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Balance Training for Neuromuscular Control and Performance Enhancement: A Systematic Review

Astrid Zech, PhD*; Markus Hübscher, PhD†; Lutz Vogt, PhD†; Winfried Banzer, MD, PhD†; Frank Hänsel, PhD‡; Klaus Pfeifer, PhD*

*Department of Sports Science and Sports, Friedrich-Alexander-University, Erlangen, Germany; †Department of Sports Medicine, Goethe-University Frankfurt, Germany; ‡Department of Sports Science, University of Darmstadt, Germany

Objective: As a result of inconsistencies in reported findings, controversy exists regarding the effectiveness of balance training for improving functional performance and neuromuscular control. Thus, its practical benefit in athletic training remains inconclusive. Our objective was to evaluate the effectiveness of training interventions in enhancing neuromuscular control and functional performance.

Data Sources: Two independent reviewers performed a literature search in Cochrane Bone, Joint and Muscle Trauma Group Register and Cochrane Controlled Trials Register, MEDLINE, EMBASE, PEDro (Physiotherapy Evidence Database), and SCOPUS.

Study Selection: Randomized controlled trials and controlled trials without randomization with healthy and physically active participants aged up to 40 years old were considered for inclusion. Outcomes of interest were postural control, muscle strength, agility, jump performance, sprint performance, muscle reflex activity, rate of force development, reaction time, and electromyography.

Data Extraction: Data of interest were methodologic assessment, training intervention, outcome, timing of the outcome assessment, and results. Standardized mean differences and 95% confidence intervals were calculated when data were sufficient.

Data Synthesis: In total, 20 randomized clinical trials met the inclusion criteria. Balance training was effective in improving postural sway and functional balance when compared with untrained control participants. Larger effect sizes were shown for training programs of longer duration. Although controversial findings were reported for jumping performance, agility, and neuromuscular control, there are indications for the effectiveness of balance training in these outcomes. When compared with plyometric or strength training, conflicting results or no effects of balance training were reported for strength improvements and changes in sprint performance.

Conclusions: We conclude that balance training can be effective for postural and neuromuscular control improvements. However, as a result of the low methodologic quality and training differences, further research is strongly recommended.

Key Words: methodologic quality assessment, postural control, motor control

Key Points

- Clinically, balance training is an effective intervention to improve static postural sway and dynamic balance in both athletes and nonathletes.
- For optimal improvement in sprint, jumping, and strength performance, strength or plyometric training appears to be more effective.
- Because of methodologic limitations and variability in the training regimens studied to date, high-quality research is needed.

Within the field of athletic training, neuromuscular training programs that include balance exercises are often implemented with the aim of optimizing performance, preventing injury, or providing rehabilitation. Several authors[1–3] have shown the effectiveness of these interventions in reducing sport-related injury risk as well as in enhancing functional performance after sport injury.[4] It has been suggested[5] that changes in proprioception and neuromuscular control are predominantly responsible for these effects. However, the application of evidence-based practice to athletic training is hampered by the large variety of exercises used for neuromuscular training programs. Whereas most authors described balance and stabilization exercises, other authors[6,7] defined neuromuscular training as multi-intervention programs with a combination of balance, strength, plyometric, agility, and sport-specific exercises. Thus, it is unclear whether a single intervention or the combination of various exercises is primarily responsible for the training effects. Because most investigators studied balance training, it seems likely that these exercises have a certain influence on neuromuscular control and functional performance. This view is supported by research[8] proving that poor balance is a predictor of increased lower extremity injury risk in athletes.

Functional improvements and decreased injury rates as a result of balance exercises are often discussed[5] in association with adaptations in neuromuscular control mechanisms, such as proprioception or spinal reflex activity. However, controlled trials showed inconsistent findings regarding the training-induced changes in several neuromuscular and motor control variables in uninjured participants. Therefore, the effectiveness of balance training for improvements in functional performance within this

Table 1. Description of Included Studies[a]

Eligible Studies	Participants	No.	Age, y (Mean ± SD or Range)	Sex (Females/Males)	Training Duration, wk
Baker et al (1998)[10]	Athletes (collegiate wrestling)	19	19.7 ± 1.1	0/19	6
Balogun et al (1992)[11]	Students (nonathletes)	33	21.9 ± 2.4	0/33	6
Cox et al (1993)[12]	Recreationally active people	27	18–36	14/13	4
Cressey et al (2007)[13]	Athletes (soccer)	19	18–23	0/19	10
Emery et al (2005)[1]	Healthy people	120	15–16	60/60	6
Gioftsidou et al (2006)[14]	Athletes (soccer)	39	16 ± 1	0/39	12
Gruber et al (2007)[15]	Healthy people	33	25 ± 3	16/17	4
Gruber et al (2007)[16]	Healthy people	30	26 ± 5	13/17	4
Heitkamp et al (2001)[17]	Physically active people	30	31.7 ± 5.7	15/15	6
Hoffman and Payne (1995)[18]	High school students	28	16.4 ± 1.1	12/16	10
Kean et al (2006)[19]	Recreationally active people	34	24.2 ± 4.1	34/0	6
Kollmitzer et al (2000)[20]	Healthy people	26	17–18	3/23	4
Kovacs et al (2004)[21]	Athletes (figure skating)	44	18 ± 3	44/0	4
Myer et al (2006)[22]	High school athletes	19	15.6 ± 1.2	19/0	7
Rasool and George (2007)[23]	Athletes (various sports)	30	21.5 ± 5.1	0/30	4
Riemann et al (2003)[24]	Recreationally active people	26	19.6 ± 2.2	12/14	4
Schubert et al (2008)[25]	Healthy people	37	26 ± 3	15/22	4
Söderman et al (2000)[26]	Athletes (soccer)	140	20.4 ± 4	140/0	4
Taube et al (2007)[27]	Athletes (ski jumping)	17	14.5 ± 1	0/17	6
Yaggie and Campbell (2006)[28]	Recreationally active people	36	22.7 ± 2.1	NA	4

Abbreviation: NA, not available.

[a] All studies were randomized controlled trials.

population remains unclear, and the current discussion in the scientific literature regarding its underlying mechanism is still more speculative than evidence based. To our knowledge, no systematic review has been conducted to determine the effectiveness of balance training with regard to performance enhancement and neuromuscular control changes in healthy athletes using methodologic quality assessment. Clarifying the influence of balance training interventions on changes in motor performance appears to be important for 2 reasons: to identify potential underlying neuromuscular control mechanisms and to implement evidence-based balance training interventions in the field of athletic training. Hence, we conducted a systematic review of randomized controlled trials (RCTs) and controlled trials without randomization (CTs) using balance training in healthy volunteers to determine if evidence supports the use of balance training interventions in athletic training and to examine underlying changes in neuromuscular control.

METHODS

Literature Search Strategy

Two independent researchers (A.Z., M.H.) performed a search for articles published between 1966 and February 2009 in the following databases: Cochrane Bone, Joint and Muscle Trauma Group Register; Cochrane Controlled Trials Register; MEDLINE; EMBASE; PEDro (Physiotherapy Evidence Database); and SCOPUS. The key words and phrases (in different combinations) searched were *neuromuscular*, *sensorimotor*, *kinaesthetic*, *proprioceptive*, *balance*, *balancing*, *training*, *exercise*, *program*, *wobble board*, *postural control*, *perturbation*, *balance board*, *proprioception*, *coordination*, *agility*, *jump*, *jumping*, *performance*, *reaction*, *muscle*, *strength*, *sprint*, and *reflex*. References listed in papers and cited references were also examined to identify additional studies. Both English and German trials were considered for this review.

Selection Criteria

Title, abstract, and key words sections of identified studies were examined by the 2 independent reviewers to determine whether they met the following inclusion criteria: RCT or CT, balance training of the intervention group, no balance interventions for the control group, and physically active participants up to 40 years of age without injuries or surgeries within the last 6 months or chronic instability of the lower extremities. For both research questions, the outcomes of interest were postural control, muscle strength, agility, jump performance, and sprint time for functional performance and muscle reflex activity, rate of force development (RFD), reaction time, and electromyography for neuromuscular control. Trials with a combination of balance training and other interventions (eg, multi-intervention programs) were excluded from this review. Papers with imprecise abstracts were considered for full-text analysis. 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 in the selected studies was extracted by the 2 independent reviewers using predetermined extraction forms. Data of interest were research question, methodologic assessment, participants, training intervention, outcome, timing of the outcome assessment, and results. To ensure agreement between the reviewers in selecting study characteristics, we pilot tested the extraction form on 5 included articles before data extraction began. Discrepancies in data extraction were solved by discussion.

Table 2. Methodologic Quality Scores of Included Trials

		Items of the Modified van Tulder Scale[a]								
Included Trials	Quality Score	Acceptable Randomization Method	Concealed Treatment Allocation	Similar Baseline Group Values	Blinded Assessor	Avoided or Similar Co-Interventions	Acceptable Compliance	Acceptable Dropout Rate	Similar Timing of Outcome Assessment in All Groups	Intention-to-Treat Analysis
Baker et al (1998)[10]	2	U	U	Y	U	NS	U	U	Y	U
Balogun et al (1992)[11]	4	U	U	Y	NS	Y	U	Y	Y	U
Cox et al (1993)[12]	1	U	U	U	U	U	U	U	Y	U
Cressey et al (2007)[13]	3	U	U	Y	U	Y	U	U	Y	U
Emery et al (2005)[1]	6	Y	NS	Y	NS	Y	U	Y	Y	Y
Gioftsidou et al (2006)[14]	2	U	U	U	U	Y	U	U	Y	U
Gruber et al (2007)[15]	3	U	U	Y	U	Y	U	U	Y	U
Gruber et al (2007)[16]	3	U	U	Y	U	Y	U	U	Y	U
Heitkamp et al (2001)[17]	3	U	U	Y	U	Y	U	U	Y	U
Hoffman and Payne (1995)[18]	3	U	U	NS	U	Y	U	Y	Y	U
Kean et al (2006)[19]	2	U	U	U	U	Y	U	NS	Y	U
Kollmitzer et al (2000)[20]	3	U	U	Y	U	NS	NS	Y	Y	U
Kovacs et al (2004)[21]	7	U	Y	Y	NS	Y	Y	Y	Y	Y
Myer et al (2006)[22]	4	U	U	U	U	Y	Y	Y	Y	U
Rasool and George (2007)[23]	5	Y	U	Y	U	Y	Y	U	Y	U
Riemann et al (2003)[24]	3	U	U	Y	U	Y	U	U	Y	U
Schubert et al (2008)[25]	4	U	U	Y	U	Y	U	Y	Y	U
Söderman et al (2000)[26]	3	U	U	U	U	Y	Y	NS	Y	U
Taube et al (2007)[27]	3	U	U	Y	U	Y	U	U	Y	U
Yaggie and Campbell (2006)[28]	2	U	U	U	U	Y	U	U	Y	U

Abbreviations: NS, no score; U, unclear; Y, yes.

Table 3. Balance Training Versus No Training Studies: Interventions, Outcomes, and Results Overview

Study	Intervention	Outcome	Reported Results	Standardized Mean Difference (95% Confidence Interval)
Baker et al (1998)[10]	EG: resistive tubing kick training during single-leg balancing (30–50 repetitions for hip extension-flexion, adduction-abduction, 3×/wk for 6 wk, PI) CG: no balance training	Single-leg dynamic postural sway (stability index = Biodex[a] balance platform displacement, °, for EO, EC)	No group × time interaction	RL CG: no balance training EC: −0.91 (−1.87, 0.04) LL EO: −0.73 (−1.67, 0.20) EC: −0.82 (−1.77, 0.13)
Balogun et al (1992)[11]	EG: wobble board training (3×/wk for 6 wk, PI) CG: No balance training	Single-leg static postural sway on a force plate (EO, EC)	Group × time interaction ($P <$ .001); greater improvements ($P <$ .05) for EG (EO, EC)	NC
		Isometric MVC (knee flexion-extension, ankle dorsiflexion-plantar flexion)	Group × time interaction ($P <$ .001); greater improvements ($P <$ .05) in all muscles for EG	NC
Cox et al (1993)[12]	EG1: balance training on hard surface (5 min/session, 3×/wk for 4 wk, PI) EG2: balance training on foam (5 min/session, 3×/wk for 4 wk, PI) CG: no balance training	Single-leg static postural sway on a force plate (EO, EC)	No group × time interaction	NC
Emery et al (2005)[1]	EG: balance training (20 min/session, 7×/wk for 6 wk, PI, home based) CG: no balance training	Single-leg stance time on hard surface (EC)	Improvement ($P <$ .001) for EG	NC
		Single-leg stance time on balance pad (EC)	Improvement ($P <$ .01) for EG	NC
Gioftsidou et al (2006)[14]	EG1: balance training before soccer training (20 min/session, 3×/wk for 12 wk) EG2: balance training after soccer training (20 min/session, 3×/wk for 12 wk) CG: no balance training	Single-leg dynamic postural sway (stability index = Biodex balance platform displacement, °)	Group × time interaction ($P <$ .05) Improvement ($P <$ .01) in EG1 and EG2	RL: −1.13 (−1.97, −0.29) LL: −0.96 (−1.77, −0.14)
		Single-leg stance time on balance boards (a–c)	Group × time interaction ($P <$ .05) Improvements ($P <$ .01) in EG1 and EG2 Improvements ($P <$ .05) for EG2 in the LL	RL a: 2.32 (1.29, 3.35) b: 2.37 (1.33, 3.41) c: 1.64 (0.73, 2.55) LL a: 1.86 (0.91, 2.80) b: 1.71 (0.79, 2.63) c: 3.18 (1.96, 4.39)
		Isokinetic MVC (knee extension-flexion)	Decrease ($P <$ .05) in EG1 and EG2	NC
Gruber et al (2007)[15]	EG: balance training (60 min/session, 4×/wk for 4 wk, PI) CG: no balance training	Isometric MVC (plantar flexion)	No changes over time in EG or CG	NC
		Maximum RFD (plantar flexion)	Group × time interaction ($P <$ .01) Improvements ($P <$ .05) in EG	NC
		EMG median frequency of the soleus and gastrocnemius medialis during plantar-flexion MVC	Group × time interaction ($P <$ .05) Improvements ($P <$ .05) in EG for both muscles	NC
		EMG mean amplitude voltage of the soleus and gastrocnemius medialis during plantar-flexion MVC	Group × time interaction ($P <$ .01) Improvements ($P <$ .05) in EG	NC
		Nerve stimulation twitch response of the soleus and gastrocnemius muscle	No changes over time in EG or CG	−0.63 (−1.53, 0.28)
Gruber et al (2007)[16]	EG: balance training (60 min/session, 4×/wk for 4 wk, PI) CG: no balance training	Isometric MVC (plantar flexion)	No changes over time in EG or CG	−0.10 (−0.98, 0.79)
		Maximum RFD (plantar flexion)	Improvement ($P <$ .05) in EG	NC
		Single-leg dynamic postural sway (Posturomed[b])	Improvement ($P <$ .01) in EG	NC

Table 3. Continued

Study	Intervention	Outcome	Reported Results	Standardized Mean Difference (95% Confidence Interval)
		H-reflex	Reduced ($P < .05$) H_{max}/M_{max} ratios in EG No changes over time in CG	NC
		Stretch reflex	No changes over time in EG or C	1.25 (0.27, 2.24)
Hoffman and Payne (1995)[18]	EG: balance training (10 min/session, 3×/wk for 10 wk, PI) CG: no balance training	Single-leg static postural sway (EO, EC) on a force plate	Improvement in ($P < .05$) EG	NC
Kean et al (2006)[19]	EG1: fixed foot balance training (20 min/session, 4×/wk for 6 wk)	Isometric MVC (knee flexion-extension, plantar flexion)	No group × time interaction	NC
	EG2: jump-landing balance training (20 min/session, 4×/wk for 6 wk)	Prelanding EMG activity (mean RMS for the quadriceps, hamstrings, plantar flexors)	No group × time interaction	NC
	CG: no balance training	Postlanding EMG activity (mean RMS for the quadriceps, hamstrings, plantar flexors)	Main effect ($P < .01$) for reactive rectus femoris activity Improvements ($P < .01$) for EG1	NC
		Jump height (contact mat)	Improvement ($P < .05$) for EG1	NC
		20-m sprint performance	No group × time interaction	NC
		Single-leg stance (No. of ground contacts during a 30-s wobble-board balance test)	Improvement ($P < .05$) for EG1	NC
Kovacs et al (2004)[21]	EG: balance and jump landing training (20 min/session, 3×/wk for 4 wk, PI)	Single-leg postural sway (EO, EC) on a force plate	No group × time interaction	EO: −0.42 (−1.00, 0.20) EC: −0.18 (−0.77, 0.42)
	CG: basic exercise training (10 min/session, 3×/wk for 4 wk)	Single-leg postural sway after jump landing (EO, EC) on a force plate	Improvement ($P < .05$) in EG with EC	EO: −0.24 (−0.83, 0.36) EC: −0.82 (−1.44, 0.20)
		Single-leg postural sway on a force plate with the skate on (EO)	Significantly greater improvements in EG ($P < .05$)	EO: −0.39 (−0.99, 0.21)
Rasool and George (2007)[23]	EG: balance training (5×/wk for 4 wk, PI) CG: no balance training	Star Excursion Balance Test	Group × time interaction ($P < .01$) Improvement ($P < .01$) in EG	3.58 (2.37, 4.78)
Riemann et al (2003)[24]	EG: multiaxial coordination training on unstable platform (approximately 5 exercises with 10 repetitions in 3 sets, 3×/wk for 4 wk, PI)	Single-leg static postural sway on a force plate (EO, EC)	No group × time interaction	Medial-lateral EO: 0.48 (−0.30, 1.26) EC: −0.08 (−0.85, 0.69)
	CG: no balance training			Anterior-posterior EO: 0.64 (−0.15, 1.43) EC: −0.40 (−1.18, 0.38)
		Single-leg postural control after jump landing on a force plate: (a) landing and (b) balance errors	No group × time interaction	a: −0.39 (−1.17, 0.39) b: −0.56 (−1.35, 0.22)
		Isokinetic MVC: (a) inversion, (b) dorsiflexion	No group × time interaction	a: −0.04 (−0.81, 0.73) b: −0.56 (−0.77, 0.77)
Schubert et al (2008)[25]	EG: balance training (50 min/session, 4×/wk for 4 wk, PI)	H-reflex during 2 tasks (plantar flexion and stance perturbation)	No group × time interaction	NC
	CG: no balance training	RFD (plantar flexion)	No changes in EG or C	NC
		EMG during plantar flexion and stance perturbation (mean RMS for the soleus, gastrocnemius medialis, tibialis anterior)	No changes in EG or C	NC

Table 3. Continued

Study	Intervention	Outcome	Reported Results	Standardized Mean Difference (95% Confidence Interval)
Söderman et al (2000)[26]	EG: balance training (10–15 min, 7×/wk for 4 wk, home based) CG: no balance training	Single-leg dynamic postural sway (balance index = moveable platform displacement)	Decrease ($P < .05$) in EG nondominant leg No group differences for dominant leg	Dominant leg: −0.25 (−0.58, 0.09) Nondominant leg: −0.10 (−0.44, 0.23)
Yaggie and Campbell (2006)[28]	EG: balance training (20 min/session, 3×/wk for 4 wk, PI) CG: no balance training	Single-leg dynamic postural sway (EO) on a force plate	Decrease in EG for total sway[c] No change in CG	−0.65 (−1.32, 0.03)
		Single-leg stance time on a balance trainer	Decreases in EG and CG[c]	0.37 (−0.29, 1.03)
		Shuttle run time	Decrease in EG[c] No change in CG	0.21 (−0.44, 0.87)
		Jump height (jump and reach)	No group × time interaction	−0.64 (−1.32, 0.03)

Abbreviations: CG, control group; EC, eyes closed; EG, experimental group; EMG, electromyography; EO, eyes open; LL, left leg; MVC, maximum contraction force; NC, not calculated because data missing; PI, progressive intensity; RFD, rate of force development; RL, right leg; RMS, root mean square.

[a] Biodex Medical Systems, Shirley, NY.

[b] Posturomed, Zebris Medical GmbH, Ismy im Allgau, Germany.

[c] The authors did not provide *P* values.

The final data reports were based on consensus of the reviewers.

Data Analysis

We used 2 methods to evaluate balance training effects. First, the individual results were summarized as reported in included trials (eg, differences in group changes over time). Second, we used Review Manager (version 5.0; The Nordic Cochrane Collaboration, Copenhagen, Denmark) to calculate standardized mean differences (SMD = the Hedges adjusted g, defined as the difference between the posttest treatment and control means divided by the pooled SD) and 95% confidence intervals (CIs) for each trial when sufficient data were available. When comparable data from multiple studies were available, they were pooled using a random-effects model. The random-effects model accounts for the heterogeneity of studies. Heterogeneity (variability in intervention effects among studies) was assessed by using χ^2 and I^2 statistics and 95% CIs.

Included studies used various assessment and data analysis methods for measured outcomes, such as postural sway or muscle strength, and often multiple results were presented for a single outcome (eg, different sway directions). To avoid bias, representative data were used for overall effect-size calculation. For example, if multiple variables were available for postural sway, we defined the sway path or medial-lateral sway of the dominant or right leg under the eyes-open condition as appropriate for meta-analysis. Furthermore, differences in training effects between athletes and nonathletes as well as between programs of various lengths were reported when sufficient data were available.

Methodologic Quality

The methodologic quality of all eligible studies was independently examined by the 2 reviewers. For this approach, the scale of van Tulder et al[9] for the assessment of internal study validity was used. Neglecting the criteria of participant and therapist blinding, we shortened the original van Tulder scale by 2 of the 11 criteria. Consequently, the modified van Tulder scale in this review included the following items: (1) acceptable method of randomization, (2) concealed treatment allocation, (3) similar group values at baseline, (4) blinded assessor, (5) avoided or similar co-interventions, (6) acceptable compliance, (7) acceptable dropout rate, (8) similar timing of the outcome assessment in all groups, and (9) intention-to-treat analysis. Adequate methods of randomization included a computer-generated random-number table or use of sealed opaque envelopes. Methods of allocation using date of birth or alternation were not accepted as appropriate.[9] Compliance with the interventions, determined by training diaries or monitoring, should not have been less than 75%. A dropout rate of up to 25% was considered acceptable for follow-up of less than 6 months, and a dropout rate of up to 30% was considered acceptable for follow-up of ≥6 months. The 9 criteria for assessment of methodologic quality were scored with *yes*, *no*, or (in case of inadequate reports) *unclear*. For each *yes* score, 1 point (on the van Tulder scale) was given. On the summary quality score (maximum of 9 points), at least 50% *yes* scores were needed for high quality.[9] The methodologic quality assessment was pilot tested by the reviewers for agreement on a common interpretation of the items and their implementation. The consensus method was used to discuss and resolve disagreements between the reviewers.

RESULTS

Literature Search and Methodologic Quality of Included Trials

On literature and reference searching, we identified 45 relevant trials, of which 36 were RCTs or CTs (based on the individual study description). We excluded 16 trials after full-text analysis because of inadequate controls, inadequate

Table 4. Balance Training Versus Strength and Plyometric Training Studies: Interventions, Outcomes, and Results Overview

Study	Intervention	Outcome	Reported Results	Standardized Mean Difference (95% Confidence Interval)
Cressey et al (2007)[13]	EG: strength training on unstable platforms (27 sessions for 10 wk, PI); CG: strength training alone (PI)	Bounce-drop jump power	Improvement ($P < .05$) greater for CG	NC
		Countermovement jump power	Improvement ($P < .05$) for CG	NC
		40-yd and 10-yd sprint performance	Improvement ($P < .05$) for CG in 40-yd sprint	NC
		T-Test for agility assessment	No group × time interaction	NC
Gruber et al (2007)[15]	EG: balance training (60 min/session, 4×/wk for 4 wk, PI); CG: ballistic strength training (60 min/session, 4×/wk for 4 wk, PI)	Isometric MVC (plantar flexion)	No changes over time in EG or CG	NC
		Maximum rate of force development (plantar flexion)	Group × time interaction ($P < .01$) Improvement ($P < .05$) for CG	NC
		EMG median frequency of the soleus and gastrocnemius medialis during plantar flexion MVC	Group × time interaction ($P < .05$); improvements in EG for both muscles ($P < .05$), in CG for the gastrocnemius	NC
		EMG mean amplitude voltage of the soleus and gastrocnemius medialis during plantar flexion MVC	Group × time interaction ($P < .01$) Improvements ($P < .05$) in CG	NC
		Nerve stimulation twitch response of the soleus and gastrocnemius muscle	No changes over time in EG or CG	−0.63 (−0.28, 1.53)
Gruber et al (2007)[16]	EG: balance training (60 min/session, 4×/wk for 4 wk, PI); CG: ballistic strength training (60 min/session, 4×/wk for 4 wk, PI)	Isometric MVC (plantar flexion)	No changes over time in EG or CG	−0.12 (−1.00, 0.76) −0.10 (−0.98, 0.79)
		Maximum rate of force development (plantar flexion)	Improvements in EG ($P < .05$) and CG ($P < .01$) No differences between EG and CG over time	NC
		Single-leg dynamic postural sway (Posturomed[a]) on a force plate	Improvements in EG ($P < .01$) and CG ($P < .05$) No differences over time between EG and CG	NC
		H-reflex	Reduced H_{max}/M_{max} ratios in EG ($P < .05$) No changes over time in CG	NC
		Stretch reflex	No changes over time in EG or CG	3.83 (2.24, 5.42)
Heitkamp et al (2001)[17]	EG: balance training (25 min/session, 2×/wk for 6 wk); CG: strength training (25 min/session, 2×/wk for 6 wk)	Single-leg stance time on a small edge	Improvements in EG ($P < .01$) and CG ($P < .05$)	NC
		Single-leg stance on unstable platform (number of ground contacts)	Improvement in EG ($P < .01$) No changes over time in CG	NC
		Isokinetic MVC (knee flexion-extension)	Improvements in both muscles in EG and CG ($P < .01$)	NC
Kollmitzer et al (2000)[20]	EG: balance training (3 sets, 4 min/d, 7×/wk for 4 wk, home based); CG: strength training (leg extensions, 3 sets, 4 min/d, 7×/ wk for 4 wk, home based)	Single-leg static postural sway on hard surface (EO, EC)	Greater training effects ($P < .05$) in EG	NC
		Single-leg postural sway on elastic surface (EO, EC)	No group × time interaction	NC
		Single-leg dynamic postural control on balance tilt	Greater training effects ($P < .05$) in EG	NC
		EMG activity during dynamic balancing (RMS for back extensors)	Decreases in EG and CG ($P < .05$)	NC
		Isometric MVC (back extension)	Increases in EG and CG ($P < .001$)	NC
Myer et al (2006)[22]	EG: balance training (90 min, 3×/wk for 7 wk, PI); CG: plyometric training (90 min, 3×/wk for 7 wk, PI)	Jump height	No group × time interaction Increases in EG and CG ($P < .001$)	NC
		Single-leg postural sway after jump landing	No group × time interaction Decrease for medial-lateral sway in EG and CG ($P < .05$)	NC
		Isokinetic MVC (knee flexion-extension)	No group × time interaction Increases for knee-flexor peak torque in EG and CG ($P < .01$)	NC

Table 4. Continued

Study	Intervention	Outcome	Reported Results	Standardized Mean Difference (95% Confidence Interval)
		Vertical impact force before jumping	Group × time interaction ($P < .05$) 7% Decrease in EG, 7.6% increase in CG	NC
		Predicted 1-repetition maximum strength during (a) bench press, (b) hang clean, and (c) squat	No group × time interaction Improvements over time for both groups ($P < .001$)	a: 0.78 (−0.17, 1.73) b: 0.43 (−0.49, 1.35) c: 0.10 (−0.81, 1.01)
Schubert et al (2008)[25]	EG: balance training (50 min/session, 4×/wk for 4 wk, PI); CG: strength training (approximately 50 min/session, 4×/wk for 4 wk, PI)	H-reflex during 2 tasks (plantar flexion and stance perturbation)	No group × time interaction Training × task interaction ($P < .01$)	NC
		Rate of force development	Increase ($P < .01$) in CG No changes in EG	NC
		EMG during plantar-flexion and stance perturbation (mean RMS for the soleus, gastrocnemius medialis, tibialis anterior)	Increased soleus RMS ($P < .05$) in CG	NC
Taube et al (2007)[27]	EG: balance training (approximately 45 min/session, 3×/wk for 6 wk, PI); CG: strength training (approximately 45 min/session, 3×/wk for 6 wk, PI)	Isometric MVC (leg press)	No changes in EG Increase ($P < .05$) in CG	NC
		Maximal rate of force development	No changes in EG or CG	NC
		Jump height	Increases ($P < .05$) in EG and CG	NC
		EMG activity during MVC (soleus, gastrocnemius medialis, tibialis anterior, quadriceps, biceps femoris)	No changes in EG Increases in CG ($P < .05$) for gastrocnemius medialis, quadriceps, biceps femoris integrated EMG	NC
		Reflex activity of plantar flexors	Decrease in H_{max}/M_{max} ratios in EG ($P < .05$)	NC

Abbreviations: CG, control group; EG, experimental group; EMG, electromyography; MVC, maximum contraction force; NC, not calculated because data missing; PI, progressive intensity; RMS, root mean square.

[a] Posturomed, Zebris Medical GmbH, Ismy im Allgau, Germany.

reports, inadequate interventions, multi-intervention training, or balance exercises in the control group. The 20 remaining RCTs (Table 1) met the selection criteria and were accepted for inclusion in this review. A total of 787 volunteers participated in the included trials (n = 39 ± 32, 47% males, reported mean age ranged between 14.5 ± 1[27] and 31.7 ± 5.7[17] years). Participants comprised athletes (n = 327), recreationally active people (n = 153), and healthy nonathletes (n = 307). Athletes were regularly engaged in organized sports (eg, school sport, club sport) practicing soccer, ski jumping, wrestling, or figure skating.

The methodologic quality scores of included trials are provided in Table 2. The range of summary quality scores was between 1 and 7, with a mean score of 3 ± 1 points. Three studies[1,21,23] had at least 50% *yes* scores (5 points or more) on the modified van Tulder scale, necessary for classification as a high-quality trial. Based on the methodologic study description, the randomization method was considered acceptable in 2 trials[1,23] and was *unclear* in 18 trials. In addition, concealed treatment allocation, blinded assessor, and intention-to-treat analysis were not sufficiently described in most of the studies.

Summary of Balance Training Interventions

The interventions consisted of balancing exercises on stable or unstable platforms with or without recurrent destabilization (eg, ball throwing or catching, strengthening exercises, or elastic-band kicks with the uninvolved leg) while exercising. Although the control groups in most trials had no intervention, some authors compared balance training with strength training[13,15–17,20,25,27] or plyometric training.[22] Treatment length varied between 4 and 12 weeks. Training sessions lasted between 5 and 90 minutes per day and were scheduled from 2 to 7 times weekly. The full overview of training interventions is given in Table 3 for balance training versus no-training studies and in Table 4 for balance training versus strength or plyometric training studies.

Functional Performance

Balance Training Versus No Training. Both significant improvements[1,11,14,16,18,19,28] and no changes[10,12,14,19,24,26,28] were reported for postural sway on stable and unstable platforms and after jump landing. For 6 trials, effect sizes were calculated (Figure 1). The overall SMD revealed a balance training effect on postural sway improvements (SMD = −0.43, 95% CI = −0.80, −0.05). Training effects were also shown for functional balance tests (SMD = 2.04, 95% CI = 0.11, 3.97) using the Star Excursion Balance Test[23] and single-leg stance time[14,28] (Figure 2). Inconsistent results or no effects were reported for changes in lower extremity muscle strength (SMD = −0.02, 95% CI = −0.60,

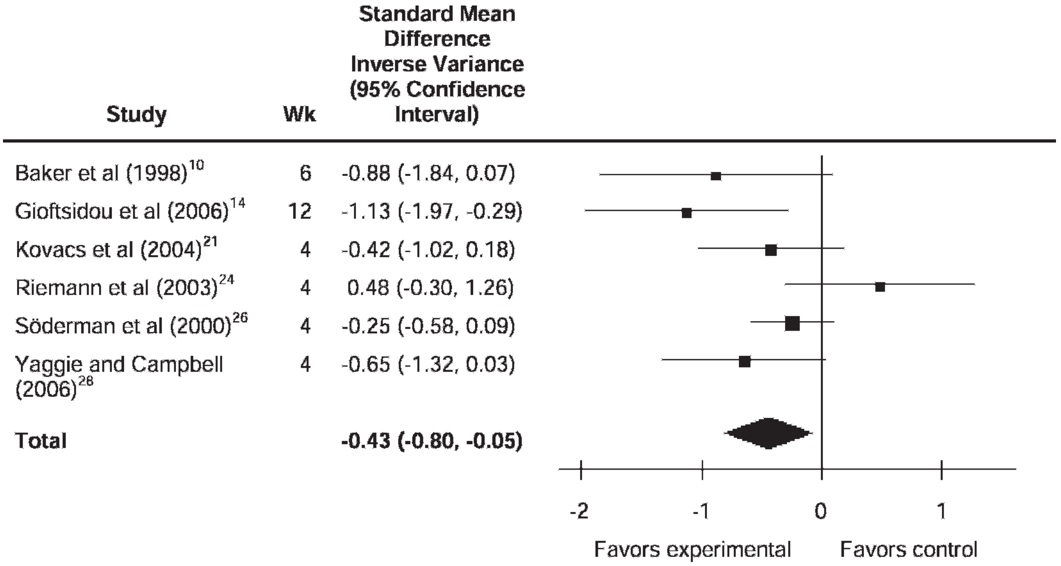

Figure 1. Forest plot of studies investigating the effects of balance training versus no training on postural sway. All studies involved athletes or recreationally active participants. Standard mean differences are presented with respect to training duration. Heterogeneity: $\tau^2 = 0.10$, $\chi^2_5 = 10.00$, $P = .08$, $I^2 = 50\%$. Test for overall effect: $Z = 2.23$, $P = .03$.

0.56),[11,14–16,19,24] jump height,[19,28] sprint performance,[19] and shuttle run agility.[28]

Balance Training Versus Strength Training or Plyometric Training. No SMDs were calculated for balance training versus strength training because data were insufficient. Inconsistent findings were reported[16,17,20,22] for postural sway changes, with both greater improvements in the balance training group and no group differences. Several authors reported no group differences for lower extremity and back extensor muscle strength,[15–17,20,22] jumping performance,[22,27] and T-Test agility.[13] Greater strength and plyometric training effects were shown in 2 studies for leg press strength,[27] jumping performance,[13] and sprint performance.[13]

Nonathletes Versus Athletes. Eight trials included athletes in various sports, 5 trials examined recreationally active participants, and in 7 trials, the physical activity level was not clarified or was defined as nonathletic. For athletes and recreationally active participants, training effects were shown with regard to postural sway (SMD = −0.43, 95% CI = −0.80, −0.05)[10,14,21,24,26,28] (Figure 1) and functional balance test improvements (SMD = 2.04, 95% CI = 0.11, 3.97) [14,23,28] (Figure 2). With regard to changes in postural sway, all studies with healthy nonathletes reported improvements when compared with results in untrained controls[1,11,16,18] or volunteers who had pursued strength training.[16,20] No global effect sizes were calculated for nonathletes because of missing data. Furthermore, balance training had no effects on lower extremity muscle strength in athletes[14,22,27] or recreationally active volunteers,[19,24] whereas knee muscle strength[11] in nonathletes improved significantly. With regard to jumping performance, no balance training effects or greater strength or plyometric training effects were shown for athletes,[13,22,27] and inconsistent results were reported for recreationally active participants.[19,28]

Training Duration. The individual SMDs revealed that training programs of longer duration (6 and 12 weeks)[10,14]

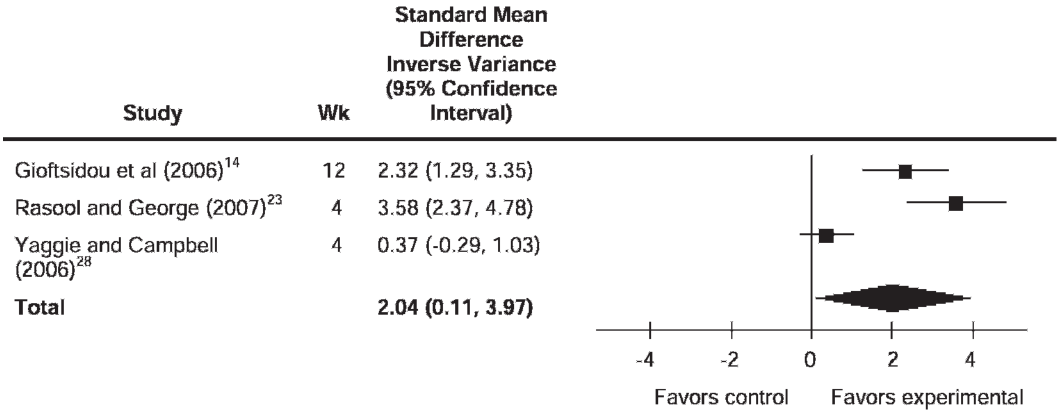

Figure 2. Forest plot of studies investigating the effects of balance training versus no training on functional balance. All studies involved athletes or recreationally active participants. Standard mean differences are presented with respect to training duration. Heterogeneity: $\tau^2 = 2.66$, $\chi^2_2 = 24.85$, $P < .00001$, $I^2 = 92\%$. Test for overall effect: $Z = 2.07$, $P = .04$.

achieved higher effect sizes in postural sway and single-leg stance time on unstable boards compared with trials of 4 weeks[21,24,26,28] (Figures 1 and 2).

Neuromuscular Control

Balance Training Versus No Training. No SMDs were calculated for the neuromuscular control group differences because data were insufficient. Both improvements in the balance training group[15,16] and no group differences[25] were reported for plantar-flexion RFD and H-reflex modulation. With regard to electromyographic (EMG) activity, balance training effects were reported for soleus and gastrocnemius medialis muscle EMG median frequency and reactive rectus femoris root mean square (RMS).[15,19] No effects were shown for EMG mean amplitude voltage or RMS of the soleus, gastrocnemius medialis, or tibialis anterior[15,25] or for prelanding and postlanding biceps femoris and soleus EMG activity.[19]

Balance Training Versus Strength Training. For plantar-flexion RFD, 1 trial showed improvements in both training groups,[16] 1 trial showed no changes after strength and balance training,[27] and 2 trials showed greater strength training effects.[15,25] Greater effects of balance training[16,27] or no between-groups differences[25] were demonstrated for H-reflex modulation. With regard to lower extremity EMG, strength training had greater effects on soleus and gastrocnemius medialis EMG mean amplitude voltage,[15] soleus RMS,[25] and gastrocnemius medialis, biceps femoris, and quadriceps integrated EMG[27] than did balance training. No group differences due to strength or balance training were shown for soleus or gastrocnemius medialis median frequency,[15,25] RMS of back extensors,[20] or soleus and tibialis anterior integrated EMG.[27]

Nonathletes Versus Athletes. Of the 6 trials involving neuromuscular control measurements, 1 included athletes,[27] 1 included recreationally active participants,[19] and 4 included healthy volunteers.[15,16,20,25] No differences were noted between athletes and nonathletes in any of the measured neuromuscular control outcomes.

Training Duration. The training duration of included neuromuscular control trials was either 4 weeks[15,16,20,25] or 6 weeks.[19,27] No differences were seen between 4-week and 6-week trials.

DISCUSSION

Balance Training and Functional Performance

With regard to changes in functional performance, our review demonstrated balance training effects on changes in static postural sway and dynamic balance in both athletes in various sports and in nonathletes. When compared with untrained control participants, the nonathletes also showed improvements in lower extremity muscle strength after balance training. However, balance training was less effective than strength training.

For lower extremity muscle strength, jumping performance, sprint time, and agility, similar or greater improvements were reported with strength training. Furthermore, Myer et al[22] established improvements in knee muscle strength, jump height, and postural control after both balance and plyometric training but no differences between groups. Thus, balance training is an effective treatment to improve balancing motor skills, but for optimal performance enhancements (eg, sprint performance, jumping, strength performance) in specific sports, other training methods might be equally effective or more effective.

Balance Training and Neuromuscular Control

In this review, we included 6 RCTs that assessed balance training effects on neuromuscular outcomes in healthy volunteers. The authors reported inconsistent findings for changes in reflex modulation, EMG activity, and RFD. For H-reflex modulation, both greater effects of balance training[16,27] and no between-groups differences[25] were shown in comparison with untrained controls and a strength training group. With regard to EMG activity[15,16,19,25] and plantar-flexion RFD,[15,16,25] both improvements in the balance training group and no group differences were reported in comparison with untrained controls. For the balance training versus strength training comparison, however, greater strength training effects and no group differences were shown.[15,16,20,25,27] The inconsistent findings produced some controversy regarding neuromuscular control adaptations to balance training. Researchers[16,27] who reported changes in H-reflex modulation associate the effects with decreased spinal reflexes after various balance control exercises that might improve movement control in unstable situations by preventing reflex-mediated joint oscillations. In the study[25] that failed to show improvements in spinal reflex activity, the authors discussed low statistical power due to small sample sizes and the short-lasting spinal training effects as possible reasons for the lack of improvement. Furthermore, it has been hypothesized[15,16,29] that changes in EMG activity and RFD were predominantly related to neural adaptations rather than to changes in muscle properties. The authors suggested that altered feedback of mechanoreceptors from balance training may lead to central nervous system reorganization processes in terms of sensorimotor integration and, subsequently, to alterations of motor response (adaptations of neuromuscular control). This view is supported by investigators[30,31] who reported persisting functional deficits, such as limited postural control, decreased maximal strength, or prolonged muscle reaction time, after structural damage to lower extremity joint receptors resulting from injuries or overuse. Therefore, functional improvements (such as postural control[4,32]) and reduced injury rates[1] after balance training are often associated with adaptations in neuromuscular control mechanisms.[5] However, because controversial training effects on neuromuscular outcomes are reported in this review, the discussion of underlying mechanisms of balance training adaptation remains speculative.

Dosage of Balance Training

Training sessions in the included studies lasted between 5 and 90 minutes per day, and the overall treatment duration ranged between 4 and 12 weeks. Training frequency ranged from 2 times per week[17] to 7 times per week,[1,20,26] with a mean frequency of 3.9 ± 1.5 times weekly. Studies with comparable designs (eg, training duration, frequency, and session length) were either from the same research group[15,16] or included participants with different activity levels.[21,28] Yet improvements in several outcomes, such as postural sway, were more pronounced when training protocols of more than 6 weeks were compared with shorter-duration protocols.[1,11,12,14,18,21,24] More precisely, although no training effects were reported after 4 weeks,[12,21,24] static postural sway on stable platforms improved after balance training of 6 weeks,[1,11] 10 weeks,[18] and 12 weeks.[14] Similar results were established for changes in balance using the Star Excursion Balance Test[23] and single-leg stance time on unstable boards.[14,28] Based on these findings, it might be hypothesized that for notable sensorimotor adaptations, a minimum balance training duration of at least 6 weeks is required. However, because no authors systematically examined the influence of balance training dosage, these assumptions remain speculative. Hamman et al[33,34] reported no difference in static stability between 5 days of balance training and a once-weekly balance program over the course of 5 weeks in healthy volunteers. Because of several methodologic limitations (eg, inadequate report of interventions), we did not consider the results of these trials for this review.

Balance Training in Athletes and Nonathletes

Furthermore, it seems likely that the pretraining performance level of included participants may have influenced the magnitude of adaptations. Most studies included amateur and professional athletes engaged in organized sports (soccer, ski jumping, wrestling, or figure skating) or recreationally active people. In some studies,[15,16,20,25] however, the participants were described as healthy nonathletes or individuals without an appropriate definition of performance level. Athletes are generally expected to have developed advanced motor performance skills compared with those not involved in regular sport activities.[35] Consequently, the range of adaptations to similar balance training regimens might be quite different in those groups. In this review, training effects were shown in athletes and recreationally active participants[10,14,21,23,24,26,28] for postural sway and functional balance test improvements. Although we were unable to calculate global effect sizes for trials with healthy nonathletes because of insufficient data, the authors of all these trials reported improvements in postural sway outcomes after balance training when compared with outcomes in untrained controls[1,11,16,18] or participants involved in strength training.[16,20] With respect to changes in muscle strength, much less agreement between physically active and inactive volunteers was found. Although balance training had no effects on lower extremity muscle strength in athletes[14,22,27] or recreationally active participants, [19,24] knee muscle strength[11] in nonathletes improved significantly. This finding most likely stems from their considerably lower muscle strength at baseline; consequently, even short-term single-leg balance exercises may have served as effective strength training for the lower extremities. Thus, intervention dose as well as a participant's performance level must be taken into account when assessing the effects of balance training on motor performance.

Methodologic Limitations

One limitation of this review was the poor methodologic quality of included studies (mean score = 3). The best methodologic quality score was 7 of 9 points on the modified van Tulder scale, and only 3 of 21 studies were considered high quality, with scores of 5 points or more.[1,21,23]

We used 2 methods of data analysis to evaluate balance training effects: (1) summarizing of reported results and (2) meta-analysis techniques (SMDs). The use of meta-analysis appeared to be problematic for several reasons. First, some authors reported multiple results for a single outcome (eg, postural sway: different sway directions, sway velocity, sway path under eyes-open and eyes-closed conditions of the right and left leg), which meant that we had to choose one representative value to investigate. Second, the use of poor-quality studies might have affected the results to a certain extent. Third, for a number of studies, no effect sizes were calculated because of insufficient data (we did not contact the corresponding authors), and fourth, included trials showed large variations in training duration, frequency, and session length. Consequently, a valid between-studies comparison of included trials was hampered, and, thus, the results of our meta-analysis should be viewed with caution.

CONCLUSIONS

From a clinical perspective, balance training is an effective intervention to improve static postural sway and dynamic balance in both athletes and nonathletes. Although controversial findings have been reported for jumping performance and agility, balance training may have some effect in improving these outcomes. Similar effects were shown for spinal reflex, EMG activity, and RFD. Discrepant findings or no effects were shown for lower extremity and back extensor strength as well as for sprint performance. Based on this evidence, we recommend the use of balance exercises for postural and neuromuscular control improvements. Given that these are desirable adaptations after injury or disease to prevent long-term functional restrictions, balance training might be useful both in rehabilitation and for preventive purposes. However, to achieve optimal enhancements in sprint, jumping, or strength performance, other training programs (eg, strength or plyometric training) are more effective. With respect to training duration, the longer training durations of 6 or 12 weeks seemed to be more effective than was a duration of 4 weeks, but methodologic limitations and high variability in assessment methods and training dosage among studies mean that these findings should be viewed with caution. Further research of high methodologic quality is needed to determine the efficacy and dose-response relationship of balance training for functional performance improvements and neuromuscular control changes.

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Address correspondence to Astrid Zech, PhD, Institute of Sports Science and Sports, Friedrich-Alexander-University, Gebbertstr. 123b, 91058 Erlangen, Germany. Address e-mail to astrid.zech@sport.uni-erlangen.de.