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RESEARCH

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The effect of six-week regular stretching exercises on regional and distant pain sensitivity: an experimental longitudinal study on healthy adults

Morten Pallisgaard Støve[1,2*], Janus Laust Thomsen[2], Stig Peter Magnusson[3,4] and Allan Riis[1,2]

Abstract

Background Stretching exercises are widely used for pain relief and show positive effects on musculoskeletal, nociplastic and neuropathic pain; the magnitude of altered pain sensitivity responses following regular stretching is currently unknown. This study aimed to investigate the effect of six weeks of regular stretching exercise on regional and widespread pain sensitivity and range of motion and the effect of stretching cessation on regional and widespread pain sensitivity and range of motion.

Methods An experimental single-blind longitudinal repeated measures study. Twenty-six healthy adults were recruited. Regional and distant pressure pain thresholds and passive knee extension range of motion were measured at three points: before (baseline) and after six weeks (post-stretch) of daily bilateral hamstring stretching exercises and following four weeks of cessation (post-cessation) from stretching exercises.

Results Participants had a mean ± standard deviation (range) age of 23.8 ± 2.1 (21–30) years. There was a 36.7% increase in regional ($p = 0.003$), an 18.7% increase in distant pressure pain thresholds ($p = 0.042$) and a 3.6% increase in range of motion ($p = 0.002$) between baseline and post-stretch measures. No statistically significant differences were found for regional ($p = 1.000$) or distant pressure pain thresholds ($p = 1.000$), or range of motion ($p = 1.000$) between post-stretch and post-cessation. A 41.2% increase in distant pressure pain thresholds ($p = 0.001$), a 15.4% increase in regional pressure pain thresholds from baseline to post-cessation ($p = 0.127$) and a 3.6% increase in passive knee extension range of motion ($p = 0.005$) were found from baseline to post-cessation.

Conclusions Six weeks of regular stretching exercises significantly decreased regional and widespread pain sensitivity. Moreover, the results showed that the hypoalgesic effect of stretching on regional and widespread pain sensitivity persisted following four weeks of cessation. The results further support the rationale of adding stretching exercises to rehabilitation efforts for patients experiencing nociceptive, nociplastic, and neuropathic pain. However, further research is needed to investigate how the long-term effects of stretching exercises compare with no treatment in clinical populations.

*Correspondence:
Morten Pallisgaard Støve
mps@ucn.dk
Full list of author information is available at the end of the article

Trial registration The trial was registered June 1st, 2021 at ClinicalTrials.gov (Trial registration number NCT04919681).

Keywords Active stretching, Pain sensitivity, Range of motion, Pain threshold, Stretching cessation

Background

Joint and muscle extensibility are essential determinants of physical function [1] and, thereby, essential determinants of maintaining independent activities of daily living [2]. Regular stretching exercises are an effective method for increasing flexibility [3], and stretching exercises are widely used in exercise and rehabilitation to increase flexibility, improve function [4, 5], and reduce bothersome muscle soreness [6]. Also, stretching exercises are widely used in rehabilitation for pain relief. Although current evidence shows a clinically relevant effect of acute stretching on musculoskeletal [7], neuropathic [8] and nociplastic pain [9], there is limited and conflicting knowledge of the effect of regular stretching exercises on regional and widespread pain sensitivity [10, 11]. If stretching exercises can reduce pain sensitivity over time, it would allow an additional low-cost and -risk treatment option for patients experiencing pain. However, applying stretching exercises for pain management in different patient populations requires understanding the mechanisms underlying the potential change in pain sensitivity.

Evidence suggests that long-standing improvements in range of motion can be achieved after four to six weeks of regular stretching [3]. There may be a relation between the frequency and total time spent stretching per week and the gains in range of motion [3]. Current evidence suggests that the main contributor to the effects of stretching exercises are caused by modifications in the subject's sensation (i.e., stretch, tightness, or pain), resulting in changes in the tolerance to stretch [12]. Stretch tolerance is defined as the capability to tolerate stretch-related discomfort [13]. Previous research indicates that changes in the range of motion following stretching may be a manifestation of altered pain sensitivity [14, 15], suggesting that the tolerance to stretching may be a marker of overall pain sensitivity [16]. The increase in stretch tolerance may be contingent on an analgesic effect, allowing for a higher tolerance to passive tension [14, 17]. There may also be a decrease in both regional (e.g., local) and distant (e.g., a remote site of the body) pain sensitivity following acute bouts of stretching in healthy adults [18]. Mechanisms such as the modulation of inputs in the spinal dorsal horns (i.e., the Gate Control Theory) [7] and endogenous pain inhibitory mechanisms [16] have been proposed to be related to the effect of stretching on pain. Previous studies have also found correlations between the relative changes in the range of motion and the relative changes in pressure pain thresholds following stretching [12, 14, 18]. However, the magnitude of altered pain sensitivity responses following regular stretching is unknown.

The gain in flexibility following regular stretching will likely abate when stretching is discontinued [19, 20], suggesting that the retention of changes in the tolerance to stretch is linked with regular modifications of somatosensory input, e.g., regular stretching. However, there is a limited scientific understanding of the way in which these changes in pain sensitivity respond when regular stretching is discontinued.

The primary objective of this study is to investigate the effect of six weeks of regular stretching on regional and distant pain sensitivity. The secondary objective of this study is to investigate if regional and distant pain sensitivity will decrease following cessation.

Methods

This is a single-blind longitudinal repeated measurement study. The study is an exploratory proof-of-concept study inspired by a previous original study [19]. The study is reported according to the Guidelines for Reporting Observational Studies (STROBE). The trial was reported to the Danish Data Protection Agency (Project ID 24000509), registered at ClinicalTrials.gov on June 1st 2021 (Trial registration number NCT04919681), and approved by The North Denmark Region Committee on Health Research Ethics (N-20210044). Participants provided written informed consent before participation. Enrolment began on November 4th, 2021.

Participants

Participants were recruited through advertisements at the University College of Northern Denmark and via social media by convenience sampling. Healthy subjects between 18 and 65 years who were naive to experimental pain testing were eligible for inclusion. Exclusion criteria were (1) medical conditions such as cognitive impairments, neurological, orthopaedic, or neuromuscular problems that preclude stretching exercises or range of motion testing at the knee. (2) regular engagement in flexibility training (e.g., stretching, tai chi, pilates, or yoga), (3) regular use of prescription medicines or over-the-counter medications that affect the somatosensory systems, such as psychotropic medicines, analgesics or anti-inflammatory drugs. Potential participants were screened against the eligibility criteria prior to enrollment and baseline assessments.

Intervention

The study protocol was inspired by previous work and consisted of a six-week, seven d/wk stretching intervention and a four-week cessation period [20]. The intervention comprised six weeks of daily bilateral static stretching of the knee flexors (supplementary material). Stretches were performed either seated on the ground or standing in an alternating fashion. For the seated stretch, the participant sat upright on the floor with one leg straight. The sole of the other foot was placed on the inside of the outstretched leg. The participant leaned slightly forward, trying to touch their toes while maintaining full knee extension. For the standing stretch, the participant placed the heel of the stretching leg on an elevated surface approximately knee to waist high, with the knee fully extended. The participant then flexed forward at the hip [20]. The stretching intensity was standardised by instructing the participants to stretch to the point of discomfort (the sensation of stretch). Each stretch was held for 30 s for two repetitions with a minimum of 30 s of rest between bouts. Participants were encouraged to maintain their normal activity levels throughout the study but refrain from performing concomitant flexibility exercises (e.g., stretching, tai chi, pilates, or yoga).

The efficacy of exercise is related to adherence. Therefore, adherence to the stretching protocol was supported using a mHealth app. *(DigiFys Patient Portal, DigiFys, Viborg, Denmark).* Adherence is defined as the extent to which a person's behaviour coincides with agreed clinical recommendations [21]. To monitor adherence, participants were asked to keep a log of the dates when they performed the stretching exercises using the calendar function in the mHealth app. In addition, the mHealth app supported video instructions for stretching procedures. MPS contacted each participant every fortnight throughout the six-week stretching intervention to enhance adherence via the mHealth app. Exercise adherence was evaluated using self-reported data from the mHealth app.

Outcomes

The primary outcome measure was pain sensitivity expressed as regional (e.g., segmental pain modulation) and distant (e.g., central pain modulation) pressure pain thresholds. Assessments were performed at baseline, after six weeks (post-stretch), and after ten weeks (after four weeks of cessation). Evidence suggests that pressure pain thresholds are a valid and reliable method for assessing pain sensitivity over time, given their high levels of correlation and agreement between intra-individual measurements [22]. Pressure pain thresholds were assessed using a handheld electronic pressure algometer with a probe size of 1 cm^2*(Algometer Type 2, SBMEDIC, Hörby, Sweden).* The algometer has demonstrated excellent within-day and between-day concordance [23–25]. The rate of pressure increase was applied perpendicular to the tissue and kept at 30 kPa/s. The first time the sensation of pressure was perceived as pain, the participant pressed a button, stopping the stimulation. The pressure value at this time point defined the pressure pain threshold. To reduce the risk of intra-subject variability (i.e., learning effect), the participant was familiarised with the pressure algometer through assessments of pressure pain thresholds at a site not included for outcome measuring (i.e., the left m. rectus femoris) before the assessments started. Pressure pain thresholds were assessed at two sites, both close and far from the location of the area investigated (i.e., the hamstrings) [26]. The tibialis anterior site (regional site) was located at 1/3 on the line connecting the head of the fibula and the proximal part of the medial malleolus. The deltoid site (distant site) was located in the middle of the most prominent muscle bulge on the line connecting the acromion and the lateral epicondyle of the elbow. Pressure pain thresholds were assessed three times at each site, alternatingly, starting with the tibialis anterior site. 20-second intervals between assessments were maintained to avoid pain summation. Mean values were used for analysis. Participants were blinded to the results of the measurements.

Pressure pain thresholds are generally found to be influenced by physical activity levels [27]. Therefore, the short form of the International Physical Activity Questionnaire (IPAQ) [28] was used to assess the participant's physical activity levels during the trial.

Passive knee extension range of motion was assessed as a secondary outcome measure at baseline, after six weeks (post-stretch), and after ten weeks (post-cessation) using the Biodex System 4 Pro isokinetic dynamometer *(Biodex Medical Systems, Shirley, New York, USA).* Participants were seated, fixed to the chair, with a hip flexion angle of 100° and a knee extension angle of 90°. The dynamometer lever arm passively extended the knee at an angular velocity of 5°/s [16]. The combined trunk and hip position ensured that tension was placed primarily on the muscle-tendon unit of the knee flexors to prevent hyperextension of the knee during testing [12]. Participants were instructed to stop the lever arm by pressing a stop button when the sensation changed from stretch to pain. Participants and the examiner were blinded to the results of the range of motion measurements. The same investigator performed all experimental measurements to avoid any inter-rater discrepancies. All outcome measurements were made at independent time points, not following a stretching protocol.

Sample size

The sample size was determined to detect a minimal difference in the primary outcome measure pressure pain thresholds of 20% as a minimal meaningful change [29]. A two-tailed power analysis was performed using a one-way repeated-measures analysis of variance (ANOVA). G*Power V.3.1 was used for calculation. According to the analysis, a sample size of 26 participants would be sufficient to detect a 20% difference in pressure pain thresholds, with β=0.1 (90% power), a correlation between repeated measures of 0.85, a correction for non-sphericity of 0.8, an α-level of 0.05 and a 20% loss to follow up.

Statistical analysis

The data were analysed using SPSS 27 (*SPSS Inc., Chicago, IL, USA*). Data were analysed using descriptive and inferential statistics. Continuous variables are presented with mean ± SD and 95% CIs. Variables were tested for normality using a visual inspection of histograms and Q-Q plots and a test of deviation from normality (Shapiro-Wilk test). The homogeneity-of-variance assumption was assessed by testing for sphericity. Parameters that did not meet the assumption of sphericity were corrected using the Greenhouse-Geisser adjustment. A One-Way Repeated Measures Analysis of Variance was performed to examine the absolute effect of time (three levels: "Baseline", "Post-stretch", and "Post-cessation") on the participant's physical activity levels (IPAQ-score). To address the first and second hypotheses of the study, One Way Repeated Measures Analyses of Variance were performed to examine the absolute effect of *time* (three levels: *"Baseline"*, *"Post-stretch"*, and *"Post-cessation"*) on the primary outcome measure regional and distant pressure pain thresholds and secondary outcome measure range of motion. Bonferroni corrected post hoc testing was used for multiple comparisons. The percentage of change between measurements was calculated to depict the effect of stretching on pain sensitivity and range of motion. A one-way repeated-measures ANOVA was performed to compare the relative (percentage) change in pressure pain thresholds from baseline to post-stretch and post-stretch to post-cessation at the regional and distant sites. The relationship between the relative changes in regional and distant pressure pain thresholds from baseline to post-stretch and post-stretch to post-cessation was analysed using Spearman's correlation coefficient. Effect size estimates were calculated using partial eta squared (η_p^2) for ANOVA and were interpreted as small (ES 0.01), moderate (ES 0.06), and large (ES 0.14) [30]. In the case of loss to follow-up, missing values will be imputed by carrying the last observation forward. An alpha level of 0.05 was defined for the statistical significance of all tests.

Results

Figure 1 shows a flowchart of participants throughout the study. One participant withdrew from the study within days after baseline measurement due to personal reasons unrelated to the study. All the remaining participants completed the study. A complete dataset of 26 participants (*n*=9 female) was available for analysis (see Table 1 for participant characteristics).

The adherence rate to the six-week stretching intervention was 87.2% ± 10.2% [95%CI: 82.9–91.5%]. Two participants tested positive for COVID-19 during the six-week stretching intervention. Due to COVID-19-related symptoms, both participants discontinued the stretching exercises for seven days during the six-week intervention. Seven more participants tested positive for COVID-19 during the four-week cessation phase of the study. Therefore, the final measurement after ten weeks (post-cessation) could not be conducted before the participants had left isolation. As a result, the mean cessation period was 4.6 ± 0.5 weeks [95%CI: 4.36–4.74].

No significant main effect of time was found for the participant's physical activity levels during the trial. This indicates no statistically significant differences in the participant's physical activity levels during the trial ($F [2, 23] = 3.111$, $p = 0.054$, $\eta_p^2 = 0.119$).

Mean values for pressure pain thresholds and range of motion are presented in Table 2. Individual participant pressure pain thresholds measured at the tibialis anterior and deltoid sites over the three time points are presented in Fig. 2A and B.

Regional and distant pain sensitivity

There was a main effect of time on pressure pain thresholds at the tibialis anterior site ($F [1, 25] = 13.337$, $p = 0.001$, $\eta_p^2 = 0.508$). Post hoc tests demonstrated a 36.7% increase in pressure pain thresholds from baseline to post-stretch (86.6 kpa, 95%CI: 145.4–27.6, $p = 0.003$) a 2.0% increase in pressure pain thresholds between post-stretch and post-cessation (21.0 kpa, %, 95%CI: 75.8–33.9, $p = 1.000$), and a 41.2% increase in pressure pain thresholds from baseline to post-cessation (107.5 kpa, 95%CI: 163.7–51.4, $p = 0.001$) at the tibialis anterior site.

A main effect of *time* was found, showing a statistically significant difference in pressure pain thresholds at the deltoid site ($F [1, 25] = 3.976$, $p = 0.025\, \eta_p^2 = 0.137$). Post hoc tests demonstrated an 18.7% increase in pressure pain thresholds from baseline to post-stretch (44.1 kpa, 95%CI: 86.9–1.2, $p = 0.042$), a 5.2% decline in pressure pain thresholds from post-stretch to post-cessation (-6.5 kpa, 95%CI: 48.8–35.7, $p = 1.000$) and a 15.4% increase in pressure pain thresholds from baseline to post-cessation (37.5 kpa, 95%CI: 82.5–7.5, $p = 0.127$) at the deltoid site.

Pressure pain thresholds were higher at the regional site compared to the distant site ($p = 0.002$). However, no

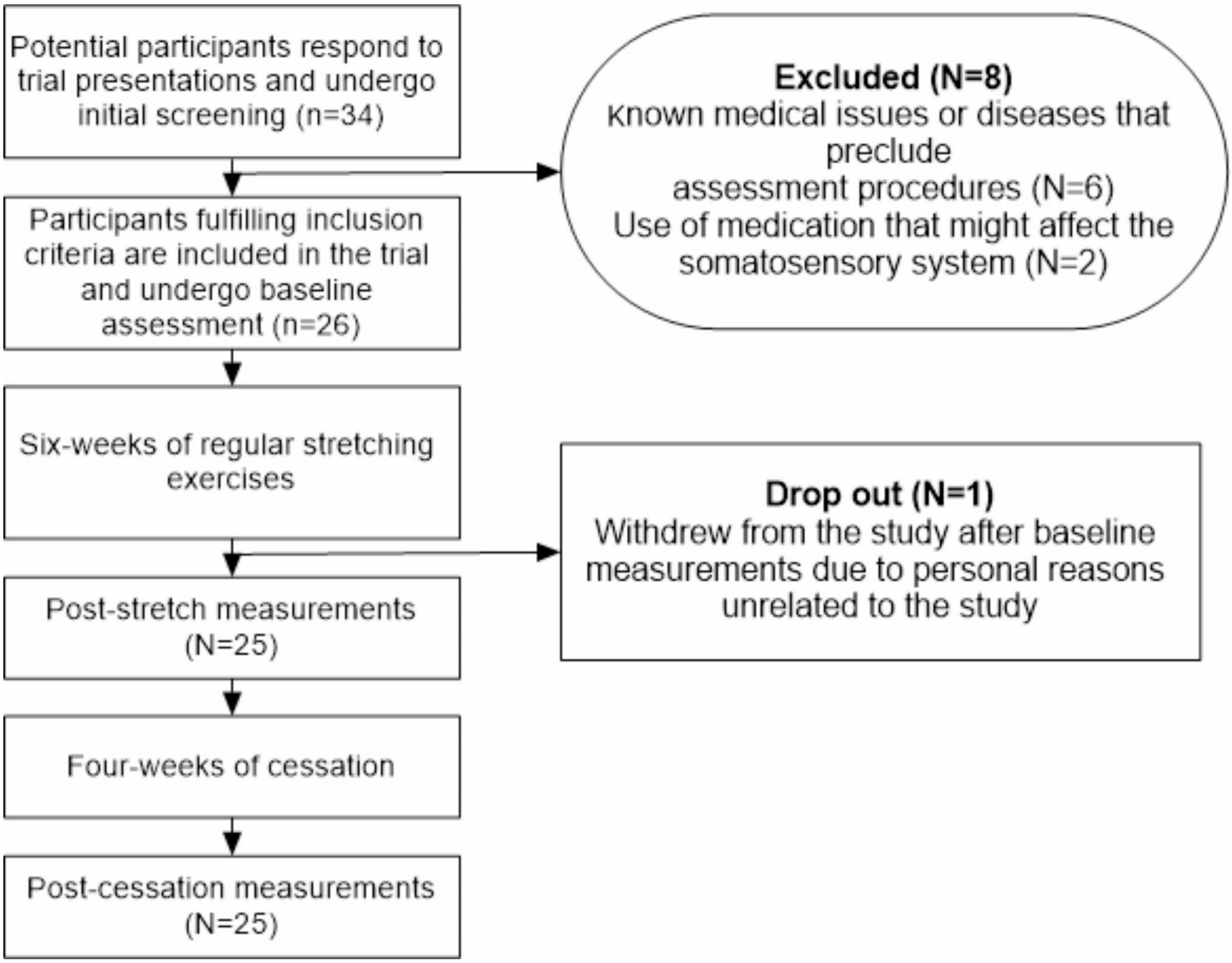

Fig. 1 Flow chart
Legend: Flow of participants through the study

Table 1 Mean / SD (range) of participant characteristics

Descriptive items	
Age (years)	23.8 ± 2.1 (21–30)
Height (m)	1.79 ± 0.09 (1.64–2.03)
Weight (kg)	75.9 ± 11.9 (55–98)
BMI (kg/m^2)	21.2 ± 2.8 (16.7–26.1)
MET score	4076 ± 2295 (360–9493)

between-site differences in the relative changes in pressure pain threshold from baseline to post-stretch (18.8%, 95%CI: -3.367–40.943, p=0.135) or post-stretch to post-cassation (-7.4%, 95%CI: -20.377–5.473, p=0.662) was found.

A weak but significant correlation was found between the relative changes in regional and distant pressure pain thresholds from baseline to post-stretch (Rho=0.479, p=0.015). A moderate and significant correlation was found between the relative changes in regional and

Table 2 Absolute values (means (SD) and 95% CI) for range of motion

	Baseline	Six weeks (Post-stretch)	Ten weeks (Post-cessation)
Range of motion (deg.)	172.5 ± 10.1 (168.3-176.8)	178.7 ± 11.9 (173.9-183.9)*	178.5 ± 10.2 (174.5–183)¤ #
Pressure Pain Thresholds (Kpa) Tibialis Anterior	304.6 ± 136.6 (249.3-359.7)	391.1 ± 132.3 (337.7-444.6)*	412 ± 174 (341.8-482.4)¤ #
Pressure Pain Thresholds (Kpa) Deltoid	263.6 ± 122.3 (214.2–312)	307.6 ± 161.9 (242.2–373)*	301.1 ± 166.2 (233.9-368.2) ¤

Legend:* = significant difference between baseline- and post-stretch, ¤ = significant difference between post-stretch and post-cessation, and # = significant difference between baseline and post-cessation, mean (SD)

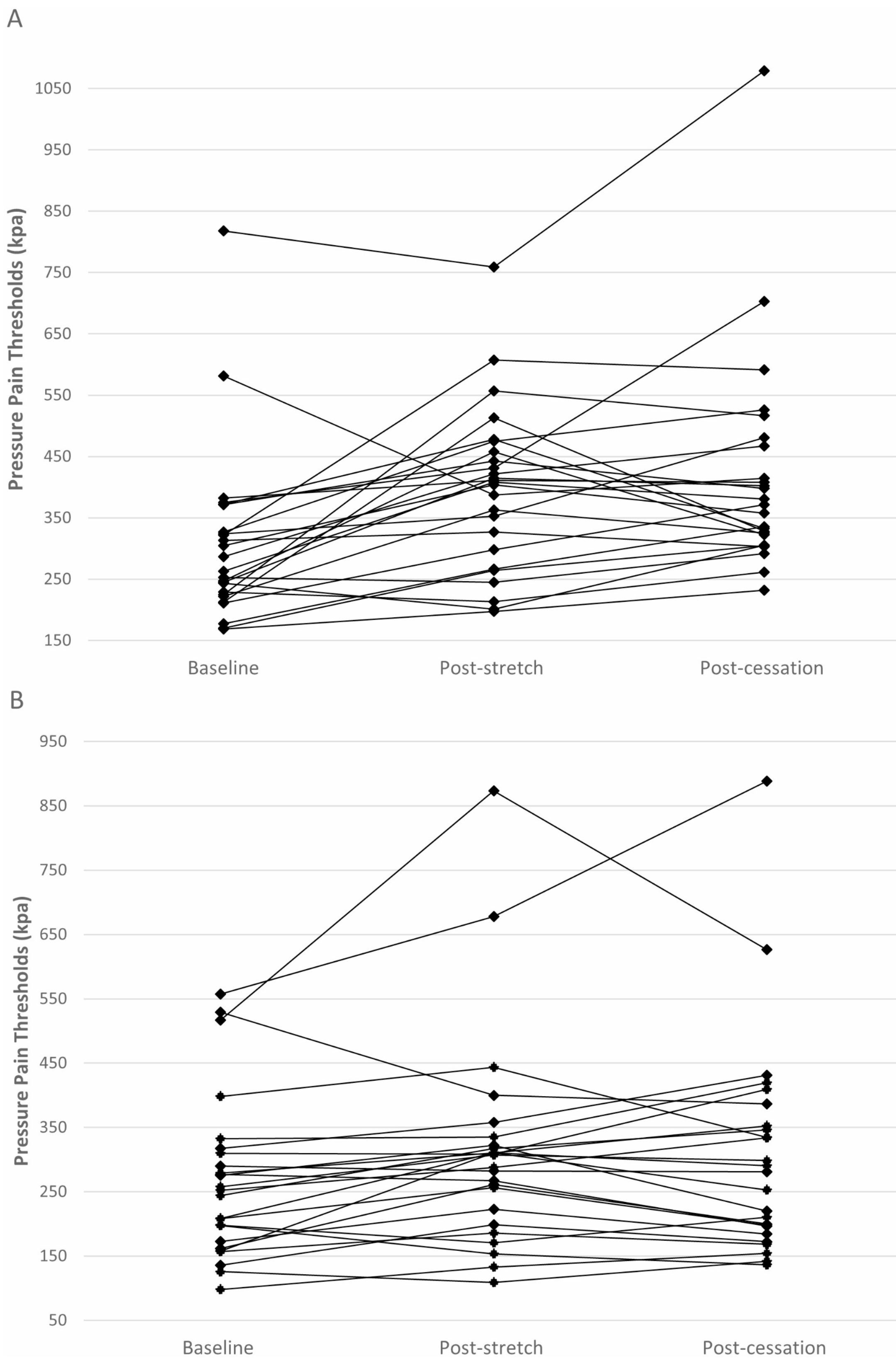

Fig. 2 Pressure pain thresholds

Legend: Individual participant pressure pain thresholds recorded at the tibialis anterior (**A**) and deltoid (**B**) muscles at baseline, after six weeks (post-stretch), and after ten weeks (post-cessation). Trajectories (lines) show the within-subjects effects over the three time points distant pressure pain thresholds from post-stretch to post-cessation (Rho = 0.597, p = 0.002).

Range of motion

A main effect of *time* was found, showing a statistically significant difference in range of motion (F [1, 25] = 11.666, p = 0.001, $\eta_p^2 = 0.318$) (Greenhouse-Geiser corrected). Post hoc tests demonstrated a 3.6% increase in passive knee extension from baseline to post-stretch (6.2°, 95%CI: 10.2–2.2, $p = 0.002$), a 0.1% decline in passive knee extension range of motion between post-stretch and post-cessation (-0,1°, 95%CI: 2.8–2.5, $p = 1.000$), and a 3.6% increase in passive knee extension range of motion from baseline to post-cessation (6.0°, 95%CI: 10.4–1.7, $p = 0.005$).

Discussion

The present study investigated the effect of six weeks of regular stretching exercise on regional and distant pain sensitivity and four weeks of stretching cessation on regional and distant pain sensitivity. The main findings demonstrated that regional and widespread pain sensitivity decreased following six weeks of regular stretching. However, in contrast to our expectations, the hypoalgesic effect of regular stretching did not abate following four weeks of cessation.

The present study found that regional and widespread pain sensitivity decreased considerably following regular stretching exercises. This broadly supports previous findings suggesting that regular stretching exercises generate long-lasting effects on regional thermal pain sensitivity [15]. The hypoalgesic effect seen in the present study occurred with multisegmental manifestations, suggesting that regular stretching exercises activated widespread central inhibitory mechanisms. This is supported by the significant correlations between the regional and widespread pressure pain thresholds, indicating that they could partly be mediated through a common mechanism. However, although the hypoalgesic effect of stretching exercises was multisegmental, the regional response (e.g., the tibialis anterior site) appeared more pronounced than the widespread response (e.g., the deltoid site) when interpreting the point estimates (i.e., the percentage differences). However, the analysis showed no statistically significant difference in the hypoalgesic response between the regional and widespread sites. Further work is needed to establish whether there is a difference in the magnitude of the regional and widespread analgesic response to stretching.

The present findings align with current evidence suggesting that the hypoalgesic effect of stretching exercises may be related to endogenous inhibitory pain mechanisms [16, 18]. However, emerging evidence indicates that other underlying mechanisms may contribute to the analgesic response following stretching exercises seen in the present study. It has been suggested that stretching exercises may alter sympathetic/parasympathetic balance [31], presumably by activating mechanosensory end organs that contribute to sympathetic nervous system inhibition [7].

Increased parasympathetic stimulation may activate descending noradrenergic pathways, inhibiting widespread pain [32]. Emerging evidence shows that increased parasympathetic activity correlates with reduced pain perception in healthy individuals and patients experiencing pain [33], suggesting that autonomic dysfunction might be an important mechanism associated with chronic pain. The potential link between sympathetic/parasympathetic balance and pain sensitivity following stretching exercises is beyond the scope of this study but might be addressed in future studies.

Current evidence suggests that the durational effect of stretching exercises is related to regular modifications of somatosensory input (i.e., the frequency of stretching exercises). However, the duration of the hypoalgesic effect of regular stretching remains unknown. The present study found no statistically significant changes in either pain sensitivity or range of motion following the cessation period in the four weeks from post-stretch to post-cessation, indicating that the hypoalgesic effect following regular stretching was retained. The present results raise interesting questions about the current knowledge regarding the long-standing effect of stretching exercises on pain sensitivity; hence, further research on the long-term hypoalgesic effect of stretching exercises in healthy and patient populations is needed.

The current study found a widespread hypoalgesic effect of regular stretching exercises in healthy individuals that may effectively reduce pain sensitivity. These results align with previous findings suggesting the existence of a systemic response to stretching exercises that produce stretch-induced hypoalgesia [18]. This may have important clinical implications and may translate to rehabilitation efforts in patients experiencing nociceptive, nociplastic, and neuropathic pain. In accordance with the present results, current evidence shows that stand-alone stretching exercises may be sufficient to reduce pain sensitivity in several clinical populations, such as individuals with knee osteoarthritis [34] and fibromyalgia [35, 36].

The present study found that regular stretching exercises induce a widespread hypoalgesic effect in healthy adults. The targeted use of regular stretching exercises may offer several promising treatment options for patients unwilling or unable to perform conventional physical exercise rehabilitation. Stretching exercises may be more acceptable for some patients than typical exercise interventions and may even attract patients who are otherwise non-adherent to physical activity.

Furthermore, given its apparent analgesic effect, stretching exercises may hold the potential to serve as a gateway to further treatment options. Also, regular stretching may be an adjunct to physical exercise when unilateral injury or pain would otherwise prevent physical activity or exercise to increase the contralateral range of motion and decrease pain without involving the affected joint, muscle, or tendons. Therefore, further studies on patient populations are warranted.

This study used PPTs to measure regional and distant pain sensitivity. PPT is one of the most commonly used procedures to assess descending pain modulation. However, pressure-cuff pain tolerance and conditioned pain modulation have also been proposed to determine descending pain modulation [37]. PPTs were chosen for this study given their high levels of correlation and agreement between intra-individual measurements [22] and ease of use.

The present study found a statistically significant increase in range of motion from baseline to post-stretch. This is consistent with the current evidence indicating that regular stretching exercises increase range of motion [38]. However, no statistically significant changes in range of motion in the four weeks from post-stretch to post-cessation were found, indicating that the effect on range of motion persisted following cessation. This outcome contradicts Willy et al. 2001 [20] and Rancour et al. 2009 [19], who showed that gains in range of motion abated following cessation of regular stretching. This contradiction may, however, be related to differences in outcome measurements given that both Willy et al. and Rancour et al. used less accurate universal goniometers to measure range of motion.

The efficacy of exercise is directly related to adherence. The literature suggests that poor exercise adherence is a common challenge [39]. In the present study, the adherence rate to the stretching intervention was 87.2%. This is considered to be a high level of adherence. The present study included only healthy young adults, but evidence suggests that patients with fibromyalgia adhere more to stretching exercises over aerobic exercises [40].

Nine participants tested positive for symptomatic COVID-19 during the study. A systematic understanding of how COVID-19 affects pain modulation is still lacking. However, evidence suggests that healthy young adults who have demonstrated only mild to moderate symptoms of COVID-19 have impaired endogenous pain-modulatory mechanisms such as conditioned pain modulation response but show no change in pain sensitivity or EIH [41]. How this affects the present study is unknown. However, given that symptomatic COVID-19 may impede pain modulation, the true analgesic effect of stretching exercises may be larger than demonstrated in the present study.

Limitations

This study was an exploratory "proof of concept" study aimed at assessing whether regular stretching exercises affect pain sensitivity and range of motion. Therefore, a single-group repeated measures design was performed by adapting the procedure used by Willy et al. [20]. The lack of a control group is a limitation, as we are unable to compare the changes in the intervention group against natural time-course changes or quantify the inherent variability in outcome measures, including a potential learning effect from repeated testing. However, familiarisation attempts were made before baseline measurements to account for potential learning effects. The absence of unblinded statistical analysis is also a limitation. This should, therefore, be considered when interpreting present findings regarding the effect of static stretching. To investigate the causal effect of regular stretching exercises on pain sensitivity and range of motion would require a comparative study design. Accordingly, further research is warranted to assess how the stretching intervention compares with no treatment.

Due to COVID-19-related restrictions at the time of enrolment, participants were recruited primarily from the University College of Northern Denmark; hence, the sample population included only younger individuals (21–30 years). However, evidence suggests that the effects of stretching exercises do not depend on age [42] or sex [18]. The use of a convenience sample had, therefore, likely little impact on the results of this study. Still, we cannot be sure the effects would be similar in older, less physically active individuals. The study population consisted of healthy participants. Hence, we do not know if the hypoalgesic effects would be similar in people experiencing pain. Therefore, further investigations of the effect of regular stretching exercises on pain sensitivity in clinical populations with pain are warranted.

The quantification of pressure pain thresholds using an algometer is often applied to sites both close and far from the location of the area investigated or the area of pain [26]. Due to the seated testing position in the Biodex, the tibialis anterior site was chosen as the regional site, given its comprehensive association with the segmental level of the hamstrings. This is in accordance with previous procedures [16].

Linear mixed-effects models have been proposed as an alternative to One Way Repeated measures analysis of variance (RM ANOVA) as they are better suited to analyse change over time [43]. However, using a linear mixed-effect model analysis yielded no significant differences or changes to the conclusions of this study.

Conclusion

Six weeks of regular stretching exercises significantly decreased regional and widespread pain sensitivity. Moreover, the results showed that the hypoalgesic effect of stretching on regional and widespread pain sensitivity persisted following four weeks of cessation. The results further support the rationale of adding stretching exercises to rehabilitation efforts for patients experiencing nociceptive, nociplastic, and neuropathic pain. However, further research is needed to investigate how the long-term effects of stretching exercises compare with no treatment in clinical populations.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-024-00995-2.

Supplementary Material 1

Supplementary material 1: Intervention delivery described using the TIDieR guidelines

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Not applicable.

Author contributions

MPS conceived the study and was responsible for data collection. MPS conducted the analyses and wrote the first draft of the paper and prepared Figs. 1 and 2, which was critically revised by AR, JLT and SPM. All authors contributed to the interpretation of the findings. All authors have read and approved the final manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Participants provided written informed consent to participate in the study. The trial was reported to the Danish Data Protection Agency (Project ID 24000509), registered at ClinicalTrials.gov (Trial registration number NCT04919681), and approved by The North Denmark Region Committee on Health Research Ethics (N-20210044). The study complied with all the relevant national regulations and institutional policies and was performed following the tenets of the Helsinki Declaration.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Physiotherapy, University College of Northern Denmark (UCN), Selma Lagerløfs Vej 2, Aalborg East 9220, Denmark
[2]Center for General Practice, Aalborg University, Selma Lagerløfs Vej 249, Gistrup 9260, Denmark
[3]Institute of Sports Medicine Copenhagen & Department of Occupational and Physical Therapy, Bispebjerg Hospital, building 8, 1st floor, Bispebjerg bakke 23, Copenhagen 2400, NV, Denmark
[4]Center of Healthy Aging, University of Copenhagen, Blegdamsvej 3B, Copenhagen N 2200, Denmark

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