JRSR 11 (2024) 1-10

Journal of Rehabilitation Sciences and Research

Journal Home Page: jrsr.sums.ac.ir

Review Article

Investigating the Effect of Warming up on Knee Position Sense: A Meta-analysis and Systematic Review

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ARTICLE INFO

Article History:
Received: 17/05/2022
Revised: 16/08/2022
Accepted: 24/08/2022

Keywords:
Lower extremity
Proprioception
Warm-up exercise

Please cite this article as:
Sayyadi P, Minoonejad H, Seidi F, Shikhhoseini R, Arghadeh R. Investigating the Effect of Warming up on Knee Position Sense: A Meta-analysis and Systematic Review. JRSR. 2024;11(1):1-10. doi: 10.30476/JRSR.2022.95542.1293.

ABSTRACT

Introduction: This systematic review and meta-analysis study aims to investigate the effect of warming up on knee position sense.
Methods: The keywords of this systematic review and meta-analysis study were searched on December 1 by two authors in the following electronic databases: PubMed, Web of Science, Scopus, and Google Scholar. The Downs and Black checklist checked the quality of articles. Statistical analysis was performed using CMA software. The I-square statistic was used to examine the data heterogeneity and estimate the percentage of heterogeneity. Besides, the Funnel Plot method was used for assessing the risk of bias in articles, and the trim-and-fill method was used in case of observation of possible bias.
Results: Out of 5,133 studies found in selected databases, 31 were selected after reviewing the title and abstract, and seven articles were included in the study after reviewing the full text. The results indicated that warming up has a significant effect on reducing the active absolute angular error (P<0.05) and increasing the active relative angular error (P<0.05) but has no significant effect on the passive absolute angular error (P>0.05).
Conclusion: Warming can reduce absolute and relative angular error. Therefore, it has a significant effect on improving proprioception.

Introduction

Knee injuries, especially those involving anterior cruciate ligament (ACL), are the most common injuries in sports [1]. These injuries occur due to inappropriate biomechanical loading and are potentially preventable. The nervous system must receive real-time sensory information about the forces and torques affecting each joint. It must supply sufficient reflexive motor commands to the muscles to counteract these forces and torques to stabilize the joint [2, 3]. Evidence suggests ACL damage is associated with a weakened position sense, possibly due to decreased proprioception inputs from mechanoreceptors [4, 5].

Proprioception, a component of the sensory-motor system, is responsible for gathering information from specific nerve terminals known as mechanoreceptors and transmitting it to the central nervous system [5, 6]. The role of various mechanoreceptors, including those in muscles, tendons, and joints in the joint position sense, has been extensively discussed [7]. It is now believed that muscle receptors play a significant role in position sense [7]. As muscle receptors provide the primary information of afferents, changes in muscle length-tension are expected to affect the accuracy of the position sense [8, 9]. Changes in joint position sense are important factors in joint coordination, muscle stiffness, movement integration, and movement disorders [10]. In sports activities, the accuracy of joint position sense is crucial as it is strongly associated with skill accuracy and injury risk [11, 12].

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A warm-up is a movement designed to increase core temperature and blood flow and prepare the body for exercise [13]. Warming up before an athletic event is a widely accepted practice in the modern sporting environment, with athletes and coaches believing it is necessary for optimal performance. Warming up is one of the most important factors in exercise that affects joint position sense [14, 15]. It is an integral part of exercise that positively impacts performance by reducing muscle stiffness, improving the viscoelastic function of structures around the joint, increasing nerve conduction velocity, and enhancing metabolic efficiency [16, 17]. Warming up reduces the reaction time of the muscles and increases the neuromuscular facilitation by enhancing the sensitivity of the receptors involved in joint position sense [18, 19].

Since the muscle spindle controls and regulates muscle contraction [19, 20], the warm-up process facilitates coordination and readiness of the nervous system by increasing muscle spindle efficiency and preventing damage to the nervous system [21, 22]. On the other hand, it maintains the mechanical feedback mechanism and keeps the soft tissue laxity at a normal level [21, 23]. Therefore, warming up improves proprioception and plays a crucial role in reducing the risk of soft tissue injuries [23, 24]. Increased laxity in the anterior-posterior direction of the knee makes the knee vulnerable. This condition may occur after severe exercise with muscle fatigue. Increased ligament laxity may lead to inadequate mechanoreceptor feedback for muscular reflexes [23]. Stretching of the ligament by stimulating the neural feedback mechanism leads to muscle contraction and restriction of bone movements. This protective mechanism prevents ligament sprain through active muscular control and reduces the risk of knee injury [25]. Warming up enhances the protective mechanism of the muscle by increasing the sensitivity of mechanoreceptors. Moreover, this mechanism positively impacts the position sense of knee joint and balance [26, 27], reducing injury.

Various articles have investigated the effect of warming up on knee position sense. For example, some studies have indicated a significant improvement in knee proprioception following a warm-up [23, 28], while another study found no significant effect on knee proprioception after warming up [29]. Therefore, conducting a systematic review and meta-analysis study to summarize these results and reach a clear, unified conclusion about the effect of warming up on knee proprioception could be beneficial. In this study, we aim to summarize the data from various studies on the effect of warming up on knee proprioception and ultimately present the final result. Since joint position sense is measured in both active and passive tests and the differences between studies may be due to different measurement methods, we have divided these studies into two parts for investigation: active and passive.

Methods

Search Strategy

The present study is a systematic review and meta-analysis conducted in accordance with the Cochrane guidelines and the PRISMA checklist. All eligible articles were identified using a strategic search approach. Articles were searched in English across selected databases using three categories of keywords and their synonyms, employing the Mesh-controlled vocabulary system. 'AND' was used between each group of keywords, and 'OR' was used between keywords within each group.

(Hip OR knee OR ankle OR foot OR feet OR "lower extremity" OR "lower limb" OR "lower-limb" OR "lower-extremity") AND (proprioception OR "position sense" OR "reposition* error" OR repositioning OR "sense of position") AND ("warm* up*" OR "pre activity" OR "FIFA 11+" OR "11+" OR "prior exercise*" OR "re*warm* up*" OR "warm*-up"* OR "warming* up")

Inclusion criteria were as follows: 1. The study examines the effect of warming up on the lower limb position sense; 2. The study is published in English; 3. The study is published in journals with a peer review process; 4. The study is searched without time limitation; 5. The study measures variables related to proprioception, including the joint position sense; 6. The warming-up protocol in the study should be a combination of at least two different protocols. The exclusion criteria were: 1. Studies performed on individuals with neurological problems, ligament laxity, osteoarthritis, and sensory or coordination problems; 2. Studies that did not provide sufficient information; 3. Data from conferences, papers, abstracts, and unpublished dissertations.

Search Process

First, the search strategy was executed in the respective databases. Records were entered into an Endnote version 8 file, preserving the authors' names, titles, and abstracts of sources. Duplicate records were then eliminated. Two authors (P.S. and R.A.) independently investigated the remaining studies. Any inconsistencies were adjudicated by the group supervisor, who served as the final reviewer. The full text of articles that were eligible for inclusion in this study contained the name of the first author, year of publication, type of study, quality, sample size, subjects (age, gender, index data, etc.), the most important methods and tools of data collection, and the most significant results obtained. These studies are summarized in Table 1. This study was registered in advance in PROSPERO under the number CRD42021274701.

Quality Assessment of Articles

This study assessed the articles' quality using the Downs and Black checklist [30]. The reviewers (P.S, R.A) independently evaluated each study. This checklist has demonstrated high reliability and validity [30]. In line with a previous review and meta-analysis article, 22 items from this checklist were utilized in this study [31] (Appendix). The overall score from this checklist was categorized as follows: scores of 75% and above were considered high; scores between 60-74% were deemed average, and scores below 60% were rated as weak [32]. We modified the last items of the checklist from a 0-5 to a 0-1 scale, following the precedent set by previous articles [33].

Table 1: A Description of Eligible Studies

Study	Subjects		Exercise Intervention Program	Control Intervention	Measured Variables	Main Outcomes	Downs and black score
	Sample description	Sample Size (Men/Women) (Age±SD)					
Bartlett et al., 2002 [23]	Rugby football player	E=12 (all men) (25)	Jogging+stretching exercises (4min)		Electro goniometer, Knee JPS, passive, open chain, between 0°-60°,(AAE)	Joint position sense significantly improved after warm-up.	12/23
Romero-Franco et al., 2019 [29]	Collegiate athletes	E=15 (8/7) (24.1±4.2) C=15 (10/5) (25.0±4.7)	8-minute jogging + 6- minute foam-rolling exercises	8-minute jogging	Digital dynamometer, Knee JPS, active, close chain, 40°–60°, (RAE, AAE)	No differences were found for proprioceptive errors in the exercise group compared with baseline.	17/23
Sevgi et al, 2008 [28]	Healthy university students	total=30(19/11) (20.70±0.98) C=10 E1=10 E2=10	Group 1 performed a 5-minute warm-up exercise, and group 2 performed a 10-minute warm-up exercise, which consisted of jogging and stretching exercises.	No exercise	Electro goniometer ,Knee JPS, open chain, 15°, 30°, 60°, (AAE)	Both warm-up periods have positive effects on knee proprioception. The 10-minute warm-up exercise improved proprioception by a greater amount than the 5-minute warm-up exercise	14/23
Romero-Franco et al., 2017 [34]	Sprinters	E: 16 (all men) (25.0±3.6) C=16 (24.7±3.4)	5 minutes of jogging (8 km/hr), 5 minutes of ballistic stretching and dynamic exercises, 10 repetitions of squats, and two sets of three vertical jumps (15 min)	No exercise	Camera, knee JPS, Active, close chain, 50° (40°-60°) (RAE, AAE)	A significant decrease in relative angular errors was detected.	18/23
Salgado et al, 2015 [35]	Semi-professional football players	E=40 (all male) (25.9±4.6)	Jogging, skipping, dynamic mobility exercises for upper and lower body, stretching, and specific football drills (pass, ball control, and kicking) (25 min)		Camera, Knee JPS, active, open chain 40°-60°, (AAE)	absolute angular error decreased significantly after the warm-up	16/23
ROMERO-FRANCO et al., 2020 [36]	National sprinters	SS=11 (all men) (24.9±4.6) DS=11 (all men) (25.8±3.8) C=10 (all men) (1.76±0.08)	SS=5 minutes of running+static stretch of gastrocnemius, hamstrings, and quadriceps for 20 S DS=5 minutes of running+dynamic stretch of gastrocnemius, hamstrings, and quadriceps for 20 repetition	5 minutes of running	Camera, Knee JPS, active, close chain, 40°-60°, (RAE, AAE)	Joint position sense did not show significant differences in any group.	19/23
Magalhães et al, 2010 (14)	Amateur karatekas	E=10 (17.6±4.03)	Jogging jumps and stretching of quadriceps, hamstring, and gastrocnemius muscles. (10 min)		Camera, Knee JPS, active, close and open chain, 40°-60°, (RAE, AAE)	After the warm-up program, a significant decrease in absolute angular error was observed only in CKC.	15/23

E: Experimental group; C: Control group, SS: static stretching; DS: dynamic stretching; JPS: Joint Position Sense; AAE: Absolute angular; RAE: Error relative angular error, CKC: close kinematic chain

Based on this scoring system, one article was rated at a low level, four were at the average level, and three were at a high level.

Data Analysis

In this study, we used the statistical software CMA version 3. The required data from eligible articles, including standard deviation, mean of pre-and post-tests, P-values of sample size, and mean difference. The I-square was employed to evaluate the data's heterogeneity and estimate the heterogeneity percentage. The Funnel Plot methods were used to assess the articles' bias risk. In the event of potential bias observed using this method and to investigate the extent to which the articles used in this field might affect the final results of this meta-analysis, we employed the trim-and-fill method.

Study Characteristics

All studies examined the immediate effect of warming up on the lower limb position sense. The total number of participants across these seven studies was 104, as indicated in Table 1. The proprioception measurement index in all studies was the joint position sense, measured using a degree scale.

Variables

Measurement of the Joint Position Sense

Several methods were used for measurement: four studies used a camera with the photogrammetric method [14, 34-36], two studies used an electrogoniometer [23, 28], and one study used a digital dynamometer [29]. Additionally, two types of measurement errors were addressed in these studies: seven studies considered the absolute measurement error (the difference between the target position and the mean of the repositioning tasks performed without regard for the direction of the difference) [14, 23, 28, 29, 34-36]. Four studies investigated the relative angular error (the difference between the target position and the mean of the repositioning tasks performed, taking into account the direction] [14, 29, 34, 36]. Two studies [23, 28] examined the joint position passively, while five studies [14, 29, 34-36] did so actively.

Warm Up Protocol

Different warm-up protocols were used in the exercises. In three studies, warm-ups included jogging with stretching exercises [14, 23, 28]. In another study, warm-ups included jogging and foam roll exercises [29]. One study used a warm-up protocol that included jogging, ballistic and dynamic stretching, squats and jumps [34]. Additionally, another study used jogging, skipping, stretching, and football drills as part of the warm-up [35]. One study also used running and stretching exercises for warming up [36].

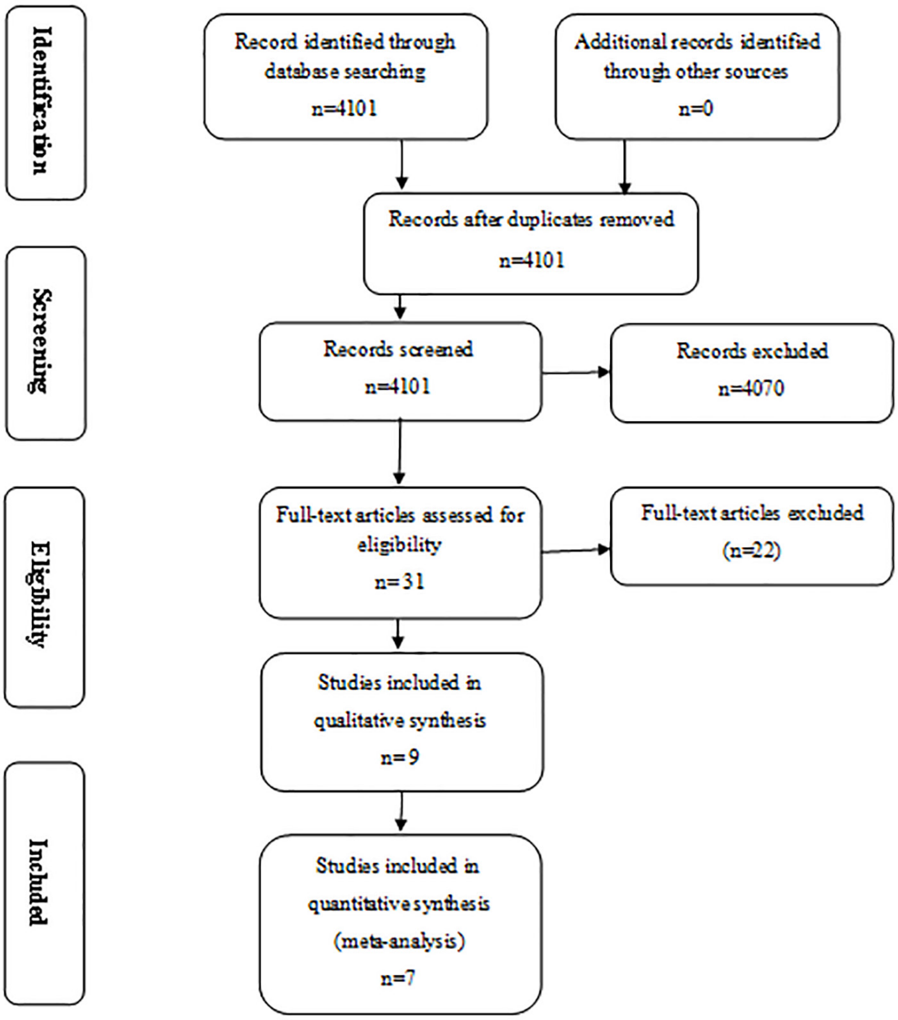

Figure 1: Search and selection of studies for systematic review according to PRISMA guidelines.

Joints

Initially, we aimed to investigate the effect of warming up on the lower limbs. However, out of the final nine articles, eight examined the effect of warming up on the position sense of the knee joint [14, 23, 28, 29, 34-36] and only one article examined the effect of warming up on the ankle joint position sense [37]. The latter was omitted due to insufficient data. Furthermore, we found no studies on the effect of warming up on the hip joint position sense. For these reasons, we changed the study title from 'lower limb' to 'knee'.

Results

Initially, 5,133 articles were identified from the selected databases. After importing into Endnote software (version 8) and removing duplicates, 4,101 articles remained. Upon reviewing the abstracts and titles, 31 articles were selected, while the rest were excluded due to not meeting inclusion criteria. Subsequently, the full texts of these 31 articles were thoroughly reviewed. Of these, nine eligible articles [14, 15, 23, 28, 29, 34-37] were deemed eligible for the study. However, 2 of these were later excluded due to insufficient data for meta-analysis [15, 37]. Ultimately, the data from 7 articles [14, 23, 28, 29, 34-36] were utilized in the meta-analysis (Figure 1).

Active absolute angular error: Figure 2 depicts warming up's impact on individuals' active absolute angular error. This effect was studied in 5 articles [14, 29, 34-36]. 92 participants. The data analysis from these studies revealed a significant effect of warming up on the active absolute angular error (P=0.001). The I-Square test was employed to evaluate heterogeneity, and no significant heterogeneity was detected (P=0.248, I^2=24.78). The funnel plot suggested that the studies may not be subject to publication bias (Figure 3).

Passive absolute angular error: Two studies [23, 28] investigated the effect of warming up on the passive absolute angular error (Figure 4) with 22 participants. The analysis of the results showed that warming up did not significantly affect the passive absolute angular error (P=0.055). The I-Square test was employed to evaluate heterogeneity, and no significant heterogeneity was detected (P=0.118, I^2=53.24). The funnel plot suggested potential publication bias in the studies. However, the Trim and Fill results showed that even adding two random studies to the left of the chart could significantly affect the final results of the meta-analysis (Figure 5).

Active Relative angular error: Five studies [14, 29, 34-36] examined the effect of warming up on the active relative angular error (Figure 6) with 92 participants. The data from these studies were analyzed using Comprehensive Meta-Analysis (CMA), and the results indicated a significant effect of warming up on the active relative angular error (P=0.032). The I-Square test was employed to evaluate heterogeneity, and no significant heterogeneity was detected (P=0.266, I^2=22.30). The funnel plot suggested potential publication bias in the studies. However, the Trim and Fill results showed that even adding two random studies to the left of the plot could significantly affect the final results of the meta-analysis (Figure 7).

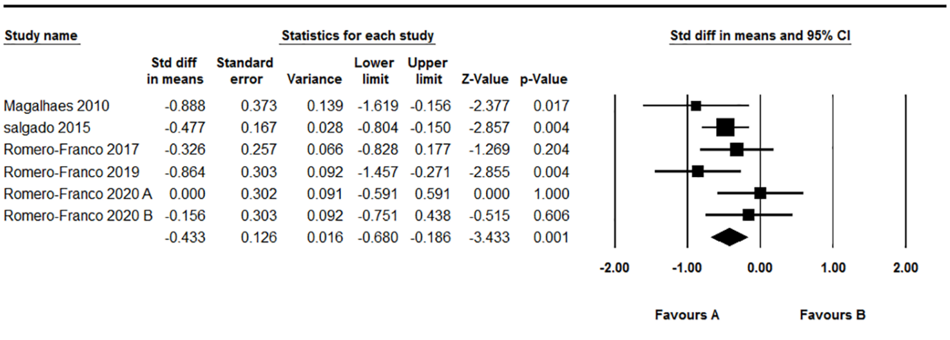

Figure 2: Forest plot of the effect of warming up on active absolute angular error.

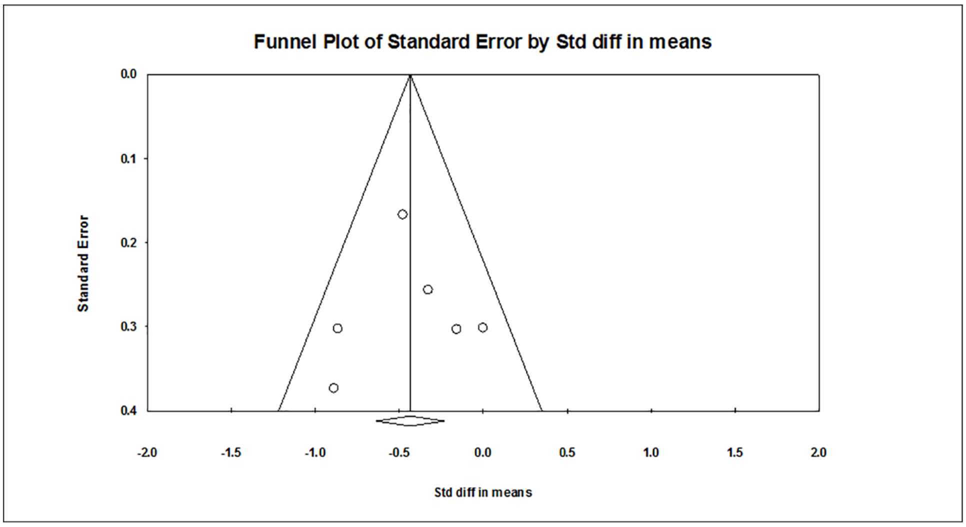

Figure 3: Funnel plot of studies worked on active absolute angular error.

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Bartlett 2002	1.009	0.355	0.126	0.314	1.705	2.846	0.004
Subasi 2008 A	0.046	0.316	0.100	-0.574	0.666	0.145	0.885
Subasi 2008 B	0.644	0.348	0.121	-0.037	1.326	1.854	0.064
	0.549	0.286	0.082	-0.013	1.110	1.916	0.055

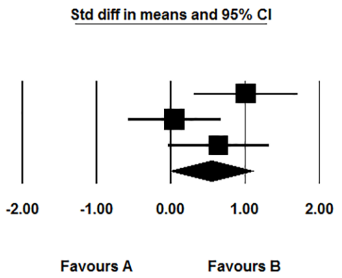

Figure 4: Forest plot of the effect of warming up on passive absolute angular error.

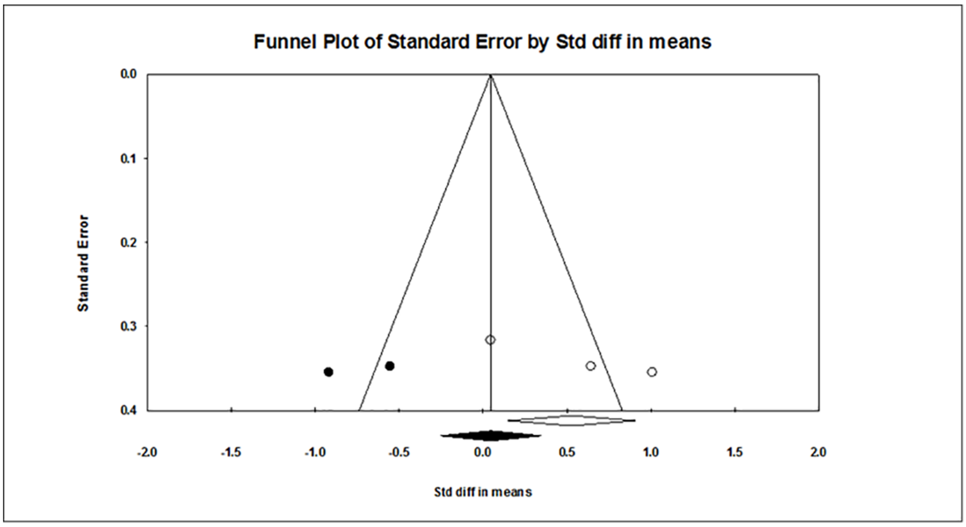

Figure 5: Funnel plot of studies worked on passive absolute angular error.

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Magalhaes 2010	0.695	0.352	0.124	0.005	1.386	1.973	0.048
salgado 2015	0.002	0.158	0.025	-0.308	0.312	0.013	0.990
Romero-Franco 2017	0.623	0.273	0.075	0.088	1.159	2.281	0.023
Romero-Franco 2019	0.355	0.266	0.071	-0.167	0.877	1.333	0.182
Romero-Franco 2020 A	0.208	0.305	0.093	-0.389	0.805	0.683	0.495
Romero-Franco 2020 B	0.060	0.302	0.091	-0.531	0.652	0.199	0.842
	0.258	0.120	0.014	0.022	0.494	2.146	0.032

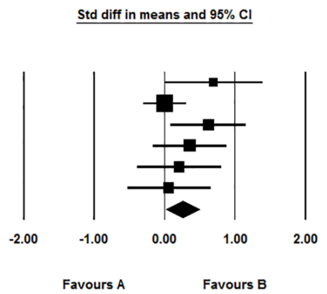

Figure 6: Forest plot of the effect of warming up on active relative angular error.

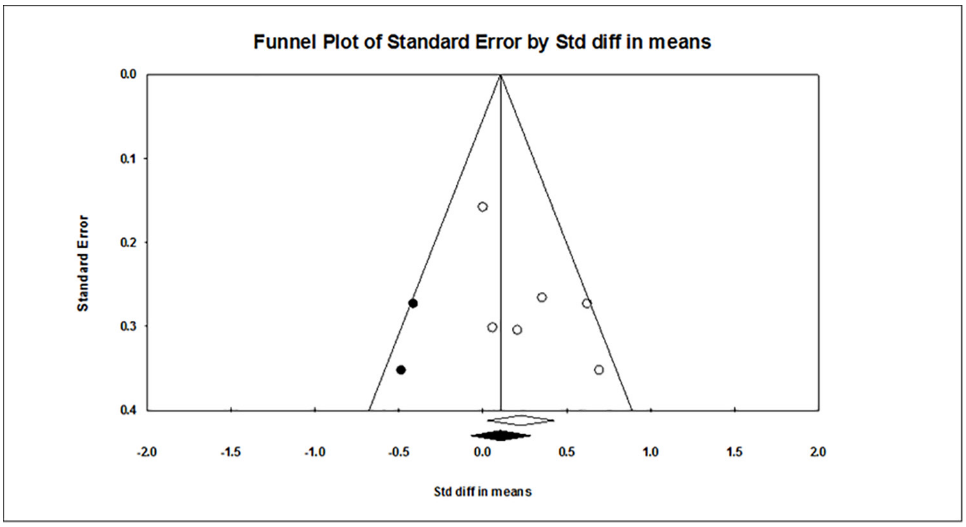

Figure 7: Funnel plot of studies worked on active Relative angular error.

Discussion

To the best of our knowledge, this is the first article aimed at a systematic review and meta-analysis of the effect of warming up on knee position sense. The results of this systematic review indicate that warming significantly affects both the absolute angular error and the active relative error. Still, it does not significantly affect the passive absolute error. Publication bias was also found to be significant in two studies. After applying the trim and fill method, the results of two studies concerning the active relative and passive absolute errors changed, which could influence our findings. Therefore, further studies are required in these two areas to obtain more definitive results.

The assessment of position sense is conducted by measuring the repositioning error in a limb, either actively or passively [38]. This article demonstrates that warming up significantly affects the active joint position sense test, not the passive one. One possible explanation for this discrepancy is that warming up increases sensitivity in the muscle spindle, the primary receptor in the active joint position sense [39]. It has been suggested that muscle activation is low during passive movement, fusimotor activity is reduced, and sensory feedback from muscle spindles is diminished. Consequently, input from Golgi and Ruffini receptors seems to play a more significant role in sensory feedback. However, in active movement, both fusimotor drive and muscle spindle feedback are involved [40]. Furthermore, in an active test, an individual must support the limb's weight, thereby involving more muscle receptors [41].

Previous studies demonstrated that the active reposition test shows joint performance better than passive tests. Furthermore, afferents increase in active testing compared to passive testing, and the brain system constantly compares the input information, leading to a more accurate angle reposition [42, 43]. In addition, during active reconstruction, the person can adjust the angle, while this is impossible in passive reconstruction, where the person can only command a stop at one point [44].

Warming up, a low-intensity exercise increases the sensitivity of mechanoreceptors [23, 45]. The increased sensitivity of mechanoreceptors seems to be caused by three mechanisms: improving the viscoelastic properties of muscle, increasing tissue oxygen, and increasing body temperature [19, 26, 46]. In addition, the role of central factors in improving joint position sense improvement cannot be ignored [22].

On the other hand, another reason for improving proprioception after warming up seems to be due to the increase in the output of the muscle spindle by the γ-motor neurons during movement [25]. The contractile elements around the fibers inside the spindle are innervated by γ-motor neurons, which directly control the muscle. Warming up can increase the spindle sensitivity, resulting in changes to the movement commands and thus reducing knee errors in sports competitions.

Since the muscle spindles are the main receptors for position sense, they inform the brain about changes in the length of muscles [47] increased sensitivity of muscle spindles results in more precise efferent to the central nervous system. Then, the CNS drives more accurate efferent messages to the muscle spindle [48]. All these processes lead to the improvement of the repositioning angle.

One of the most common preventative measures for sports injuries is proper warming up [49]. The effectiveness of warming up in injury prevention can be increased even further by using specialized injury prevention programs related to each sport, with minimal equipment needs and time requirements. For example, a study by Zarei et al. demonstrated that incorporating specialized exercises into the warm-up program of volleyball players leads to increased shoulder dynamic stability, which may reduce long-term injuries [50].

Another study showed that using a warm-up program (FIFA+11) significantly reduces the risk and severity of injuries in football players [49]. A sports injury is a collective term for all types of injuries that can occur in physical activities and can be a significant barrier to participation in physical activity [51, 52].

Treating sports injuries can be time-consuming, difficult, and costly [53, 54], making preventative strategies medically beneficial and economically advantageous. These preventive measures, also known as countermeasures, are one of the most important methods to control the risk of injury and reduce the incidence and severity of injuries [55].

This study had its limitations. It investigated only the immediate effects of warming up, with no examination of long-term effects. Additionally, the review was confined to articles in English. Furthermore, none of the studies included a follow-up process. Among the three components of proprioception, only the position sense was examined, leaving a lack of information about the force sense and motion sense. Consequently, the results may not be generalizable to individuals with injuries or illnesses.

Conclusion

Warming up affects the active absolute and relative angular error significantly but does not significantly affect the passive absolute error. This discrepancy may be due to the involvement of different receptors. However, as the number of articles examining the passive absolute error was limited, a definitive conclusion cannot be drawn. More studies are needed to clarify the issue. It can be concluded that warming up has a significant effect on proprioception.

Acknowledgment

This article is derived from the Ph.D. Thesis of Physical Education and Sports Science authored by Ms. Parisa Sayyadi. The thesis was guided by Dr. Hooman Minoonejad and Dr. Foad Seidi, with advice from Dr. Rahman Shikhhoseini)

Conflicts of Interest: None declared.

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Appendix: Downs and Black checklist

Reviewer's initials:	**First Author:** **Journal:**				**Year published:**
Reporting		**Yes**	**No**	**Unclear**	**Partially**
1.	Is the hypothesis/aim/objective of the study clearly described?	1	0		
2.	Are the main outcomes to be measured clearly described in the Introduction or Methods section?	1	0		
3.	Are the characteristics of the patients included in the study clearly described?	1	0		
4.	Are the interventions of interest clearly described?	1	0		
5.	Are the distributions of principal confounders in each group of subjects to be compared clearly described?	2	0		1
6.	Are the main findings of the study clearly described?	1	0		
7.	Does the study provide estimates of the random variability in the data for the main outcomes?	1	0		
8.	Have actual probability values been reported (e.g., 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?	1	0		
Total reporting score: ________ /9					
External validity		**Yes**	**No**	**Unclear**	**Partially**
9.	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	1	0	0	
10.	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?	1	0	0	
***Total external validity score*: ________ /2**					
Internal validity – bias		**Yes**	**No**	**Unclear**	**Partially**
11.	Was an attempt made to blind study subjects to the intervention they have received?	1	0	0	
12.	Was an attempt made to blind those measuring the main outcomes of the intervention?	1	0	0	
13.	If any of the results of the study were based on "data dredging," was this made clear?	1	0	0	
14.	Were the statistical tests used to assess the main outcomes appropriate?	1	0	0	
15.	Was compliance with the intervention/s reliable?	1	0	0	
16.	Were the main outcome measures used accurate (valid and reliable)?	1	0	0	
***Total bias score*: _________ /6**					
Internal validity – confounding		**Yes**	**No**	**Unclear**	**Partially**
17.	Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?	1	0	0	
18.	Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?	1	0	0	
19.	Were study subjects randomized to intervention groups?	1	0	0	
20.	Was the randomized intervention assignment concealed from both patients and health care staff until recruitment was complete and irrevocable?	1	0	0	
21.	Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	1	0	0	
***Total confounding score*: ________ /6**					
Power		**Yes**	**No**	**Unclear**	**Partially**
22.	Were appropriate power calculations reported?	1	0	0	
Total power score: ________ /1					
*Total quality score: ________ /24					