Journal of Human Kinetics volume 58/2017, 45-64 DOI: 10.1515/hukin-2017-0088
Section I – Kinesiology

Balance Training Programs in Athletes – A Systematic Review

by
Anna Brachman[1], Anna Kamieniarz[1], Justyna Michalska[1], Michał Pawłowski[1], Kajetan J. Słomka[1], Grzegorz Juras[1]

It has become almost routine practice to incorporate balance exercises into training programs for athletes from different sports. However, the type of training that is most efficient remains unclear, as well as the frequency, intensity and duration of the exercise that would be most beneficial have not yet been determined. The following review is based on papers that were found through computerized searches of PubMed and SportDiscus from 2000 to 2016. Articles related to balance training, testing, and injury prevention in young healthy athletes were considered. Based on a Boolean search strategy the independent researchers performed a literature review. A total of 2395 articles were evaluated, yet only 50 studies met the inclusion criteria. In most of the reviewed articles, balance training has proven to be an effective tool for the improvement of postural control. It is difficult to establish one model of training that would be appropriate for each sport discipline, including its characteristics and demands. The main aim of this review was to identify a training protocol based on most commonly used interventions that led to improvements in balance. Our choice was specifically established on the assessment of the effects of balance training on postural control and injury prevention as well as balance training methods. The analyses including papers in which training protocols demonstrated positive effects on balance performance suggest that an efficient training protocol should last for 8 weeks, with a frequency of two training sessions per week, and a single training session of 45 min. This standard was established based on 36 reviewed studies.

Key words: *proprioceptive training, plyometrics, neuromuscular training, postural control, injury prevention.*

Introduction

It has become almost routine practice to incorporate balance exercises into training programs for athletes from different sports, fall prevention programs for the elderly and rehabilitation programs. The objectives and benefits seem obvious, e.g., performance improvement and injury prevention as commonly cited goals (Hrysomallis 2011; Kümmel et al., 2016; Lesinski et al., 2015). However, the type of training that is most efficient still remains unclear, and the frequency, intensity and duration of exercise that would be most beneficial have not yet been determined. The main goal of this review was to establish whether a gold standard of balance training exists in this field.

Posture and balance control are fundamental in daily life to safely accomplish any type of movement and motor task that involves displacement of body segments or the entire body. Balance is the process of maintaining the body's center of gravity (CoG) vertically over the base of the support, and it relies on rapid and continuous feedback from visual, vestibular and somatosensory structures for the subsequent execution of smooth and coordinated neuromuscular actions (Winter, 1995; Zatsiorsky and Duarte, 1999). Efficient postural balance not only reduces the risk of body imbalance, fall, or subsequent injuries, but also contributes to the optimization of motor performance in a number of athletic disciplines (Hrysomallis, 2007; McGuine et al., 2000; Watson, 1999).

[1] - *Department of Human Motor Behavior, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland.*

Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 58/2017 in September2017.

Each sport involves specific motor skills that require the completion of particular postures and movements (Hrysomallis et al., 2006; Maurer et al., 2006; Paillard, 2017). Balance is an important factor in many athletic skills, but the relationship between sports competition results and balance is not yet fully understood (Adlerton et al., 2003; Hrysomallis, 2011). A lower level of balance is associated with injuries, such as sprains and, muscle, tendon and ligament strains among others (McGuine et al., 2000; Emery and Meeuwisse, 2010; Eils et al., 2010). Maintaining a standing posture on a stable surface is a major determinant of balance. A sway analysis in a simple task, such as quiet standing, is used as a variable of its description (Visser et al., 2008; Duarte and Freitas, 2010). However, controversy exists in the literature regarding the influence of balance training on athletes' performance and balance improvement, as well as injury prevention.

Literature search

The following review is based on papers that were found through computerized searches of PubMed and SportDiscus from 2000 to 2016. There is no general consensus in the literature regarding what to call training programs and exercise, therefore, we searched for various terms of training programmes. Based on a Boolean search strategy, consistent with previous meta-analyses on the effects of balance training (Kümmel et al., 2016; Lesinski et al., 2015; Zemková, 2014), the following search terms were (individually or in various combinations) used: "balance training" OR "proprioceptive training" OR "core stability training" OR "injury prevention", OR "postural control" AND "injury prevention" AND "sport" OR "athletes" OR "basketball" OR "baseball" OR "volleyball" OR "football" OR "soccer" OR "handball" OR "tennis" OR "ski" OR "runners" OR "judo" OR "taekwondo" OR "capoeira" OR "figure skating" OR "bicycling". The search was limited to English language and full-text original articles.

Study selection

Only the studies that met the following criteria were included: (1) the participants of an intervention and a control group had to be healthy at the time of the study, (2) the study subjects were in an age range of 7-30 years old, (3) balance tests were performed before and after the intervention programs. Studies were excluded if (1) they did not meet the criteria for CTs (Control Trials), (2) the PEDro scale was lower than four (Table 3), or (3) balance training was not described in detail. We made an exception for the four papers (PEDro 3) because of the better quality description of training protocols. The reviewers conducted the literature review independently, based on inclusion and exclusion criteria. In total, 50 studies met the inclusion criteria for review (Figure 1).

Balance training

Training methods

No general agreement may be found in the literature regarding which terms should be used to summarize training programs that aim at the improvement of postural stability (Kümmel, Kramer, Giboin, Gruber, et al., 2016). Some authors (Verhagen et al., 2005; Cumps et al., 2007; Kachanathu et al., 2014; Hammami et al., 2016) described balance or core stability exercises in their training programs. Others (Benis et al., 2016; Hammami et al.; Malliou et al., 2004; 2016; Pau et al., 2012; Verhagen et al., 2002; Zech et al., 2010) described neuromuscular or proprioceptive training and included multi-intervention programs with a combination of balance, strength, plyometric, and sport-specific exercises. Some authors describe the implemented exercises as balance training (Verhagen et al., 2005; Gioftsidou et al., 2006), and others call it sensorimotor training (Heleno et al., 2016; Pauet al., 2011), neuromuscular training (Zech et al., 2014; Benis et al., 2016) or proprioceptive training (Eils et al., 2010; Malliou et al., 2004; Mandelbaum et al., 2005). However, the most common term used seems to be balance training. Therefore, as in other systematic reviews (Kümmel et al., 2016), we use the term "balance training" to describe any training program primarily directed at the improvement of postural stability, regardless of the term used in the studies. Each of the training program described above presents a large variety of exercises. The balance training interventions consisted of balance exercises on both a stable and unstable surface, with or without recurrent destabilization during performance (Cumps et al., 2007; Hübscher et al., 2010; McHugh et al., 2007; Soderman et al., 2000; Verhagen et al., 2002, 2005;

Zech et al., 2010). In some studies, training programs also included exercises with visual feedback (Malliou et al., 2004).

Frequently, studies that examined neuromuscular or proprioceptive training interventions similar to balance training included balance exercises on stable and unstable platforms with or without perturbations of postural control (Hübscher et al., 2010; Zech et al., 2010). Some authors also described neuromuscular training as multi-intervention programs with a combination of balance, weight, plyometric and sport-specific agility drills to address all aspects of neuromuscular control (Holm et al., 2004; Hübscher et al., 2010; Mandelbaum et al., 2005; Myer et al., 2009). In some papers, the authors implemented plyometric training alone to improve balance or combined it with balance exercises (Asadi et al., 2015; Manolopoulos et al., 2015; Myer et al., 2006; Pfile et al., 2013, 2016).

Balance assessment

To assess static and dynamic balance, some researchers used clinical and laboratory tests. Balance tests were performed before and after an intervention program. In some reports, also strength, aerobic endurance and specific performance were assessed (Hammami et al., 2016; Imai et al., 2014; Kang et al., 2013; Manolopoulos et al., 2015; Myer et al., 2006).

Static balance was evaluated using simple tests such us the stork test (Daneshjoo et al., 2012; Hammami et al., 2016) or the single leg stance (SLS) test (Dobrijević et al., 2016; Kang et al., 2013; Karami et al., 2014). These tests require the participants to keep their hands on the hips and maintain the foot of their non-tested leg at the knee level with their eyes open or closed. The participants attempted the task a few times, and the best scores were recorded for further analysis. More sophisticated procedures were performed on a force plate (FP) which can monitor the movement of the center of pressure (COP). Different variables derived from the path of the COP during the single leg stance test (Ahmadabadi et al., 2015; Malliou et al., 2004; Saunders et al., 2013), the quiet standing (QS) test (Cankaya et al., 2015; Pau et al., 2011; Steib et al., 2016) or the limit of stability (LOS) test (Mahieu et al., 2006; Romero-Franco et al., 2012) have been used as measures of balance. A balance assessment can also be conducted on an unstable surface. One example is a kinesthetic ability trainer (KAT) (Holm et al., 2004). The KAT consists of an electronic moveable platform that is supported by a small pivot at its central point. The stability of the platform is controlled by pressure that varies in a circular pneumatic bladder between the platform and the base of the unit. High pressure indicates an inflated platform (stable), while low pressure a deflated platform (unstable). An unstable surface makes the balance test more dynamic and possibly more applicable in a sports context.

Dynamic balance was assessed by the Balance Error Scoring System (BESS) (Imai et al., 2014; Mcleod et al., 2009), the Star Excursion Balance Test (SEBT) (Eisen et al., 2010; Filipa et al., 2012; Sato and Mokha, 2009) and the Y-Balance Test (YBT) (Trecroci et al., 2015; Benis et al., 2016; Hammami et al., 2016). The BESS consists of 6 separate 20 s balance tests that the subjects perform in different stances and on different surfaces. The test comprises 3 stance conditions (double-leg, single-leg, and tandem stance) and 2 surfaces (firm and foam). All trials are performed with the eyes closed (Finnoff et al., 2009). Errors are recorded as the quantitative measurement of postural stability under different testing conditions. Another test, originally described by Gray (Gray, 1995) as a rehabilitation tool, the SEBT, is a series of single-limb squats using the non-stance limb to perform maximal reach in order to touch a point along 1 of 8 designated lines on the ground. The lines are arranged in a grid that extends from a center point and are 45° from one another. The reach distances are normalized to leg length. The YBT, was inspired by clinical applications of the SEBT (Coughlan et al., 2012). The participants push the reach-indicator block with one foot in the anterior, posteromedial and posterolateral directions while standing on the other foot on a central footplate. Some researchers used the Modified Star Excursion Balance Test (MSEBT), where the subjects performed movements in the same directions as in the YBT (Zech et al., 2014; Heleno et al., 2016). Dynamic balance was also evaluated by a jumping test. For example, Heleno et al. (2016) conducted the Side Hop Test (SHT) with lateral jumps, and the Figure Eight Test (F8) using forward jumps with rotation. O'Malley et al. (2016) used the Landing Error Scoring System

(LESS). The LESS identifies poor jump-landing techniques, such as decreased knee and hip flexion motion, knee valgus, and hip internal rotation, which can cause greater joint loading. Zech et al. (Zech et al., 2014) assessed the time to stabilization (TTS) following single-leg jump landing.

To assess proprioception and the stability of the upper and lower limbs, the isokinetic dynamometer (ID) was used to evaluate joint position sense (Daneshjoo et al., 2012).

Equipment and exercises

We found that there were numerous balance exercises that effectively improve static and dynamic balance. Training methods included exercises on stable and unstable surfaces in anterior/posterior and mediolateral directions, with or without recurrent destabilization (e.g., ball throwing or catching, strengthening exercises, or external perturbation applied by a partner) (Cumps et al., 2007; DiStefano et al., 2009; Hübscher et al., 2010; McHugh et al., 2007; Paillard, 2017; Soderman et al., 2000; Verhagen et al., 2002, 2005; Zech et al., 2010). The balance training programs typically included progression of the exercises. In some studies, balance exercises were performed first with the eyes open and then with the eyes closed in order to increase the difficulty (Hammami et al., 2016; Heleno et al., 2016; McGuine and Keene, 2006; Verhagen et al., 2005). Additionally, the balance training programs included transitions from a double-leg stance to a single-leg stance (Gioftsidou et al., 2006; O'Malley et al., 2016; Pau et al., 2011) on a stable or unstable surface (Eisen et al., 2010; Manolopoulos et al., 2015; Steib et al., 2016).

Occasionally, the authors also used exercises with visual feedback, such as moving a cursor to a target by shifting the weight (Malliou et al., 2004) or maintaining a single-leg stance on a board (Gioftsidou et al., 2006). For these types of exercises, the Biodex Stability System was used. In the studies, wobble boards that allow for multiplanar movement (Eisen et al., 2010; Holm et al., 2004; Hrysomallis, 2007; Soderman et al., 2000), tilt boards permitting uniplanar movement (Dobrijević et al., 2016; Hrysomallis, 2007), BOSUs (Myer et al., 2006; Romero-Franco et al., 2012), foam mats (McHugh et al., 2007), inflated rubber discs (Saunders et al., 2013) and Swiss balls (Kang et al., 2013; Sato and Mokha, 2009) were frequently used. These devices were used for different movements such as tilting, rotating, squatting, hopping, jumping, throwing and catching a ball (Eisen et al., 2010; Daneshjoo et al., 2012; Myer et al., 2006; Soligard et al., 2008). These activities were also combined with resistance exercises while balancing (Filipa et al., 2012; Petersen et al., 2005; Romero-Franco et al., 2012). In some papers, the authors implemented plyometric training alone to improve balance or combined plyometric training with balance exercises. These exercises emphasized jumping movements with feedback regarding technical performance and proper limb alignment (Asadi et al., 2015; Manolopoulos et al., 2015; Myer et al., 2006; Pfile et al., 2013, 2016). The plyometric exercises consisted of athletic positions, squat jumps, line jumps, bounding in place, and box drops, among others (Asadi et al., 2015; Myer et al., 2006). Core stability training was also used to improve balance. Some authors understood core exercises as bracing the abdominal muscles with low intensity limb movements (Kachanathu et al., 2014); however, most authors applied global training of larger superficial muscles around the abdominal and lumbar regions (Filipa et al., 2012; Iacono et al., 2014; Lust et al., 2009; Myer et al., 2006; Sato and Mokha, 2009). Core stability training included front planks, side planks, back bridges, quadruped exercises and exercises on a Swiss ball.

The influence of balance training on balance in various sport disciplines

The most widely studied disciplines were soccer (Cankaya et al., 2015; Daneshjoo et al., 2012; Gioftsidou et al., 2006; Imai et al., 2014), basketball (Asadi et al., 2015; Benis et al., 2016; Mcleod et al., 2009; Pfile et al., 2016) and handball (Holm et al., 2004; Karadenizli, 2016a, 2016b; Steib et al., 2016). The majority of the studies revealed significant differences between the groups after the interventions (Asadi et al., 2015; Daneshjoo et al., 2012; Kachanathu et al., 2014; Mcleod et al., 2009; O'Malley et al., 2016; Pfile et al., 2016; Steib et al., 2016). However, a few publications were found that did not show any significant influence of balance training on balance in various sport disciplines (Benis et al., 2016; Eisen et al., 2010; Sato and Mokha, 2009; Zech et al., 2014).

Table 1

Influence of balance training on balance in various sports disciplines

References	Subjects			Discipline	Training Modality			Training Type	Device + Procedure	Conclusions
	N/Sex	Age (years)	Status Training		D (min)	F (n/week)	T (week)			
Lust et al. (2009)	IG: open kinetic chain/closed kinetic chain (OKC/CKC): 12M, open kinetic chain/ closed kinetic chain/core stability (OKC/CKC/CS): 13M CG: 15M	20.00 ± 1.54	NR	baseball	30-45	3	6	CST	no device, a single test consisted of a continuous alternating procedure to lift one hand to touch the line then lift the other hand to touch the line for 15 s	The OKC/CKC/CS group and the OKC/CKC group demonstrated significantly greater scores than the control group after training.
Asadi et al. (2015)	IG (PLT): 8 M CG (Basketball): 8 M	IG (PLT): 20.1 ± 0.8 CG : 20.5 ± 0.3	amateur	basketball	30	2	6	PLT	SEBT	After a 6-week training period, the PLT + BT group showed significant improvements in all directions, whereas the basketball group did not show any significant changes.
Benis et al. (2016)	IG: 14 F CG: 14 F	IG: 20 ± 2 CG: 20 ± 1	national league players practicing 4 times a week for 2 hours	basketball	30	2	8	NMT	YBT	Improvement over baseline scores was noted in the posteromedial and posterolateral reach directions and in the composite YBT scores of the experimental group. No differences in anterior reach were detected in either group. Differences were noted in postintervention scores for posteromedial reach and composite scores between the experimental and control groups.
McLeod et al. (2009)	IG:37 F CG: 25 F	IG: 15.6 ± 1.1 CG: 16.0 ± 1.3	competitive	basketball	90	2	6	NMT (functional strengthening, PLT, agility BT)	BESS SEBT	Trained subjects scored significantly fewer BESS errors on the single-foam and tandem-foam conditions at the posttest than the control group and demonstrated improvements on the single-foam compared with their pretest, the authors found a significant decrease in total BESS errors in the IG at the posttest compared with their pretest and the CG.

Imai et al. (2014)	IG: 10 M CG: 9 M	IG: 16,5 ± 0,5 CG: 16,1± 0,6	high school soccer club, practice six times per week	soccer	NR	3	12	CST	FP: SLS (EO, EC) 20s/ 2x SEBT	Significant differences in the posterolat. and posteromed.directions between the pre and post test. Significantly lower values of length of COP between the pre and post test.
Pfile et al. (2016)	IG: 11 F	IG: 19.40 ± 1.35	11 Division I women's basketball	basketball	about 30	2	6	NMT+PLT	SEBT- 3 directions x3 LESS (Landing error scoring system)	The mean composite reach significantly improved over time. LESS scores significantly improved over time
Saunders et al. (2013)	IG:14 F CG:12 F	14.7 ± 4.5	1 year of competition experience 2h of on-ice practice per w.	figure skating	20	3	6	NMT	FP: SLS 15 s/3x, SLL 15 s/3x	No statistically significant differences between the groups
Ahmadabadi et al. (2015)	IG: 8 F CG: 8 F	9.62 ± 1.45	more than three years of athletic experience	gymnastics	30	3	4	BT	FP: QS (EO, EC) SLS – 30 s	A significant increase in balance performance, a significant increase in dynamic and static balance with double feet
Dobrijević et al. (2016)	IG: 33 F CG: 27F	7-8	recreational	gymnastics	60	2	12	PT	no device SLS (EO, EC) time to losing balance	After proprioceptive training, the experimental group significantly improved performance in all the tests for maintaining a balance position.
Holm et al. (2004)	IG: 35 F	23 (± 2.5)	elite division 14.9 (± 3.2) years, 4.7 (± 2.8) years at the top level experience 10 to 11 h/week - total number of hours	handball	about 15	min. 3 during 5-7weeks 1 during the season	NR	NMT	Balance KAT 2000: SLS (right, left leg) x3, 2-leg dynamic test x3 custom made device: assessment of knee kinesthesia	There was a significant improvement in dynamic balance between test 1 and test 2. The effect on dynamic balance was maintained 1 year after training. For static balance, no significant changes were found. For the other variables measured, there were no statistical differences during the study period.
Karadenizli (2016)	IG: 16 F	14.57 ± 0.92	3.66 ± 0.63 years sport experience	handball	NR	2	10	PLT	FP: QS (EO, EC), SLS – 30 s Dynamic Balance - Slalom Test – 60 s	Significant differences were observed between the pre- and post-test of plyometric education training of flexibility, standing long jump, left leg ellipse area at unipedal static balance.
Verhagen et al. (2004)	29 (F/M) IG: 10 IG (volleyball): 8 CG: 11	IG: 22.5 ± 2.4 IG (volleyball): 23.6 ± 3.2 CG: 25.5 ±7.8	second and third volleyball players	volleyball	NR	2	5.5	BT	FP: SLS, QS	Balance training did not lead to a reduction in the centre of pressure excursion in a general population consisting of non-injured and previously injured subjects.

Malliou et al. (2004)	30 (IG: 15 M/F, CG: 15 M/F)	19.3 ± 9	no experience	skiing	20	4	NR	PT	BBS: SLS 20 s/3x (right, left leg)	No statistically significant differences between the groups were found.
Karadenizli et al. (2016)	IG: 14 F CG: 12 F	IG:15.64 ± 0.82 CG: 15.38 ± 0.92	3.5 years of sport experience	handball	NR	2	10	PLT	FP: SLS (right, left leg) – 30 s	The IG made significantly greater improvements than the CG in the SLS (left).
Matin et al. (2014)	IG: 12 M CG: 12 M	11.34 ± 3.68	the representativ e physical fitness team of the elementary schools	fitness	60	3	4	NMT	SLS 3x Dynamic test: (jumping) five scores were dedicated for covering the mark and five scores for holding the balance stance as static for 5 s	Neuromuscular training can enhance important factors of static and dynamic balance and the results showed a significant increase in performance of the individuals participating in neuromuscular training.
Eisen et al. (2010)	36 F/M IG (dynadisc): 12 IG (rocker board): 12 CG: 12	18-22	NR	soccer/baske tball	NR	3	4	BT	SEBT	There was no difference for each group individually, and no difference between trained and untrained legs within a subject
Zech et al. (2014)	IG: 15 CG: 15	IG: 15.7 ± 3.9 CG: 14.1 ± 1.4	first regional youth divisions	hockey	20	2	10	NMT	FP: 3x jump-landing time to stabilization (TTS), SLS 30 s/3x (preferred leg) MSEBT BESS	All balance measures except the medial–lateral TTS improved significantly over time in both groups. Significant group by time interactions were found for the BESS score. The IG showed greater improvements after 10 weeks of training in comparison to the CG.
Myer et al. (2006)	IG (PLT): 8 F IG2 (CST+BT): 11 F	IG 15.9+/-0.8 IG2 15.6+/-1.2	not less than 4 years of experience	voleyball	90	3	7	IG: PLT IG2: CST+BT	FP: a single-leg hop and BT x3 (randomized trials on each side)	The percentage change from the pretest to posttest in vertical ground reaction force was significantly different between the PLT and CST+BT groups considering the dominant side.
Romero-franco et al. (2012)	IG: 16 M CG: 17 M	IG: 22.5 ± 5.12 CG: 21.18 ± 4.47	NR	running	30	3	6	PT	FP: QS (EO, EC) 2x52s BBS: EO 3x20 s, LOS in 8 different directions	Significant differences were found in stability in the medial-lateral plane with EO, gravity center control in the right direction and gravity center control in the back direction after the exercise intervention in the IG.
Sato and Mokha (2009)	IG:12 F/M CG: 8 F/M	IG:37.75 ± 10.63 CG: 39.25 ± 10.81	recreational and competitive	running	NR	4	6	CST	SEBT	CST had no significant influence on scores measured by the SEBT or any GRF variables.

Mahieu et al. (2006)	IG: 6 F, 11 M CG: 8 F, 8 M	9-15	competitive	skiing	30	3	6	VT	SMART Balance Master: LOS 8 s/8x, rhythmic weight shift left /right, forward/back ward	No significant differences except for directional control during the LOS and the left-right excursion of the rhythmic weight shift test were found.
Cankaya et al. (2015)	IG: athletes 25 M, sedentary: 25 M CG: 25 M	11	NR	soccer	40	3	8	BT	FP: QS (EO, EC), SLS – 30 s clockwise rounds 5 x 60 s	Balance performance of the athletes and sedentary group improved compared to the CG.
Daneshjoo et al. (2012)	CG: 12 M; IG (FIFA 11): 12 M, IG (HarmoKnee): 12 M	CG: 19.7 ± 1.6 IG FIFA 11: 19.2 ± 0.9 IG Ham o Knee: 17.7 ± 0.4	professional (five year experience of playing soccer at professional level)	soccer	20-25	3	6	FIFA 11: BT + ST + PT Harm o Knee: BT + ST + CST	ID: JPS SEBT Stork Stand Balance Test	Both warm up programs improved proprioception in the dominant leg at 45° and 60° knee flexion. Dynamic balance assessed by the SEBT also showed improvement in both groups, with the HarmoKnee group showing significant difference when compared to the CG.
Iacono et al. (2014)	IG: 10 M CG: 10 M	IG: 18.7 ± 0.67 CG: 19 ± 0.63	competitive players	soccer	NR	4	5	CST	FP: SLS (EO, EC) - 3x20 s SEBT	CST significantly improved static and dynamic balance
Gioftsidou et al. (2006)	39 (CG:13, IG - before appropriate training: 13 M, IG - after appropriate training: 13)	16 ± 1	The young championshi p of the first Greek division	soccer	20	3	12	BT	BBS: SLS 20 s/3x (right, left leg)	Significant differences in the IG after training.
Heleno et al. (2016)	IG: 12 M CG: 10 M	14-16	players with a minimum of 3 years of training experience; participation in state and national competitions; training 5 times a week	soccer	NR	3	5	SMT	SLS, Side Hop Test (SHT), Figure of Eight Test (F8) MSEBT	After a five-week training program, the intervention group obtained significant results in the F8, SHT and SEBT, as well as in the following variables: area of pressure of sway center (COP), mean velocity and mean frequency of COP
Trecroci et al. (2015)	IG: 12 M CG: 12 M	11.3 ± 0.70	sub-elite players	soccer	15	2	8	BT	YBT	Significantly greater improvements in the YBT
Manolopoulos et al. (2015)	IG: 20 (ST: 10 M SMT: 10 M)	ST: 21.3 ± 1.3 SMT: 22 ± 1.7	amateur	soccer	NR	2	8	ST ST + SMT	FP: stork stance, raise the heel off the ground – 5 s	COP (cm) in anteriorposterior and mediolateral axes decreased significantly after training
Kachanathu et al. (2014)	IG: 23 M CG: 23 M	18 ± 2	NR	soccer	60	Phase-I: 6 Phase-II: 6 Phase-III: 3	4	CST	Double Straight Limb Lowering test: x3 SEBT: 8 directions x3	Significant differences of dynamic balance and core stability in the IG compared to the CG
Granacher et al. (2016)	IG: 12 M CG: 12 M	12-13	first division Tunisian	soccer	NR	2	8	BT PLT	Standing Stork Test, YBT	Results indicated that BT provided significantly greater improvements in the YBT

Gioftsidou et al. (2012)	IG1: 13 IG2: 13 CG: 12	22.7 ± 3.5	first Greek division	soccer	20	IG1: 6 IG2: 3	IG1: 3 IG2: 6	BT	BBS: SLS 20 s x3 (each leg) Balance board: SLS time to lose balance	Both training groups demonstrated significant improvements on Biodex stability tests. Similarly for the balance board, the results revealed significant improvements for both IGs.
Alyson et al. (2012)	IG: 13 F CG: 7 F	IG: 15.4 ± 1.5 CG:14.7 ± 0.8	competitive	soccer	50	2	8	NMT	SEBT	After NMT, subjects demonstrated a significant improvement in the SEBT score on the right and left limb.
O'Malley et al. (2016)	IG: 41 M CG: 37 M	IG: 18.6 (18.4-18.8) CG: 18.3 (18.1-18.5)	teams were required to train at least twice per week.	2 teams: 1 football 1 hurling	15	2	8	GAA 15 (Gaelic Athletic Association) training program	YBT LESS (Landing Error Scoring System)	There was a greater reduction in mean LESS score in favour of the IG post exercise training. Clinically and statistically significant improvements in dynamic balance and jump-landing technique occurred in collegiate level Gaelic football and hurling players.
Pau et al. (2012)	IG: 13 F CG: 13 F	IG:13.2 ± 0.2 CG: 13.0 ± 0.1	0–3 years of experience	volleyball	20-30	2-3	6-9	NMT	FP: QS (EO,EC) – 20 s SLS 10 s	The IG exhibited smaller sway areas in EC conditions in the bipedal stance, while the other variables were unaffected. BT also reduced sway area and A-P COP displacements of the nondominant limb for SLS.
Kang et al. (2013)	*36 M IG (high school): 8 IG (middle school: 8 CG (high school): 8 CG (middle school): 8*	NR	middle school: exp. of 25.44 months; high school: exp. of 55.44 months	weightlifters	NR	NR	8	BT	SLS (EC)	Significant changes were found in one-leg standing time with eyes closed in the IG.

***NR** = non reported; **IG** = intervention group; **CG** = control group; **F** = females; **M** = males; **n** = group size; **PT** = prioproceptive training; **BT** = balance training; **CST** = core stability training; **PLT** = plyometric training; **ST** = strength training; **SLS** = single leg stance; **NMT** = neuromuscular training; **D** = training duration (min); **F** = frequency (n/week); **T** = duration of the intervention (week); **FP** = force plate; **BBS** = biodex balance system; **SEBT** = star excursion balance test; **ID** = isokinetic dynamometry; **EO** = eyes open; **EC** = eyes close; **QS** = quiet standing; **BESS** = balance error scoring system; **YBT** = Y balance test; **SLL** = single leg landing; **SMT** = sensory motor training*

Table 2

Relationship between different balance prevention training and injuries

References	Subjects			Discipline	Training Modality			Training Type	Conclusions
	N/Sex	Age (years)	Status Training		D (min)	F (n/week)	T (week)		
Eils et al. (2010)	n = 198 IG1 = 81 49M : 32F CG1 = 91 54M : 37F IG2 = 8 4M : 4F CG2 = 8 4M : 4F	IG1 22.6 ± 6.3 CG1 25.5 ± 7.2 IG2 24.3 ± 2.9 CG2 25.9 ± 8.2	performance level of the players varied between the seventh highest (Kreisliga) and the highest league (Bundesliga) in Germany	basketball	20	1	NR (all season)	PT	The risk of sustaining an ankle injury was significantly reduced in the IG by approximately 35%. The IG showed a significantly more stable SLS concerning the mediolateral direction. The degree of error for 10- dorsiflexion and 15- plantarflexion and the mean error were significantly reduced in the posttest in the IG, but not in the CG.
Soligard et al. (2008)	n = 1892 F IG = 1055 CG = 837	13-17	at least two training sessions a week in addition to match play	soccer	20	NR	NR (8 months- all season)	Running exercises BT CST PLT	There was a significantly lower risk of injuries overall, overuse injuries, and severe injuries in the IG.
Kraemer and Knobloch (2009)	IG = 24 F	21 ± 4	German premier league	soccer	3000	NR	NR (3 years)	PT BT PLT	One year after training implementation, noncontact injuries decreased significantly by 65% (p = .021). Overall, the mean injury rate of all noncontact injuries during all intervention periods significantly decreased by 42% (p = .045) versus the control period.
Owen et.al. (2013)	n = 67 M IG = 44 CG = 23	IG = 28.6 ± 3.75 CG=27.4 ± 4.85	competitive players	soccer	NR	2	NR (2 seasons: 2008-2010)	BT ST CST FT	During the intervention season, the number of muscle strain/tears was less (25% of total injuries) than the control season (52% of total injuries).
Timothy et al. (2006)	n = 765 F/M IG =373 CG = 392	IG = 16.4 ± 1.2 CG = 16.6 ± 1.1	high school students trained by certified coaches	basketball soccer	10	3	NR (all season)	BT	A reduced risk of an ankle sprain was observed after intervention.
Eils et al. (2010)	n = 198 IG1 = 81 49M : 32F CG1 = 91 54M : 37F IG2 = 8 4M : 4F CG2 = 8 4M : 4F	IG1 22.6 ± 6.3 CG1 25.5 ± 7.2 IG2 24.3 ± 2.9 CG2 25.9 ± 8.2	performance level of the players varied between the seventh highest (Kreisliga) and the highest league (Bundesliga) in Germany	basketball	20	1	NR (all season)	PT	The risk of sustaining an ankle injury was significantly reduced in the IG by approximately 35%. The IG showed a significantly more stable SLS concerning the mediolateral direction. The degree of error for 10- dorsiflexion and 15- plantarflexion and the mean error were significantly reduced in the posttest in the IG, but not in the CG.
Soligard et al. (2008)	n = 1892 F IG = 1055 CG = 837	13-17	at least two training sessions a week in addition to match play	soccer	20	NR	NR (8 months- all season)	Running exercises BT CST PLT	There was a significantly lower risk of injuries overall, overuse injuries, and severe injuries in the IG.

Kraemer and Knobloch (2009)	IG = 24 F	21 ± 4	German premier league	soccer	3000	NR	NR (3 years)	PT BT PLT	One year after training implementation, noncontact injuries decreased significantly by 65% ($p = .021$). Overall, the mean injury rate of all noncontact injuries during all intervention periods significantly decreased by 42% ($p = .045$) versus the control period.
Owen et.al. (2013)	n = 67 M IG = 44 CG = 23	IG = 28.6 ± 3.75 CG=27.4 ± 4.85	competitive players	soccer	NR	2	NR (2 seasons: 2008-2010)	BT ST CST FT	During the intervention season, the number of muscle strain/tears was less (25% of total injuries) than the control season (52% of total injuries).
Timothy et al. (2006)	n = 765 F/M IG =373 CG = 392	IG = 16.4 ± 1.2 CG = 16.6 ± 1.1	high school students trained by certified coaches	basketball soccer	10	3	NR (all season)	BT	A reduced risk of an ankle sprain was observed after intervention.
Malachy et al. (2007)	n = 175 IG = 175	15-18	high school students	football	10	2	13	SLS BT	The injury incidence for the players after the intervention was significantly lower than the combined injury incidence before the intervention ($p < .01$).
Cumps et al.(2007)	n = 50 M/F IG = 26 CG = 24	IG= 17.7 ± 3.9 CG= 18.0 ± 2.7	elite youth and young senior basketball players	basketball	10	3	22	BT SLS PLT Dynamic exercises	Relative risks showed a significantly lower incidence of lateral ankle sprains in the IG compared to the CG.
Mandelbaum et al. (2005)	IG1: 1041 F CG1: 1905 F IG2: 844 F CG2: 1913 F	14-18	competitive female youth soccer players in a southern California soccer league	soccer	20	NR	NR (2 season)	Stretching ST PLT Agility NMT	During the first period (IG; CG1), there was an 88% decrease in ACL injury in the IG subjects compared to the control group. In the second period (IG2; CG2) there was a 74% reduction in ACL tears in the IG compared to the age- and skill-matched controls.
Verhagen et al. (2005)	IG = 641 CG = 486	IG= 24.4 ± 2.8 CG= 24.2 ± 2.5	the second and third Dutch volleyball divisions; experience in years 13.3 ± 2.3	voleyball	5	NR	NR (one season 2001/2002)	BT SLS	Significantly fewer ankle sprains in the IG were found compared to the CG. A significant reduction in the ankle sprain risk was found only for players with a history of ankle sprains.
Soderman et al. (2000)	n = 140 F IG = 62 CG = 78	IG= 20.4 ± 4.6 CG= 20.5 ± 5.4	players of the second and third Swedish divisions	soccer	15	NR	NR (12 weeks)	BT	The results showed no significant differences between the groups with respect either to the number, incidence, or type of traumatic injuries of the lower extremities.
Emery et al. (2012)	n = 744 M/F IG = 380 CG = 364	IG: U13–15=46.6% U16–18=53.4% CG: U13–15=48.9% U16–18=51.1%	first and second Calgary youth division of indoor football	soccer	30	NR	20	NMT BT ST Agility Stretching	There was a 38% reduction in all injury in the IG compared with the CG and a 43% reduction in acute-onset injury.
Hewett et al. (1999)	n = 1263 F/M IG = 366 FCG = 463 F CGPopulation = 434 M	high school students	high school students, females were players, males were not	soccer, basketball, volleyball	60-90	3	6	NMT PLT	The untrained group demonstrated an injury rate 3.6 times higher than the trained group and 4.8 times higher than the male control group. The trained group had a significantly lower rate of noncontact injuries than the untrained group ($p = 0.01$).

Petersen et al. (2005)	N = 276 F IG = 134 CG = 142	NR	2 of the teams were from the third highest league; 4 teams were of a superior amateur level; 4 teams were at a lower amateur level	handball	10	3	8	PT PLT	Ankle sprain was the most frequent diagnosis in both groups with 11 ankle sprains in the CG and 7 ankle sprains in the IG. The knee was the second frequent injury site. In the CG, 5 of all knee injuries were anterior cruciate ligament (ACL) ruptures, while in the IG only one.
Steffen et al. (2008)	n = 36 F IG = 18 CG = 16	16-18 (17.1 ± 0,8)	competitive players with 13.3 ± 2.1 hours of football activities per week and that had been involved in organized football for 10 ± 1.5 years	football	15	NR	10	CST BT PLT ST	There was no difference between the IG and CG in performance from the pre to post-test for any of the tests used.

***NR** = non reported; **IG** = intervention group; **CG** = control group; **F** = females; **M** = males; **n** = group size; **PT** = prioproceptive training; **BT** = balance training; **CST** = core stability training; **PLT** = plyometric training; **ST** = strength training; **SLS** = single leg stance; **NMT** = neuromuscular training; **D** = training duration (min); **F** = frequency (n/week); **T** = training duration (week)*

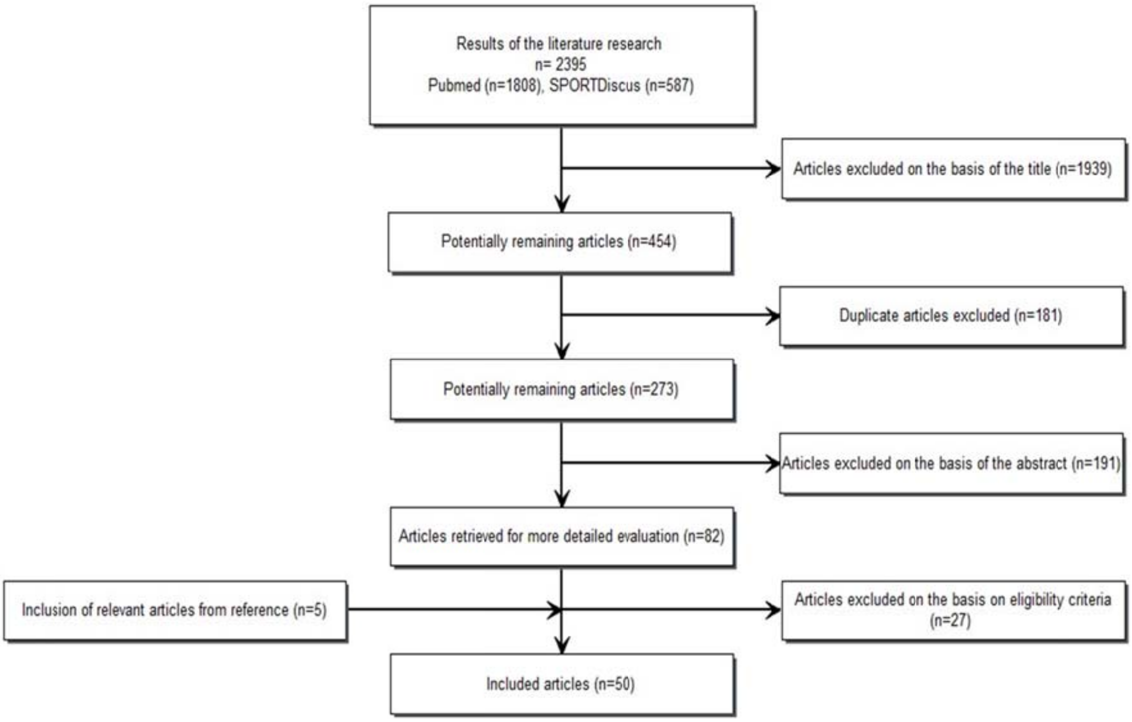

Figure 1
A flowchart illustrating the different phases of the search and study selection

Table 3
Physiotherapy evidence database (PEDro) scores of the reviewed studies-

References	Eligibility criteria specified	Subjects randomly allocated to groups	Allocation concealed	Groups similar at baseline	Blinding of all subjects	Blinding of all therapists	Blinding assessors	Dropout <15%	Intention- to-treat method	Statistical comparison between group	Point measures and measures variability	Score
Benis et al.. (2016)	+	+	-	+	+	-	-	+	-	+	+	7
Gioftsidou et al.. (2012)	+	+	-	-	-	-	-	+	+	+	+	6
Malliou et al.. (2004)	+	+	-	-	-	-	-	+	+	+	+	6
Mahieu et al.. (2006)	+	+	-	+	-	-	-	+	+	+	+	7
Zech et al.. (2014)	+	+	+	+	-	-	-	+	+	+	+	8
Pau et al. (2012)	+	-	-	+	-	-	-	-	+	+	+	5
Daneshjoo et al.. (2012)	+	+	-	+	-	-	-	+	+	+	+	7
Heleno et al.. (2016)	+	+	-	+	-	-	+	+	+	+	+	8
Saunders et al. (2013)	+	+	-	-	-	-	-	+	+	+	+	6
Gioftsidou et al.. (2006)	+	+	-	+	-	-	-	-	+	+	+	6
Sato and Mokha (2009)	+	+	-	+	-	-	-	-	-	+	-	4
Matin et al.. (2014)	-	+	-	+	-	-	-	+	+	+	-	5
Romero-franco et al.. (2012)	-	+	-	+	-	-	-	+	+	+	+	6
Myer et al.. (2006)	+	+	-	-	-	-	-	-	+	+	+	5
Lust et al.. (2009)	+	+	-	-	-	-	-	+	+	+	+	6
Dobrijevic et al.. (2016)	+	+	-	-	-	-	-	+	+	+	+	6
Pfile et al.. (2016)	+	-	-	-	-	-	-	+	-	+	+	4
Hammami et al. (2016)	+	-	-	-	+	-	-	+	+	-	+	5
Emery and Meeuwisse (2012)	+	+	-	+	-	-	-	+	+	+	+	7
Verhagen et al.. (2004)	+	+	+	+	-	-	+	+	+	+	+	9
Petersen et al.. (2005)	-	-	-	-	-	-	-	+	+	+	-	3
Imai et al.. (2014)	+	+	-	+	-	-	-	-	+	+	+	6
O'Malley et al.. (2016)	+	+	+	+	-	-	-	+	+	+	+	8
Trecroci et al.. (2015)	+	+	+	+	-	-	-	+	-	+	+	7
Steib et al.. (2014)	+	+	-	+	-	-	-	+	-	+	+	6
Valovich et al.. (2009)	+	-	-	+	-	-	+	-	-	+	+	5
Eisen et al.. (2010)	+	+	-	+	-	-	-	-	-	+	+	5
Holm et al.. (2004)	+	-	-	-	-	-	-	+	-	+	+	4
Asadi et al.. (2015)	+	+		+	-	-	-	+	+	+	+	7
Verhagen et al.. (2005)	-	+	-	-	-	-	-	+	-	+	+	4
Kachanathu et al.. (2014)	+	+	-	+	-	-	-	-	-	+	+	5
Cankaya et al.. (2015)	-	+	-	-	-	-	-	-	-	+	+	3
Karadenizli (2016)	+	-	-	-	-	-	-	+	-	-	+	3
Ahmadabadi et al.. (2015)	+	+	-	+	-	-	-	+	-	+	-	5
Iacono et al.. (2014)	+	+	-	+	-	-	-	+	-	+	+	6
Karadenzili (2016)	+	+	-	+	-	-	-	+	-	+	+	6

Eils et al.. (2010)	+	+	-	+	-	-	-	+	+	+	+	7
Soligard et al..(2008)	+	+	-	+	-	-	-	+	+	+	+	7
Kraemer and Knobloch (2009)	-	-	-	-	-	-	-	+	-	+	+	3
Owen et al.. (2013)	-	+	-	+	-	-	-	+	+	+	-	5
McGuine and Keene (2006)	+	+	-	+	-	-	-	+	+	+	+	7
McHugh et al.. (2007)	+	-	-	-	-	-	-	+	-	+	+	4
Steffen et al.. (2008)	+	+	+	+	-	-	-	+	+	+	+	8
Cumps et al.. (2007)	-	-	-	+	-	-	-	+	-	+	+	4
Mandelbaum et al.. (2005)	-	-	-	-	-	-	-	+	+	+	+	4
Soderman et al.. (2000)	+	+	-	+	-	-	-	-	-	+	+	5

"+" indicates a "YES" score; "-" indicates a "NO" score

The influence of balance training on balance in various sport disciplines

The most widely studied disciplines were soccer (Cankaya et al., 2015; Daneshjoo et al., 2012; Gioftsidou et al., 2006; Imai et al., 2014), basketball (Asadi et al., 2015; Benis et al., 2016; Mcleod et al., 2009; Pfile et al., 2016) and handball (Holm et al., 2004; Karadenizli, 2016a, 2016b; Steib et al., 2016). The majority of the studies revealed significant differences between the groups after the interventions (Asadi et al., 2015; Daneshjoo et al., 2012; Kachanathu et al., 2014; Mcleod et al., 2009; O'Malley et al., 2016; Pfile et al., 2016; Steib et al., 2016). However, a few publications were found that did not show any significant influence of balance training on balance in various sport disciplines (Benis et al., 2016; Eisen et al., 2010; Sato and Mokha, 2009; Zech et al., 2014).

The majority of the study interventions used full training units (Dobrijević et al., 2016; Filipa et al., 2012; Hewett et al., 1999; Kachanathu et al., 2014; Myer et al., 2006), but several authors applied balance training only as a warm-up (Ahmadabadi et al., 2015; Holm et al., 2004; O'Malley et al., 2016; Trecroci et al., 2015). Among the various exercise types, balance training and neuromuscular training (Eisen et al., 2010; Kang et al., 2013; Verhagen et al., 2005; Matin et al., 2014) were most commonly incorporated, followed by plyometric exercises and core stability training (Asadi et al., 2015; Karadenizli, 2016a, 2016b; Lust et al., 2009; Sato and Mokha, 2009).

To assess static balance, the authors mostly applied the SLS test (n = 18) with 13 studies that used measurements conducted on a force plate. The most common procedure was the QS test (n = 16), and the LOS test was used twice. In the analyzed studies, the researchers mainly relied on the SEBT (n = 13), YBT (n = 4) and BESS (n = 2) to assess dynamic balance. Although the SEBT was the most popular in these studies, at least two difficulties accompanied this procedure. In many cases, the SEBT was assessed only in three directions that corresponded to the YBT (Filipa et al., 2012; Imai et al., 2014; Heleno et al., 2016). In addition, in several studies, the results were presented as composite reach scores (Daneshjoo et al., 2012; Eisen et al., 2010; Pfile et al., 2016). Therefore, even if the differences reached significance, it was not possible to ascertain the direction in which the improvement occurred. The detailed characteristics of the training protocols and tested tasks are shown in Table 1.

The influence of balance training on injury prevention

Balance control is a crucial factor in sports and an important component of common motor skills. Disturbances in balance control can increase the risk of injuries during high intensity activities (Burke-Doe et al., 2008; McGuine et al., 2000). The importance of balance control in the prevention of damage and musculoskeletal injuries during sports performance has been emphasized

(Carolyn A Emery, 2005) and investigated in many studied cases (see review by Hrysomallis, 2007). Although the cause of injury is not always known, several risk factors for impairment in balance during training have been indicated (McKay et al., 2001). These factors include an insufficient warm-up (Woods et al., 2007), poor flexibility (Hartig and Henderson, 1999; Zakas et al., 2005), muscle imbalances (Parry and Drust, 2006; Croisier et al., 2008), muscle weakness (Croisier, 2004; Junge and Dvorak, 2004), neural tension (Turl and George, 1998), fatigue (Worrell, 1994), and previous injuries (Ekstrand et al., 2011; Parry and Drust, 2006).

The most common sports injuries (60%) are sprains, dislocations, and ligament ruptures that occur at the knees and ankles and at the hands, elbows, and shoulders (Conn et al., 2003; Hawkins and Fuller, 1999; Powell and Barber-Foss, 1999; Schneider et al., 2006). Improving balance in athletes by appropriate training has proven to engender positive effects on the reduction of the discussed injuries (Hrysomallis, 2007). Exercises may be included into a training program as part of an injury prevention strategy or with the primary goal of improving an athlete's performance (Sannicandro et al., 2014). According to Hrysomalis (2007), Hùbscher (2010) and other authors, we are able to distinguish different design concepts and components of preventive exercises for balance including plyometrics, strengthening, balancing, endurance and stability, with a different approach to preventive programs (Heidt et al., 2000; Myklebust et al., 2003; Soderman et al., 2000). The results of our analysis of the relationship between different balance prevention training protocols and injuries are shown in Table 2. It indicates the effectiveness of balance training in reducing the incidence of sports injuries among athletes. The analysis of the prevention programs contains the results for team sports (such as basketball, soccer, handball, and volleyball), mainly because of their specificity (high-risk of injuries), which may consequently cause long-term disabilities for the injured player (Lohmander et al., 2004; Myklebust and Bahr, 2005; von Porat et al., 2004).

Conclusions

In most of the reviewed articles, balance training has proven to be an effective tool for the improvement of postural control. However, a few articles stated that such effect did not occur (Eisen et al., 2010; Mahieu et al., 2006; Malliou et al., 2004; Sato and Mokha, 2009; Saunders et al., 2013; Verhagen et al., 2005), and a few studies, in which the effect was not reflected in all balance measures, suggested that balance training did not influence all of the dimensions of postural control (Benis et al., 2016; Holm et al., 2004; Pau et al., 2011; Zech et al., 2014). In some cases where the authors carried out both static and dynamic tests, significant results occurred in only one test type. Therefore, we would recommend the execution of both types of tests to decrease the risk of making inappropriate or global conclusions that training is ineffective in general.

Another issue is that the duration of training was heterogeneous. In most cases, it was approximately 40-50 min and was implemented as a full training session; however, in some articles, this time was rather short, i.e., only 10-20 min. In several studies, duration was not reported (Table 1). No gold standard is apparent in this field; therefore, it is difficult to make a global conclusion about the effectiveness of various types of balance training. Moreover, we are aware that it may be very difficult to establish one model of training that would be appropriate for each sport discipline, including its characteristics and demands. The main aim of this review was to identify a training protocol that is most commonly used and may lead to improvements in balance. Therefore, on the basis of analyses including papers in which training protocols resulted in positive effects on balance performance, it may be stated that an efficient training protocol should last for 8 weeks, with a frequency of two training sessions per week, and a single training session of 45 min.

Acknowledgements

This research was supported by a grant of the Ministry of Science and Higher Education of Poland (RSA3 00953).

References

Adlerton A-K, Moritz U, Moe-Nilssen R. Forceplate and accelerometer measures for evaluating the effect of muscle fatigue on postural control during one-legged stance. *Physiother Res Int*, 2003; 8(4): 187–199

Ahmadabadi F, Avandi S, Aminian-Far A. Acute versus chronic dynamic warm-up on balance and balance the vault performance in skilled gymnast. *Int J Appl Exerc Physiol*, 2015; 4(2): 20–33

Asadi A, Saez de Villarreal E, Arazi H. The effects of plyometric type neuromuscular training on postural control performance of male team basketball players. *J Strength Cond Res*, 2015; 29(7): 1870–1875

Benis R, Bonato M, Torre A La. Elite female basketball players' body-weight neuromuscular training and performance on the y-balance test. *J Athl Train*, 2016; 51(9): 688–695

Burke-Doe A, Hudson A, Werth H, Riordan DG. Knowledge of osteoporosis risk factors and prevalence of risk factors for osteoporosis, falls, and fracture in functionally independent older adults. *J Geriatr Phys Ther*, 2008; 31(1): 11–17

Cankaya S, Gokmen B, Tasmektepligil MY, Con M. Special balance developer training applications on young males- static and dynamic balance performance. *Anthropologist*, 2015; 19(1): 31–39

Conn JM, Annest JL, Gilchrist J. Sports and recreation related injury episodes in the US population, 1997-99. *Inj Prev*, 2003; 9(2): 117–123

Coughlan GF, Fullam K, Delahunt E, Gissane C, Caulfield BM. A comparison between performance on selected directions of the star excursion balance test and the Y balance test., 2012; 47(4): 366–371

Croisier J-L. Factors associated with recurrent hamstring injuries. *Sports Med*, 2004; 34(10): 681–695

Croisier J-L, Ganteaume S, Binet J. Strength Imbalances and Prevention of Hamstring Injury in Professional Soccer Players: A Prospective Study. *Am J Sports Med*, 2008; 36: 1469–1475

Cumps E, Verhagen E, Meeusen R. Efficacy of a sports specific balance training programme on the incidence of ankle sprains in basketball. *J Sport Sci Med*, 2007; 6(2): 212–219

Daneshjoo A, Mokhtar AH, Rahnama N, Yusof A. The effects of comprehensive warm-up programs on proprioception, static and dynamic balance on male soccer players. *PLoS One*, 2012; 7(12): 1–10

DiStefano LJ, Clark MA, Padua DA. Evidence supporting balance training in healthy individuals: a systemic review. *J Strength Cond Res*, 2009; 23(9): 2718–2731

Dobrijević S, Moskovljević L, Dabović M. The influence of proprioceptive training on young rhythmic gymnasts balance. *Facta Univ*, 2016; 14(2): 247–255

Duarte M, Freitas SM. Revision of posturography based on force plate for balance evaluation. *Rev Bras Fisioter*, 2010; 14(3): 183–192

Eils E, Schröter R, Schröder M, Gerss J, Rosenbaum D. Multistation proprioceptive exercise program prevents ankle injuries in basketball. *Med Sci Sports Exerc*, 2010; 42(11): 2098–2105

Eisen T, Danoff J, Leone J, Miller T. The effects of multiaxial and uniaxial unstable surface balance training in college athletes. *J Strength Cond Res*, 2010; 24(7): 1740–1745

Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football - the UEFA injury study. *Br J Sports Med*, 2011; 45(7): 533–538

Emery CA. Injury prevention and future research. *Individ Sport Med Sport Sci Basel*, 2005; 48: 179–200

Emery CA, Meeuwisse WH. The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: a cluster-randomised controlled trial. *Br J Sports Med*, 2010; 44(8): 555–562

Filipa A, Byrnes R, Paterno MV, Gregory D, Hewett TE. Neuromuscular training improves performance on the star excursion balance test in young female athletes. *J Orthop Sport Phys Ther*, 2012; 40(9): 551–558

Finnoff JT, Peterson VJ, Hollman JH, Smith J. Intrarater and interrater reliability of the balance error scoring system (BESS). *PM&R*, 2009; 1(1): 50–54

Gioftsidou A, Malliou P, Pafis G, Beneka A, Godolias G, Maganaris CN. The effects of soccer training and timing of balance training on balance ability. *Eur J Appl Physiol*, 2006; 96(6): 659–664

Gray GW. Lower extremity functional profile.*Wynn, Marketing Incorporated*; 1995

Hammami R, Granacher U, Makhlouf I, Behm DG, Chaouachi A. Sequencing effects of balance and plyometric training on physical performance in youth soccer athletes. *J Strength Cond Res*, 2016; 12: 3278-3289

Hartig DE, Henderson JM. Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *Am J Sports Med*, 1999; 27(2): 173–176

Hawkins R, Fuller C. A prospective epidemiological study of injuries in four English professional football clubs. *Br J Sports Med*, 1999; 33(3): 196–203

Heidt RS, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med*, 2000; 28(5): 659–662

Heleno LR, da Silva RA, Shigaki L, Araujo CGA, Coelho Candido CR, Okazaki VHA, Frisseli A, Macedo C de SG. Five-week sensory motor training program improves functional performance and postural control in young male soccer players. A blind randomized clinical trial. *Phys Ther Sport*, 2016; 22: 74–80

Hewett TE, Lindenfeld T, Riccobene J, Noyes F. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sport Med Med*, 1999; 27(6): 699–706

Holm I, Fosdahl MA, Friis A, Risberg MA, Myklebust G, Steen H. Effect of neuromuscular training on proprioception, balance, muscle strength, and lower limb function in female team handball players. *Clin J Sport Med*, 2004; 14(2): 88–94

Hrysomallis C. Relationship between balance ability, training and sports injury risk. *Sport Med*, 2007; 37(6): 547–556

Hrysomallis C. Balance ability and athletic performance. *Sport Med*, 2011; 41(3): 221–232

Hrysomallis C, McLaughlin P, Goodman C. Relationship between static and dynamic balance tests among elite Australian Footballers. *J Sci Med Sport*, 2006; 9(4): 288–291

Hübscher M, Zech A, Pfeifer K, Hänsel F, Vogt L, Banzer W. Neuromuscular training for sports injury prevention: a systematic review. *Med Sci Sports Exerc*, 2010; 42(3): 413–421

Iacono Dello A, Martone D, Alfieri A, Ayalon M. Core Stability Training Program (CSTP) effects on static and dynamic balance abilities. *Gazz Med Ital*, 2014; 173(4): 197-206

Imai A, Kaneoka K, Okubo Y, Shiraki H. Effects of two types of trunk exercises on balance and athletic performance in youth soccer players. *Int J Sports Phys Ther*, 2014; 9(1): 47–57

Junge A, Dvorak J. Soccer injuries: A review on incidence and prevention. *Sport Med*, 2004; 34(13): 929–938

Kachanathu S, Tyagi P, Anand P, Hameed U, Algarni A. Effect of core stabilization training on dynamic balance in professional soccer players. *Phys Medizin, Rehabil Kurortmedizin*, 2014; 24(6): 299–304

Kang SH, Kim CW, Kim Y IL, Kim KB, Lee SS, Shin KO. Alterations of muscular strength and left and right limb balance in weightlifters after an 8-week balance training program. *J Phys Ther Sci*, 2013; 25(7): 895–900

Karadenizli ZI. The effects of plyometric education trainings on balance and some psychomotor characteristics of school handball team. *Univers J Educ Res*, 2016; 4(10): 2286–2293

Karadenizli ZI. The effects of plyometric training on balance, anaerobic power and physical fitness parameters in handball. *Anthropologist*, 2016; 24(3): 751–761

Karami B, Ali M, Farzaneh Y, Homayoun G, Parmoon A. Neuromuscular training as the basis for developing the level of the static and dynamic balance in selected students of physical. *Int J Sport Sci Fit*, 2014; 4(1): 20–38

Kümmel J, Kramer A, Giboin L-S, Gruber M. Specificity of balance training in healthy individuals: a systematic review and meta-analysis. *Sport Med*, 2016; 46(9): 1261–1271

Lesinski M, Hortobagyi T, Muehlbauer T, Gollhofer A, Granacher U. Dose-response relationships of balance training in healthy young adults: a systematic review and meta-analysis. *Sport Med*, 2015; 45(4): 557–576

Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis Rheum*, 2004; 50(10): 3145–3152

Lust KR, Sandrey MA, Bulger SM, Wilder N. The effects of 6-week training programs on throwing accuracy, proprioception, and core endurance in baseball. *J Sport Rehabil*, 2009; 18(3): 407–426

Mahieu NN, Witvrouw E, Van De Voorde D, Michilsens D, Arbyn V, Van Den Broecke W. Improving strength and postural control in young skiers: Whole-body vibration versus equivalent resistance training. *J Athl Train*, 2006; 41(3): 286–293

Malliou P, Amoutzas K, Theodosiou A, Gioftsidou A. Proprioceptive training for learning downhill skiing. *Percept Mot Skills*, 2004; 99(1): 149–154

Mandelbaum BR, Silvers HJ, Watanabe DS, Knarr JF, Thomas SD, Griffin LY, Kirkendall DT, Garrett WiJ. Effectiveness of a neuromuscular and proprioceptive training program in preventing the incidence of anterior cruciate ligament injuries in female athletes : 2-year follow up. *Am J Sports Med*, 2005; 33(7): 1003–1010

Manolopoulos K, Gissis I, Galazoulas C, Manolopoulos E, Patikas D, Gollhofer A, Kotzamandis C. Effect of combined sensorimotor-resistance training on strength, balance and jumping performance of soccer players. *J Strength Cond Res*, 2015; 30(1): 53–59

Matin KB, Yalfani A, Farzaneh G, Homayoun A, Parmoon A. Neuromuscular training as the basis for developing the level of the static and dynamic balance in selected students of physical. *Int J Sport Sci Fit*, 2014; 4(1): 20-38

Maurer C, Mergner T, Peterka RJ. Multisensory control of human upright stance. *Exp Brain Res*, 2006; 171(2): 231–250

McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med*, 2000; 10(4): 239–244

McGuine TA, Keene JS. The effect of a balance training program on the risk of ankle sprains in high school athletes. *Am J Sports Med*, 2006; 34(7): 1103–1111

McHugh MP, Tyler TF, Mirabella MR, Mullaney MJ, Nicholas SJ. The effectiveness of a balance training intervention in reducing the incidence of noncontact ankle sprains in high school football players. *Am J Sports Med*, 2007; 35(8): 1289–1294

McKay GD, Goldie PA, Payne WR, Oakes BW. Ankle injuries in basketball: injury rate and risk factors. *Br J Sports Med*, 2001; 35(2): 103–108

Mcleod TCV, Armstrong T, Miller M, Sauers JL. Balance improvements in female high school basketball players after a 6-week neuromuscular-training program. *J Sport Rehabil*, 2009; 18 465–481

Myer GD, Ford KR, McLean SG, Hewett TE. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *Am J Sports Med*, 2006; 34(3): 445–455

Myer GD, Chu DA, Brent JE, Hewett TE. Of knee joint injury. *Med Sci Sport*, 2009; 27(3): 1–23

Myer GD, Ford KR, Brent JL, Hewett TE. The effects of plyometric versus dynamic stabilization and balance training on power, balance and landing force in female athletes. *J Strength Cond Res*, 2006; 20(2): 345–353

Myklebust G, Bahr R. Return to play guidelines after anterior cruciate ligament surgery. *BMJ*, 2005; 39 127–132

Myklebust G, Engebretsen L, Braekken IH, Skjølberg A, Olsen O-E, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med*, 2003; 13(2): 71–78

O'Malley E, Murphy JC, McCarthy Persson U, Gissane C, Blake C. The effects of the GAA 15 training program on neuromuscular outcomes in Gaelic football and hurling players; a randomized cluster trial. *J Strength Cond Res*, 2016;

Paillard T. Plasticity of the postural function to sport and/or motor experience. *Neurosci Biobehav Rev*, 2017; 72 129–152

Parry L, Drust B. Is injury the major cause of elite soccer players being unavailable to train and play during the competitive season?. *Phys Ther Sport*, 2006; 7(2): 58–64

Pau M, Loi A, Pezzotta MC. Does sensorimotor training improve the static balance of young volleyball players?. *Sport Biomech*, 2011; 11(1): 97–107

Petersen W, Braun C, Bock W, Schmidt K, Weimann A, Drescher W, Eiling E, Stange R, Fuchs T, Hedderich J, Zantop T. A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Arch Orthop Trauma Surg*, 2005; 125(9): 614–621

Pfile KR, Gribble PA, Buskirk GE, Meserth SM, Pietrosimone BG. Sustained improvements in dynamic balance and landing mechanics after a 6-week neuromuscular training program in college women's basketball players. *J Sport Rehabil*, 2016; 25(3): 233–240

Pfile KR, Hart JM, Herman DC, Hertel J, Kerrigan DC, Ingersoll CD. Different exercise training interventions and drop-landing biomechanics in high school female athletes. *J Athl Train*, 2013; 48(4): 450–462

Powell JW, Barber-Foss KD. Injury patterns in selected high school sports: a review of the 1995-1997 seasons. *J Athl Train*, 1999; 34(3): 277–284

Romero-Franco N, Martinez-Lopez E, Lomas-Vega R, Hita-Contreras F, Martinez-Amat A. Effects of proprioceptive training program on core stability and center of gravity control in sprinters. *J Strength Cond Res*, 2012; 26(8): 2071–2077

Sannicandro I, Cofano G, Rosa RA, Piccinno A. Balance training exercises decrease lower-limb strength asymmetry in young tennis players. *J Sport Sci Med*, 2014; 13(2): 397–402

Sato K, Mokha M. Does core strength training influence running kinetics, lower-extremity stability and 5000-m performance in runners? *J Strength Cond Res*, 2009; 23(1): 133–140

Saunders NW, Hanson NJ, Koutakis P, Chaudhari AM, Devor ST. Figure skater level moderates balance training. *Int J Sports Med*, 2013; 34(4): 345–349

Schneider S, Seither B, Tönges S, Schmitt H. Sports injuries: population based representative data on incidence, diagnosis, sequelae, and high risk groups. *Br J Sports Med*, 2006; 40(4): 334–339

Soderman K, Werner S, Pietilä T, Engström B, Werner S. Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surgery, Sport Traumatol Arthrosc*, 2000; 8: 356–363

Soligard T, Myklebust G, Steffen K, Holme I, Silvers H, Bizzini M, Junge A, Dvorak J, Bahr R, Andersen TE. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. *BMJ*, 2008; 337(2): 2469–2469

Steib S, Zahn P, zu Eulenburg C, Pfeifer K, Zech A. Time-dependent postural control adaptations following a neuromuscular warm-up in female handball players: a randomized controlled trial. *BMC Sports Sci Med Rehabil*, 2016; 8(1): 33–40

Trecroci A, Cavaggioni L, Caccia R, Alberti G. Jump rope training: Balance and motor coordination in preadolescent soccer players. *J Sport Sci Med*, 2015; 14(4): 792–798

Turl SE, George KP. A factor in repetitive hamstring strain?. *J Orthop Sport Phys Ther*, 1998; 27(1): 16–21

Verhagen E, Bobbert M, Inklaar M, Van Kalken M, Van Der Beek A, Bouter L, Van Mechelen W. The effect of a balance training programme on centre of pressure excursion in one-leg stance. *Clin Biomech*, 2005;

20(10): 1094–1100

Verhagen E, van der Beek A, Twisk J, Bouter L, Bahr R, van Mechelen W. The effect of a proprioceptive balance board training program for the prevention of ankle sprains. *Am J Sports Med*, 2002; 32(6): 1385–1393

Visser JE, Carpenter MG, van der Kooij H, Bloem BR. The clinical utility of posturography. *Clin Neurophysiol*, 2008; 119(11): 2424–2436

von Porat A, Roos EM, Roos H. High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *Ann Rheum Dis*, 2004; 63(3): 269–273

Watson AWS. Ankle sprains in players of the field-games gaelic football and hurling. *J Sport Med Phys Fit*, 1999; 39(1): 66–70

Winter DA. Human balance and posture control during standing and walking. *Gait Posture*, 1995; 3(4): 193–214

Woods K, Bishop P, Jones E. Warm-up and stretching in the prevention of muscular injury. *Sport Med*, 2007; 37(12): 1089–1099

Worrell T. Factors associated with hamstring injuries. An approach to treatment and preventive measures. *Sport Med*, 1994; 17(5): 338–345

Zakas A, Balaska P, Grammatikopoulou MG, Zakas N, Vergou A. Acute effects of stretching duration on the range of motion of elderly women. *J Bodyw Mov Ther*, 2005; 9(4): 270–276

Zatsiorsky VM, Duarte M. Instant equilibrium point and its migration in standing tasks: rambling and trembling components of the stabilogram. *Motor Control*, 1999; 3(1): 28–38

Zech A, Hübscher M, Vogt L, Banzer W, Hänsel F, Pfeifer K. Balance training for neuromuscular control and performance enhancement: a systematic review. *J Athl Train Natl Athl Trainers' Assoc*, 2010; 45(4): 392–403

Zech A, Klahn P, Hoeft J, Zu Eulenburg C, Steib S. Time course and dimensions of postural control changes following neuromuscular training in youth field hockey athletes. *Eur J Appl Physiol*, 2014; 114(2): 395–403

Zemková E. Sport-specific balance. *Sport Med*, 2014; 44(5): 579–590

Corresponding author:

Kajetan J. Słomka
Department of Human Motor Behavior
The Jerzy Kukuczka Academy of Physical Education in Katowice.
72A Mikolowska Street; 40-065 Katowice, Poland
tel +48 32 2075141
fax +48 32 2516868
E-mail: k.slomka@awf.katowice.pl