Journal of Bodywork & Movement Therapies 40 (2024) 1008–1013

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

The influence of circulating cold water cryotherapy with or without intermittent pneumatic compression on shoulder joint position sense (JPS) in recreationally active adults: A randomized crossover trial

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ARTICLE INFO

Handling Editor: Dr Jerrilyn Cambron

ABSTRACT

Objectives: Cryotherapy is a widely used intervention in sports settings to facilitate the return of injured athletes to competition, despite a lack of high-quality evidence. Given the possibility cryotherapy may increase the risk of injury, by reducing nerve conduction velocity, muscle force production, and proprioceptive afferent information, further research is needed to evaluate its effects on proprioception, particularly in the shoulder joint, which has the greatest range of motion of any joint in the body, where there is a dearth of studies.
Methods: We conducted a pre-registered, 1:1 block randomized, baseline controlled, double blind (outcome assessor and statistician), crossover trial of cryotherapy without compression and cryotherapy with compression.
Results: Analysis indicated there were no statistically significant changes in the accuracy of achieving the target angle because of either the cryotherapy or compression intervention. The small effect sizes observed between the groups indicate that cryotherapy is unlikely to have a clinically significant negative impact on shoulder joint position sense.
Conclusion: Consequently, returning athletes to the field of play after cryotherapy treatment is not expected to pose an increased risk of injury due to proprioceptive deficits. These findings align with the majority of studies investigating the effects of cryotherapy on proprioception.
Impact statement: This pre-registered, randomized, crossover trial on the effects of cryotherapy on joint position sense (JPS) in physical therapy and rehabilitation provides valuable insights into a widely used treatment modality. The small effect sizes observed in our study suggest that cryotherapy is unlikely to have a clinically significant negative effect on shoulder JPS. Cryotherapy remains a viable therapeutic option, without concerns for adverse effects or further injury risk, in returning athletes to the field of play.

1. Introduction

The term cryotherapy, which refers to the reduction of tissue temperatures by removing heat from the body (Khanmohammadi et al., 2011), has been extensively used in the management and treatment of acute musculoskeletal injuries (Uchio et al., 2003). It has the potential to decrease tissue temperature, metabolism, nerve conduction velocity, inflammation, pain, edema, circulation, tissue stiffness, muscle spasm and stiffness, and symptoms of delayed-onset muscle soreness (Costello and Donnelly, 2010; Furmanek et al., 2014). Consequently, many practitioners use cryotherapy with the expectation that it will enable athletes to return to the field of play by reducing pain and swelling. Despite the widespread use of cryotherapy, beyond the reduction of surface skin temperature there is a notable lack of high-quality, rigorous evidence supporting its efficacy and even fewer studies that consider the adverse effects of cryotherapy.

To achieve an analgesic effect from cryotherapy requires a reduction in skin temperature to approximately 13.6 °C (Jutte et al., 2001). However, studies report an inverse relationship between the degree of tissue cooling and nerve conduction velocity (Abramson et al., 1966; Ruiz et al., 1993). Even a modest reduction in skin temperature to 15 °C may cause action potential propagation and reduce nerve conduction

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https://doi.org/10.1016/j.jbmt.2024.07.022
Received 10 October 2023; Received in revised form 12 June 2024; Accepted 7 July 2024
Available online 9 July 2024

velocities up to 17% (Algafly and George, 2007). It is entirely plausible then, that cryotherapy, applied prior to an athlete returning to play, may indeed increase the risk of injury by reducing nerve conduction velocity, muscle force production, and proprioceptive afferent information (Hopper et al., 1997; Oliveira et al., 2010; Uchio et al., 2003).

The impact of cryotherapy on proprioception remains poorly understood, despite the well-established importance of proprioceptive acuity to performance, injury prevention, and rehabilitation (Costello and Donnelly, 2010; Furmanek et al., 2018). While joint position sense (JPS) testing is the most widely used method for evaluating proprioception (Costello and Donnelly, 2010) there is considerable variation in how it has been administered, as well as in the mode, surface area, temperature, duration, and location of cryotherapy (Han et al., 2016), making it challenging to syntheses data.

The most recent review found eleven studies that investigated the effects of locally applied cryotherapy on JPS (Furmanek et al., 2014). Among these studies, four reported negative effects of cryotherapy on proprioceptive acuity (Hopper et al., 1997; Oliveira et al., 2010; Surenkok et al., 2008; Uchio et al., 2003), while most found cooling elicited no change in JPS (Costello and Donnelly, 2011; Dover and Powers, 2004; Hart et al., 2005; Khanmohammadi et al., 2011; LaRiviere and Osternig, 1994; Ozmun et al., 1996; Wassinger et al., 2007).

The shoulder has the greatest range of motion of any joint in the body, and the rotator cuff muscles play a crucial role in providing dynamic stability. This degree of functionality makes it a pivotal joint in many sporting activities, particularly in those characterized by throwing mechanisms. Yet, few studies have evaluated the effects of cryotherapy on this joint and the mechanisms associated with proprioceptive control for these muscles remains unclear (Dover and Powers, 2004).

Evidence suggests that proprioception, specifically JPS, is mediated by mechanoreceptors, such as muscle spindles and golgi tendon organs, located in the muscle and tendon structures (Eldred et al., 1960). Therefore, the superficial cryotherapy techniques used by many studies may not have been capable of cooling the deeper articular structures associated with the should joint, which may explain, in part, the null findings.

Since Furmanek et al. (2014) review,we were able to identify one published study of cryotherapy on shoulder proprioception, which reported a decrease in JPS (Torres et al., 2017). However, there have been no studies, that we could identify, which use circulating cold water to provide a deeper and more consistent cooling, capable of targeting the mechanoreceptors. It is also worth noting that studies were generally small and except for Dover and Powers (2004) did not report any a priori sample size calculations. Most studies also had moderate to high risk of bias, and were not pre-registered; therefore, practices such as selective outcome reporting, p-hacking, and harking could not be ruled out (Yamada, 2018).

Given the potential for cryotherapy to increase injury risk, due to factors like decreased nerve conduction velocity, reduced muscle force production, and impaired proprioceptive signaling, this randomized controlled crossover study aimed to investigate whether cryotherapy affects JPS. If indeed cryotherapy has a detrimental effect on JPS, practitioners may be more cautious about using this intervention before returning athletes to competition.

Furthermore, many of the cryotherapy devices being used in practice today also provide intermittent pneumatic compression, the additive effects of which are unclear. The design of this randomized controlled crossover study therefore enables the effects of cryotherapy in isolation and cryotherapy with pneumatic compression to be evaluated. In doing so, practitioners can be more informed about the choice and implementation of these cryotherapy techniques.

As far as the researchers are aware, there have been no pre-registered studies exploring the impacts of cryotherapy using continuous cold-water circulation on proprioception and JPS. This pre-registered study seeks to mitigate the uncertainties linked with non-registered study designs and enhance the certainty of evidence by determining the effects, if any, of continuous circulating cold water cryotherapy with or without compression on shoulder JPS.

2. Methods

This trial is reported in accordance with the CONSORT 2010 statement: extension to randomized crossover trials (Dwan et al., 2019) (Appendix 1) and TIDieR guidelines (Hoffmann et al., 2014) (Appendix 2). The trial protocol was pre-registered on the open science framework (DOI:10.17605/OSF.IO/RW5DZ).

2.1. Ethics statement

Institutional ethical approval was obtained by the University Ethics Committee (Staffordshire University) and all procedures were carried out in accordance with the Declaration of Helsinki (Version, 2013).

2.2. Changes from protocol

This trial was disrupted by the COVID-19 pandemic and as such a pause in recruitment took place between February 2020 and September 2021. Participants were not blindfolded during JPS assessment as we decided it was more important to replicate the sporting environment, maintaining eco-validity. Only the 50th percentile joint position replication angle was assessed due to time restrictions. Lastly, due to the violation of the normality assumption, we deviated from our pre-specified analysis plan and performed non-parametric analysis.

2.3. Participants

From December 2019, healthy, recreationally active, adults were invited to participate via an announcement on the university virtual learning environment (MS Teams) and via word of mouth. Participants who had experienced an I) upper limb injury within the last 6 months, II) had a cold intolerance, III) were in acute stages of inflammatory phlebitis, IV) had any history/risk factors for deep vein thrombosis or pulmonary embolus, V) significant arteriosclerosis or other vascular ischemic disease, VI) a condition in which increased venous or lymphatic return, VII) significant vascular impairment or acute paroxysmal cold hemoglobinuria or cryoglobulinemia were excluded. Participants were requested to refrain from vigorous physical activity, alcohol, and caffeine consumption 24 h prior to testing. Recruitment was stopped in March 2023 because the a priori sample size was achieved.

2.4. Sample size

To establish a difference of small effect (reported by Costello and Donnelly (2010)) in JPS between baseline, cryotherapy without compression, and cryotherapy with compression, 54 participants were required to achieve 80% power with a 5% two-sided type I error rate and a 1:1 allocation ratio.

2.5. Settings and location

All testing was performed at the Staffordshire University Human Performance Laboratory, Leek Road, Stoke on Trent.

2.6. Randomization

The order in which participants received treatment was randomly allocated using a block randomized design (block size = 4) using RStudio (available at https://osf.io/8vmna/) to either cryotherapy without compression followed by cryotherapy with compression a week later, or, the inverse. To preserve allocation concealment an independent person generated the randomization list and produced a series of numerically ordered sealed opaque envelopes containing the participant allocation. Envelopes were subsequently opened by the cryotherapy administrator after participant eligibility had been established; the outcome assessor remained blind to the allocation.

2.7. Interventions

GameReady is an easy-to-use, fully adjustable system that continuously circulates cold water from the unit's reservoir, via a connected hose, through an inner chamber of the selected anatomical wrap, before returning to the reservoir. The cold water is refreshed through the ice before returning through the anatomical wrap, thus delivering 'continuous' cold water/therapy. The unit can also simultaneously pump air into the outer chamber of the anatomical wrap, intermittently inflating and deflating it according to the pressure settings selected.

After baseline JPS assessment, participants were randomized with a 1:1 allocation ratio to either cryotherapy with compression or cryotherapy without compression. In both instances, the game ready unit was filled with crushed ice equivalent to that of two standard ice bags (2392 cm2) and applied locally via a standard shoulder wrap for 30 min, as per manufacturing guidelines (Game ready shoulder wrap user guide,) and previously published trials (Ostrowski et al., 2019).

During the cryotherapy with compression intervention, cyclical pneumatic compression was applied at 5–75 mmHg for approximately 3-min pressure cycles (90 s to pressurize and 90 s to depressurize) for the duration of treatment. Treatments were applied by the same trained sports therapist one week apart to minimize any carryover effects.

2.8. Outcomes

The primary outcome, shoulder JPS, was measured on four separate occasions immediately before and immediately after each intervention. The testing procedure was adapted from Olsson et al. (2004), who found this test to be a reliable measure of knee position sense movements.

An isokinetic dynamometer was used to track joint position due to its strong validity and reliability (ICC2, k = 0.99, r > 0.999) (Drouin et al., 2004; Taylor et al., 1991). After calibration, participants were positioned in a seated position and their dominant arm was placed firmly to the isokinetic dynamometer lever arm. The axis of the isokinetic dynamometer rotation shaft was aligned precisely with the olecranon process and centre of the glenohumeral joint, and the arm was placed into full protonation, 90° frontal plane shoulder abduction and 90° elbow flexion using basic goniometer.

Due to individual variability in shoulder internal and external rotation it was necessary to obtain relative mid-range values for each participant. Participants were instructed to relax their shoulder whilst a trained clinician measured their total range of motion by passively internally rotating the shoulder to end of range before passively rotating the shoulder externally to end of range. The mid-range position was calculated as the 50th percentile and was chosen because joint afferents (muscle spindles) are more susceptible to stimulation in this position (Oliveira et al., 2010; Safavi-Farokhi et al., 2021), and previous research found poorer joint accuracy at the mid-range (Janwantanakul et al., 2001).

Once the relative mid-range position had been established, the shoulder was passively rotated to full internal rotation (starting position) and held for 10 s. The shoulder was then externally rotated from the starting position to the relative mid-range position. The participant was held in this position for 10 s and verbally instructed to 'remember this position'. The shoulder and arm were then passively returned to the starting position. After a further 10 s, the participant was instructed to actively replicate the mid-range position. This sequence was performed three times to generate reliable results (ICC2, k = 0.980 (Furmanek et al., 2018)).

A single practice trial was given before testing on each testing occasion to allow for familiarisation with the procedures and to minimize practice effects. The participants were given no feedback regarding their performance.

2.9. Blinding

Due to the nature of the intervention, it was not possible to blind the participant or those applying the cryotherapy. We were, however, able to blind outcome assessors and the trial statistician.

2.10. Statistical methods

Descriptive data was calculated for anthropometric measurements and expressed as mean ± standard deviation. The average angle of the three trials (attempts) for each post and pre and across two different interventions (cryotherapy with compression and cryotherapy without compression) were calculated for each condition. The absolute differences for each intervention were calculated between pre and post angles against the reference point, representing the mid-point range of motion. The difference between absolute-pre and absolute-post angles were calculated and reported as the increase in inaccuracy when using the intervention. Hence, the higher the inaccuracy the lower the effectiveness of that intervention. Normality was assessed by the Kolmogorov-Smirnov test and given the non-normal distribution of the data a Wilcoxon Signed Rank test was used to assess significant differences. All data was analysed using SPSS (IBM, SPSS Inc. Version 26) and data visualisation were generated using Jamovi (Version 2.4). All tests were two sided with an alpha level of 0.05.

3. RESULTS

Fifty-four (54% male) participants (age 22.1 (6.16) years, height 172.3 (10.85) centimetres, and weight 73.2 (16.93) kilograms) were recruited to this study. Most of the participants (87%) were right-handed. Prior to completing the cryotherapy without compression, the average total range of movement was 200.4 ° (33.24), and prior to completing the cryotherapy with compression, the average total range of movement was 202.2 ° (33.16) (Table 1). Two participants, who were assigned to receive the interventions, in different orders, withdrew from the study after their first testing session (Figure 1)().

Before cryotherapy without compression was administered, participants achieved an average joint position angle of 95.72 ° (18.46), which compared with the average target angle (100.33 °) was a relative difference of 4.61 ° (4.91), and an absolute difference of 5.29 ° (4.15). After cryotherapy without compression was applied, participants scored an average joint angle of 95.81 ° (18.24); a relative difference of 4.53 ° (5.51), and an absolute difference of 5.37 ° (4.67) (Table 2 and Fig. 2).

Prior to cryotherapy with compression, participants achieved an average joint position angle of 97.94 ° (17.57), which compared to the target angle (101.24 °) was a relative difference of 3.29 ° (4.68), and an absolute difference of 4.20 ° (3.87). After cryotherapy with compression participants exhibited an average joint angle of 98.33 ° (17.50), resulting in a relative difference of 2.90 ° (4.88), and an absolute difference of 4.37 ° (3.60) (Table 3 and Fig. 3).

The results of the Wilcoxon Signed Rank test indicated that there

Table 1
Baseline characteristics.

	N	Mean	SD	95% Confidence Interval	
				Lower	Upper
Age (years)	54	22.1	6.16	20.4	23.8
Height (cm)	54	172.3	10.85	169.3	175.2
Weight (kg)	54	73.2	16.93	68.6	77.8
Total Range of movement (degrees)					
Cryotherapy without compression	53	200.4	33.24	191.3	209.6
Cryotherapy with compression	53	202.2	33.16	193.1	211.4

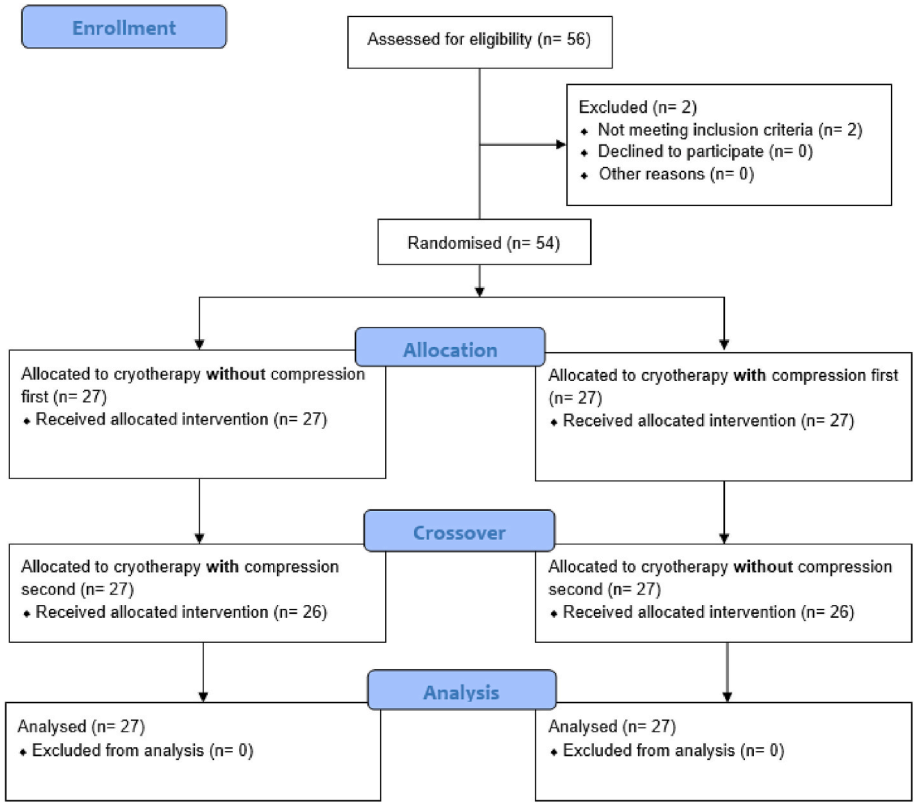

Fig. 1. PRISMA flow diagram.

Table 2
Mean, relative and joint position sense scores for pre and post cryotherapy **without** compression.

	N	Mean	SD	95% Confidence Interval	
				Lower	Upper
Mid-Range Position (degrees)	53	100.33	16.62	95.75	104.91
Mean Joint Position Sense (degrees)					
Before Treatment	53	95.72	18.46	90.63	100.80
After Treatment	53	95.81	18.24	90.78	100.83
Relative Difference (degrees)					
Before Treatment	53	4.61	4.91	3.26	5.97
After Treatment	53	4.53	5.51	3.01	6.04
Absolute Difference (degrees)					
Before Treatment	53	5.29	4.15	4.15	6.44
After Treatment	53	5.37	4.67	4.09	6.66

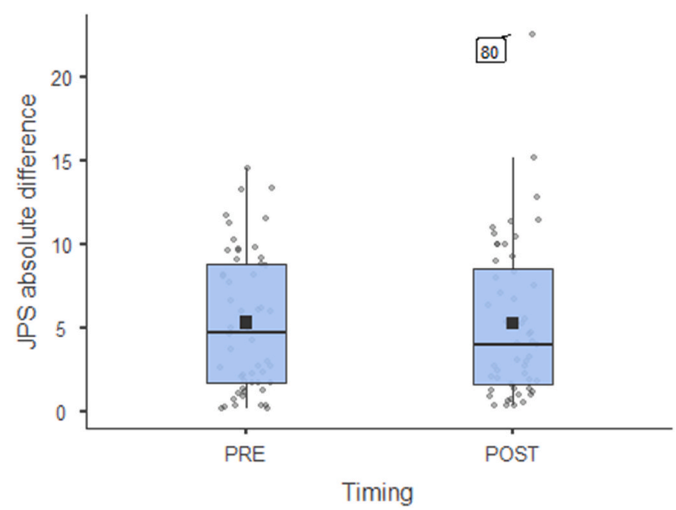

Fig. 2. Absolute change in joint position sense pre versus post cryotherapy without compression.

were no statistically significant changes, in either the cryotherapy without compression or cryotherapy with compression interventions, in the accuracy of achieving the target angle. These findings suggest that neither intervention had a significant impact on shoulder JPS.

4. Discussion

The objective of this pre-registered, randomized, crossover trial, with a 1:1 allocation ratio, with baseline control and double-blind design was to investigate the effects of cryotherapy, with or without compression, on shoulder JPS. Despite having sufficient statistical power to detect small differences in JPS, the results did not provide enough evidence to conclude that cryotherapy has an impact on JPS. It is important to note that the 'absence of evidence is not evidence of absence' (Alderson, 2004, p. 1). However, the small effect sizes observed in this study suggest that it is highly unlikely that cryotherapy has a clinically significant negative effect on shoulder JPS. This finding is consistent with the majority of studies that have investigated the effects of cryotherapy on JPS (Costello and Donnelly, 2011; Dover and Powers, 2004; Hart et al., 2005; Khanmohammadi et al., 2011; LaRiviere and Osternig, 1994; Ozmun et al., 1996; Wassinger et al., 2007).

This study adopted a similar design to Dover and Powers (2004) in that it was a crossover, repeated measures design that subjected participants to a 30- minute cryotherapy treatment at the shoulder to determine the effects of cooling on JPS. There were, however, concerns whether the ice bag technique used by Dover and Powers (2004) was able to maintain a consistent temperature for 30-min, and if it would reach the deep tissue structures responsible for JPS, especially at the

Table 3
Mean, relative and joint position sense scores for pre and post cryotherapy **with** compression.

	N	Mean	SD	95% Confidence Interval	
				Lower	Upper
Mid-Range Position (degrees)	53	101.24	16.60	96.66	105.81
Mean Joint Position Sense (degrees)					
Before Treatment	53	97.94	17.57	93.10	102.79
After Treatment	53	98.33	17.50	93.51	103.16
Relative Difference (degrees)					
Before Treatment	53	3.29	4.68	2.00	4.58
After Treatment	53	2.90	4.88	1.56	4.25
Absolute Difference (degrees)					
Before Treatment	53	4.20	3.87	3.13	5.26
After Treatment	53	4.37	3.60	3.38	5.36

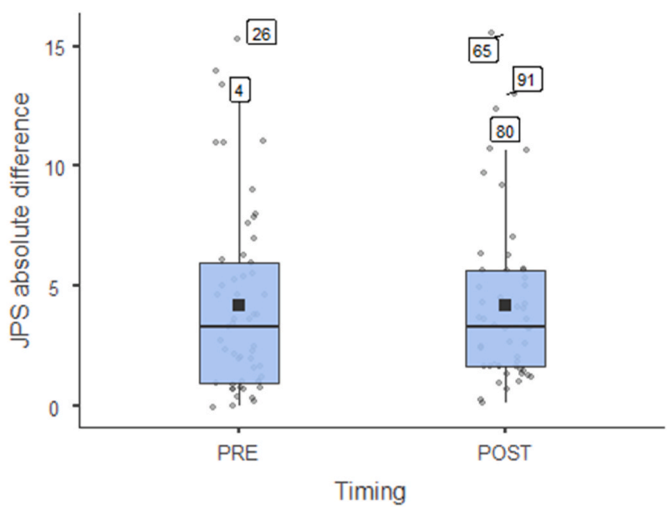

Fig. 3. Absolute change in joint position sense pre versus post cryotherapy with compression.

shoulder joint. Our study adopted a more contemporary cryotherapy technique (GameReady device) that continuously circulated cold water and that offered intermittent pneumatic compression to maintain a consistent tissue temperature, which was believed to target deeper tissue structures. Our study also used isokinetic dynamometry to more accurately assess JPS, and used a relative mid-range position because the literature suggested joint accuracy was poorest in this position (Janwantanakul, 2004; Proske, 2005; Safavi-Farokhi et al., 2021). Despite these methodological differences, both studies concluded no evidence of effect.

Wassinger et al. (2007) also reported that the application of a 1500g ice pack to the shoulder joint for 20- min did not influence shoulder JPS. However, the authors did observe a significant change in joint motion path during movement from 90 ° of abduction with 90 ° of external rotation to 20 ° of flexion with neutral shoulder rotation, as well as a decrease in Functional Throwing Performance Index. Perhaps indicating that open path movements are more vulnerable to cryotherapy changes compared with the fixed plane testing used in this study. However, Wassinger et al. (2007) employed a single group, pre-test post-test design, and lacked a control group, making it difficult to attribute these changes to cryotherapy alone.

A more recent randomized, double-blind, controlled trial by Torres et al. (2017) involving 48 healthy participants reported significant impairment to shoulder JPS following a 15-min crushed-ice intervention. In the present study, we applied cryotherapy for twice that duration and used circulating cold water to maintain temperature but were unable to replicate these findings. Notably, the Torres et al. (2017) study focused solely on a female population, while our study included predominantly male participants (54%). It is possible that the effects of cryotherapy on JPS may be mediated by gender and warrants further investigation.

In addition, the regulation of motor control is reliant on a combination of incoming sensory information (afferent) and outgoing motor commands (efferent). The study by Torres et al. (2017) blindfolded participants during the JPS evaluation, resulting in restricted visual feedback availability. Conversely, in the present study, participants were not blindfolded and may have adjusted their motor responses through additional peripheral information. Whilst this has high external validity, in that athletes use sensory information to modify motor control during sport performance, this may explain the null findings observed and the conflicting evidence base. Future researchers may consider implementing a similar but blindfolded arm to limit visual feedback during JPS testing, thus isolating the influence of cryotherapy on motor control. This could potentially elucidate whether the presence or absence of visual feedback significantly impacts proprioceptive performance.

This paper presents the first pre-registered study that has reported the effects of cryotherapy and JPS according to CONSORT and TIDieR guidelines. Prior to this study, only one study in the literature reported a sample size calculation, with the intention of detecting a large effect (Dover and Powers, 2004). However, considering the outcomes of previous studies, we consider this effect size to be overly ambitious. In contrast, our study was powered to detect a small within-participant effect size, making it the only one of its kind.

Most previous studies that examined cryotherapy have used superficial cold therapy techniques, which are likely to reduce the temperature of superficial tissues but may not have a substantial impact on nerve conduction velocity of muscle spindles and golgi tendon organs. Our hypothesis was that continuously circulating cold water through crushed ice would lead to a more consistent and greater reduction in temperature of the deep tissue structures. The increasing use of such devices in the management and treatment of athletes underlined the need for a better understanding of their effects.

An inherent limitation of our investigation is that cryotherapy interventions are typically administered pitchside in reaction to soft tissue injuries with the goal of expediting the player's return to the playing field. As with most of the research in this area, our study was carried out on a sample of healthy, physically active adults, and it remains uncertain as to the extent to which these results can be generalized to those who have sustained injuries. Conducting future research among individuals with acute injuries would provide valuable insights into the consistency of these findings and their applicability to sporting environments. We also assessed JPS at a single joint angle (mid-range) and in a fixed plane of motion. It is plausible that effects of cryotherapy may differ at alternative joint angles and or when the limb is free to move through multiple planes, which might be possible through 3D biomechanical analysis.

The modest effect sizes observed in this study suggest that cryotherapy is unlikely to have a clinically significant adverse impact on shoulder JPS. Therefore, administering cryotherapy before an athlete's return to the field of play is unlikely to heighten the risk of (re)-injury from a joint proprioceptive standpoint. Practitioners can thus employ these techniques with increased assurance that the benefits of cyrotherapy outweigh the possible risks.

5. Conclusion

In conclusion, the present research did not find evidence supporting an effect of cryotherapy on JPS. Although the absence of statistically significant changes does not necessarily imply the absence of an effect, the small effect sizes observed between the groups suggest that cryotherapy is highly unlikely to have a clinically significant negative effect on shoulder JPS. Further research is needed to explore alternative interventions or factors that may influence shoulder joint position sense and to investigate potential gender differences in the response to cryotherapy.

6. Data availability statement

The data that support the findings of this study are openly available in the open science framework at https://osf.io/dut9n/?view_only=6829ffd0d9d242ed90502a354399e518.

7. Details of funding sources

No funding to declare.

8. GRANT numbers

No authors are/were in receipt of grants

CRediT authorship contribution statement

E.N. Stanhope: Writing – review & editing, Writing – original draft, Visualisation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **R.L. Warnett:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **D.G. Burt:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **S.W. Cutler:** Writing – review & editing, Investigation, Data curation, Conceptualization. **J.W. G. Kell:** Writing – review & editing, Investigation, Data curation. **R. Naemi:** Writing – review & editing, Visualisation, Validation, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

The authors declare no competing interests and no funding was received for this work.

Acknowledgements

No acknowledgments to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbmt.2024.07.022.

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