Effects of Yoga on Injuries Associated with Long-Distance Running

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by

Anthony Clemens Perry

California Baptist University

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Abstract

Running-related injuries (RRIs) occur at high prevalence across all levels of experience in endurance runners. The purpose of this study is to examine the effectiveness of a structured Hatha Yoga intervention in preventing overuse injuries in long-distance runners. Fifty experienced marathoners aged 22–35 will be randomly assigned to a yoga intervention group ($n = 25$) or a control group ($n = 25$) for a 12-week period during marathon preparation. The intervention group will participate in three 90-minute guided Hatha Yoga sessions per week in addition to their standard training regimen, while the control group will continue their usual marathon preparations. Both groups will undergo weekly physical assessments including range of motion testing via goniometry, core muscle activation assessment via surface electromyography (EMG), postural analysis, and pain evaluation via numeric rating scale. Suspected injuries will be classified using the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire. The primary outcome is the between-group difference in OSTRC severity scores at 12-week post-test, analyzed using a 2×2 mixed-design analysis of variance. Secondary outcomes include goniometric range of motion, EMG-assessed core muscle activation, and injury incidence compared by chi-square test.

Keywords: yoga, running-related injuries, randomized controlled trial, electromyography, goniometry, overuse injury prevention, core stability

1 Introduction

1.1 Statement of the Problem

The purpose of this study is to determine whether yoga can serve as an effective intervention for common injuries associated with long-distance running. These injuries include musculoskeletal compensations and degradations stemming from postural inefficiencies, which can result in biomechanical compensations, decreased performance, back pain, hip pain, and shortened or weakened muscles (Loudon and Reiman, 2014). Investigating this problem is of particular interest to anyone who participates in long-distance running or who has sustained injuries or compensations from the activity.

Yoga has been successfully utilized to treat similar conditions (Posadzki and Ernst, 2011); however, further research is required to validate its effectiveness as an intervention for the broad range of possible consequences of maintaining a strenuous running protocol. It is common for athletes of all levels to be unaware of the importance of maintaining lower-extremity flexibility, core strength, and stability, which when neglected can lead to a variety of injuries (Fredericson and Moore, 2005). Establishing a generally accepted preventive practice would be highly beneficial for the running population. Yoga has demonstrated effectiveness in not only maintaining healthy range of motion but also in strengthening and stabilizing the core (Ni et al., 2014). The high prevalence of running-related injuries underscores the need for objective physiological measurement—including electromyography and goniometry—to identify biomechanical risk factors and evaluate intervention effectiveness.

1.2 Background

Running is internationally one of the most popular physical activities and has experienced significant growth in popularity over the past decade (Lopes et al., 2012). Virtually all sports require some form of distance running for competition or maintenance of aerobic conditioning. In the United States, between the thousands of annually organized events and individuals running for health benefits, running is a form of activity performed by a substantial portion of the population.

The repetitive nature of running can lead to the development of numerous types of injuries, including overuse injuries, which are described as an overloading of the musculoskeletal structure (Lopes et al., 2012). Neglecting core musculature and strength can result in strain, inefficient movements, compensatory movement patterns, overuse, and injury (Fredericson and Moore, 2005). An estimated 50% of runners acquire at least one running-related injury per year (Fields et al., 2010), with lower back pain being one of the most common.

A study conducted by Sato and Mokha (2009) on long-distance runner performance before and after a core-strengthening intervention demonstrated improved performance, implying previously present postural inefficiencies in runners with untrained core muscles. Core stability exercises are also an important component of rehabilitating and preventing lower back pain (Wang et al., 2012). A simple assessment of core musculature can be performed using the Bunkie test, which reveals dysfunction or weakness causing postural instability or pain (Brumitt, 2011).

Yoga is practiced for a variety of reasons; the primary benefits relating to this research are the aligning, strengthening, and balancing properties of its poses (Posadzki and Ernst, 2011). In one study, yoga was demonstrated to be an effective treatment for lower back pain by enhancing dynamic control of stabilizing muscles and by increasing hip and spinal flexibility (Ni et al., 2014). The purpose of this study is to explore yoga as a preventive measure for overuse injuries associated with long-distance running.

1.3 Significance of the Study

It is common for habitual runners to neglect the maintenance requirements of strengthening and stretching, particularly concerning the core and hip muscles, which can lead to overuse injuries. Establishing a generally accepted regimen or intervention would be highly beneficial for any individual participating in long-distance activities. The field of kinesiology concerns itself with improving understanding of all aspects relating to human movement; discovering an effective treatment for the causes of degraded movements associated with running would have broadly positive implications for athletic populations and clinical practice.

1.4 Research Question

1. Can the implementation of a structured yoga practice effectively prevent or reduce injuries sustained from long-distance running?

1.5 Delimitations

The following delimitations define the scope of this study:

1. Participants must run a minimum of three days per week.
2. Participants must run at least 15 miles per week.
3. Participants must be injury-free for the previous six weeks.
4. Participants must have no history of lower-extremity or back surgery.
5. Participants must be between 22 and 35 years of age.
6. Participants must have completed at least two prior marathons.

1.6 Limitations

The following limitations are acknowledged:

1. The study will be conducted with a sample of 50 participants. A larger sample may be required to establish greater statistical power and generalizability.
2. The study prescribes only three yoga sessions per week. A more frequent yoga regimen may be necessary to produce larger effects.

1.7 Assumptions

The following assumptions underlie this study:

1. All participants will complete at least 90 minutes of guided yoga per session when attended.
2. Participants will give full effort during yoga sessions.
3. Participants will continue their usual running habits throughout the study duration.
4. Participants will give maximal effort on physical assessments.

1.8 Hypotheses

Alternative Hypothesis (H_1): Participants in the yoga intervention group will demonstrate significantly lower scores on the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire and significantly greater improvement in range of motion as measured by goniometry compared to the control group following a 12-week intervention period.

Null Hypothesis (H_0): There will be no statistically significant difference in OSTRC Overuse Injury Questionnaire scores or goniometric range of motion measurements between the yoga intervention and control groups following a 12-week intervention period.

2 Review of Literature

2.1 Introduction

Running yields numerous health benefits, including chronic disease prevention, weight management, increased longevity, cardiovascular fitness, and improved mental health (Lee et al., 2017), making distance running a highly appealing activity for able-bodied individuals. Running has become an increasingly popular sport and recreational activity across most demographics worldwide (Loudon and Reiman, 2014). However, the ease of accessibility of distance running—requiring minimal equipment and no formal training—is accompanied by increased risk of injury due to improper training, technique, and preparation.

Some of the most common injuries caused by long-distance running are related to musculoskeletal compensations, back pain, hip tightness, and overuse. Yoga has demonstrated effectiveness in treating and preventing conditions relating to muscular imbalances and overuse injuries (Ni et al., 2014), and its specific applicability to runners warrants evaluation. This review of literature consists first of an overview of the injuries commonly associated with long-distance running, followed by an examination of the established physical benefits of yoga practice. The chapter concludes with an analysis of the potential applicability of yoga to treating and preventing injuries common among long-distance runners.

2.2 Overview of Injury in Long-Distance Running and Yoga

Running is widely regarded as a low-impact activity, making it appealing for individuals of all fitness levels. The repetitive nature of running, however, especially at longer distances, can lead to the development of numerous injuries, primarily overuse injuries caused by overloading of the musculoskeletal structure (Saragiotto et al., 2014). Raabe and Chaudhari (2018) describe compromised core musculature and strength as another factor leading to muscular strain, inefficient movements, compensatory movement patterns, and eventual injury. Approximately 27% of novice runners acquire at least one running-related injury (RRI) within a year of running (Nielsen et al., 2013a), with lower back pain being one of the most common. Given the high prevalence of RRIs in long-distance runners, Ramskov et al. (2018) conducted a study investigating the effects of running intensity compared to running volume in order to identify the causes of RRIs in endurance athletes.

The benefits of yoga, another popular and growing form of exercise, are described as mental, physical, and spiritual in nature (Park et al., 2016). With respect to injury prevention, yoga has demonstrated effectiveness in treating musculoskeletal imbalances, core instability, and postural inefficiencies (Ni et al., 2014). The most common injuries for long-distance runners are related to overuse, muscular imbalance, and core weakness (Loudon and Reiman, 2014), making yoga a compelling intervention candidate.

2.3 Injuries Typical in Long-Distance Running

A running-related injury is defined as any musculoskeletal complaint regarding the back or lower extremity caused by running (Nielsen et al., 2014). The main risk factor for acquiring an RRI has been reported as any previous injury within the past 12 months (Saragiotto et al., 2014). Saragiotto et al. (2014) utilized electronic databases for scholarly articles to compile the main risk factors surrounding RRIs; a limitation of that study was substantial heterogeneity of statistical methods between studies, precluding meta-analysis.

Running athletes, particularly those conducting runs longer than two to three miles, frequently suffer from lower-extremity injuries (Loudon and Reiman, 2014). Hip and pelvic injuries are common, as repetitive hip flexion required in running can result in shortened or lengthened muscles that alter the normal joint motion pathway. Injuries such as femoroacetabular impingement (FAI) can be the painful result of such musculoskeletal compensations and can be remedied by increasing hip and trunk musculature (Loudon and Reiman, 2014). Other lower-extremity injuries—including patellofemoral pain, iliotibial band syndrome, gluteus medius injury, tensor fascia latae injury, and patellar tendinopathy—have been related to running distance specifically rather than running frequency (Nielsen et al., 2014). Musculoskeletal compensations can be indicative of overuse injury. Running frequency plays a substantial role regarding the impact and severity of overuse injuries; one study reports that running three to seven times per week can be a significant risk factor (Saragiotto et al., 2014). Overuse injuries are commonly linked to training or running technique errors (Nielsen et al., 2014). Nielsen et al. (2014) used a sample of 874 healthy novice runners to evaluate the correlation between increased weekly running distances and risk of RRIs. RRIs are more prevalent in beginner runners starting a new running regimen compared to those who run more than 40 miles per week (Nielsen et al., 2013b). The sample Nielsen et al. (2014) utilized consisted of novice runners, rendering them more vulnerable to postural inefficiencies, training errors, and therefore overuse injuries.

Runners can develop biomechanical running errors due to postural inefficiencies, which often can be traced to weakened deep core muscles (Raabe and Chaudhari, 2018). Deep core muscles—comprising the quadratus lumborum, psoas major, multifidus, and erector spinae—are considered crucial to stabilization of the lumbar spine and postural control (Raabe and Chaudhari, 2018). The study on deep core muscle weakness by Raabe and Chaudhari (2018) tested the effects of deep core weaknesses on running kinematics utilizing three participants and the OpenSim simulator. The study found that running kinematics were significantly affected by core muscle weaknesses, especially when the weakness occurred in the erector spinae. In order to maintain normal running kinematics and prevent injuries relating to postural imbalances, it is vital to maintain strength in all of the deep core muscles (Raabe and Chaudhari, 2018).

Core (trunk) muscle weakness is frequently associated with lower back pain (LBP), which is reported by as many as 13.6% of all recreational runners (Cai and Kong, 2015). When lower back pain becomes chronic, individuals may experience inferior gluteus maximus endurance, decreased knee and hip flexibility, and other functional limitations (Cai and Kong, 2015); it is an injury that results in numerous worsening musculoskeletal compensations. Chronic lower back pain can result from muscular imbalances or postural inefficiencies that lead to transmission of force to the structures of the lower back. Compensations or weaknesses leading to lower back pain include diminished lumbar extensor muscle strength and endurance, delayed onset of transversus abdominis, and smaller lumbar multifidus size (Cai and Kong, 2015).

2.4 Physical Benefits of Yoga

Yoga is a widely accessible form of exercise requiring minimal equipment. Individuals engage in yoga for a multitude of reasons, including physical fitness, mental health, spirituality, and increased flexibility (Park et al., 2016). Yoga originates from India and was originally intended to improve a wide range of health conditions; the poses (asanas) were developed to strengthen, align, and balance the structures of the body (Ni et al., 2014). Weakness, misalignment, and structural imbalances are among the leading causes of RRIs (Loudon and Reiman, 2014). Notably, injury rehabilitation and prevention represent important motivations for individuals choosing to practice yoga.

With respect to runners, the literature has established that many injuries associated with postural inefficiencies, compensations, musculoskeletal imbalances, and overuse can be directly linked to lack of core strength or imbalances of the trunk (Raabe and Chaudhari, 2018). This evidence makes yoga an attractive intervention for pathologies stemming from core weakness. Ni et al. (2014) utilized 30 healthy yoga practitioners to evaluate the muscle activation of selected hip and trunk muscles in order to determine their effectiveness as rehabilitative exercises. The eleven poses included the halfway tilt, forward fold, downward-facing dog, upward-facing dog, high plank, low plank, chair, mountain arms up, mountain arms down, dominant-side warrior I, and non-dominant-side warrior I. Using electromyography (EMG), the researchers measured and recorded varying levels of activation for particular core muscles during selected yoga poses. After analyzing the data, it was determined that yoga poses can be beneficial and particularly effective in targeting specific core muscles during rehabilitation programs aimed at strengthening and stabilizing the core. These findings suggest that yoga may be an effective method of treating one of the most common pathologies stemming from long-distance running.

Yoga is currently utilized as an injury prevention and performance enhancement method by athletes across a variety of sports (Sharma, 2015). Participation in repetitive-motion sports in particular leads to imbalances in muscles and joints, eventually resulting in overuse injuries. One of the primary benefits athletes derive from yoga is increased flexibility; yoga has the ability to maintain and even restore full range of motion in muscles, tendons, and ligaments (Sharma, 2015). Balance is another important benefit of yoga practice that can reduce the risk of injury for runners, as sustaining impact injuries from falls constitutes an additional risk. Improved balance stems from the muscular endurance and strength-promoting poses of yoga that enhance the supportive muscles rather than the primary movers, creating a strengthening balance within musculoskeletal structures and improving overall functionality and control.

Park et al. (2016) utilized a cross-sectional survey, contacting 110 yoga studios and collecting responses from 542 yoga practitioners. They found that pain relief was one of the primary reasons individuals practiced yoga, superseded only by stress relief and relaxation. These findings confirm that yoga is already being utilized by a substantial number of athletes and active individuals to effectively treat and prevent injuries of varying degrees.

2.5 Summary and Research Gap

The literature reviewed in this chapter establishes three convergent lines of evidence: (1) running-related injuries are highly prevalent among endurance athletes, stemming primarily from core weakness, muscular imbalance, and postural inefficiency; (2) yoga has demonstrated effectiveness in strengthening core musculature, improving range of motion, and correcting postural imbalances; and (3) the biomechanical mechanisms underlying common RRIs correspond directly to the physiological systems that yoga is known to address. However, no study has directly evaluated a structured yoga intervention as a preventive measure specifically for the running-related injury population. Previous research has examined yoga for general lower back pain (Posadzki and Ernst, 2011), core muscle activation during yoga poses (Ni et al., 2014), and injury risk factors in runners (Saragiotto et al., 2014) as independent lines of inquiry—but the intersection of these three domains remains untested. The present study addresses this gap by evaluating the effectiveness of a 12-week Hatha Yoga intervention on injury incidence, range of motion, and core muscle activation in experienced marathoners using a randomized controlled trial design with multimodal physiological outcome measures.

3 Methods

3.1 Research Design

This study employs an experimental design evaluating the effects of a structured yoga intervention on treating and preventing running-related injuries. The sampling procedure utilizes purposive sampling to ensure that participants are appropriate in their overall health and long-distance running experience. Participants will be randomly assigned to either a yoga intervention group or a control group of runners not practicing yoga.

3.2 Participants

Fifty participants will be recruited from among individuals currently training for a full marathon scheduled for completion three months after the onset of the study. All participants will meet the following inclusion criteria: (a) aged 22–35 years; (b) completed at least two prior marathons;

(c) injury-free for a minimum of six weeks; (d) no history of lower-extremity or back surgery; and (e) currently running at least three days and 15 miles per week. These criteria ensure a rigorous training regimen and level of health and fitness required to evaluate the hypothesized effects of yoga in long-distance runners. Athletes will be recruited via an online notification following their registration for a specific running event and will be invited to participate in a study examining injury prevention techniques.

3.3 Randomization and Allocation Concealment

Participants will be assigned to the yoga intervention group ($n = 25$) or the control group ($n = 25$) using a computer-generated block randomization sequence with a block size of four, stratified by sex. The randomization sequence will be generated by a researcher not involved in participant enrollment or assessment. Allocation will be concealed using sequentially numbered, opaque, sealed envelopes that will be opened only after each participant has completed all baseline assessments and confirmed enrollment. This procedure ensures that neither the enrolling researcher nor the participant can predict group assignment prior to allocation.

3.4 Intervention

The intervention consists of a 12-week Hatha Yoga program comprising three 90-minute guided sessions per week (36 total sessions). Sessions will be structured as follows: (a) 10-minute centering and breathing exercises (pranayama); (b) 15-minute warm-up sequence emphasizing joint mobilization; (c) 50-minute main practice including standing poses, balance poses, forward folds, backbends, and core-strengthening postures; and (d) 15-minute cool-down with restorative poses and final relaxation (savasana).

Poses will be selected to target the muscle groups most relevant to running biomechanics, including hip flexors, hamstrings, quadriceps, gluteal muscles, and deep core stabilizers. Sessions will be conducted primarily in park settings, with laboratory-based sessions during assessment periods at the California Baptist University Kinesiology Laboratory. All sessions will be led by a Registered Yoga Teacher (RYT-200 minimum) with experience in athletic populations. Session content will be standardized using a detailed protocol manual to ensure fidelity across all sessions. The control group will continue their usual marathon preparation without any prescribed yoga practice.

Compliance criterion. Participants in the yoga group who attend fewer than 80% of scheduled sessions (fewer than 29 of 36 sessions) will be excluded from per-protocol analyses but retained in intent-to-treat analyses.

3.5 Instruments and Outcome Measures

The instruments and scales utilized in this study have been demonstrated to be valid and reliable in the kinesiology, sports medicine, and biomechanics literature. Measurements will focus on musculoskeletal range of motion, core muscle activation, pain, and injury incidence.

Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire. The OSTRC questionnaire serves as the primary evaluative tool for classifying and quantifying overuse injuries. An RRI is defined as an injury sustained in muscles, joints, tendons, or bones during or after running and attributed to running (Ramskov et al., 2018). The OSTRC questionnaire will be administered weekly to evaluate and classify any reported symptoms, producing a severity score ranging from 0 (no problems) to 100 (maximal severity) that serves as the primary outcome measure.

Goniometry. The Prestige Medical 12-inch Protractor Goniometer will be used to record range of motion (ROM) at the hip, knee, and ankle joints. The goniometer measures the angle created within the examined joint and can be utilized to evaluate the effect of musculoskeletal imbalances on the musculoskeletal system (Amraee et al., 2017). Goniometric measurements will record baseline values for comparison of ROM progression in participants assigned to the yoga intervention.

Surface Electromyography (EMG). A surface EMG device utilizes electrodes placed onto the skin above the target muscles to evaluate the level of muscle activation. EMG can assess the strength and responsiveness of individual muscles within the core during core-centric yoga poses (Ni et al., 2014). EMG will record baseline values of core muscle activation—specifically the rectus abdominis, external obliques, erector spinae, and gluteus maximus—to track and compare values as participants progress throughout the intervention.

Kent Postural Analysis Grid Chart. The postural analysis grid will be utilized to evaluate posture and perform movement analyses, identifying possible musculoskeletal injuries, weaknesses, imbalances, or compensations. The grid chart provides an accessible method of posture analysis for recording baselines and tracking progression.

Numeric Pain Rating Scale. A numeric pain rating scale (0–10) will be used to record the onset or alleviation of pain throughout the course of the study. The numeric pain scale can assess the level of pain in runners at rest, directly following activity, and during activity (Cai and Kong, 2015).

Range of Motion Testing. Standardized range of motion tests—including the Thomas test (hip flexor tightness), Ober's test (iliotibial band tightness), and Straight Leg Raise test (hamstring flexibility)—will evaluate functional ROM and track progression (Loudon and Reiman, 2014).

Demographics. Participant demographics will be collected to ensure validity and generalizability of findings and to control for potential confounding variables.

3.6 Procedure

All participants will undergo extensive baseline testing to establish initial measurements. Baseline assessments will include: (a) range of motion testing at the hip, knee, and ankle joints using goniometry; (b) core and hip muscle activation assessment using surface EMG during standardized contractions; (c) postural assessment using the Kent grid chart; and (d) completion of demographic and running history questionnaires.

Following baseline assessment and randomization, participants in the intervention group will begin the 12-week yoga program. Both groups will continue their standard marathon training regimens. Ongoing assessments will be conducted as follows:

- **Weekly:** OSTRC Overuse Injury Questionnaire, numeric pain rating scale, postural assessment via grid chart, and EMG assessment of core and hip musculature during standardized core-centric yoga poses.
- **Bi-weekly:** Full ROM testing using goniometry and standardized ROM tests (Thomas test, Ober's test, Straight Leg Raise test).
- **Post-intervention (Week 12):** Complete repetition of all baseline assessments.

Any pain reported via the numeric scale that exceeds a threshold of 4 out of 10 will trigger administration of the OSTRC questionnaire and, if classified as an RRI, will be followed by referral for clinical evaluation.

Ethical oversight. The study will be submitted to the California Baptist University Institutional Review Board for full review. Informed consent procedures will ensure that all participants are fully aware of the nature and purpose of the research, provide voluntary consent, and possess the capacity to give legal consent. Participant confidentiality and privacy will be maintained in accordance with federal policy (45 C.F.R. §46). Participants will not be subjected to harm; they will be prescribed a yoga protocol to incorporate with their usual training regimen and will be assessed on a weekly basis.

3.7 Statistical Analysis

Descriptive statistics. Means, standard deviations, and 95% confidence intervals will be computed for all continuous outcome variables (OSTRC severity scores, goniometric ROM measurements, EMG activation levels, numeric pain ratings) at baseline and post-intervention for each group. Frequency distributions will be reported for categorical variables (injury incidence, participant demographics).

Assumption testing. Prior to parametric analyses, data will be screened for normality using the Shapiro–Wilk test, homogeneity of variance using Levene's test, and sphericity using Mauchly's test where applicable. Violations of sphericity will be addressed with the Greenhouse–Geisser correction. If normality assumptions are substantially violated, non-parametric alternatives (Mann–

Whitney U, Wilcoxon signed-rank) will be employed.

Primary analysis. A 2×2 mixed-design analysis of variance (ANOVA) will serve as the primary analytical method, with group (yoga intervention vs. control) as the between-subjects factor and time (baseline vs. 12-week post-test) as the within-subjects repeated-measures factor. The Group $\times$ Time interaction effect constitutes the primary test of the hypothesis, indicating whether the yoga intervention produces differential change relative to the control condition. Effect sizes will be reported as partial eta-squared (η_p^2), interpreted as small (0.01), medium (0.06), or large (0.14) per Cohen's conventions. Separate mixed-design ANOVAs will be conducted for each primary outcome: OSTRC severity score and composite goniometric ROM.

Secondary analyses. Independent-samples t-tests will compare between-group differences at post-test for each continuous outcome variable (ROM at individual joints, EMG activation, pain ratings). Paired-samples t-tests will evaluate within-group changes from baseline to post-test. Chi-square tests of independence will compare injury incidence (injured vs. not injured) between groups over the 12-week period.

Multiple comparisons. Because ROM will be assessed at multiple joints (hip, knee, ankle) and EMG will be recorded from multiple muscle sites, Bonferroni correction will be applied to control the family-wise error rate across joint-specific and muscle-specific analyses.

A priori power analysis. The required sample size was determined using G*Power 3.1 software for a 2×2 mixed-design ANOVA with the following parameters: medium effect size ($f = 0.25$, corresponding to $\eta_p^2 = 0.06$), alpha level of 0.05, and statistical power of 0.80. This analysis indicated a minimum total sample of 34 participants. The planned sample of $N = 50$ (25 per group) provides a buffer of approximately 47% above the minimum requirement, accommodating anticipated attrition of up to 20% while maintaining adequate statistical power with at least 40 completers.

Missing data. Primary analyses will follow the intent-to-treat (ITT) principle, including all randomized participants regardless of compliance or dropout status. Missing data will be addressed using multiple imputation with 20 imputed datasets, assuming data are missing at random. A per-protocol sensitivity analysis will be conducted excluding participants who fail to meet the 80% attendance criterion or who withdraw before the 12-week post-test, to evaluate the robustness of findings.

Software. All analyses will be conducted using IBM SPSS Statistics (Version 26) with the significance level set at $\alpha = 0.05$ for all tests unless adjusted by Bonferroni correction.

3.8 Threats to Validity

3.8.1 Internal Validity

History effects. Over the 12-week intervention period, participants may experience seasonal changes, life stressors, or external events that differentially affect injury rates independently of the yoga intervention.

Attrition bias. Dropout may be non-random; participants experiencing injury or dissatisfaction may be more likely to withdraw, potentially inflating the apparent effectiveness of the intervention in completers. The intent-to-treat analysis with multiple imputation (Section 3.7) mitigates this threat.

Performance bias. Because participants cannot be blinded to group assignment in an exercise intervention, knowledge of allocation may influence training behavior, injury-avoidance strategies, or symptom reporting. Outcome assessors will be blinded to group assignment (single-blind design) to reduce measurement bias.

Instrumentation reliability. Surface EMG measurements are sensitive to electrode placement, skin preparation, and subcutaneous tissue thickness. Despite standardized protocols, between-session variability in electrode positioning may introduce measurement error. Standardized electrode placement protocols following Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines will be employed to minimize this threat.

Testing effects. Repeated weekly assessments may sensitize participants to their own physical status, potentially altering running behavior or self-care practices independently of the yoga intervention.

3.8.2 External Validity

Population generalizability. The study sample is restricted to experienced marathoners aged 22–35, limiting generalizability to novice runners, ultra-endurance athletes, older populations, or non-competitive recreational runners.

Ecological validity. The supervised yoga sessions, conducted in controlled settings with qualified instruction, may not reflect the conditions under which runners would independently practice yoga. Results may differ for self-directed yoga practice using video instruction or other modalities.

Yoga protocol specificity. Results obtained from this specific Hatha Yoga protocol (three 90-minute sessions per week) cannot be generalized to other yoga styles (e.g., Vinyasa, Ashtanga, Yin), different session durations, or different practice frequencies.

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