International Journal of EXERCISE SCIENCE

Review Article

Effects of Isometric Exercises versus Static Stretching in Warm-up Regimens for Running Sport Athletes: A Systematic Review

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ABSTRACT

International Journal of Exercise Science 14(6): 1204-1218, 2021. The objective of this review was to identify studies that report the pre-exercise effects of isometric exercise versus static stretching on performance and injury rates of running athletes in comparison to their outcomes. Seven electronic databases were searched: Cochrane, PEDro, CINAHL, PubMed, MEDLINE, SportDiscus, and GoogleScholar. Data was collected using an established PICO question, and assembled logic grid. The included articles were required to (1) assess running performance or injury prevention and (2) include isometric exercises/muscle activation and/or static stretching. Articles published prior to the year 2000, non-English, and non-human studies were excluded. Quality was assessed using the PEDro quality appraisal tool for RCTs, and NIH-NHLBI appraisal tool for others. The Cochrane collaboration tool for risk of bias as well as the PRISMA 2020 statement were also used in this review. In the nine articles appraised in the study, variables assessed included running economy, injury rate, soreness levels, sprint times, and countermovement and drop jump height. Static stretching demonstrated a significant negative effect on sprint performance and countermovement/drop jump height. It also demonstrated a decrease in variables associated with injury over extended periods and no impact on running economy. Isometric holds demonstrated no significant effect on sprint performance or countermovement/drop jump height. It also demonstrated decreases in soreness levels and no impact on running economy. Isometric holds have positive effects/fewer negative results on running athletes when compared to static stretching for pre-exercise performance. Research with decreased risk of bias is needed to determine maximal benefits from timing/dosage of isometric hold in warm-up.

KEY WORDS: Post-activation potentiation; athletic competition; distance runners; endurance runners; muscle activation; lower extremity

INTRODUCTION

As the popularity of running has grown, so have the strategies to maximize performance and decrease risk of injury. Warm-up plans, defined as any pre-exercise activity used to improve performance and decrease injury rate, has long been the topic of discussion when addressing the above discussed performance (20, 21).

Running athletes are often misled, confused, and oversaturated with conflicting information on how best to prevent injury and improve performance. Previous studies suggest that up to 75.4% of runners still name static stretching as the most frequent warm-up strategy to prevent musculoskeletal injuries (30). The popularity of static stretching among the athletic population can be misleading, as it has been shown to affect athletic performance and injury rates in a negative way and may have little to no significant impact on soreness levels when used as a pre-activity technique (4, 11, 23). Dynamic warm-ups have a significant positive impact on an athlete's performance and injury rates when used prior to activity and should be considered the gold standard for muscular performance and injury prevention (5, 21, 24). This article does not aim to replace dynamic warm-up strategies, but rather discuss new strategies that may be added to increase its effectiveness.

As experts continue to research the most effective warm-up strategies, youth running populations continue to search how best to increase performance while decreasing injury rates (27). A strong correlation between poor strength, or improperly trained muscle groups, and injury rates have been identified in youth runners (16). Muscular weakness added to sport specialization and a youth athlete's tendency to over train, a current popular and unhealthy trend, has led to an increase in preventable injuries (27). It is hypothesized that by identifying a time efficient way to correct muscular imbalances, injury rates may decrease and proper muscular coordination may minimize the effects of overtraining. Currently, dynamic warm-ups combined with isometric exercises have been utilized as the more effective strategy to decrease injury rates compared to static stretching (18). Isometric holds are hypothesized to increase the post-activation potentiation of the targeted muscle groups and therefore increase muscular performance following intervention while performing more complex activities (6, 13).

By increasing the activation of targeted muscle groups by using isometric holds of weakened, targeted muscles, it is hypothesized that the injury rates may decrease, and performance may improve. Gluteal group weakness is often associated with dynamic knee valgus leading to additional stress on the lower extremity and loss of functional power (6, 19). Strengthening exercises of the gluteal group have been studied extensively using EMG activity, but specific pre-exercise warm-up strategies that include the muscle group are still unclear (7, 8, 19). By increasing proper muscular coordination prior to athletic performance through short term neurological changes made by isometric holds (17, 24), it is hypothesized that the muscle groups may be able to perform at a higher level, leading to an increase in strength, decreased injury rates, and increased performance for running athletes (6, 25).

A clear and organized study that compares static stretching to isometric exercises of gluteal muscle groups and their effect on youth running athlete's performance and injury rates is currently missing from the research. This analysis will review the research presently established on the use of static stretching compared to the use of pre-exercise isometric holds on jump performance, sprint performance, running economy, and injury rates.

The purpose of this review is to compare the effects of isometric exercise versus static stretching on performance and injury rates of running athletes.

METHODS

The data was collected using an established PICO (population, intervention, control, and outcomes) question of, "For the running athlete, does lower extremity isometric exercise included in dynamic warm-up lower soreness levels, decrease injury rates, or improve running times compared to lower extremity static stretching?". An assembled logic grid with associated terms, and a specific group of databases using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement for reporting systematic reviews were also used. Duplicate articles identified were removed from inclusion, all full-text articles assessed and considered for inclusion of synthesis were chosen based on their specific pertinence to PICO and on limitations and exclusion standards. The American Physical Therapy Association (APTA) Levels of Evidence was used to rate each included article's level of evidence, which are grades assigned to an article based on its methodological quality of design and validity. A meta-analysis was not completed due to heterogeneity of the studies and number of studies used.

Search dates were conducted from April to June 2020 and again in January 2021. To retrieve potential articles, the databases: Cochrane, PEDro, CINAHL, PubMed, MEDLINE, SportDiscus, and Google Scholar were used. Two panelists independently searched the databases with the PICO question: "For the running athlete, does lower extremity isometric exercise included in dynamic warm-up lower soreness levels, decrease injury rates, or improve running times compared to lower extremity static stretching?" Search terms can be found in Table 1.

Table 1. Primary Logic Grid.

P	I	C	O	Excluding	Limits
High school OR youth OR 14-18-year-old* AND distance runners OR runner* OR athlete* OR cross country OR track	Hip extensor OR isometric OR isometric contraction OR post activation potentiation OR hip OR isometric hold OR activation OR glute OR hamstring NOT rehabilitation	Stretch* OR stretching OR dynamic stretch OR static stretch OR hamstring stretch* OR hip extensor stretch*	Injury rate OR season OR running times OR soreness OR personal record OR missed run* OR missed session* OR pain	Before 2000	English Human

Note: Primary logic grid for search strategy which was modified for each database.

Studies were considered eligible if they met the following inclusion criteria: (1) assess running performance or injury prevention on running athletes; and (2) include isometric exercises/muscle activation and/or static stretching. Exclusion criteria: (1) study was conducted before the year 2000, (2) done with non-human subjects, (3) not written in the English language.

Two raters trained in the use of the Physiotherapy Evidence Database (PEDro) and National Heart, Lung, and Blood Institute (NHLBI) of the National Institutes of Health (NIH-NHLBI) appraisals independently appraised the articles for internal validity. Differences were discussed between the two raters, arbitrated, and the final score validated by a third rater. For six randomized controlled trials, the PEDro was used. For the one controlled intervention study, a quality assessment tool from the NIH-NHLBI was used. For three observational and cross-sectional studies the NIH-NHLBI assessment tool was used. A summary of study quality can be found in Table 2, along with the level of evidence.

Cochrane tool to assess risk of bias in randomized control trials and Cochrane tool to assess risk of bias in cohort studies was used based on the recommendation by the Cochrane Collaboration Handbook (12). A summary of study assessment of bias can be found in Table 2.

Table 2. Study Level, Quality Score, and Risk of Bias.

Study	Level of Evidence	Quality Rating	Risk of Bias
Allison et al., 2008	2	5/10 Fair	4/8 Moderate
Franettovich Smith, 2017	3	Good	6/7 Low
Hayes & Walker, 2007	2	5/10 Fair	4/8 Moderate
Lima et al., 2018	2	6/10 Good	2/6 Moderate
Luedke et al., 2015	3	Good	5/7 Low
Makaruk et al., 2010	2	6/10 Good	4/8 Moderate
Nelson et al., 2005	2	6/10 Good	4/8 Moderate
Pojskic et al., 2015	2	6/10 Good	4/8 Moderate
Young & Elliott, 2001	3	Fair	5/7 Low

Note: For PEDro the score out of 10 and the Quality Rating was provided according to the following scale: 9-10 excellent, 6-8 good, 4-5 fair, < 4 poor. For all other appraisals, scoring was stated as Good, Fair, or Poor. The level of evidence was based on the APTA levels of evidence. PEDro quality appraisal tool was used for randomized control trials and all others used the NIH-NHLBI appraisal tool. Cochrane collaboration tool was used to assess risk of bias.

A total of 562 studies were found through the electronic searching (Figure 1). Nine articles were included in this review based on eligibility criteria. There were six randomized controlled trials, one controlled intervention study, and two prospective cohort studies.

The authors declare no ethical conflicts regarding systematic review. The articles collected have been approved by an ethical committee to perform the clinical trials. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (22).

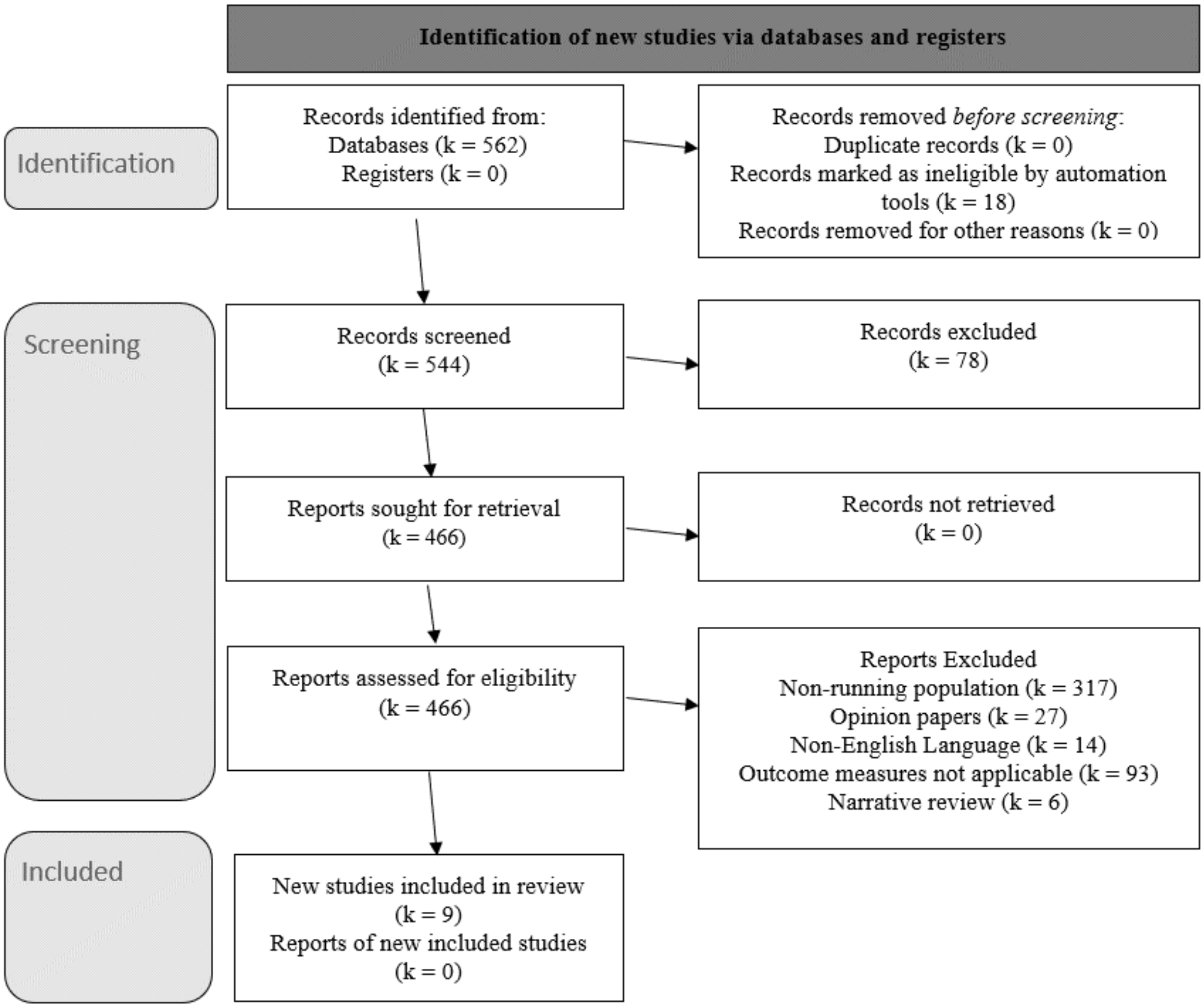

Figure 1. Adapted PRISMA 2020 Diagram. Note. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 diagram.

RESULTS

The above discussed categories are all important variables of running athletes and show differences in results when comparing pre-exercise static stretching or pre-exercise isometric holds. We have also included the category of injury/soreness because we are interested in the best route to improve performance while reducing injury/soreness rates. Calculated effect sizes and 95% confidence intervals are summarized in Table 3.

Running Economy: In terms of running economy, which this paper defines as the energy demand for a given velocity of submaximal running (calculated as maximal oxygen consumption (VO^2max)/respiratory exchange ratio (RER), or VO^2max), Allison et al. (1) and Hayes et al. (10) both showed no significant change when performing a static stretching intervention. Lima et al. (15) used pre-exercise isometric holds as the intervention and saw no significant change in RE when compared to a control group.

Injury Prevention: When discussing injury prevention and soreness prevention, Lima et al. (15) showed a statistically significant decrease in soreness levels, after maximal voluntary isometric contraction (MVIC), compared to the control group, two and four days post downhill run. While Makaruk et al. (18), static stretching demonstrated a statistically significant decrease in asymmetries for flexibility and strength, which over time may lead to injury prevention. Isometric holds showed no significant change in strength or flexibility. When discussing the effects of muscle activation and its effect on injury prevention, Franettovich Smith et al. (9) showed higher gluteus medius activation was a risk factor for hamstring injury, while no significant relationships were noted between gluteus maximus size or activation or with gluteus medius size demonstrating weak muscles need an increase in recruitment to fire. Luedke et al. (16) showed that weakness in hip abductor, knee extensors, and knee flexor strength lead to significant increase in incidence of anterior knee pain.

Sprint Performance: Sprint performance following isometric holds and static stretching were also studied as they play a large role in any running athlete's performance. While a sprint can be its own athletic event, it is an integral part of many other running sports as well as a common reason for injury. Nelson et al. (23) showed static stretching of any sort significantly decreased 20 m sprint time. Pojskic et al. (24) showed isometric holds to have no significant change in 15 m sprint time compared to the control group.

Countermovement Jump (CMJ) Test: Regarding CMJ performance, Allison et al. (1) showed a statistically significant decrease in jump height after static stretch intervention. Pojskic et al. (24) and Lima et al. (15) both found no significant difference between control and isometric hold group when looking at CMJ performance. Although Young et al. (31) did not look specifically at CMJ, the article showed a statistically significant decrease in drop jump performance after static stretch intervention, while isometric hold intervention showed no significant change.

Table 3. Randomized Control Trials.

Author/s	Participants, Time, and Setting	Intervention/ Comparison	Outcome/ Physical Performance Measures	Results
Allison et al., 2008	*n* = 10 Male runners ages 25 ± 5, and similar height, body mass, and maximal oxygen uptake (VO2max) Endurance runners > 5 hours a week of activity Four visits over a 10-day period separated by at least 48 hours	I: Prolonged static stretching 40 s of eight different stretches repealed 3 times C: No stretching	Gas exchange through automated gas analysis system during 10 min of treadmill running at 70% VO2max Sit and reach range of motion (ROM) Isometric strength Countermovement jump height	Running economy changes not significant Significant Sit and Reach ROM + 2.7 ± 0.6 cm Significant isometric strength decrease - 5.6% ± 3.4% Significant countermovement jump height - 5.5% ± 3.4% All $p < 0.05$ CMJ: (95% CI: -1.76 to 5.76) $d = 0.5$ RE/EE: (95% CI: -8.44 to 7.64) $d = 0.047$
Hayes & Walker, 2007	*n* = 7 Male distance runners ages 32.5 ± 7.7, and similar height, body mass, and VO2max 5 tests separated by 24 hours each During the competitive phase of their year	I: Static stretch I: Progressive static stretching I: Dynamic stretching 2x30 second stretches C: No stretching	Sit and reach test running economy (10 min run) steady-state oxygen uptake	Increase of range of motion (ROM) ($p = 0.008$) No sig change in running economy ($p = 0.915$) No sig change in VO^2 (p = 0.943) RE/VO^2max (95% CI: -23.94 to 19.74) $d = 0.112$

Lima et al., 2018	n = 30 Untrained male participants (22.8 ± 2.3 years,) No history of injuries Assessments done between immediately after run to 4 days after	I: Isomeric pre-conditioning (IPC) (10 Maximal voluntary isometric contractions (MVIC) 2 days prior to downhill run C: No MVIC	Muscle damage Running economy countermovement jump height	Muscle soreness 48 hours after downhill run was greater for control than experimental group. RE was shown to have no significant change Isometric peak torque recovered faster in experimental group (3 days vs no full recovery) No sig effect in countermovement jump height or serum creatine kinase activity Effect size = 0.25
Makaruk et al., 2010	Thirty (30) athletes (19 sprinters and 11 jumpers). Mean age 19.3 ± 4.0. Offseason training, exercise programs were 3 sessions per week for 4 weeks	I: Isometric group (8 sec isometric hold of calf, clam shell, glute bridge, SL glute extension) I: Stretching group (calf, HS, V sit, quad stretch) C: Control group	Isokinetic strength test, active knee-extension test (AKE) done before and after.	Bilateral asymmetry of both strength and flexibility of HS muscles. Isometric strength exercises did not lead to changes in asymmetry. Isometric Strength (95% CI: 0.03 to 2.35) d = 0.53 SS Strength (95% CI: 1.63 to 4.59) d = 1.42 Isometric H/Q ratio (95% CI: -.50 to .62) d = 0.321 SS H/Q ratio (95% CI: 0.20 to 2.20) d = 0.62 Isometric flexibility (95% CI: -0.69 to 1.21) d = 0.141 SS flexibility (95% CI: 1.05 to 2.93) d = 1.096
Nelson et al., 2015	Sixteen (16) members of a DI NCAA track team One trial was completed per week (4 weeks total)	I: No stretch of either leg (NS) I: Both stretched (BS) I: Forward leg in the stretching position stretched (FS) I: Rear leg in the starting position stretched (RS)	20 M sprint time was recorded	The BS, FS, and RS protocol induced a statistically significant increase in the 20 M time.

Pojskic et al., 2015	n = 21 healthy male college soccer players 48 hours between interventions, 1 min inter test rest intervals	I: Dynamic stretching (DS) I: Prolonged intermittent low-intensity isometric exercise (ST) I: Prolonged low-intensity isometric exercise with additional external load equal to 30% of body weight C: No conditioning contraction protocol (NCC)	Participants performed countermovement jump tests, 15 m sprint, and modified agility test.	In jumping, dynamic stretching showed superior results. DS, ST, and ST + 30% BW were all statistically different from NCC on agility performance. Isometrics proved to be statistically significant increase in performance compared to NCC. In sprint performance, DS showed sig positive effects compared to NCC and ST CMJ: (95% CI: - 4.64 to 2.04) 15 m Sprint: (95% CI: 0.03 to 0.17)

Note: RCT indicates randomized control trial. VO_2max indicates maximal oxygen consumption. ROM indicates Range of motion. Running economy in (Hayes, 2007) was assessed using a 10-minute run. IPC indicates Isomeric pre-conditioning. MVIC indicates Maximal voluntary isometric contractions. Running economy in (Lima et al. 2018) was assessed using a 30-minute downhill run at 70% VO_2max. CMJ indicated counter movement jump. RE/EE indicates running economy / energy expenditure. RE/VO_2max indicates running economy maximal oxygen consumption. CI indicates confidence interval. d indicates Cohen's effect size. SL indicates single leg. H/Q indicates hamstring to quadriceps ratio. SS indicates static stretch.

Table 4. Controlled Intervention Studies.

Author/s	Participants, Time, and Setting	Intervention/ Comparison	Outcome/ Physical Performance Measures	Results
Young & Elliott, 2001	n = 14 male participants (Mean age = 22 years old) required to have one season's experience in a sport requiring jumping performance	I: Static stretch I: PNF stretch I: MVC C: Control condition	2 different vertical jump tests. Concentric (squat jump): measured for height, peak force, rate of force developed Eccentric (Drop jump): Height/time was measured	The only significant difference between conditions was for the drop jump test Static condition produced significantly lower height/time score than all other conditions Isometric drop jump (DJ): (95% CI: - 16.66 to 20.66) SS DJ: (95% CI: - 4.59 to 30.59) Isometric DJ: 0.083 SS DJ: 0.574

Note: CI indicates confidence interval. Km/hr indicates kilometers per hour. SS indicates static stretch. DJ indicates drop jump.

Table 5. Observational Cohort and Cross-Sectional Studies.

Author/s	Participants, Time, and Setting	Intervention/ Comparison	Outcome/ Physical Performance Measures	Results
Franettovich Smith, 2017	*n* = 26 Elite male footballers from a professional Australian Football League (AFL) mean age, height and body mass of the participants was 22.2 (2.8) years, During a season	I: Gluteus Medius (GMED) muscle volume and muscle activation using surface EMG recordings during treadmill gait I: Gluteus Maximus (GMAX) muscle volume and muscle activation	Hamstring injury rates via subjective testing and Magnetic resonance imaging (MRI)	Nine players (35%) had hamstring injuries Higher GMED muscle activity during running was a risk factor for hamstring injury ($p = 0.03$, effect sizes 1.1 – 1.5) No sig in GMED muscle volume, GMAX muscle activation or volume GMED: (95% CI: 6.4 to 45.9) GMAX: (95% CI: -3.1 to 25.0) GMED Cohen's *d*: 1.1 GMAX Cohen's *d*: 0.7
Luedke et al., 2015	Sixty-eight (68) high school cross country runners One high school season	I: Isometric strength tests of hip abductors, knee extensors, and flexors were performed.	Occurrence of anterior knee pain (AKP) and shin injury rates	Weak hip abductors, knee extensors and knee flexors indicate higher incidence of AKP. GMED weak: (95% CI: 0.5 to 10.9)

Note: BER indicates bilateral hip external rotation with resistance band. FL forward lunge with resisted band. SLS indicates single-leg rotational squats. GMED indicates gluteus medius. GMAX indicates gluteus maximus. AFL indicates Australian Football League. MRI indicates magnetic resonance imaging. CI indicates confidence interval. OR indicates odds ratio. RRR indicates relative risk reduction. ARR indicates absolute risk reduction. NNT indicates number needed to treat.

The discussed categories are important variables when discussing running athlete's performance and health. They show conflicting results when comparing pre-exercise static stretching or pre-exercise isometric holds. Summary of results can be found in Table 6.

Table 6. Summary of Results.

	Static Stretch	Isometric Holds
Running Economy	(?) Allison et al., (2008), Hayes et al., (2007)	(?) Lima et al., (2018)
Countermovement Jump	(−) Allison et al., (2008), Young et al., (2013)*	(?) Pojskic et al., (2015), Lima et al., (2008)
Sprint	(−) Nelson et al., (2007)	(?) Pojskic et al., (2015) (?) Makaruk et al., (2010)
Injury/Soreness	(+) Makaruk et al., (2010)	(−) Franettovich Smith et al., (2017)* (+) Luedke et al., (2015)*, Lima et al., (2018)

Note: (−) = negative impact on the outcome, (+) positive impact on the outcome, and (?) meaning the intervention has no statistically significant change on the outcome. *Young et al., (2013) had an outcome of drop jump height not countermovement jump. * Franettovich Smith et al., (2017) showed that having higher glute medius activation may be a risk factor for hamstring injury. *Luedke et al., (2015) showed that weakness in hip abductor, knee extensors, and knee flexor strength may lead to significant increase in incidence of anterior knee pain.

Studies, which were evaluated using the Cochrane collaboration tool for assessing risk of bias, showed 11.1% to be high risk of bias (Lima et al., 2018), 66.7% to be a moderate risk of bias (Allison et al., 2008; Hayes & Walker, 2007; Makaruk et al., 2010; Nelson et al., 2015; Pojskic et al., 2015; Young & Elliott, 2001), and 22.2% to be a low risk of bias (Franettovich Smith et al., 2017; Luedke et al., 2015). When studies were analyzed by individual domains, 66.6% showed a high risk of bias pertaining to any blinding of participants, personnel, or outcome data, and high risk of bias in allocation concealment. Any domain pertaining to outcome reporting or followup reporting/selective reporting showed low risk of bias in 100% of studies, excluding one study (Lima et al., 2018), which left the status of selective reporting bias unclear.

Publication bias was not performed due to low number of studies included in review (28).

DISCUSSION

The articles analyzed above contribute to a clinician's ability to understand the proper timing to implement isometric holds and static stretching to prevent injuries and increase performance. Timing, dosage, and targeted muscle groups are all components that need to be further researched to produce a complete understanding of the value of isometric holds for running athletes when used as part of the dynamic warm-up. The generality of the included studies adds difficulty to understanding the true impacts of the intervention.

The data on static stretching's effects on immediate performance post-intervention revealed a decrease in CMJ, drop jump height, and sprint performances which had been established prior. These effects are hypothesized to take place due to the lack of ability of the musculotendinous junctures to operate over their most favorable lengths by increasing 'slack' (23). Contrary to reducing 'slack' it was suggested that isometric holds may increase the ability to perform under the force velocity curve by increasing the 'stiffness' of the musculotendinous junctions allowing for an increase in performance. This is an attempt to limit passive insufficiency and orient muscle fibers to an optimal length prior to activity. Isometric holds may limit passive insufficiency and increase neural responsiveness, known as post-activation potentiation.

Imbalances are frequently discussed as the main area leading to injury prevalence and soreness, with post exercise static stretching being considered the gold standard for correcting these imbalances (18). Static stretching in Makaruk et al. (18), Allison et al. (1), and Hayes et al. (10) was efficient in increasing the ROM and correcting the imbalances that frequently lead to injury among running athletes over extended periods of time. These improvements went on to hypothesize a decrease in injury rates over time; however, due to impacts on short term performance, static stretching may be best suited for post-activity recovery rather than as part of dynamic warm-up. Static stretching following running activity in combination with recruiting and strengthening proper musculature using isometric hold prior to performance may prove to be an efficient training method that should be investigated further to understand full implications.

Isometric holds are also hypothesized to increase post-activation potentiation of targeted muscle groups by increasing a recruitment of higher order motor units following intervention (2). This increase in recruitment prior to performance may hypothetically allow for the muscle group to increase neuromuscular firing while training and increase neuromuscular activity (13, 14). By firing more frequently after being primed to perform, myofilament recruitment during activity may increase (6). This added stress may increase muscular activity and over time increase strength of the weakened muscle group (8). Theoretically, by performing isometric holds, which target the weakened or under-active muscle group, strength should increase and potentially lead to a reduction in injury risk and increase in performance. This strength gain will hypothetically help reduce muscular imbalances, which have frequently been correlated with injury in running athletes (3, 18).

Increasing neuromuscular firing rates, following post-activation potentiation, among targeted weakened groups may be ideal for under-active muscles when looking to increase sprint performance, jump height, and decreasing injury rates. To understand the potential benefits of post-activation potentiation following isometric holds, one needs to understand the alternative benefits it may bring. One of these alternative benefits is a transient adaptation at the cellular level that allows for the body to increase sensitivity to Ca^{2+} in striated muscle, allowing for an increased force production with less Ca^{2+} needed following a contraction of a muscle (17). In theory, by decreasing the amount of Ca^{2+} needed to stimulate the contractile fibers, an increase in muscular recruitment may be seen. Other alternative benefits may also include an increase of muscle temperature, metabolic response, and in blood flow, which all have been linked to increase in performance (2). The combination of the above factors, if able to be established, can allow for significant differences in running athlete performance and injury prevention.

In the case of Franvettovich Smith et al., (9), runners who demonstrated a weakened glute medius also showed an increase in EMG activity during running. Although counterintuitive, a weakened muscle still needs to fire so an increase in recruitment compensates for the weakness and in turn causes an increase in EMG activity. This idea is different from original hypothesis that weakened muscles also have decreased EMG activity, when there is extra stimulation required to fire weakened muscle groups. Post activation potentiation could potentially increase reception of Ca^{2+} which would decrease need for heightened EMG activity. To the knowledge of this review, there have been no previous studies which attempted to understand the effects of isometric holds in a dynamic warm-up on identified weakened muscle groups.

This review is looking to implement an additional injury prevention and performance technique that can be included with the standard and proven effective dynamic warm-ups. This data collection is looking for additional time efficient techniques to maximize a running athlete's ability to perform and prevent injury. When looking to include static stretching compared to isometric holds in practice, the data shows increased benefits and/or decreased negative effects from isometric holds prior to performance. Further research should include two topics: the effects of isometric holds implemented in conjunction with dynamic warm-ups on both short-term and long-term injury prevention and athletic performance and the effect on isometric holds on known weakened muscle groups such as the gluteus medius prior to performance with both short- and long-term outcomes. More research is needed on the topics when looking to determine implementation to clinical application.

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