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Does induced fatigue alter dynamic balance in athletes? A systematic review

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Objectives: *To determine the influence of induced fatigue on dynamic balance in healthy athletes.*

Design: *Systematic review*

Data sources: *PUBMED, MEDLINE, CINAHL, Sports Discus, and the Cochrane library from onset to May 28, 2019*

Eligibility criteria: *Eligible studies included any study examining the effects of induced-fatigue on dynamic balance, as measured by the SEBT/YBT, in healthy athletic populations. Studies with a low risk of bias were considered scientifically admissible for a best evidence synthesis.*

Results: *Fifteen studies with low risk of bias were included – seven investigated recreational athletes while eight focused on competitive athletes. In the recreational population, five of the studies found significant decrease in dynamic balance following the fatiguing intervention.*

La fatigue musculaire modifie-t-elle l'équilibre dynamique chez les athlètes? Étude systématique

Objectifs : *Déterminer si la fatigue musculaire a des effets sur l'équilibre dynamique chez les athlètes en bon état de santé.*

Méthodologie : *Revue systématique*

Sources des données : *PUBMED, MEDLINE, CINAHL, Sports Discus et la bibliothèque Cochrane du début des publications jusqu'au 28 mai 2019.*

Critères d'admission : *Les études admissibles comprenaient toutes celles qui avaient porté sur les effets de la fatigue musculaire sur l'équilibre dynamique, telle qu'elle mesurée par le SEBT/YBT dans des populations de sportifs sains. Les études comportant un faible risque de biais ont été considérées comme scientifiquement admissibles pour faire une synthèse des meilleures données probantes.*

Résultats : *Quinze études présentant un faible risque de biais ont été retenues; sept portaient sur des athlètes amateurs et les huit autres, sur des athlètes de compétition. En ce qui concerne les athlètes amateurs, cinq études ont montré une diminution importante de*

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However, the remaining two concluded with insignificant changes. As for the competitive population, three studies showed significant effects of induced fatigue on dynamic balance, while five showed no effects.

Conclusion: *There are conflicting results regarding the effects of induced fatigue on dynamic balance. The majority of studies focused on competitive athletes found that fatigue did not alter their dynamic balance. Per contra, the majority of studies focused on recreational athletes concluded the opposite – fatigue did indeed affect dynamic balance.*

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KEY WORDS: postural balance, muscle fatigue, athlete, leg injuries, dynamic balance

l'équilibre dynamique après une activité causant de la fatigue. Cependant, dans les deux autres études, les changements n'étaient pas importants. En ce qui concerne les athlètes de compétition, trois études ont montré que la fatigue musculaire avait d'importants effets sur l'équilibre dynamique, tandis que cinq n'en ont montré aucun.

Conclusion : *Les résultats des études sur les effets de la fatigue musculaire sur l'équilibre dynamique sont contradictoires. La majorité des études portant sur des athlètes de compétition ont montré que la fatigue n'avait aucun effet sur l'équilibre dynamique. Par contre, la majorité portant sur les athlètes récréatifs ont conclu le contraire, c'est-à-dire que la fatigue avait un effet sur l'équilibre dynamique.*

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MOTS CLÉS : équilibre postural, fatigue musculaire, athlète, blessures aux jambes, équilibre dynamique

Introduction

While static balance is defined as maintaining a stable base of support with minimal body movement, dynamic balance is defined as withstanding movement within the base of support.[1] Deviations of the extremities occurring during movement can influence the center of mass (CoM) away from the base of support. Balance is gained by maintaining the CoM within the base of support. It can be argued that dynamic balance is required in skills such as jumping, hopping, and switching directions.

Dynamic balance has previously been identified as a vital athletic skill among gymnasts[2], footballers[3], golfers[4], volleyballers[5], fencers[6], and taekwondo athletes[7]. Deficits of dynamic balance have been shown to be a risk factor for injuries, particularly in the lower extremities such as muscular/tendon strains and ligamentous sprains.[8–11] Furthermore, it has been shown that dynamic balance enhances sport performance.[12,13]

Notwithstanding, this ability to maintain postural control within the base of support during dynamic movements may be compromised during fatigue. Previous soccer studies have identified an increase of musculoskeletal injuries toward the end of matches in both professional[14] and amateur footballers[15], which may be related to fatigue. In light of this, subsequent studies investigated the effects of induced fatigue on dynamic balance in athletes as a potential risk factor for dynamic balance alterations and injury.

One of the most feasible ways to assess dynamic balance, especially for the side-line sport practitioner, is through the Star Excursion Balance Test (SEBT), or its modified version, the Y-Balance Test (YBT). The outcome from the SEBT/YBT is how far the subject can reach with a lower limb without losing balance from the stance limb. Because these tests do not require any special equipment, they are feasible for sideline practicality. They have previously been used to assess lower extremity musculoskeletal injury risk[8–11] and rehabilitation progress[12,13], and have been shown to have excellent inter and intra rater reliability when used in healthy adults[16].

A previous systematic review by Gribble *et al.* [1] investigated the clinical utility of the SEBT as a diagnostic tool and its response to fatiguing, yet only provided a broad overview of its prediction for injury and responsiveness to training. Since its publication in 2012[1], very few studies have investigated the effects of fatigue on balance. There were only three such studies that demonstrated fatigue negatively affects dynamic postural-control of healthy participants and those with chronic ankle instabilities.[17–19] Given the dearth of available research on the topic, a more updated review focussing particularly on the impact of fatigue on dynamic balance is warranted.

Given the need for adequate dynamic balance within the sports context, this review limits its scope to the athletic population only. Furthermore, this review limits its search to the SEBT/YBT given these tests' feasibility for the sideline practitioner. Thus, this review aims to appraise the literature on the effects of induced fatigue on dynamic balance using the SEBT/YBT to measure dynamic balance in the healthy athletic population.

Methods

A search strategy was developed and reviewed using the Peer Review of Electronic Search Strategies (PRESS) Checklist.[20] The following electronic databases were systematically searched from inception to May 28, 2019: PubMed, MEDLINE, CINAHL, Sports Discus, and Cochrane. Search terms consisted of subject headings specific to each database (e.g., MeSH in MEDLINE) and free text words relevant to fatigue, dynamic balance, and athlete (Appendix 1).

The review targeted healthy asymptomatic athletes, defined as injury free for at least three months. Athletes were defined as engaged in competition, whether at a high school, college, university, provincial, national, international or professional level. Considering the scarce amount of literature analyzing this particular topic, the authors did not exclude studies of subjects described as trained individuals corresponding to physical educational students or recreational athletes.

Studies of interest included any intervention used to induce fatigue. Given variations in the nature of physiological fatigue and its demands on different sports disciplines, any fatigue protocol was acceptable.

The outcome of interest was the assessment of dynamic balance using the SEBT/YBT, regardless of whether it is the primary or secondary outcome measure in a study.

Eligibility for inclusion in the review was based on the following criteria: 1) English language; 2) published in a peer-reviewed journal; 3) study design of randomized controlled trial, cohort, case-control, quasi-experimental, pre-post intervention, or cross-sectional; 4) study population of healthy athletes (studies including injured athletes must have provided separate results for asymptomatic controls); 5) well described fatigue protocol as an intervention; and 6) outcome measures based on SEBT/YBT as dynamic balance assessments.

Studies fulfilling any of the following criteria were excluded: 1) publication types including: guidelines, editorials, unpublished manuscripts, dissertations, books, conference proceedings, meeting abstracts, consensus statements; 2) study designs including: pilot studies, case reports, case series, qualitative studies, non-systematic and systematic reviews, practice guidelines, and studies not reporting on methodology; 3) cadaveric or animal studies; and 4) studies on injured patients, or those with previously diagnosed conditions including severe injuries (e.g. spinal cord injuries, brain injuries, amputations, blindness, joint dislocation, neurologic deficits, or medications that may have affected their balance).

All citations identified by the search strategy were exported into EndNote X8 for reference management and tracking of the screening process. A two-phase approach to screening was used with two independent reviewers screening each citation and article. Phase one included screening of titles and abstracts for possible relevance. Phase two included screening of possibly relevant citations using full text screening, with citations rated as either relevant or irrelevant. Any disagreement was resolved by discussion between the paired reviewers. If consensus was not reached, then a third reviewer independently appraised the citation and discussed with the other two reviewers, until consensus was reached.

All relevant studies were independently critically appraised for risk of bias by the two reviewers. Risk of bias was assessed using the Scottish Intercollegiate Guidelines Network (SIGN) criteria for randomized controlled trials[21], the Joanna Briggs Institute (JBI) critical appraisal checklist tool for Quasi-Experimental studies[22], and the Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group for pre-post intervention studies[23]. A quantitative score (or cut point) was used to determine internal validity. Risk of bias scores of 1 to 2 were deemed "Unacceptable", scores of 3 to 4 were deemed "Acceptable", and scores of 5 to 6 were deemed "High Quality". If there were disagreements in the risk of bias assessments between the reviewers, then a third reviewer independently assessed for risk of bias and discussed with the other two reviewers, until consensus was reached. Following critical appraisal, studies with a low risk of bias ("high quality", or "acceptable") as determined by the quantitative score were considered scientifically admissible for best evidence synthesis. A sensitivity analysis was not performed as this was considered beyond the scope of this review.

The following methodological aspects (where appropriate or applicable) in each study were critically assessed: research question's clarity; randomization method; sample size estimation; population definition and description; appropriate utilization of control group; description of fatigue intervention; methodology of SEBT/YBT administration; repeatability of outcome measure for learning effects; and statistical analysis utilization.

Data was extracted from scientifically admissible studies to build evidence tables such as: effect sizes ((pre-fatigue mean balance minus post-fatigue mean balance)/SD(pre-fatigue)) and 95% CI where possible, best evidence on each topic, and identified consistencies/inconsistencies in the evidence. Cohen's criteria for effect size were used to guide interpretation, namely d=0.2 as small, d=0.5 as medium and d=0.8 as large.[24] The tables were then used to create summary statements describing the body of evidence. Evidence was stratified based on population, either recreational or competitive athletes. Meta-analyses of findings were considered, but not undertaken due to heterogeneity in study populations, fatiguing protocols, variation in measures of dynamic balance reported, and inability to compute effect sizes for some studies. This systematic review was organized and reported based on the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) statement.[25]

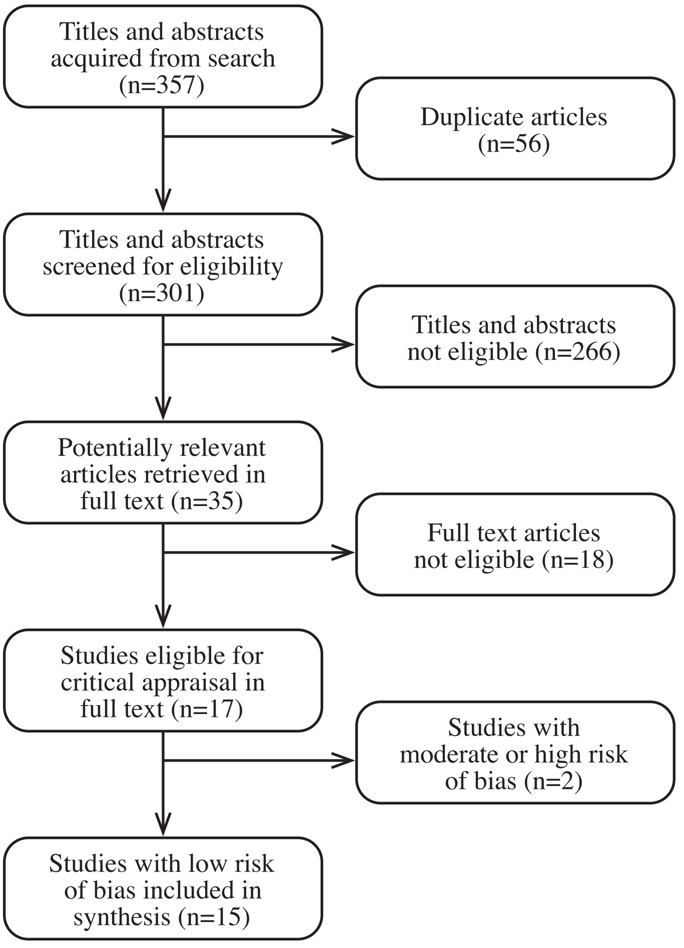

Figure 1.
Flowchart Of literature search and study identification

Results

Figure 1 shows the flow of articles through the systematic review. The search yielded 357 articles. After removing duplicates, 301 met phase 1 eligibility. Phase 1 interrater agreement, showing 91.0% agreement with ϰ=0.58, 95%CI (0.45, 0.72). After reaching consensus at phase 1, thirty-five articles remained eligible for full text phase 2 screening. Phase 2 interrater agreement was 80.0% with ϰ=0.60, 95%CI (0.33, 0.86). Disagreements were primarily related to the screened studies' broad definition of athletes.

Articles were excluded at phase 2 screening for ineligible study design, dynamic balance outcome not measured by SEBT/YBT, and subjects not consistent with the definition of a healthy athlete. Seventeen articles remained eligible for review.

All studies were appraised using the SIGN criteria for RCT, the JBI critical appraisal checklist tool for Quasi-Experimental studies, or the Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group. Of the 17 critically appraised studies, two were deemed to have a high risk of bias (Table 1) and were not included in the evidence tables and synthesis. For this review's purpose, methodological weakness of the studies with a high risk of bias included not meeting athlete definition

Table 1.
Risk of bias table for all critically appraised articles (n=17). The sign, JBI, and the quality assessment tool for before-after were used against the included studies. The appraisal was conducted with our systematic review purpose in mind – that is to measure the effects of fatigue on dynamic balance, though this might not have been the main purpose of the original study.

Study	Criteria	Population			Intervention (Fatigue)	Outcome (SEBT/YBT)			Overall
	SIGN/JBI/ Pre-post	Representa-tiveness of athletes	Sample Size estimation	Control Group	Clearly described	Clearly described	Learning effects	Statistics	(++) High Quality; (+) Acceptable; (-) Unacceptable
Gribble et al. 2007 [17]	Pre–Post	No	No	–	Yes	Yes	Yes	Yes	4/6 ; (+)
Baghbani et al. 2016 [32]	Pre–Post	Yes	Yes	–	Yes	Yes	Yes	Yes	6/6 ; (++)
Baghbaninaghadehi et al. 2013 [33]	Pre–Post	Yes	NR	–	Yes	Yes	Yes	Yes	5/6 ; (++)
Mirmoezzi et al. 2018 [26]	Pre–Post	No	NR	–	Yes	No	NR	Yes	2/6 ; (–)
Hosseinimehr et al. 2010 [34]	Pre–Post	No	NR	–	Yes	Yes	Yes	Yes	4/6 ; (+)
Steib et al. 2013 [35]	Pre–Post	Yes	Yes	–	Yes	Yes	Yes	Yes	6/6 (++)
Sarshin et al. 2011 [36]	Pre–Post	No	NR	–	Yes	Yes	Yes	Yes	4/6 (+)
Gribble et al. 2009 [19]	JBI	No	NR	Yes	Yes	Yes	Yes	Yes	5/7 (+)
Zulfikri et al. 2017 [37]	SIGN	No	NR	Yes	Yes	Yes	No	Yes	4/7 (+)
Zech et al. 2012 [38]	Pre–Post	Yes	NR	–	Yes	Yes	No	Yes	4/6 (+)
Valldecabres et al. 2018 [27]	Pre–Post	No	NR	–	Yes	No	NR	Yes	2/6 (–)
Steib et al. 2013 [40]	Pre–Post	No	NR	–	Yes	Yes	No	Yes	3/6 (+)
Whyte et al. 2015 [39]	Pre–Post	Yes	NR	–	Yes	Yes	Yes	Yes	5/6 (++)
Armstrong et al. 2018 [28]	Pre–Post	Yes	No	–	Yes	Yes	Yes	Yes	5/6 (++)
Johnston et al. 2018 [29]	Pre–Post	Yes	NR	–	Yes	Yes	Yes	Yes	5/6 (++)
Cavanaugh et al. 2016 [30]	Pre–Post	No	Yes	–	Yes	Yes	No	Yes	4/6 (+)
Mcmullen et al. 2011 [31]	Pre–Post	No	Yes	–	Yes	Yes	Yes	Yes	5/6 (++)

for population, lack of sample size estimation reporting, poorly described dynamic balance assessment, and lack of reporting on learning effect consideration (n=2).[26,27]

The remaining 15 articles[17,19,36–40,28–35](Table 2), were deemed to have a low risk of bias. These articles include a randomized controlled crossover study[37], a quasi-experimental study with a control group[19] and thirteen pre-post studies with no control group[17,27,29–39]. Their methodological weaknesses include a lack of a precise definition of an athlete regarding their choice of subjects (n =8), lack of sample size estimation (n=10), and lack of reporting on learning effect consideration (n=4).

Variations across the studies include: athlete populations, fatigue protocols, and utilization of SEBT/YBT's reach directions. Seven studies recruited recreational athletes[17,19,30,31,34,36,37] while eight studies recruited competitive athletes[28,29,32,33,35,38–40]. Fatigue protocol variations include: isolated body-segment/muscle[17,19,31], functional movement[17,19,30], multiple exertional stations[32–34,36,37,39], anaerobic treadmill[35,38,40], anaerobic cycling[29], high intensity interval training[39], dance aerobic fitness fatigue[28] or a combination thereof. Two studies utilized the SEBT in 3 directions: anterior, medial, posterior in bilateral stance[17,19]; four studies utilized the SEBT in all eight directions in only the dominant leg[32–34,39]; four studies utilized the SEBT in four directions: anterior, posterior, medial, lateral in unilateral stance[35,37,38,40]; four studies utilized the YBT in the dominant leg[29–31,36]; and one study utilized the YBT in bilateral stance[28].

Of the seven studies investigating the effects of fatigue on dynamic balance in recreational athletes, five found significant decreases, three of which used functional-mul-

Table 2.
Study characteristics of fifteen articles relevant and low risk of bias

Reference	Subjects, number (n) targeted	Study design	Athletic level, involvement	Intervention (fatigue protocol)	Outcome (dynamic balance)	Key findings
Gribble et al. 2007 [17]	30 physically active subjects. Healthy group (8 males, 8 females; (age 22.5 ± 2.4 years) Chronic ankle instability (CAI) group (7 males, 7 females; 21.9 ± 2.9 years)	Pre-post	All subjects participated in at least thirty minutes of exercise three times per week. Exercise description and level is not described. Recreational.	Ankle fatigue induced using an isokinetic dynamometer through a concentric-concentric protocol for plantar flexion/dorsiflexion movement. Lunge fatigue consisted of subjects lunging forward with the testing leg to a target on the floor at a distance equal to the leg length of the testing leg. The rate of lunge performance was generated with a metronome at a rate of one lunge cycle per two seconds.	SEBT; 3 directions: anterior, medial, posterior; bilaterally	Insignificant normalized reaching distance in both groups with both fatigue interventions. However, knee and hip kinematics is affected in CAI group after lunging fatigue protocol in two of the reaching directions. Effect size cannot be computed
Baghbani et al. 2016 [32]	15 healthy female, non-athletes (age 16.1±1.8 years) 15 female athletes (mean age ± sd: 16.1 ± 1.1 years)	Pre-post	All athletes (handball and basketball players) were all competing at the provincial level and had been involved in sport-specific training for at least 7 hrs/week for the previous two years. Competitive.	The fatigue protocol (7-station exertion protocol). The subjects jogged moderately at a self-selected pace for five minutes in station one. In station two, they sprinted up and down the length of a basketball court for three minutes. Station three was two minutes of push-ups. Sit ups were performed in station four for two minutes. Station five was three minutes of 30 cm step-ups. Station six was another three minutes of sprinting up and down the length of basketball court. The final station was two minutes at the fastest speed that each subject could run.	SEBT; 8 directions; dominant leg	The average of the 8 directions of the SEBT balance performance in the non-athlete group significantly decreased after fatigue (p=0.0003). The athlete group however had no significant changes in balance performance before and after the fatigue protocol (p=0.78). Additionally, they found that the athlete group had significantly better balance performance in pre (p=0.005) and post-tests (p=0.0001) when compared to their healthy control counterparts. Effect sizes (post mean – pre mean)/SD(pre)*athletes non-athletes SEBT composite 0.02-0.19 *SD not in publication, obtained from first author via email
Baghbaninaghadehi et al. 2013 [33]	15 female athletes from high school. Subjects' mean (standard error) of age, height, and body weight were: 16.1(1.1) years, 164.1 (4.6) cm and 53.1 (6.7) kg, respectively.	Pre-post	Basketball players who had four to five exercise sessions per week. Competitive.	Seven station exertion protocol. The subjects jogged moderately at a self-selected pace for five minutes in station one. In station two, they sprinted up and down the length of a basketball court for three minutes. Station three was two minutes of push-ups. Sit ups were performed in station four for two minutes. Station five was three minutes of 30 cm step-ups. Station six was another three minutes of sprinting up and down the length of basketball court. The final station was two minutes at the fastest speed that each subject could run.	SEBT; 8 directions; dominant leg	The mean and the standard deviations of dynamic balance performance of the subjects in eight directions before and after the fatigue protocol were not significant. Effect sizes (post mean-pre mean)/SD(pre) Anterior -0.67 Anteromedial 0.05 Medial -0.33 Posteromedial -0.48 Posterior -0.08 Posterolateral 0.92 Lateral 0.57 Anterolateral -1.41 Total -0.14
Hosseinimehr et al. 2010 [34]	30 subjects: healthy group (7 males, 8 females, age = 21.78±0.79 years, height = 168.3±5.6 cm and weight = 63.6±2.6 kg) CAI (7 males, 8 females, age = 21.43±0.83 years, height = 168.4±5.5 cm and weight = 63.3±3.2 kg)	Pre-post	Physical education students. Training level and frequency not specified. Recreational.	Seven stations protocol. Station one consisted of a 5 min moderate jog at the subjects self-selected pace. This jog took place around the perimeter of the gym in order to help the participant maintain a steady pace. Station two consisted of 2 min of sprints up and down the length of a basketball court. Station three was 1 min of push-ups. Station four consisted of 1.5 min of sit-ups. Station five was 2 min of 12 inch step-ups. Station six consisted of another 2 min of sprints up and down the basketball court and station seven was 1.5 min run at as fast a pace as the participant could maintain for the entire 1.5 min	SEBT; 8 directions; dominant leg	Dynamic postural control decreased after fatigue in two groups (p<0.05) Effect sizes (post mean-pre mean)/SD(pre) Control Experimental Anterior -1.04 -1.07 Anteromedial -0.80 -0.73 Medial -1.51 -0.66 Posteromedial -0.89 -0.17 Posterior -0.46 -0.77 Posterolateral -1.00 -0.95 Lateral -0.76 -1.43 Anterolateral -1.71 -1.49

Reference	Subjects, number (n) targeted	Study design	Athletic level, involvement	Intervention (fatigue protocol)	Outcome (dynamic balance)	Key findings
Steib et al. 2013 [35]	19 individuals with functional ankle instability (FAI) (male: 14, female: 5, age 24.95±3.17), 19 ankle sprain copers (male: 16, female: 6, age 24.53±2.76) 19 non-injured controls (male: 13, female: 6, age 23.32±3.79)	Pre-post	All athletes are in local ball sports teams (handball, volleyball, basketball, soccer). Participants exercised at least three times per week for a minimum of 30 min per session. Competitive.	Fatigue was induced by a running exercise on a motorized treadmill until subjective exhaustion. With a constant grade of 1° inclination, the protocol started at 8 km/h, and speed was increased stepwise by 2 km/h every 3 min. Participants were instructed to run as long as possible until complete exhaustion.	SEBT; 4 directions: anterior, posterior, medial, lateral; unilateral	Treadmill running negatively affected dynamic postural control in all three groups. Particularly, it had significantly affected SEBT in medial reach distances in the FAI (p = .002; ES = –0.42) and control group (p = .031; ES = –0.29), and anterior reach distances in copers (p ≤ .001; ES = – 0.55). The magnitude of these effects, however, did not differ between groups. Thus, ankle status does not appear to have an effect on fatigue-induced sensorimotor control impairments. Effect sizes (post mean-pre mean)/SD(pre) Control Copers FAI Anterior -0.16 -0.31 -0.03 Medial -0.29 -0.13 -0.28 Lateral -0.21 -0.16 -0.08 Posterior -0.13 -0.02 -0.10
Sarshin et al. 2011 [36]	20 healthy athletes (age 21.4 ± 1.63 year)	Pre-post	Physical education athletes that played badminton for at least 2 years. Training level and frequency not specified. Recreational.	Six phases of functional fatigue protocol: agility drill, box jumping, two-legged hop sequence, side-to-side bounds, mini-tramp, resistance arc	YBT; dominant leg	Functional fatigue decreased dynamic balance performance Effect sizes (post mean-pre mean)/SD(pre) Anterior -2.04 Posterolateral -1.92 Posteromedial -0.94
Gribble et al. 2009 [19]	16 physically active athletes (8 men: age 22.5 ± 2.45 years; 8 women: age 22.5 ± 2.56 years)	Quasi-experi-mental with control	All athletes participated in sustained physical activity at least 3 times per week for 30 minutes. Physical activity is not specified. Recreational.	Fatiguing conditions: Ankle plantar flexion and dorsi flexion. Knee flexion and extension. Hip flexion and extension. Athletes performed 5 continuous maximum trials at 60°/s for the designated movement pattern to determine peak torque. After a 2-minute rest, they repeated the movement pattern at 60°/s continuously until force production dropped below 50% of the peak torque in both directions of motion being tested. 4th fatiguing condition consisted of a lunging task a maximum number of times at the rate of 1 lunge every 2 seconds. Fatigue was induced by having them perform the task a maximum number of times until they could not complete it with proper form or were unable to meet the required rhythm for 2 repetitions in a row. The 5th testing session was used as control condition. No fatiguing task was implemented.	SEBT; 3 directions: anterior, medial, posterior; bilaterally	For anterior direction, fatigue created a decrease in MAXD for both genders compared with the control day. Knee fatigue condition produced a significantly greater decline in MAXD in men(–.043) than in the other conditions (gender-by-condition-by-time interaction: (p = .012) For medial direction, all 4 fatigue conditions created pre–post decreases in MAXD (condition-by-time interaction: (p < .001) compared with the control day. For posterior direction, fatigue at the ankle, knee, and lunge exercises created significant pre–post decreases in MAXD (condition-by-time: (p = .001). Fatigue produced deficits in normalized reach distances in all 3 reaching directions. Women were able to reach farther than men while simultaneously demonstrating a greater amount of knee flexion, and fatigue amplified these differences. Effect sizes cannot be derived. Results presented graphically without values for pre and post mean and SD
Zulfikri et al. 2017 [37]	72 male recreational athletes ranging from 18-25 years old. Four groups: Group A; KTape and fatigue, age 21.32 (1.29) Group B; no tape and fatigue, age 21.79 (1.44) Group C; KTape and no fatigue, age 21.11 (1.33) Group D; no tape and no fatigue, age 21.93 (0.88)	RCT	Recreational athlete was defined as people undertaking any sports for leisure and not representing the college, national nor international. Training level and frequency not specified. Recreational.	Functional agility short term fatigue protocol (fast-fp) was used to induce fatigue for group A and B. This protocol consisted of vertical jumping, stepping up and down, squatting and l-drill. Completing the four tasks was counted as one set of the protocol. This was repeated until maximal fatigue was achieved.	SEBT; 4 directions: anterior, medial, lateral, posterior; dominant leg	Group A (90.10±9.40) and group B (86.14±10.50) attained lower mean for SEBT composite score compared to group C (97.30±10.83) and group D (98.13±9.47) suggests that fatigue have a diminishing effect on dynamic balance. KTape application inhibit the effects of fatigue and preserved lateral and posterior direction of SEBT. KTape application may lower the risk for injuries in the lateral and posterior directions following fatigue induction. Effect sizes (post mean-pre mean)/SD(pre) Group A Group B Anterior -0.71 -1.29 Medial -0.47 -0.81 Lateral -0.43 -1.31 Posterior -0.40 -1.00

Reference	Subjects, number (n) targeted	Study design	Athletic level, involvement	Intervention (fatigue protocol)	Outcome (dynamic balance)	Key findings
Zech et al. 2012 [38]	19 male team handball players (age: 16.8 6 ± 0.6 years). 2 German youth handball teams, first and second divisions.	Pre-post	Athletes were regularly active and currently engaged in regular summer preseason handball and structured exercise training sessions (2–3 times per week). Competitive.	Whole-body fatigue – treadmill running was induced by running on a motorized treadmill with increasing speed at a constant grade of 1.5% Localized muscle fatigue – unilateral barbell step-ups induced fatigue by using 3 sets of single- leg barbell step-ups on a bench (30-cm height) with subsequent heel raises.	SEBT; 4 directions: anterior, medial, lateral, posterior; dominant leg	No fatigue effects were found for the SEBT. Effect sizes (post mean-pre mean)/SD(pre) Treadmill Localized Overall 0.09 -0.22 Anterior 0.24 -0.15 Medial 0.14 -0.09 Posterior -0.06 -0.41 Lateral -0.03 -0.15
Whyte et al. 2015 [39]	40 university athletes: 20 male (20.83±1.50) and 20 female (20.45±1.34) athletes.	Pre-post	Gaelic football, hurling/camogie, soccer. Training level and frequency not specified. Competitive.	The HIIP consisted of 4 repetitions of 10-m forward sprinting with a 908 change of direction and then backward sprinting for 5 m, 2 repetitions of 2- legged jumping over 5 hurdles, 2 repetitions of high-knee side stepping over 5 hurdles, and 4 repetitions of lateral 5-m shuffles. Participants rested for 30 seconds before repeating the circuit.	SEBT; 8 directions; dominant leg	A main effect for time, with a decreased average of all 8 directions normalized maximal SEBT scores postfatigue ($p < .001$; ES 0.695) indicating HIIP negatively affected dynamic postural control as assessed by the SEBT in athletes. They also found there was a time X sex effect (p 0.007; ES 0.719), indicating that women were affected less negatively (effect sizes closer to zero) by the HIIP. Effect sizes (post mean-pre mean)/SD(pre) Male Female Overall -1.45 -0.71 Anterior -0.93 -0.44 Anteromedial -0.92 -0.31 Medial -1.27 -0.33 Posteromedial -1.12 -0.59 Posterior -1.07 -0.99 Posterolateral -1.21 -0.62 Lateral -0.92 -0.48 Anterolateral -0.82 -0.18
Armstrong et al. 2018 [28]	35 university dancers: 30 females (age 20.09), 5 males (age 20.62)	Pre-post	Dancers enrolled in an undergraduate dance program who performed primarily contemporary dance. Attended dance classes for a minimum of 6 hours per week. Duration and competitiveness not described. Competitive.	Dance aerobic fitness test. Daft is a dance-specialized test involves a 16-beat dance sequence consisting of 5 x 4-minute stages of increasing intensity associated with increased size of movement or additional movements. Subjects were removed from the test if the supervising investigator observed that they fell behind the beat of the test or their performance of the movement was judged to be compromised.	YBT; bilaterally Percentage maximized reach	Post-daft, the mean SEBT percentage maximized reach distances for dominant and non-dominant legs were non-significant compared to pre-daft scores, and in fact for PL and PM directions, the post-fatiguing balance measures were higher on average than the pre-fatiguing. Lack of a main effect for exercise was observed in each of the anterior dominant and non-dominant, posterolateral dominant and non-dominant, and posteromedial dominant and non-dominant scores. Effect sizes (post mean-pre mean)/SD(pre) Non-dominant Dominant Anterior -0.19 -0.07 Posterolateral 0.29 0.17 Posteromedial 0.38 0.19 Composite 0.16 0.24
Johnston et al. 2018 [29]	20 male and female (age 23.75, university students engaged in competitive sport	Pre-post	University students engaged in competitive sport. Training type, level and frequency not specified. Competitive.	Modified version of the Wingate anaerobic test was performed. The test required the participant to cycle for 60 s rather than the traditional 30 s. Prior to maximal exercise testing, the subject initially completed a low-resistance warm-up for 5 min. During the warm-up, participants completed 3 × 5 s sprints. On completion of the warm-up, participants commenced cycling at a cadence of between 50–60 rpm for 30 s. The participants were instructed that the test would commence at the completion of the 30s and that they should accelerated maximally. Participants were encouraged to maintain maximal effort throughout the 60 s in order to ensure maximal fatigue. Changes in the power generated were monitored over the course of the test to ensure that each individual had maintained a maximal effort throughout the Wingate protocol.	YBT; dominant leg	All 3 reach directions of YBT showed statistically significant differences between pre-fatigue and the first post-fatigue measurement (anterior; $p = 0.019$, posteromedial; $p = 0.019$ & posterolateral; $p = 0.003$). The anterior reach direction returned to pre-fatigue levels within 10min ($p=0.632$). The posteromedial reach direction returned to pre-fatigue levels within 20 min ($p = 0.236$), while the posterolateral direction maintained a statistically significant difference at 20 min ($p = 0.023$). Effect sizes cannot be derived. Pre and post means presented graphically without SD.

Reference	Subjects, number (n) targeted	Study design	Athletic level, involvement	Intervention (fatigue protocol)	Outcome (dynamic balance)	Key findings
Cavanaugh et al. 2016 [30]	12 healthy and recreationally active participants from university population 7 male (age 24.1 years) 5 women (age 23.7 years)	Pre-post	Does not indicate type, level, or frequency of activity. Recreational.	Participants performed 4 sets of unilateral (dominant leg) Bulgarian squats to failure with 1 minute rest between sets. The Bulgarian squats were conducted in a lunge position with the nondominant leg extended and the foot resting on a platform (50 cm) behind the participant. Using body weight as resistance, the participants were instructed to flex the front knee (dominant) to 90 degrees and return to an extended knee position, until they were unable to continue. With the aid of a metronome, the frequency of concentric and eccentric contractions was 1 per second. The number of repetitions performed in each set was recorded.	YBT; dominant leg	There were no significant main effects or interactions for the y balance test Effect sizes for prefatigue 2 to postfatigue 1 min Effect sizes (post mean-pre mean)/SD(pre) Anterior -0.24 Posterior medial -0.18 Posterior lateral -0.21
McMullen et al. 2011 [31]	18 men (avg. age 22 years) and 18 women (avg. age 22).	Pre-post	All volunteers had at least a moderately active lifestyle, deemed, participating in 150 to 300 minutes of physical activity per week. Recreational.	Participants performed repeated side-lying, eccentric hip-abduction contractions until the G-Med was fatigued. Participants performed a maximal voluntary isometric contraction before the fatiguing protocol and before any practice trials or testing. This contraction served as the participant's baseline median frequency. Participants were instructed to abduct the hip to 15° with the knees slightly flexed, then lower it back to neutral. Concentric contractions lasted less than 2 seconds, during which time the participants actively abducted the hip to 15°. Eccentric contractions lasted 5 seconds. Participants slowly lowered the abducted hip back to the starting position. With every fifth contraction, participants performed a 2-second isometric contraction against the canvas belt (ie, at 15° of hip abduction), and a 1-second clip of G-Med EMG was recorded during the middle 1.0 second of the contraction. Median frequency was calculated immediately in real time. The participant continued this process until successfully reaching a 15% downward shift in median frequency compared with a baseline measure of median frequency established before the fatiguing exercise.	YBT; dominant leg	After the fatiguing protocol, both groups displayed a decrease in dynamic postural control, as demonstrated by shorter reach distances on the SEBT ($f3,32 = 30.3$, $p < .001$). When men and women were pooled, we observed decreases in the anterior ($f1,34 = 70.7$, $p < .001$), posteromedial ($f1,34 = 57.9$, $p < .001$), and posterolateral ($f1,34 = 54.4$, $p < .001$) reach directions. Postural control was affected negatively after a g-med-fatiguing exercise. Pooled results across men and women Effect sizes (post mean-pre mean)/SD(pre) With 95%CI Anterior -1.04 (-1.74, -0.34) Posterior medial -0.62 (-1.28, 0.05) Posterior lateral -0.54 (-1.21, 0.12)
Steib et al. 2013 [40]	30 young athletes: Ankle sprain copers, consisting of 14 athletes with a history of a severe ankle sprain (22.71±2.81) Control group of 16 healthy athletes (25.88 6 2.66)	Pre-post	Athletes from different sports. Training level and frequency not specified. Competitive.	Whole-body fatigue was induced by having participants run on a motorized treadmill with increasing speed. The protocol started at 8 km/h, and speed was increased stepwise by 2 km/h every 3 minutes. Participants were instructed to run as long as possible until complete exhaustion.	SEBT; 4 directions: anterior, posterior, medial, lateral; dominant leg Mean over 4 directions used for each subject	Treadmill running had significantly reduced the mean of 4 directions of the normalized SEBT maximum reach distance in the copers group ($p \leq 0.00$), the healthy athletes had insignificant reductions in SEBT. A group x time interaction ($p = .03$) was evident for the SEBT, with larger reductions in mean reach distances in the coper group (-2.43) than in the control group (-0.37). Fatiguing running significantly affected dynamic postural control in participants with a history of ankle sprain. Fatigue-induced alterations of dynamic postural control were greater in athletes with a previous ankle sprain. Effect sizes (post mean-pre mean)/sd(pre) Controls Copers SEBT -0.09 -0.27

tiple station protocols. Hosseinimehr *et al*.[34] fatigued 15 healthy (age 21.78±0.79 years) physical education students and 15 students with chronic ankle instability (age 21.43±0.83 years), using a seven-station protocol including sprinting, push-ups, and sit-ups. For the healthy control group, paired t-tests showed significant differences (p<0.05) in the mean of reached distance (cm) between pre and post-tests in eight directions. Sarshin *et al*.[36] fatigued 20 physical education students (age 21.4±1.63 years) with two years of badminton experience and found a significant decrease in the YBT (p≤0.001) after a six-phase functional fatigue protocol involving agility drills, box jumps, two-legged hop sequences, side-to-side bounds, mini-trampoline, and resistance band exercises. Zulfikri *et al*.[37] studied 72 male recreational athletes in a randomized controlled study design involving four groups: Group A (Kinesiology Tape (KT) application and fatigue), Group B (no tape and fatigue, age 21.79±1.44 years), Group C (KT and no fatigue), Group D (no tape and no fatigue). Their protocol involved functional agility stations involving vertical jumping, stepping up/down, squatting, and L-Drill. Results showed group A and group B attaining lower mean SEBT composite scores compared to Group C and Ground D. More importantly, significant reductions were found in mean normalized reach distance in Group B for anterior (p<0.001), medial (p<0.001), lateral (p<0.001), posterior (p<0.001) direction, and composite score (p<0.05). The fourth study by Gribble *et al*.[19] utilized a five-arm quasi-experimental study-design including four different fatigue conditions: 1) isolated ankle dorsi-and-planar-flexion, 2) isolated knee flexion and extension, 3) isolated hip flexion and extension, 4) a functional repeated lunging task, and 5) control of no fatigue. Subjects were 16 physically active individuals (eight men: age 22.5 ± 2.45 years; eight women: age 22.5 ± 2.56 years) and all underwent all four fatiguing protocols, each separated by at least one week. All fatigue conditions created a decrease in maximum normalized reaching distance for both genders compared with the control condition (p<0.05). However, women performed farther than men while demonstrating a greater amount of knee flexion, and fatigue amplified these differences. Similarly, McMullen *et al*.[31] studied 36 moderately active men (age 22 ± 3.64 years) and women (age 22 ± 3.14 years) performing the YBT before and after repeated side-lying, eccentric hip-abduction contractions. After the fatiguing protocol, both groups displayed a decrease in dynamic balance, as demonstrated by shorter reach distances on the SEBT (p<0.001). When men and women were pooled, they found significant decreases in anterior (p<0.001), posteromedial (p<0.001), and posterolateral (p<0.001) reach directions. When considering the effect sizes for the aforementioned studies, they were typically in the medium-to-large range: 1.04-2.04 in the anterior direction; 0.8 in the anteromedial direction; 0.81-1.51 in the medial direction; 0.62-0.94 in the posteromedial direction; 0.46-1.00 in the posterior direction; 0.54-1.00 in the posterolateral direction; 0.76-1.92 in the lateral direction; 1.71 in the anterolateral direction. Effect sizes for Gribble *et al*.[19] could not be computed.

In contrast to the previously mentioned studies, two studies also involving recreational athletes, found insignificant changes. Gribble *et al*.[17] studied 30 physically active (16 healthy (22.5 ± 2.4 years) and 14 chronic ankle instability (CAI) (21.9 ± 2.9 years)) subjects. Each subject underwent the following fatiguing protocols on different days: 1) ankle fatigue isokinetically in a concentric-concentric protocol for plantar flexion/dorsiflexion movement, and 2) repeated lunging tasks. Results demonstrated insignificant normalized distances in both groups with both fatigue interventions. The second study by Cavanaugh *et al*.[30], found that 12 recreationally active university participants also showed no significant differences in the YBT before-and-after fatigue protocol involving unilateral, repeated concentric and eccentric contractions of one Bulgarian split squat per second. The effect sizes for the Cavanaugh *et al*.[30], were typically in the small-to-medium range: 0.24 in the anterior direction, 0.18 in the posteromedial direction, and 0.21 in the posterolateral direction. Effect sizes for Gribble *et al*.[17] could not be computed.

As for the competitive athletes, three studies showed significant effects of induced fatigue on dynamic balance. In the first study by Steib *et al*.[40], 57 local athletes (including 19 healthy controls (age 23.32±3.79)) involved in handball, volleyball, basketball, and soccer practicing at least three times per week were fatigued by running on a treadmill until exhaustion. The running significantly affected SEBT in medial reach distances in the healthy control group (p = 0.031; ES = –0.29). A second study by Whyte *et al*.[39] used a high-intensity intermittent exercise protocol (HIIP) to fatigue two groups of university athletes (20 male (age 20.83±1.50) and 20 female (age 20.45±1.34)) involved in Gaelic football, hurling, and soccer, with no mention of training level or frequency. Results showed a decreased average for all eight directions of normalized maximal SEBT scores post fatigue (P < .001; ES 0.695) indicating HIIP's negative effect on dynamic postural control. Of note, there was an interaction in effect based on gender (P 0.007; ES 0.719), as women were affected less negatively than men (P <.001; ES 0.695). The third study by Johnston *et al*.[29] investigated 20 male and female university students (age 23.75 ± 4.79) engaged in competitive sport with no mention of type of sport, training level, or frequency. This is the first study to investigate SEBT/YBT at pre-determined times post fatigue, rather than immediately following fatigue. Subjects underwent a modified Wingate anaerobic fatigue cycling test, and were tested at zero, 10, and 20 minutes post fatigue. All three reach directions of the YBT demonstrated statistically significant differences between pre-fatigue and the first post-fatigue measurements (anterior; p = 0.019, posteromedial; p = 0.019 & posterolateral; p = 0.003). The anterior reach direction returned to pre-fatigue levels within 10min (p = 0.632); the posteromedial reach direction returned to pre-fatigue levels within 20 min (p = 0.236); while the posterolateral direction maintained a statistically significant difference at 20 min (p = 0.023). These results indicate a negative effect of maximal anaerobic fatigue on normalised YBT scores in all three directions. The effect sizes for the aforementioned studies varied considerably ranging from small-to-large: 0.16-0.93 in the anterior direction; 0.31-0.93 in the anteromedial direction; 0.29-1.27 in the medial direction; 0.59-1.12 in the posteromedial direction; 0.13-1.07 in the posterior direction; 0.62-1.21 in the posterolateral direction; 0.21-0.92 in the lateral direction; and 0.18-0.82 in the anterolateral direction. Effect sizes for Johnston *et al*.[29] could not be computed.

While the aforementioned three studies showed significant effects, there were five studies that concluded otherwise. In a comparison of 16 healthy athletes (n=16, age 25.88±2.66) with 14 ankle-sprain copers (n=14 age 22.71±2.81), Steib *et al*.[35] showed no significant changes among the healthy control athletes from pre- to post-treadmill running. A second study by Baghbani *et al*.[32] recruited 15 healthy female non-athletes (age 16.1±1.8 years) and 15 female (mean age ± SD: 16.1 ± 1.1 years) handball and basketball athletes, competing at a provincial level and involved in sport-specific training for a minimum of seven hours weekly for two years. They measured SEBT before and after induced fatigue involving multiple exertional stations comprised of jogging, sprinting, push-ups, sit-ups, and step-ups. The average of the eight directions of the SEBT balance performance in the non-athlete group significantly decreased after fatigue (p = 0.0003); however, the athlete group had no significant changes in balance performance (p = 0.78). Additionally, the athlete group had significantly better balance performance in pre (p = 0.005) and post-tests (p = 0.0001) when compared to the healthy control counterparts. The third study by Baghbaninaghadehi *et al*.[33] studied 15 female basketball athletes who had four to five practices per week for two years. Fatigue was induced using multiple exertional stations comprised of jogging, sprinting, push-ups, sit-ups, and step-ups. Results concluded no significant difference in the mean deviation of dynamic balance performance of the subjects in eight directions before and after the fatigue protocol. A fourth study by Zech *et al*.[38] fatigued 19 male 1st and 2nd division handball athletes engaged in summer preseason training two to three times per week. Subjects were tested under two fatigue conditions: 1) treadmill running for whole-body fatigue, and 2) unilateral barbell step-ups for localized muscle fatigue. Results showed no fatigue effects for mean SEBT under either fatigue condition. The fifth study by Armstrong *et al*.[28] investigated undergraduate dancers who attended classes a minimum of six hours per week, though level of intensity was not reported. The dancers were fatigued with a Dance Aerobic Fitness Test (DAFT) requiring increasing sequence dance intensity. Mean YBT results revealed insignificant post-DAFT YBT compared to pre-DAFT YBT. The effect sizes for the five aforementioned studies were typically in the low-to-high range: 0.07-0.67 in the anterior direction; 0.05 in the anteromedial direction; 0.09-0.33 in the medial direction; 0.19-0.48 in the posteromedial direction; 0.06-0.41 in the posterior direction; 0.17-0.92 in the posterolateral direction; 0.03-0.57 in the lateral direction; and 1.41 in the anterolateral direction; 0.02-0.24 for the composite of all directions.

Discussion

Our review found that the impact of inducing fatigue on dynamic balance as measured by the SEBT/YBT in the athletic population was inconsistent. Of the 15 articles comparing recreational and competitive athletes, eight suggest significant effects of various induced fatigue protocols on SEBT/YBT in both groups, while seven suggest insignificant effects of various induced fatigue protocols on SEBT/YBT.

Heterogeneity in the populations studied may in part explain the variety of findings in the relationship between fatigue and dynamic balance. The two types of athletes assembled in this review can be distinguished by their training regimens. When considering recreational athletes, there is a stronger trend supporting significant effects of induced fatigue affecting dynamic balance[19,31,34,36,37]; and only two studies reporting insignificant effects[17,30]. However, in studies involving competitive athletes, the opposite trend was seen: three studies supported the effects of induced fatigue on dynamic balance[29,39,40], whereas five studies negated the effect of induced fatigue on dynamic balance[28,32,33,38]. However, these trends may be explained by the competitive athletes' increased capacity to withstand the deleterious effects of induced fatigue. This may explain why the majority of studies analyzing competitive athletes yield insignificant results, while those analyzing recreational athletes yield otherwise. This assessment of the studies' findings is supported by the results of Baghbani *et al*.[32] , where athletes compared with healthy controls noted that only the latter had significant differences following fatigue.

A second reason that might explain the equivocal findings is the heterogenous types of sports included in single studies. All but three studies including competitive sports were heterogenous. Namely, Baghbaninaghadehi *et al*.[33] studied 15 female basketball athletes, Zech *et al*.[38] studied 19 male handball 1st and 2nd division athletes, and Armstrong *et al*.[28] studied 35 undergraduate dancers. Depending on the requirements of each sport, different balance control strategies may be developed.[6,41,42] Thus, it may be more appropriate to consider a homogenous athlete population in order to avoid confounding the relationship between fatigue and balance by different athletic endeavors.

Finally, a third reason behind the equivocal findings is that laboratory-induced fatigue may not be challenging enough (in method or duration) to alter dynamic balance postural control in these athletes.

This systematic review is the first to consider effects of induced fatigue on the SEBT/YBT in the athletic population. A previous review by Gribble *et al*.[1] investigated the effect of fatigue on dynamic balance but did not focus on the athletic population. Since then, more studies have been published on this topic. Only two of the three studies from the previous review[1] were included in the current review as one of them did not meet the current eligibility criteria.

This systematic review finds the impact of induced fatigue on dynamic balance to be equivocal. Currently, the relevance of considering fatigue as a risk factor for poor dynamic posture control is unclear. Further investigation with greater methodological rigor is required. Future investigators should carefully consider the variations in training regiments, the heterogeneity of the athletic population recruited, and the fatigue protocols. They should utilize adequate sample size with control groups that don't receive fatiguing protocols and assess outcomes over longer temporal intervals. Lastly, they should record any difficulty the subjects encounter while performing the SEBT/YBT post fatigue (i.e. failed attempts) as this may provide important information regarding the effects of fatigue on balance assessments.

Additionally, the majority of studies included in the review are pre-post study design, in which the subjects serve as their own control by measuring a pre-SEBT/YBT assessment prior to the intervention. However, this does not fulfill the criteria of having a control that does not undergo the fatiguing regimen. Only two studies fulfill this criteria: Gribble *et al*.[19] in quasi-experimental study-design used the same subjects but had a control condition where they did not render any fatigue on a different experimental day and; the randomized control trial of Zulfikri *et al*.[37] which had subjects randomly allocated to not receive any fatigue. Utilizing proper control arms better attributes any changes in dynamic balance to the fatiguing protocol used. Moreover, only one study by Johnston *et al*.[29] followed up on their outcome at different intervals: immediately after intervention, 10 minutes after, and 20 minutes after, noting that dynamic balance remained significantly affected at 20 minutes. The implication of fatigue affecting balance longer than 20 minutes may be clinically meaningful within the context of injury and prolonged training hours.

The strengths of this review include a search strategy that was verified through peer review and adapted for a broad set of databases to ensure identification of all possibly relevant articles. The authors narrowed search terms to include only athletic (and not "generally healthy") populations to draw distinction between the two demographics, which may enhance the direction of future research in this field of knowledge. Additionally, two independent reviewers were used for screening and critical appraisal purposes to minimize error and bias, using a well-accepted and valid set of criteria for critical appraisal of relevant studies.

Limitations of this systematic review include lack of sensitivity analysis on thresholds for low risk of bias studies. Additionally, the definition of athlete in the research question was broad, which may have made it difficult to identify relevancy during the critical appraisal and evidence syntheses process. Lastly, inclusion of studies published solely in English may have excluded relevant studies. However, previous reviews have found that this has not led to biases in the reported results.[43]

Future studies investigating the effects of fatigue on dynamic balance should consider the following suggestions: recruit homogenous athletic populations whose training is well described; conduct a sample size estimation to ensure an adequate numbers of subjects; use non-laboratory fatigue protocols to simulate a more realistic fatigue intervention (especially for the competitive athlete population); use a control group not receiving any fatigue intervention; repeat follow-up outcome measures to assess for longevity of fatigue effects, and report frequency of errors while subjects attempt the SEBT/YBT post-fatigue as an additional outcome.

Conclusions

The impact of induced fatigue on dynamic balance is inconsistent as measured by the SEBT/YBT in the athletic population. In the competitive athletic population, evidence suggests dynamic balance performance remains intact following induced fatigue. However, in the recreational athletic population, evidence suggests dynamic balance performance is significantly impacted by fatigue. Further high-quality athlete specific studies are required to confirm these preliminary findings. Nevertheless, there is no conclusive evidence that induced fatigue affects dynamic balance outcomes in the asymptomatic athletic population.

Practical implications

- Evidence suggests the impact of induced fatigue on dynamic balance in the athletic population is inconsistent.
- Preliminary evidence suggests that competitive athletes' dynamic balance performance is more likely to remain unaffected by induced fatigue.
- Preliminary evidence suggests that recreational athletes' dynamic balance performance is more likely to be affected by induced fatigue.

Key Points

- Evidence suggests the impact of induced fatigue on dynamic balance in the athletic population is inconsistent.
- Preliminary evidence suggests that competitive athletes' dynamic balance performance is more likely to remain unaffected by induced fatigue.
- Preliminary evidence suggests that recreational athletes' dynamic balance performance is more likely to be affected by induced fatigue.

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Appendix 1.
Search strategy

MEDLINE SEARCH STRATEGY – May 28, 2019	
1.	MH Athletes
2.	MH Sports +
3.	TI athlete* or AB athlete*
4.	TI sport* or AB sport*
5.	TI archery* or AB archery*
6.	TI badminton* or AB badminton*
7.	TI biath* or AB biath*
8.	TI bmx* or AB bmx*
9.	TI bobsle* or AB bobsle*
10.	TI bowling* or AB bowling* or TI bowler* or AB bowler*
11.	TI boxing* or AB boxing* or TI boxer* or AB boxer*
12.	TI basketball* or AB basketball*
13.	TI baseball* or AB baseball*
14.	TI canoe* or AB canoe*
15.	TI cricket* or AB cricket*
16.	TI curling* or AB curling*
17.	TI cycling* or AB cycling* or TI cyclist* or AB cyclist*
18.	TI diving* or AB diving* or TI diver or AB diver or TI divers or AB divers
19.	TI equest* or AB equest*
20.	TI fencing* or AB fencing* or TI fencer* or AB fencer*
21.	TI golf* or AB golf*
22.	TI football* or AB football*
23.	TI gymnast* or AB gymnast*
24.	TI hockey* or AB hockey*
25.	TI jiu jitsu* or AB jiu jitsu* or TI jiu-jitsu* or AB jiu-jitsu* or TI ju-jitsu* or AB ju-jitsu*
26.	TI jogging* or AB jogging* or TI jogger* or AB jogger*
27.	TI judo* or AB judo*
28.	TI karate* or AB karate*
29.	TI kayak* or AB kayak*
30.	TI kendo* or AB kendo*
31.	TI kung fu* or AB kung fu* OR TI kung-fu* or AB kung-fu*
32.	TI lacrosse* or AB lacrosse*
33.	TI luge* or AB luge*
34.	TI martial art* or AB martial art*
35.	TI mountaineer* or AB mountaineer*
36.	TI qigong* or AB qigong*
37.	TI racquet* or AB racquet*
38.	TI ringette* or AB ringette*
39.	TI rower* or AB rower* or TI rowing* or AB rowing*
40.	TI rugby* or AB rugby*
41.	TI runner* or AB runner*
42.	TI running* or AB running*

APPENDIX 1 – MEDLINE SEARCH STRATEGY – May 28, 2019 – continued	
43.	TI sailing* or AB sailing* or TI sailor* or AB sailor*
44.	TI soccer* or AB soccer*
45.	TI skiing* or AB skiing* or TI skier* or AB skier*
46.	TI skating* or AB skating* or TI skater* or AB skater*
47.	TI sledding* or AB sledding*
48.	TI snowboard* or AB snowboard*
49.	TI softball* or AB softball*
50.	TI speed-skat* or AB speed-skat*
51.	TI squash* or AB squash*
52.	TI swim* or AB swim*
53.	TI taekwondo* or AB taekwondo*
54.	TI tai ji or AB tai ji or TI tai chi* or AB tai chi* or TI taiji* or AB taiji* or TI taichi* or AB taichi*
55.	TI tennis* or AB tennis*
56.	TI (track n2 field) or AB (track n2 field)
57.	TI triath* or AB triath*
58.	TI volleyball* or AB volleyball*
59.	TI wakeboard* or AB wakeboard*
60.	TI water polo* or AB water polo*
61.	TI wrestling* or AB wrestling* or TI wrestler* or AB wrestler*
62.	TI weightlift* or AB weightlift* or TI weight lift* or AB weight lift*
63.	TI walking* or AB walking*
64.	**1-63/OR [** sports]**
65.	TI star excursion* or AB star excursion* or TI star-excursion* or AB star-excursion*
66.	TI y-balance* or AB y-balance*
67.	TI y balance* or AB y balance*
68.	TI y-test* or AB y-test*
69.	TI star n2 test* or AB star n2 test*
70.	TI ybt* or AB ybt*
71.	TI sebt or AB sebt
72.	MH Postural Balance
73.	TI dynamic* n2 postural balance* or AB dynamic* n2 postural balance*
74.	TI dynamic* n2 balance test* or AB dynamic* n2 balance test*
75.	TI postural balance n2 test*
76.	**65-76 / OR [** star-excursion test]**
77.	MH Fatigue
78.	MH Muscle Fatigue
79.	TI fatigu* or AB fatigu*
80.	**77-80/ OR [**fatigue]**
81.	64 AND 76 AND 80
82.	LIMIT 81 English language

APPENDIX 1 – SportDiscus Search Strategy	
1.	DE Athletes +
2.	DE Sports +
3.	TI athlete* or AB athlete*
4.	TI sport* or AB sport*
5.	TI boxing* or AB boxing* or TI boxer* or AB boxer*
6.	TI basketball* or AB basketball*
7.	TI baseball* or AB baseball*
8.	TI cycling* or AB cycling* or TI cyclist* or AB cyclist*
9.	TI diving* or AB diving* or TI diver or AB diver or TI divers or AB divers
10.	TI fencing* or AB fencing* or TI fencer* or AB fencer*
11.	TI golf* or AB golf*
12.	TI football* or AB football*
13.	TI gymnast* or AB gymnast*
14.	TI hockey* or AB hockey*
15.	TI jiu jitsu* or AB jiu jitsu* or TI jiu-jitsu* or AB jiu-jitsu* or TI ju-jitsu* or AB ju-jitsu*
16.	TI jogging* or AB jogging* or TI jogger* or AB jogger*
17.	TI judo* or AB judo*
18.	TI karate* or AB karate*
19.	TI kayak* or AB kayak*
20.	TI kendo* or AB kendo*
21.	TI kung fu* or AB kung fu* OR TI kung-fu* or AB kung-fu*
22.	TI martial art* or AB martial art*
23.	TI mountaineer* or AB mountaineer*
24.	TI qigong* or AB qigong*
25.	TI racquet* or AB racquet*
26.	TI rugby* or AB rugby*
27.	TI runner* or AB runner*
28.	TI running* or AB running*
29.	TI soccer* or AB soccer*
30.	TI skiing* or AB skiing* or TI skier* or AB skier*
31.	TI skating* or AB skating* or TI skater* or AB skater*
32.	TI swim* or AB swim*
33.	TI taekwondo* or AB taekwondo*
34.	TI tai ji or AB tai ji or TI tai chi* or AB tai chi* or TI taiji* or AB taiji* or TI taichi* or AB taichi*
35.	TI tennis* or AB tennis*
36.	TI (track n2 field) or AB (track n2 field) track*
37.	TI volleyball* or AB volleyball*
38.	TI water polo* or AB water polo*
39.	TI wrestling* or AB wrestling* or TI wrestler* or AB wrestler*
40.	TI weightlift* or AB weightlift* or TI weight lift* or AB weight lift*
41.	TI walking* or AB walking*
42.	**1-41 /OR**
43.	DE Exercise Test

APPENDIX 1 – SportDiscus Search Strategy – continued	
44.	TI star excursion* or AB star excursion* or TI star-excursion* or AB star-excursion*
45.	TI y-balance* or AB y-balance*
46.	TI y balance* or AB y balance*
47.	TI y-test* or AB y-test*
48.	TI star n2 test* or AB star n2 test*
49.	TI ybt* or AB ybt*
50.	TI sebt or AB sebt
51.	**43-50 / OR**
52.	DE Fatigue
53.	TI fatigu* or AB fatigu*
54.	**52-53/ OR**
55.	DE Posture
56.	TI dynamic* n2 postural balance* or AB dynamic* n2 postural balance*
57.	TI dynamic* n2 balance test* or AB dynamic* n2 balance test*
58.	**55-57/OR**
59.	42 AND 51 AND 54
60.	42 AND 54 AND 58
61.	59 OR 60
62.	LIMIT 61 English language