Balance Ability and Athletic Performance

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BALANCE ABILITY AND ATHLETIC PERFORMANCE

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Abstract

The relationship between balance ability and sport injury risk has been established in many cases, but the relationship between balance ability and athletic performance is less clear. The aims of this review were to: compare the balance ability of athletes from different sports; determine if there is a difference in balance ability of athletes at different levels of competition within the same sport; determine the relationship of balance ability with performance measures; and examine the influence of balance training on sport performance or motor skills.

Based on the available data from cross-sectional studies, gymnasts tended to have the best balance ability, followed by soccer players, swimmers, active control subjects, and then basketballers. Surprisingly, no studies were found that compared the balance ability of rifle shooters with other athletes. There were some sports where elite athletes were found to have superior balance ability compared to their less proficient counterparts such as rifle shooting, soccer and golf but this was not found to be the case for alpine skiing, surfing and judo. Balance ability was shown to be significantly related to rifle shooting accuracy, archery shooting accuracy, ice hockey maximum skating speed and simulated luge start speed but not for baseball pitching accuracy or snowboarding ranking points. Prospective studies have shown that the addition of a balance training component to the activities of recreational active subjects or physical education students has resulted in improvements in vertical jump, agility, shuttle run and downhill-slalom skiing. A proposed mechanism for the enhancement in motor skills from balance training is an increase in the rate of force development. There are limited data on the influence of balance training on motor skills of elite athletes. When the

effectiveness of balance training was compared to resistance training, it was found that resistance training produced superior performance results for jump height and sprint time.

Balance ability was related to competition level for some sports with the more proficient athletes displaying greater balance ability. There were significant relationships between balance ability and a number of performance measures. Evidence from prospective studies supports the notion that balance training can be a worthwhile adjunct to the usual training of non-elite athletes to enhance certain motor skills but not in place of other conditioning such as resistance training. More research is required to determine the influence of balance training on the motor skills of elite athletes.

1. Introduction

Balance is the process of maintaining the position of the body's centre of gravity (CoG) vertically over the base of support and relies on rapid, continuous feedback from visual, vestibular and somatosensory structures and then executing smooth and coordinated neuromuscular actions.[1] The relationship between balance ability and sport injury risk has been established in many cases[2], but the relationship between balance ability and athletic performance is less clear. The importance of balance to activities such as gymnastics, rifle shooting and ice hockey may appear apparent but the relationship to performance in many sports and motor skills hasn't been fully elucidated. The rationale for inclusion of balance training in an overall conditioning program can be strengthened if it is also shown to have a positive influence on athletic performance. The aims of this review were to: compare the balance ability of athletes from different sports; determine if there is a difference in balance ability of athletes at different levels of competition within the same sport; determine the relationship of balance ability with performance measures; and examine the influence of balance training on sport performance or motor skills. The review was based on journal articles identified from electronic literature searches using MEDLINE, CINAHL, and SPORTDiscus data bases from the years 1970-2009 using the following search terms in various combinations: "balance", "postural", "proprioceptive", "ability", "training", "sport", "athlete" and "performance".

2. Static and Dynamic Balance

Static balance is the ability to maintain a base of support with minimal movement. Dynamic balance may be considered the ability to perform a task while maintaining or regaining a stable position[3] or the ability to maintain or regain balance on an unstable surface[4,5] with minimal extraneous motion. When examining the relationship between balance ability and athletic performance, researchers have used a number of different tests to assess static and dynamic balance. A simple field test for static balance is the timed unipedal stance.[4,6] The most prevalent laboratory test for static balance is monitoring the centre of pressure (CoP) motion for a specified duration as an athlete attempts to stand motionless on a force platform, unipedal or bipedal, eyes open or eyes shut.[7-9] While it is acknowledged that CoP motion is not identical to CoG motion[10], minimal CoP motion is indicative of good balance and CoP measured from a force platform is generally considered the gold standard measure of balance.[11] Examples of field tests of dynamic balance include unipedal stance on a wobble board and counting the number of floor contacts in 30s[12] and the Star Excursion Balance Test (SEBT) which involves stable unipedal stance with maximal targeted reach distance of the free limb in a number of directions[13,14]; results from the SEBT might also be influenced by strength, flexibility or coordination. Laboratory tests of dynamic balance include the use of a stabilometer which requires athletes to continuously adjust posture during bipedal stance to maintain an unstable, swinging platform in the horizontal position.[4,15] Another device used to assess dynamic balance is the Biodex Balance System consisting of an instrumented movable platform, not dissimilar to the motions of a wobble board but with adjustable levels of stability and it measures the degrees of deviation from the horizontal position.[16,17] The force platform has also been incorporated into tests for dynamic balance by monitoring CoP motion for unipedal stance with maximum forward trunk lean[18] or by placing a tilt board on top and monitoring CoP motion.[19] It should be noted that the validity of the balance tests other than those using a force platform and CoP data has usually been inferred and hasn't been established by comparing the balance scores with CoP data from a force platform and displaying high correlation.[20]

3. Balance Ability of Gymnasts Compared to Others

An athletic population commonly assessed for balance ability is gymnasts (Table I), not unexpected since balance ability is a component of gymnastics. The balance ability of gymnasts has mostly been compared to active control subjects[4,9,15,21-24], while two studies have compared them to other specific athletes.[13,15] Majority of studies reported some differences in balance ability; the one study that didn't[21] had the smallest sample size and might have been underpowered to detect statistical differences. When looking at the data collectively, a number of trends can be identified. Overall, it was found that gymnasts were equal to or out-performed non-gymnasts. When the balance test duration exceeded 20s, gymnasts did better than non-gymnasts[4,9,15,22-24] but not when the test was 20s or less.[13,21] This result is a little surprising considering that gymnasts don't maintain static postures for much more than 2s during their routines. Gymnasts tended to have superior static unipedal balance[9,13,22], superior bipedal dynamic balance[4,15] but not static bipedal balance.[9,13,21,24] The ability to maintain balance is likely to be specific to the task and possibly not a general trait. Unipedal balance may be considered difficult and specific to gymnasts; female gymnasts often practice unipedal balance skills on the balance beam while the floor routine of male gymnasts requires unipedal stability. Bipedal stance may be considered easy and unspecific to gymnasts. There were insufficient data on dynamic unilateral balance to identify any trends. When analyzing the comparative studies it needs to be noted that gymnasts tend to be shorter and lighter than other athletes and stature and body mass may influence balance ability[15] and normalizing balance scores relative to height or limb length should be considered when comparing groups with notable differences in stature or body mass[13] but this isn't always done.[24] When compared to other specific athletes, gymnasts were found to have superior stabilometer bipedal dynamic balance to soccer players and swimmers.[15] The other study[13] using Balance Error Scoring System (BESS) and SEBT found no difference in static or dynamic balance when compared to soccer players but gymnasts had superior static balance to basketballers. The BESS involved three stance positions (bipedal feet together, unipedal, tandem), stable and unstable surface, holding each position for 20s with hands on hips, eyes closed and then various “errors” were counted: opening eyes, lifting hands off the hips, foot touchdown, lifting forefoot or heel and others.[13] Gymnasts often practice and perform stationary balance and dynamic landings and may develop superior attention focus on cues such as small changes in joint position and acceleration that lead to superior balance.[13]

4. Balance Ability of Various Athletes

Although gymnasts and rifle shooters appear to be the most commonly assessed for balance ability, it is the balance ability of soccer players that has been most widely compared to that of other athletes (Table II). Soccer players were found to have inferior dynamic bipedal or similar static and dynamic balance to gymnasts.[13,15] They displayed similar dynamic bipedal or superior static unipedal balance to swimmers.[15,29] Compared to basketballers and active control subjects, soccer players had superior static unipedal and dynamic balance ability.[13,14,29] Soccer players frequently support their body mass on one leg when kicking a ball and may be expected to have better unipedal stability than athletes in other sports such as basketball.[29] Basketballers were not shown to have superior balance to any comparison group (Table II). They had similar static unipedal balance to swimmers and inferior static and dynamic unipedal balance to soccer players and gymnasts and inferior dynamic bipedal or similar static bipedal balance to active control subjects.[13,25,29] Swimmers displayed inferior dynamic bipedal balance to gymnasts, similar dynamic bipedal or inferior static unipedal balance to soccer players, similar static unipedal balance to basketballers and control subjects or superior dynamic bipedal balance to control subjects.[15,29]

The cross sectional studies (Tables I and II) have found that athletes generally have superior balance ability compared to control subjects; this implies that sport participation improves balance. Based on the available data (Table II), gymnasts tended to have the best balance ability, followed by soccer players, swimmers, active control subjects, and then basketballers. Basketball players rarely engage in unilateral stationary balance. Soccer players often perform dynamic unilateral movements when kicking the ball.[13] Swimmers don't usually practice or perform static or dynamic balance motions and possibly don't provide substantial stimuli to the sensorimotor systems required to enhance balance ability. Surprisingly, no studies were found that compared the balance ability of rifle shooters with other athletes. Rifle shooters were found to have superior static bipedal balance to a control group and their balance was further enhanced when they wore their competition attire weighing 7 to 13.5 kg; the stiff and supportive clothing and shoes diminished their body sway.[7]

5. Comparison of Balance Ability of Athletes at Different Levels of Competition

There are some sports where elite athletes have been shown to possess superior balance ability to their less proficient counterparts (Table III). International level rifle shooters had superior bipedal static balance to national level shooters who in turn were superior to novice shooters.[30-32] National level soccer players had superior unipedal and bipedal static and unipedal dynamic balance compared to regional level players.[5,19] Elite golfers were found to have better unipedal static balance than less proficient golfers[34]; unipedal stability isn't automatically associated with golf but it was suggested that it may assist weight shift during the swing, golfers may also be required to perform the golf swing with an uneven lie of the ball, uphill or downhill lie or a lie that requires one foot in a sand trap and the other on the grass.[34] Superior balance of elite athletes may be the result of repetitive experience that influences motor responses and the athlete's ability to attend to relevant proprioceptive and visual cues.[13] Training experience might also improve coordination, strength and range of motion that may enhance balance ability.[13] There are other sports where it might be expected that more proficient athletes would display better balance but this was not found for different competition levels for alpine skiing, surfing and judo.[8,33,35] National and international level alpine skiers had similar static and dynamic bipedal balance to regional level skiers when tested with ski boots but inferior bare foot static and dynamic balance to regional skiers.[33] To explain this unexpected result, it was proposed that elite skiers spend more time in ski boots and possibly don't get as much postural control conditioning of the ankle-foot complex.[33] There was no difference found in the bipedal static balance ability between elite and intermediate recreational surfers.[35] Surfing performance is conducted in a highly unstable and changing environment[35] and a static balance test is possibly not specific or challenging enough to discern any differences in balance ability; it could be argued that a dynamic test would be more appropriate for surfers.

6. Relationship of Balance Ability to Performance Measures

Balance ability has been found to be significantly related to a number of performance measures in a number of sports (Table IV). Bipedal static balance while shooting was associated with shooting accuracy for elite and novice rifle shooters.[37,40] Other factors such as rifle stability may be independent of balance and can also influence shooting accuracy.[37]

Balance ability was significantly related to shooting accuracy for junior archers but not senior archers.[36] The senior archers had superior balance ability to junior archers; a high level of stability is a prerequisite to becoming an elite archer and at this level of expertise the range of postural sway is small and was not an important discriminating factor for elite senior archers.[36] The dynamic balance of young ice hockey players displayed a significant relationship with maximum skating speed; balance is required in ice hockey because of the small surface area of the skate blades in contact with the low friction ice surface.[39] Dynamic unipedal balance as measured by the Biodex Balance System was shown to be associated with speed during simulated luge starts[17] but not with snowboarders' ranking points.[41] The static unipedal balance of elite golfers correlated with certain performance measures: greens in regulation and average putt distance after a chip shot; it was proposed that weight shift during the golf swing and standing on uneven ground may require proficient balance.[6] One study investigating the unipedal static balance of college baseball pitchers in the "balance point" posture did not find a significant association with pitching accuracy; it was previously assumed that balance was important for pitching because the action involves a "balance point" during the wind-up where there is unipedal stance as the stride leg reaches the apex of the leg lift.[38]

7. Influence of Balance Training on Sports Performance or Motor Skills

Balance training programs designed to enhance performance might start with exercises on a stable surface and bipedal stance and progress to unipedal stance and unstable surfaces (foam mat, tilt board, wobble board, inflated rubber disc) with eyes open, eyes shut and may then incorporate movements: tilting, rotating, squatting, hopping, jumping, throwing and catching a ball or resistance exercises while balancing.[42] There have been a number of investigations into the influence of balance training on athletic performance measures (Table V). These prospective studies have ranged from 2 to 10 weeks and mostly involved physically active, non-elite subjects. It has been found that the addition of a balance training component to the activities of recreational active subjects or physical education students has resulted in improvements in vertical jump[12,46], agility[46], shuttle run[18] and downhill-slalom skiing.[16] It is unclear what portion of the improvements is due to the actual balance training stimulus as opposed to just the increased overall volume of physical conditioning brought about by the inclusion of balance training. It has been proposed that improvement with balance could decrease the proportions of muscles allocated to stabilization and allow them to contribute more to the motive force.[12] There are of course activities that would benefit directly from enhanced balance; down-hill slalom skiing involves unpredictable surfaces in addition to the ankle-foot being fixed in the ski boot and unable to make major postural adjustments.[16] The evidence supports the notion that balance training can be a worthwhile adjunct to the usual training of non-elite athletes but not in place of other conditioning such as resistance training. When the effectiveness of balance training was compared to resistance training, it was found that resistance training produced superior performance results for jump height and sprint time.[43,44]

Conditioning programs for most athletes are multifaceted but often it is unknown what contribution each training component makes to the overall performance. A multifaceted eight week training program for recreational golfers that included strength, flexibility and balance training produced significant increases in golf performance measures; a more stable base with greater functional flexibility and strength of the upper body allows for greater upper body rotational velocity resulting in greater club head speed.[45] The effectiveness of the program was not compared to a control group or another conditioning program that just involved the strength and flexibility training; this would have allowed for an evaluation of the contribution of the balance training component. This is an area for future research.

8. Proposed Mechanisms for Enhancement in Performance from Balance Training

The relative contribution of improved motor or sensory function to enhanced performance in a motor task from balance training is unknown. Proprioception is a part of the sensory system that provides information on joint position sense or detecting joint motion and is a component of the balance system. Whether proprioception can really be improved by exercise has been questioned and it is speculated that athletes might just become more skilled at focusing and attending to important sensory cues with training and producing refined motor responses. For example, gymnasts balancing on the beam may learn to pay full attention to ensure they detect all larger body segment acceleration so as to minimize motion and improve performance.[47]

Balance training may lead to task-specific neural adaptations at the spinal and supraspinal levels. It may suppress spinal reflex excitability such as the muscle stretch reflex during postural tasks which leads to less destabilizing movements[48] and improved balance such as required in sports like gymnastics and rifle shooting. The inhibition of muscle stretch reflexes may enhance agonist-antagonist muscle co-contraction which increases joint stiffness, stabilizing the joints against perturbations and therefore may improve balance.[49] Task-specific reduced cortical excitability has also been associated with improved balance from training. It is postulated that balance training promotes a shift in movement control from cortical to subcortical and cerebellar structures.[48] These adaptations help explain the improvement in balance ability from balance training but not the increase in motor skills such as vertical jump. It needs to be noted that the reduced spinal and supraspinal excitability was task-specific and demonstrated during the balance tasks and is not necessarily evident during other movements so it can't be assumed that there is reduced neural excitation during various motor skills as it could be counterproductive to force and power production.

It was found that balance training increased rectus femoris activation during jump landing. Greater muscle activation might optimize musculotendinous and joint stiffness reducing the amortization phase in the stretch-shortening cycle and subsequently improve performance in eccentric-concentric actions such as countermovement jumps.[12]

An initial study demonstrated an increase in maximum voluntary isometric contraction (MVIC) force of the knee extensors and flexors of recreationally active subjects after 6 weeks of balance training[50] but several subsequent balance training studies have failed to generate any significant increase in strength.[43,51-53] On the weight of the evidence, it appears unlikely that an increase in strength is a significant adaptation to balance training but what might be likely is an increase in the rate of force development (RFD). Four weeks of balance training was found to increase RFD for MVIC during a multijoint unipedal leg press action[52] and single joint ankle plantar flexion action of untrained subjects.[53] An increase in RFD may lead to an increase in power and subsequently motor skill performance such as vertical jump.

There have been a number of proposed sensory adaptations to the balance training stimuli inherit in many sport activities. As with some other proposed mechanisms they are based on low-level evidence, not on the finding of any prospective studies. It has been suggested that repetitive experience of expert athletes such as elite surfers might enhance balance ability by neurological adaptations that rely less on visual input and more on the other components of postural control such as proprioception[35] The reduced necessity for visual contribution for postural control may allow more attention to be paid to other sensory input important for balance and sport performance. It has been reported[54] that gymnasts were able to more rapidly re-establish a balance position than non-gymnasts after a period of disturbed proprioceptive information caused by applying vibration to the muscle tendons around the ankle. The authors suggest that the efficiency of the process of integrating and reweighting postural control sensory information is improved by gymnastics training. Another study[55] investigated the influence of disturbing sensory input on the postural control of elite and non-elite soccer players. Sensory input was disturbed by a combination of cooling the subjects' feet to desensitize plantar cutaneous receptors, electrically stimulating the calf and thigh muscles to disturb myotatic proprioceptive information and bracing the neck to limit information from the cervical vertebral joints. It was found that for both the disturbed and non-disturbed conditions, the elite athletes displayed better static bilateral balance. It was concluded that the elite athletes probably possessed a better knowledge of body axis and verticality. More high-level evidence from prospective studies is required to substantiate many of the proposed mechanisms for enhanced balance ability

9. Conclusions

Cross-sectional studies revealed that gymnasts tended to have the best balance ability, followed by soccer players, swimmers, active control subjects, and then basketballers. No studies were found that compared the balance ability of rifle shooters to other athletes. There were sports such as rifle shooting, soccer and golf where elite athletes were found to have superior balance ability compared to their less proficient counterparts but this was not found for alpine skiing, surfing and judo. Balance ability was shown to be significantly related to rifle shooting accuracy, archery shooting accuracy, ice hockey maximum skating speed and simulated luge start speed but not for baseball pitching accuracy or snowboarding ranking points. Prospective studies have found that the addition of a balance training component to the activities of recreational active subjects or physical education students has resulted in improvements in vertical jump, agility, shuttle run and downhill-slalom skiing. Balance training may lead to task-specific neural adaptations at the spinal and supraspinal levels. It may suppress spinal reflex excitability such as the muscle stretch reflex during postural tasks which leads to less destabilizing movements and improved balance ability. Furthermore, balance training may increase the RFD which can increase muscular power and subsequent performance of motor skills such as vertical jump. There are limited data on the influence of balance training on motor skills of elite athletes. When the effectiveness of balance training was compared to resistance training, it was found that resistance training produced superior performance results for jump height and sprint time.

Balance ability was related to competition level for some sports with the more proficient athletes displaying greater balance ability. There were significant relationships between balance ability and a number of performance measures. Evidence from prospective studies supports the notion that balance training can be a worthwhile adjunct to the usual training of non-elite athletes to enhance certain motor skills but not in place of other conditioning such as resistance training. More research is required to determine the influence of balance training on the motor skills of elite athletes.

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Table I. Balance ability of gymnasts vs non-gymnasts

Study (year)	Athletes and level	Balance test	Significant findings ($p<0.05$)
Kioumourtzoglou et al.[4] (1997)	Rhythmic gymnasts national 60f Controls 60f	Static balance, timed "releve" position. Dynamic balance, stabilometer, bipedal, 90s, maintaining platform with 10° horizontal.	Gymnasts superior static and dynamic balance
Vuillerme et al.[21] (2001)	Gymnasts 6m Controls 6m	Static balance, force platform, CoP sway, bare foot, 10s, bipedal, unipedal, unipedal on foam mat, eyes opens, eyes shut	No difference in any test with eyes open (small sample size) Gymnasts superior with no vision and unipedal stance
Aydin et al.[22] (2002)	Gymnasts 20f Controls 20f	Unipedal stance for 60s eyes open then another 60s with eyes shut on soft surface. Each surface contact with opposite limb counted	Gymnasts superior balance No difference between limbs within each group
Davlin[15] (2004)	Gymnasts elite 29m 28f Swimmers elite 32m 38f Soccer players elite 30m 28f Controls 31m 30f	Dynamic balance, stabilometer, bipedal, 30s, maintaining platform with 5° horizontal	Gymnasts superior to all others Athletes superior to controls No difference between swimmers and soccer No difference between males and females
Bressel at al.[13] (2007)	Gymnasts college 12f Soccer players college 11f Basketballers college 11f	Static balance, BESS, bipedal, unipedal, tandem on stable and unstable surface, 20s eyes shut. Dynamic balance, SEBT, results normalized to limb length	No difference between gymnasts and soccer Gymnasts superior static balance to basketballers Soccer players superior dynamic balance to basketballers
Carrick et al.[23] (2007)	Gymnasts elite 156 m f Controls 80 m f	Static balance, foam mat on force platform, CoP sway, 25s, bipedal, eyes shut	Gymnast superior balance
Asseman et al.[9] (2008)	Gymnasts international 13f Controls 13f	Static balance, force platform, CoP sway, 30 s, barefoot, unipedal, bipedal, eyes open, eyes shut	Gymnasts superior in unipedal balance with eyes open
Calavalle et al.[24] (2008)	Rhythmic gymnasts elite 15f Controls 43f	Static balance, force platform, CoP sway, 60 s barefoot, bipedal, eyes open, eyes shut	Gymnasts had superior balance in lateral direction but inferior in anterior-posterior. Results not normalized despite notable differences in stature and body mass between groups

BESS = Balance Error Scoring System; CoP = centre of pressure; f = female; m = male; SEBT = Star Excursion Balance Test

Table II. Comparison of balance ability of athletes in various sports

Study (year)	Athletes and level	Balance test	Significant findings ($p<0.05$)
Aalto et al.[7] (1990)	Rifle (8) + pistol shooters (2) national level 8m 2f Controls 27	Static balance, force plate, CoP sway, 27s, bipedal, eyes open, eyes shut, with and without competition clothing	Shooters superior balance to control Rifle shooters superior balance with competitive clothing than without
Kioumourtzoglou et al.[25] (1998)	Basketballers national level 13m Controls 15m	Dynamic balance, stabilometer, bipedal, 60s, maintaining platform with 10° horizontal.	Basketballers inferior balance but height not reported nor results normalized to height
Perrin et al.[26] (2002)	Judoists elite 17m Ballets dancers professional 14f Controls 21m 21f	Static balance, force platform, CoP sway, 20s, bipedal, eyes opens, eyes shut. Dynamic balance, support surface moved - slow rotational oscillations of force platform, 20s, bipedal, eyes opens, eyes shut	Judoists superior to controls in all conditions Judoists superior static balance with eyes shut than dancers No difference between male and female controls
Davlin[15] (2004)	Gymnasts elite 29m 28f Swimmers elite 32m 38f Soccer players elite 30m 28f Controls 31m 30f	Dynamic balance, stabilometer, bipedal, 30s, maintaining platform with 5° horizontal	Gymnasts superior to all others Athletes superior to controls No difference between swimmers and soccer No difference between males and females
Schmidt et al.[27] (2005)	Track runners college 5m 5f Ballet dancers college 5m 5f	Static balance, force platform, with and without foam mat, CoP sway, 30s, bipedal, barefoot, eyes opens, eyes shut.	No difference between runners and dancers but sample size small
Bressel at al.[13] (2007)	Gymnasts college 12f Soccer players college 11f Basketballers college 11f	Static balance, BESS, bipedal, unipedal, tandem on stable and unstable surface, 20s eyes shut. Dynamic balance, SEBT, results normalized to limb length	No difference between gymnasts and soccer Gymnasts superior static to basketballers Soccer players superior dynamic to basketballers
Gerbino et al.[28] (2007)	Soccer players college 32f Modern & ballet dancers college 32f	Static balance, pressure mat with foam mat, CoP sway, 10s, unipedal, bare foot, eyes opens, eyes shut. Dynamic balance, landing from a jump and a side weight shift (cutting)	Soccer inferior to dancers in 5 of 20 tests, no difference in other 15. Ability to stand quietly (sway index) and ability to recover from perturbation (jumps, cutting) mostly differed.
Matsuda et al.[29] (2008)	Soccer players non-elite 10m Basketballers non-elite 10m	Static balance, triangular force platform, CoP sway, 60s, unipedal.	Soccer superior to all others

	Swimmers non-elite 10m		No difference between limbs within each group
	Controls 10m		(Basketballers not taller than other subjects)
Thorpe & Ebersole[14] (2008)	Soccer players college 12f	Dynamic balance, SEBT, unipedal stance with maximum targeted reach distance of free limb in anterior, posterior, medial and lateral directions. Results normalized to limb length	Soccer superior in anterior and posterior reach
	Controls 12f		No difference between limbs within each group

BESS = Balance Error Scoring System; CoP = centre of pressure; f = female; m = male; SEBT = Star Excursion Balance Test

Table III. Comparison of balance ability of athletes at different levels of competition

Study (year)	Athletes and level	Balance test	Significant findings ($p<0.05$)
Niinimaa & McAvoy[30] (1983)	Rifle shooters elite 4m experienced biathletes 4m rookie biathletes 4m controls 4m	Static balance, force platform, bipedal, CoP, at rest, while aiming, 60s, before and after a bout of 4mins of strenuous exercise (bike riding) to simulate cross-country ski racing	Experience shooters superior balance to less experienced Balance was better at rest than in the aiming position and better before exercise
Era et al.[31] (1996)	Rifle shooters international 6m 3f national 8m novice 7m	Static balance, force platform, bipedal, CoP sway while shooting, 1.5s durations at 7.5s and 1.5s before shooting	International superior balance to national level National level superior to novice
Konttinen et al.[32] (1999)	Rifle shooters International 6m national 6m	Static balance, force platform, bipedal, CoP sway while shooting, 6s before shooting	International superior balance to national level
Paillard et al.[8] (2002)	Judoists national & international 11m regional 9m	Static balance, force platform, bipedal, CoP sway, 51.2s, eyes open, eyes shut	No difference between groups
Noe & Paillard[33] (2005)	Alpine skiers national & international 7m regional 7m	Static balance, force platform, 51.2s. Dynamic balance, tilt board on force platform, 25.6s. Both bipedal, CoP sway, bare foot & knees extended, ski boots & knee flexed, eyes open, eyes shut	No difference when tested with ski boots National & international inferior bare foot static and dynamic balance to regional skiers
Paillard & Noe[5] (2006)	Soccer players professional national 15m amateur regional 15m	Static balance, force platform, bipedal, CoP sway, 51.2s, eyes open, eyes shut	Professional superior balance to amateurs
Paillard et al.[19] (2006)	Soccer players national 15m regional 15m	Static balance, force platform, 51.2s. Dynamic balance, tilt board on force platform, 25.6s. Both unipedal, CoP sway, eyes open, eyes shut	National superior static and dynamic balance to regional
Sell et al.[34] (2007)	Golfers handicap < 0 45m handicap 0-9 120m handicap 10-20 92m	Static balance, force platform, unipedal, 10s, GRF sway, eyes open, eyes shut	Most proficient golf group had superior balance to other groups

Chapman et al.[35] (2008)	Surfers elite 21m intermediate, recreational 20m	Static balance, balance platform, bipedal, 30s, sway, head neutral, head back, eyes open, eyes shut	No difference between groups

CoP = centre of pressure; f = female; GRF= ground reaction force; m = male

Table IV. Relationship between balance ability and performance measures

Study (year)	Athletes and level	Balance test	Performance measure	Significant relationships ($p<0.05$)
Mason & Pelgrim [36] (1986)	Archers national juniors national seniors	Static balance, force platform, bipedal, CoP sway while shooting arrows, 1s to shot	Arrow shooting accuracy	Balance ability associated with shooting accuracy for juniors and less experienced ($r = 0.51$) but not for seniors or more experienced archers
Ball et al.[37] (2003)	Rifle shooters international 4m 2f	Static balance, force platform, bipedal, CoP sway while shooting, 5,3,1s to shot.	Rifle shooting accuracy	Balance ability associated to performance for 4 shooters.
Marsh et al.[38] (2004)	Baseball pitchers college 16m	Static balance, force platform, unipedal in the pitching balance point posture, CoP sway, 10s, eyes open, eyes shut	Pitching accuracy- distance of ball from catcher's mitt	No association
Behm et al.[39] (2005)	Ice hockey players high school & junior 30m	Dynamic balance, timed balance on a wobble board during 30s	Maximum skating speed	Balance ability associated to skating speed, particular for younger players ($r = 0.65$)
Moonenen et al. [40] (2007)	Rifle shooters novice 58m	Static balance, force platform, bipedal, CoP sway while shooting, 3s to shot.	Rifle shooting accuracy	Balance ability was associated with shooting accuracy ($r = 0.291$ to 0.450)
Platzer et al.[17] (2009)	Luge international 13m	Dynamic balance, Biodex Balance System, unipedal, 30s	Luge start stimulator- end & maximal speed	Balance ability associated with end speed ($r = 0.590$) but not maximal speed
Platzer et al.[41] (2009)	Snowboarders international 21m 16f	Dynamic balance, Biodex Balance System, unipedal, 30s	World Cup & International Federation of Skiing points	No association
Wells et al.[6] (2009)	Golfers elite 15m 9f	Static balance, timed unipedal stance	Ball speed & distance, average score, greens in regulation, short game measures, putting accuracy	Balance ability associated with greens in regulation ($r = -0.43$) and average putt distance after a chip shot ($r = 0.50$)

CoP = centre of pressure; f = female; m = male; r = correlation coefficient

Table V. Prospective studies on the influence of balance training on performance

Study (year)	Subjects	Balance training program and other interventions	Performance measures. Balance test	Significant findings ($p<0.05$)	Comments
Bruhn et al.[43] (2004)	Balance Training 6m 6f Strength Training 5m 6f Control group 6m 4f	1hr, 2/wk for 4wks. Balance group- different balancing tasks on wobbly or unsteady surfaces. Strength training group- single repetitions, high intensity	Unipedal isometric MVC and jump height Dynamic balance, unipedal, barefoot, swinging platform (Posturomed) displacement, 40s	Only strength training group ↑ MVC, jump height and balance	Training status of subjects not reported. Limited details on training programs
Malliou et al.[16] (2004)	PE students- novice skiers Balance group 8m 7f Control group 8m 7f	20mins, 4/wk for 2wks. Indoor, unipedal balance with ski boot on floor, on tilt board, with and without ski poles Both groups had basic ski lessons for 2 wks	Downhill-slalom agility test and snowploughing test. Dynamic balance, unipedal, Biodex Balance System, 20s.	Balance group better (26%) than control for downhill-slalom skiing agility test. Both groups ↑ balance but no difference between groups	Additional volume of training of the balance group may be partly responsible for improvement
Kean et al.[12] (2006)	Recreationally active Wobble board group 11f Jump landing group 7f Control group 6f	20mins, 4/wk for 6wks. Wobble board- bipedal tilting, squats, ball tosses and unipedal balancing. Jump landing- unipedal, multi directional, controlled	Vertical jump height, 20m sprint time. Dynamic balance, wobble board, unipedal, 30s, number of contacts	Wobble board group ↑ vertical jump (9%) and balance (33%)	Jump landing group used low-to-moderate heights; training stimulus not high
Yaggie & Campbell[18] (2006)	Recreationally active Balance group 17 m f Control group 19 m f	20mins, 3/wk for 4wks. BOSU- unipedal stance, upright, trunk lean, head movement, eyes open, eyes shut	Shuttle run time, timed unipedal balance on BOSU eyes shut, vertical jump and reach test. Static balance, force platform, CoP sway, unipedal, 15s. Dynamic balance, CoP sway for maximum forward trunk lean	Balance group ↑ shuttle run (6%), static balance CoP sway and timed unipedal balance on BOSU (37%)	Balance training for 4wks only, possibly insufficient to increase vertical jump
Cressey et al.[44] (2007)	Soccer players college Unstable training group (UG) 10m Stable training group (SG) 9m	3/wk for 9wks. Both groups did the same resistance training program but the UG did one of the supplementary exercise per session (e.g. lunges,) on inflated rubber discs	Vertical jump predicted power, 10 a 40 yard sprint times, T-test agility time	SG ↑ jump power (2.4-3.2%) and ↑ 40 yard sprint time more than UG (1.8 vs 3.9%). Both groups ↑ 10 yard sprint and agility test but no difference between	No control group Difference between programs was only one exercise
Lephart et al.[45] (2007)	Recreational golfers Multifaceted training group 15m	3-4/wk for 8wks. Combined strength, flexibility and balance program. Elastic resistance for hip, torso & shoulder rotational strengthening. Static stretches for torso rotation, shoulder flexibility and hip flexion/extension. Static squats, unipedal stance on floor & foam mat for balance (1 x 30s each).	Strength, flexibility, golf performance (club head speed and total distance) Static balance, force platform, unipedal GRF sway, 10s, eyes open, eyes closed	↑ in multiple strength, flexibility, balance and golf performance measures	No control group Multifaceted program, individual components not evaluated
Simek Salaj et al. [46] (2007)	PE students Balance group 37m Control group 38m	60mins, 3/wk for 10wks. Tilt and wobble boards, bipedal, unipedal, static, tilting, eyes open, eye shut, hops, jumps and strength exercises on boards	Vertical jump, horizontal jump and agility	Balance group ↑ vertical jump (1.2-1.6cm) and agility	Balance group did a greater overall training load than the control

BOSU = Both Sides Up balance trainer; CoP = centre of pressure; f = female; GRF = ground reaction force; m = male; MVC= maximal voluntary contraction: ↑ = increased