
Bernier and Perrin (4)	3	u	u	u	u	x	u	x	x	
Chaiwanichsiri et al. (5)	4	u	u	x	u	x	u	x	x	
Clark and Burden (7)	3	u	u	x	u	x	u	u	x	u
Cooper et al. (8)	7	x	x		x	x	x	x	x	u
Eils and Rosenbaum (9)	3			x	u		u	x	x	u
Fitzgerald et al. (10)	5	x	u	x	u	x	u	x	x	u
Hale et al. (14)	2	u	u	u	u		u	x	x	u
Hess et al. (16)	2	u	u	u	u	x	u	u	x	u
Holme et al. (19)	3	x	u	u	u	x	u		x	u
Kaminski et al. (22)	2	u	u	u	u	x	u	u	x	u
Kidgell et al. (25)	2	u	u	u	u	x	u	u	x	u
Powers et al. (35)	3	u	u	u	x	x	u	u	x	u
Ross and Guskiewicz (38)	4			x	u	x	u	x	x	u
Wester et al. (47)	3	u	u	u	u	x	u	x	x	u

a, acceptable method of randomization; b, concealed treatment allocation; c, similar group values at baseline; d, blinded assessor; e, avoided or similar cointerventions; f, acceptable compliance; g, acceptable dropout rate; h, similar timing of the outcome assessment in all groups; and i, intention-to-treat analysis.
x, "yes" score; u, "unclear" score; free fields, "no" score.

TABLE 4. Intervention, outcome, and results overview of studies examining PT/NT after ankle injuries.

	Intervention	Outcome	Reported Results
Bernier and Perrin (4)	EG: balance training (10 min per session, three times a week for 6 wk). C1: no training. C2: EMS training	Single-leg postural sway (static and dynamic conditions; eyes open and closed)	No group × time interaction for sway index (SD from center of balance); significant effect ($P < 0.05$) of balance training on the modified equilibrium score (anterior/posterior; medial/lateral sway)
		Active and passive ankle joint position sense (15° inversion, 0° and 10° eversion in 0° and 20° of plantarflexion)	No group × time interaction; significant improvement ($P < 0.05$) from pre- to posttest in all subjects
Chaiwanichsiri et al. (5)	EG: star excursion balance training (10 min per session, three times a week for 4 wk). C: no balance training	Single-leg stance times (eyes open and closed)	Significant increase in EG ($P < 0.001$) and C ($P < 0.05$); significantly longer stance times for EG at posttest ($P < 0.01$)
		Recurrent sprains	No statistically differences between groups at 3 months of follow-up
Clark and Burden (7)	EG: wobble board training (10 min per session, three times a week for 4 wk). C: no training	Tibialis anterior EMG onset time in response to a sudden 20° inversion	Significant group × time interaction ($P < 0.05$); significant decrease in EG ($P < 0.05$); no changes in C
		Peroneus longus EMG onset time in response to a sudden 20° inversion	Significant group × time interaction ($P < 0.01$); significant decrease in EG ($P < 0.05$); no changes in C
		Ankle Joint Functional Assessment Tool Questionnaire	Significant increase in EG ($P < 0.01$); no changes in C
Eils and Rosenbaum (9)	EG: combined balance and plyometric training (20 min per session, 6 wk) C: No training	Passive ankle joint position sense (10° and 20° dorsiflexion and 15° and 30° plantarflexion)	Significant improvement for 20° dorsiflexion ($P < 0.05$) and 15° and 30° plantarflexion ($P < 0.01$) in EG; no changes in C for all testing conditions
		EMG onset times (tibialis anterior, peroneus longus, peroneus brevis) in response to a sudden 30° inversion	Significantly prolonged times for peroneus longus and peroneus brevis muscle in EG after training; no changes in C
		Single-leg postural sway (static)	Significant improvements in EG for medio/lateral sway ($P < 0.01$), in C for antero/posterior sway ($P < 0.05$). Significant improvements in EG and C for total sway distance ($P < 0.01$)
		IEMG of tibialis anterior, peroneus longus, peroneus brevis	No changes in EG and C
		Recurrent sprains	Significantly ($P < 0.001$) fewer reinjuries in EG (60%) at 12 months of follow-up
Hale et al. (14)	EG: multi-intervention training (flexibility, strength, agility, and balance exercises) (35 min per session, one to two times a week for 4 wk). C: no training	FADI	Significant group × time interaction ($P < 0.001$); significantly greater improvements in EG ($P < 0.01$)
		FADI–Sports Subscale	Significant group × time interaction ($P < 0.01$); significantly greater improvements in EG ($P < 0.01$)
		Center of pressure velocity during static single-leg stance (eyes open and closed)	No group × time interaction; no group differences after training
		Star excursion balance test	Significant group × time interaction ($P < 0.05$); significantly greater improvements of mean reach in EG ($P < 0.05$)
Hess et al. (16)	EG: combined agility and plyometric training (20 min per session, three times a week for 4 wk) C: No training	Single-leg postural sway (static)	No group × time interaction for sway index (RMS of distance from center of balance) or anterior/posterior and median/lateral sway amplitude
Holme et al. (19)	EG: combined agility and balance training (60 min per session, twice weekly) C: No training	Single-leg postural sway (static)	No group × time interactions or pre- to posttest differences for total length of sway reported; significant differences between involved and uninvolved ankle after 6 wk for EG and C ($P < 0.001$)
		Active ankle joint position sense (l0°, 15°, and 20° of inversion)	No group × time interactions or pre- to posttest differences reported
		Isometric strength during ankle joint dorsiflexion, plantarflexion, eversion, inversion	No group × time interactions or pre- to posttest differences reported; significant differences between involved and uninvolved ankle after 6 wk for EG and C ($P < 0.05$)
		Recurrent sprains	Significantly ($P < 0.05$) fewer reinjuries in EG (7%) compared with C (29%) at 12 months after injury
Kaminski et al. (22)	EG1: balance training while exercising with Thera-Band kicks of the uninvolved leg (two sets with 25 repetitions, three times a week for 6 wk). EG2: combined strength and balance training with Thera-Band kicks (two sets with 25 repetitions, three times a week for 6 wk). C1: strength training. C2: no training	Concentric and eccentric isokinetic strength during ankle joint eversion and inversion	No group × time interaction for average torque and peak torque; no posttest differences between groups

Kidgell et al. (25)	EG1: dura disc balance training (increasing training volume, three times a week for 6 wk). EG2: mini trampoline balance training (increasing training volume, three times a week for 6 wk). C: no training	Single-leg postural sway (static)	Significant group × time interaction for mean postural sway ($P < 0.01$); significant decrease of mean postural sway in EG1 and EG2 ($P < 0.01$); no statistically significant posttest differences between groups
Powers et al. (35)	EG1: balance training while exercising with Thera-Band kicks of the un-involved leg (two sets with 25 repetitions, three times a week for 6 wk). EG2: combined strength and balance training with Thera-Band kicks (two sets with 25 repetitions, three times a week for 6 wk). C1: strength training. C2: no training	Changes in tibialis anterior and peroneus longus EMG median frequency during 60-s single-leg balancing (muscle fatigue)	No group × time interaction for both muscles
		Single-leg postural sway (static)	No group × time interaction for sway index (SD from center of pressure); no group × time interaction for median/lateral and anterior/posterior sway
Ross and Guskiewicz (38)	EG1: balance training (10 min per session, five times a week for 6 wk). EG2: combined balance and EMS training (10 min per session, five times a week for 6 wk). C: no training	Time to stabilization after single-leg jump landing	No training group × time interaction for anterior/posterior and median/lateral time to stabilization for 6 wk; significant improvement of anterior/posterior time to stabilization in EG1 and EG2 after 2 wk of training; significant improvement of median/lateral time to stabilization in EG1 and EG2 after 4 wk of training
Wester et al. (47)	EG: Wobble board training (15 min per session, four to six times a week for 12 wk). C: no training	Edema	No group × time interaction reported; significant decrease in EG and C ($P < 0.05$); no significant differences between groups
		Recurrent sprains	Significantly fewer reinjuries in EG (25%) compared with C (54%) 7.5 months after injury ($P < 0.05$)
		Functional instability (subjective feeling of the ankle giving way)	Significantly fewer functional instabilities in EG (0%) compared with C (25%) 7.5 months after injury ($P < 0.01$)

Results were reported as described in the papers.
C, control group; RMS, root mean square.

anterior cruciate ligament (ACL) ruptures and reconstruction, respectively. A summary of all included trials is given in Table 2.

Methodological Quality of Included Trials

Methodological quality scores of included trials are specified in Table 3. Out of a maximal 9 points, the range of summary quality score was between 2 and 7 with a mean score of 3.5 ± 1.5 points. Three studies (3,8,10) had at least 50% "yes" scores on the modified van Tulder scale that were needed for a classification as a trial of methodological high-quality status. All these studies were trials examining subjects after ACL injuries, whereas none of the ankle joint trials reached high-quality status. On the basis of the methodological study description, the method of randomization was considered acceptable in 4 trials and was scored "unclear" in 9 of the 15 trials. Quality items with poor ratings among all studies were concealed treatment allocation, compliance, and true intention-to-treat analysis. The lack of "yes" scores for these items was mostly because of an unclear description of methods in most included studies.

Summary of PT/NT Interventions

Ten trials tested balance training with recurrent voluntary (e.g., ball throwing/catching; Thera-Band kicks with the noninvolved leg) or involuntary (sudden perturbation) destabilization while exercising. Three trials used a combined training of two interventions with at least one PT/NT intervention. Combined programs included balance and plyometric (9), agility and plyometric (16), or agility and balance exercises (19). Two trials examined the effectiveness of multi-intervention programs on the rehabilitation of ACL (8) and ankle joint injuries (14) in which the therapy consisted of flexibility, strength, agility, cardiovascular, and balance training. Although the majority of trials had controls with no intervention, some authors compared the PT/NT with other interventions such as electromyostimulation (EMS) (4) or strength training (3,8,22,35). The length of treatment varied from 4 to 12 wk. Training sessions lasted between 10 and 60 $min{\cdot}d^{-1}$ and were scheduled from once to five times weekly. The full overview of training interventions is given in Tables 4 and 5. The impact of different training modalities on the treatment effect is shown in Tables 6 and 7.

Efficacy of PT/NT for Rehabilitation after Ankle Injuries

Twelve trials were focused on ankle joint injuries. Nine of these trials had patients with chronic ankle instability diagnosis and three trials examined patients after acute ankle sprains. Outcome measures for the effectiveness of PT/NT were as follows: incidence of recurrent sprains and giving way episodes, postural control, ankle joint position

TABLE 5. Intervention, outcome, and results overview of studies examining PT/NT after knee injuries.

Study	Intervention	Outcome	Reported Results
Beard et al. (3)	EG: multi-intervention training (balance, strength, cycling and ballistic exercises) (60 min per session, twice weekly for 12 wk). C: lower extremity strength training	Subjective knee function (Lysholm score)	Significant improvements in EG and C ($P < 0.05$); significantly greater improvement in EG ($P < 0.01$)
		Muscle reaction time after perturbation (hamstrings)	Significant reductions in EG and C ($P < 0.05$); significantly greater reduction in EG ($P < 0.05$)
		Knee laxity	No changes in EG and C
Cooper et al. (8)	EG: balance training (40–60 min per session, twice weekly for 6 wk). C: lower extremity strength training	Cincinnati Knee Rating System	Significant posttest group differences for swelling, walking, kneeling/squatting ($P < 0.05$). Significant improvements in C, no changes in EG ($P < 0.05$); no group differences or changes in groups for pain and stair running
		Patient's Specific Functional Scale	No posttest group differences. Significant improvements in C ($P < 0.05$); no pre- to posttest changes in EG
		Knee ROM	No posttest group differences; no pre- to posttest changes in EG and C
		Single- and triple-hop distance	No posttest group differences; no pre- to posttest changes in EG and C
Fitzgerald et al. (10)	EG: Perturbation training (perturbation while balancing; two to three times a week for 5 wk) and standard rehabilitation (strength, cardiovascular, agility, and sport-specific training). C: standard rehabilitation (strength, cardiovascular, agility, and sport-specific training)	Episode of the knee giving way	Significantly less episodes of giving way in EG ($P < 0.05$) 6 months postinjury
		Activities of Daily Living Scale	Significant group × time interaction ($P < 0.05$); training-induced improvements in both groups; reduction in C from postintervention to follow-up.
		Global rating of knee function scores	Significant group × time interaction ($P < 0.05$); training-induced improvements in both groups; Reduction in C from postintervention to follow-up
		Sports Activity Scale	No significant group × time interaction
		Maximum isometric quadriceps femoris strength	No significant group × time interaction
		Knee laxity	No significant group × time interaction
		Single-limb hop tests	Significant group × time interaction ($P < 0.05$); training-induced improvements in both groups; significant reduction in C from postintervention to follow-up

C, control group.

sense, muscle reaction time, functionality, strength, and edema (Table 4). For a better understanding, the term ''postural control'' is used in this review to subsume several measurement methods such as postural sway of a force plate or single-leg stance time.

Recurrent sprains and giving way episodes. Four trials recorded the incidence of recurrent ankle sprains 3 (5), 7.5 (47), and 12 months (9,19) after PT/NT intervention. Whereas at 3 months of follow-up, no difference between a training and a nontraining group was found after 4 wk of training (5), Wester et al. (47), Holme et al. (19), Eils and Rosenbaum (9) reported significantly fewer reinjuries in the experimental group (EG) compared with the nontrained controls at 7.5 and 12 months of follow-up for at least 6 wk of training.

A significant effect of training for the decrease of ankle giving way episodes was shown by Wester et al. (47) at 7.5 months of follow-up.

Postural control. Postural control was assessed in nine trials by using several measurement methods. Significant training effects compared with no training have been established for dynamic postural control, using the modified equilibrium score (4) or star excursion balance test (14) as well as for SD of static anterior/posterior or medial/lateral sway on a force plate (25). No such effects were shown for sway index (4,16,35), center of pressure velocity (14), total

TABLE 6. Standardized mean difference, odds ratio (OR), and 95% CI for different outcomes and treatment dose of trials examining ankle joint injuries.

Treatment Dose				Postural Control					
Length of Treatment (wk)	Training Frequency per wk	Duration of Sessions (min)	First Author	Single-Leg Stance Time (Eyes Open)	Single-Leg Stance Time (Eyes Closed)	Modified Equilibrium Score (Eyes Closed)	Single-Leg Static Sway (Eyes Open)	Time to Stabilization (Jump)	Star Excursion Balance Test
4	3	10	Chaiwanichsiri (5)	1.14 (0.38 to 1.89)	1.27 (0.50 to 2.04)				
	3	10	Clark (7)						
	1–2	35	Hale (14)						0.80 (−0.02 to 1.62)
	3	20	Hess (16)				NC		
6	3	10	Bernier (4)			0.45 (−0.31 to 1.21)	−0.01 (−0.72 to 0.69)		
	NR	20	Eils (9)				0.05 (−0.71 to 0.82)		
	3	~10	Kaminski (22)						
	3	NR	Kidgell (25)				−1.32 (−2.52 to −0.13)		
	3	~10	Powers (35)				0.00 (−0.98 to 0.98)		
	5	10	Ross (38)					NC	
12	4–6	15	Wester (47)						
NR	2	60	Holme (19)				−0.92 (−1.41 to −0.42)		

NC, not calculated because of missing data; NR, not reported.

length of sway (19), and distance from center of balance (16) under static conditions. Significant improvements in both experimental and control group were assessed by Eils and Rosenbaum (9).

Positive effects have also been shown for single-leg stance time (5). No group difference in changes of time to stabilization after single-leg jump landing was reported by Ross and Guskiewicz (38).

Ankle joint position sense. Significant improvements in EG compared with nontrained controls were reported for passive reproduction of 20° dorsiflexion as well as 15° and 30° plantarflexion by Eils and Rosenbaum (9).

No effects were shown for active and passive reproducibility of 0° and 20° ankle joint plantarflexion (4), active reproducibility of 10°, 15°, and 20° inversion (19), and passive reproducibility of 10° dorsiflexion (9).

Muscle reaction time to sudden perturbation. Clark and Burden (7) determined a significant decrease of tibialis anterior and peroneus longus onset time in response to a sudden involuntary ankle inversion for EG after a sensorimotor training of 4 wk. No such effects were shown for nontrained controls. Contrary results with significantly prolonged times for peroneus longus and peroneus brevis in response to a sudden involuntary ankle inversion for EG because of the training for 6 wk, and no changes in controls have been shown by Eils and Rosenbaum (9).

Ankle joint functionality scores. Significant training effects on ankle joint functionality compared with no training were established by the use of "Foot and Ankle Disability Index" (FADI), "FADI–Sports Subscale," (14) and "Ankle Joint Functional Assessment Tool Questionnaire" (7).

Muscle strength. No training effects on isometric or isokinetic strength during ankle joint dorsiflexion, plantarflexion, eversion, and inversion compared with no training were shown by Holme et al. (19) and Kaminski et al. (22).

EMG. No PT/NT effects on integrated electromyogram and median frequency of tibialis anterior, peroneus longus, and peroneus brevis were reported by Eils and Rosenbaum (9) in comparison with nontrained controls and by Powers et al. (35) in comparison to no training or strength training.

Edema. No training effects were shown for the reduction of ankle joint edema after acute ankle sprains (47).

Efficacy of PT/NT for Rehabilitation after Knee Injuries

Two of the three included trials related to the knee joint examined patients with ACL injury diagnosis and one had patients after ACL reconstruction. Various outcomes were assessed to determine the effectiveness of training (Table 5). The results for these outcomes are summarized in the following.

Knee functionality scores. Significant effects of 12-wk multi-intervention training on knee joint functionality compared with strength training were shown for conservative treatment of ACL injuries with the "Lysholm Score" (3). Fitzgerald et al. (10) established significant improvements in "global rating of knee function score" after 5 wk of balance and perturbation training. For ACL-reconstructed patients, Cooper et al. (8) reported no changes in knee function ("Cincinnati Knee Rating System" and the "Patient's Specific Functional Scale") after balance training, whereas significant improvements were observed after strength training.

Giving way episodes. A significant training effect for the decrease of knee giving way episodes was shown by Fitzgerald et al. (10) at 6 months of follow-up.

Daily living and sports activity. Fitzgerald et al. (10) showed significant improvements in "Activities of Daily Living Scale" but no effects on the "Sports Activity Scale."

Knee laxity. No effects on knee joint laxity of ACL-injured patients were shown by Beard et al. (3) and Fitzgerald et al. (10).

Muscle reaction time to sudden perturbation. Beard et al. (3) reported a significant effect of training on hamstrings onset time in response to a sudden perturbation in comparison to lower extremity strength training.

ROM. No PT/NT effect compared with lower extremity strength training was shown for the knee joint ROM after ACL reconstruction (8).

Jumping performance. Whereas for the conservative treatment of ACL injuries, a positive effect on single-limb hop performance was shown (10), no such finding was recorded for single- or triple-hop distance after ACL reconstruction (8).

TABLE 6. *(Continued).*

Reaction Times						
Tibialis Anterior Response	Peroneus Longus Response	Peroneus Brevis Response	Functionality Scores	Ankle Joint Position Sense	Strength (Ankle Joint Muscles)	Recurrent Sprains, OR (95% CI)
						0.54 (0.04 to 6.58)
NC	NC					
−0.31 (−1.07 to 0.46)	−0.10 (−0.86 to 0.66)	−0.40 (−1.17 to 0.46)		0.26 (−0.5 to 1.02)		NC
			0.42 (−0.37 to 1.22)			
				−0.09 (−0.28 to 0.10)		
					NC	
			NC			0.28 (0.08 to 0.96)
				−0.56 (−1.04 to −0.07)	0.49 (−0.03 to 1.01)	0.18 (0.04 to 0.90)

TABLE 7. Standardized mean difference and 95% CI for different outcomes and treatment dose of trials examining knee joint injuries.

Treatment Dose				Outcomes								
Length of Treatment (wk)	Training Frequency per wk	Duration of Sessions (min)	First Author	Functionality Scores	Cincinnati Knee Rating System	Knee ROM	Hamstring Response to Perturbation	Knee Laxity	Jumping Performance	Giving Way Episodes	Daily Living and Sports Activity	Quadriceps Strength
5	2–3	NR	Fitzgerald (10)	NC				NC	NC	NC	NC	NC
6	2	40–60	Cooper (8)		−0.15 (−2.16 to 1.86)	0.49 (−1.17 to 2.16)			−0.27 (−1.73 to 1.19)		0.01 (−1.34 to 1.37)	
12	2	60	Beard (3)	0.39 (−0.22 to 0.99)			−1.10 (−1.75 to −0.45)	NC				

NC, not calculated because of missing data; NR, not reported.

Muscle strength. No PT/NT effect on maximal isometric quadriceps strength was shown by Fitzgerald et al. (10).

DISCUSSION

This review suggests that PT/NT after ankle sprain is effective at increasing joint functionality (7,14) as well as at decreasing the incidence of recurrent sprains and "giving way" episodes between 7 and 12 months after intervention (9,19,47). The lack of significant effects of training on the reinjury rate reported by Chaiwanichsiri et al. (5) at 3 months of follow-up might be due to the relative short period of intervention (4 wk) compared with those of Wester et al. (47), Holme et al. (19), and Eils and Rosenbaum (9) within 6 to 12 wk. The duration of PT/NT interventions in this review varied between a minimum of 4 wk and a maximum of 12 wk. It seems possible that the longer training periods of at least 6 wk are more effective for remarkable physiological adaptations responsible for recurrent injury prevention. However, no study was found that examined the influence of different training duration on the reinjury rate after ankle sprains systematically. The conflicting results reported for postural control, ankle joint position sense, and muscle reaction time (tibialis anterior, peroneus longus, and brevis) might be partly due to the relatively low methodological quality status of included studies and variety of used methods for assessment and data analysis. For example, multiple methods for data extraction or analysis with contrary results were reported in studies that used static postural sway measurements on a force plate (4,9,14,16,19,25,35). Therefore, a valid between-study comparison for postural control values is hampered. The variety of data analysis methods might also be responsible for the discrepancies between previous review findings regarding the training-induced changes in postural control (28,44). However, our review shows that both studies with dynamic postural control assessment (4,14) reported significantly greater improvements after training. These results suggest that PT/NT interventions may have more impact on dynamic balance compared with static balance conditions. Furthermore, no efficacy of PT/NT was shown in this review for muscle strength as well as for electromyographic variables and edema. These findings, however, were based on a small number of studies and should therefore be viewed with caution. For the implementation of evidence-based practice into neuromuscular and proprioceptive rehabilitation care after ankle injuries, future research should focus on study designs of high methodological quality examining time-related changes and persistence of PT/NT effects in relation to volume and intensity of training. Furthermore, standardized assessments and data analyzing methods are needed for a valid interpretation of forthcoming research. For the rehabilitation of ankle joint injuries, in general, no studies were available for the efficacy of PT/NT after ligament or Achilles tendon ruptures.

Three trials of high methodological quality were found that examined PT/NT effects in subjects after knee injuries. Two of these trials included patients with conservative-treated ACL rupture diagnosis, and one trial had patients with surgical reconstructed ACL tears. Positive effects of PT/NT compared with standard rehabilitation or strength training interventions on knee joint functionality were shown for conservative (3,10) but not for operative treatment (8). In fact, the lower extremity strength training has been shown to be superior to PT/NT in knee functionality after ACL reconstruction. No advantages of strength or PT/NT for rehabilitation of ACL-reconstructed patients were reported for changes in knee ROM or jumping performance. Nevertheless, positive effects of PT/NT in combination with standard rehabilitation (strength, cardiovascular, agility, and sport-specific training) on the decrease of knee giving way incidence and improvements in jumping performance has been shown by Fitzgerald et al. (10) for conservative treatment. In addition, compared with strength training, the PT/NT intervention has led to greater improvements in hamstring reaction time to sudden perturbation (3). Because of these findings, it is suggested that PT/NT is predominantly effective for conservative treatment of ACL ruptures. For operative treatment, however, 6 wk of PT/NT intervention starting between 4 and 14 wk after surgery intervention did not result in significant functional improvements (8). In spite of the small number of ACL studies available for this review, there was a strong (e.g., functionality improvement after conservative treatment) or moderate (e.g., reduction of giving way episodes) evidence for the reported findings because of the high methodological quality. Nevertheless, especially for the treatment of persisting functional restrictions after ACL reconstruction (48), more studies that examine long-term training effects on sensorimotor control and joint function are needed. Furthermore, there is no evidence for the efficacy of PT/NT on rehabilitation of shoulder and other knee (meniscus repairs, posterior cruciate, or lateral ligament ruptures) injuries.

We refrained from doing a comprehensive metaanalysis mainly because of the diversity of measured outcomes and data analysis methods. This diversity might be a result of the lack of knowledge regarding the mechanism of physiological adaptations after PT/NT. It is assumed that altered feedback mechanism of mechanoreceptors after joint injuries lead to CNS reorganization processes in sensorimotor integration (learning) and subsequently to alterations of motor response (e.g., adaptations of neuromuscular control) (23). For rehabilitation of pathological motor patterns and for prevention of long-term movement disorders, the overload PT/NT is used to provoke physiological sensory feedback alterations and therefore improvements of proprioceptive and neuromuscular control mechanisms. Further methodological drawbacks in the studies reviewed were the variety of intervention programs and the considerable low-quality status of trials examining PT/NT after ankle joint injuries. Whereas in most trials, a training session took approximately 10 min in some studies, the patients exercised 20, 35, or even 60 $\text{min}\cdot\text{d}^{-1}$. The range of summary quality score of ankle injury-related studies is between 2 and 4 points on the modified van Tulder scale with a maximum of 9 points. However, the low-quality score is not necessarily a result of actual deficient methodological approaches but rather because of unclear descriptions of methods in most studies.

In conclusion, on the basis of this review, there is moderate evidence that PT/NT (balance, perturbation, or plyometric exercises) is effective for the prevention of further injuries and for the enhancement of joint functionality after ankle instability and ACL ruptures. However, PT/NT had no impact on muscle strength and electromyographic outcomes for the rehabilitation of ankle or surgically treated knee injuries. Discrepant results were reported for muscle reaction abilities, postural control, and joint position sense. These findings might be because of the methodical limitations that include the low-quality status and the variety of outcomes and/or training programs. In particular, none of the included studies regarding ankle joint injuries were of high methodical quality. Therefore, future research should focus on high methodical quality studies that are needed to clarify the efficacy and dose–response relationship of PT/NT after ankle, knee, and shoulder joint injuries. In addition, more studies that examine physiological adaptation mechanism in response to training should be done.

This study was supported by the Federal Institute of Sports Science, Germany. The results of the present study do not constitute endorsement by ACSM.

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