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Abstract

Background and aims: The effect of stretching on joint range of motion is well documented and is primarily related to changes in the tolerance to stretch, but the mechanisms underlying this change are still largely unknown. The aim of this study was to investigate the influence of a remote, painful stimulus on stretch tolerance.

Methods: Thirty-four healthy male subjects were recruited and randomly assigned to an experimental pain group ($n=17$) or a control group ($n=17$). Passive knee extension range of motion, the activity of hamstring muscles and passive resistive torque were measured with subjects in a seated position. Three consecutive measures were performed with a 5-min interval between. A static stretch protocol was utilized in both groups to examine the effect of stretching and differences in stretch tolerance between groups. Following this, the pain-group performed a cold pressor test which is known to engage the endogenous pain inhibitory system after which measurements were repeated.

Results: A significant increase in knee extension range of motion was found in the pain group compared with controls (ANCOVA: $p<0.05$). No difference was found in muscle activity or passive resistive torque between groups (ANCOVA $p>0.091$).

Conclusions: Passive knee extension range of motion following stretching increased when following a distant, painful stimulus, potentially engaging the endogenous pain inhibitory systems. Current findings indicate a link between increased tolerance to stretch and endogenous pain inhibition.

Implications: The current findings may have implications for clinical practice as they indicate that a distant painful stimulus can influence range of motion in healthy individuals. This implies that the modulation of pain has significance for the efficacy of stretching which is important knowledge when prescribing stretching as part of rehabilitation.

Keywords: stretch tolerance; range of motion; pain; stretching.

1 Introduction

Flexibility is an important factor in the ability to maintain independent activities of daily living [1] and reduced flexibility is likewise associated with both musculoskeletal pain [2] and reduced balance [3]. Stretching is commonly used in relation to both exercise and rehabilitation where the purpose is to improve function, reduce pain and to prevent injury [4]. The acute increase in joint flexibility following stretching is commonly related to changes in the viscoelastic properties of the muscle-tendon unit or an acute neuromuscular relaxation [5]. However, the mechanical properties of the muscle-tendon unit are largely unaffected by stretching, hence the increase in range of motion following both acute and chronic stretching is mainly related to alterations in the sensory system [6, 7]. Current evidence suggests that the increase in range of motion following stretching is strongly related to an increase in the tolerance to stretch [5, 8–10]. Moreover, a recent study showed that range of motion following stretching was significantly and positively associated with average pain sensitivity ratings [11]. Stretch tolerance is defined as the ability to tolerate the discomfort related to stretching [12]. An increase in stretch tolerance seems

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to depend on a reduction in pain sensitivity [13] and is associated with average pain sensitivity ratings [11]. This may be related to an analgesic effect allowing the person to tolerate increased levels of passive tension required to stretch the muscle farther than it was before [14]. These findings may indicate that by reducing the input from regional peripheral nociceptive afferents, the stretch tolerance could be increased.

The nervous system has an inbuilt ability to modulate the perceived magnitude of afferent noxious stimuli via supraspinally mediated endogenous pain inhibition or facilitation [15] and by engaging endogenous mechanisms in healthy individuals pain tolerance is known to increase [16, 17]. Given the relationship between tolerance to pain and stretch tolerance, increasing tolerance to pain could potentially increase range of motion following stretching. Whether such modulating mechanisms affect the stretch tolerance is unclear, warranting an investigation of how and if engaging endogenous inhibitory pain mechanisms may increase joint flexibility during stretching.

The purpose of this study was to extend the findings of previous literature by investigating the influence of a remote, painful stimulus, known to modulate pain perception in healthy adults, on stretch tolerance following stretching, as measured by changes in passive knee extension range of motion. The hypotheses were that i) passive, pain-free range of motion and passive resistive torque would increase following a tonic, painful stimulus at a remote site of the body but ii) muscle activity during passive knee extension would remain unchanged.

2 Materials and methods

A sample of convenience consisting of 34 healthy male university students was recruited for this cross-sectional study. Participants were randomly assigned to a pain group ($n=17$) or a control group ($n=17$) using counterbalanced block randomization. Only males were included to avoid the potential effect that fluctuations in gonadal hormone values may have on the endogenous pain inhibitory mechanisms [18]. According to International Knee Documentation Committee (IKDC) criteria a patient is considered to have normal range of motion if extension is within 2° of the opposite knee [19, 20], hence a difference in knee extension of >2° must be detected in order to properly categorize knee function [21]. The sample size was thus determined to detect a minimum difference in knee extension range of motion of 2° with $\alpha=0{:}05$, $\beta=0.2$ (80% power). Based on these data, an n value of 16 subjects in each group was calculated to be necessary which was increased to $n=17$ in each group to account for possible technical errors during the study. Eligibility for participation included the absence of any pain or other neurological, psychological or cardiovascular conditions that might affect the somatosensory system. All subjects were asked to refrain from physical exercises, caffeinated beverages and the use of pain medication on the day of participation. The participants entered the study after providing their written informed consent. The study was conducted in accordance with the declaration of Helsinki and approved by the local ethical committee (N-20160019). The study was registered at ClinicalTrials.gov with the registry ID NCT03713788.

Following an introduction to the testing procedures, passive knee extension range of motion was measured in a seated position (Fig. 1) three consecutive times with 5-min intervals between measurements (Fig. 2).

A Biodex system 4 pro isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA) was used

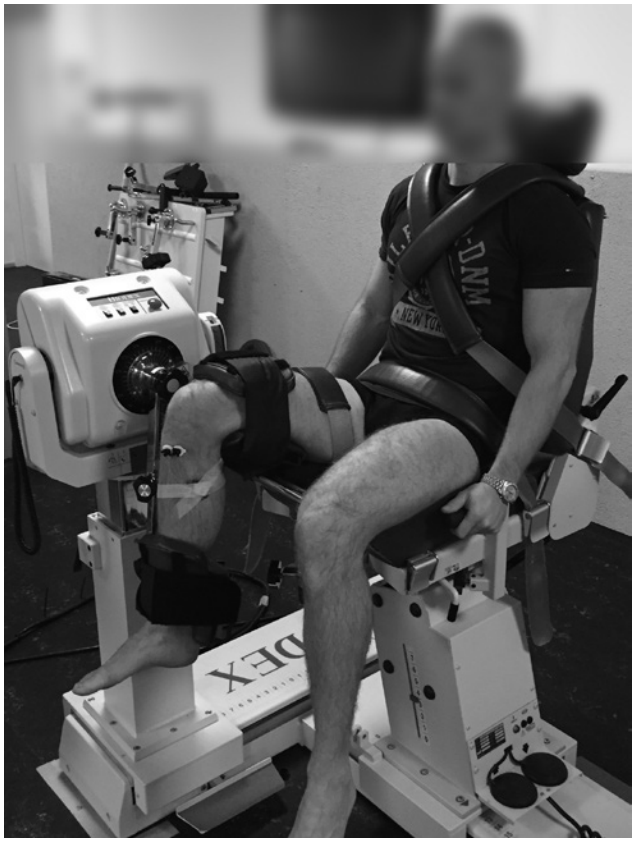

Fig. 1: The picture illustrates the experimental set-up using the isokinetic dynamometer. Here, the participant was comfortably seated with the trunk and lower extremities securely fastened with straps. The lever arm of the biodex passively moved the leg towards extension at a speed of 5°/s. The participant was instructed to press a button when the stretch sensation in the posterior thigh changed to pain.

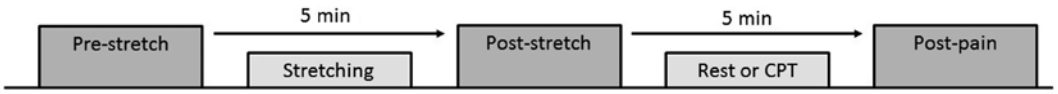

Fig. 2: Illustration of the procedures presented in experimental order. Knee extension ROM, muscle activity and passive resistive torque were measured three times, pre-stretch, post-stretch and post-pain. Two bouts of 30 s Constant Angle stretching was administered in both groups and the pain group performed the cold pressor test while the control group rested passively.

to quantify knee extension range of motion and passive resistive torque during the passive knee extension motions. The torque values were corrected for gravity using the embedded software. The subjects were seated and fixed to the chair in accordance with previous procedures [22] with restraining straps over the pelvis, trunk, thigh and lower leg with a hip flexion angle of 100°, and a knee extension angle of 80° with 180° being equal to full knee extension. Posterior pelvic tilt was prevented by placing a firm wedge (22.5*6*5 cm) at the low back (the level of L5) (Fig. 1). The seated position ensured that no subject was able to reach full knee extension hence the stretch manoeuvre placed tension primarily on the muscle-tendon unit [23]. To exclude any reflexive muscle activity, the dynamometer lever arm passively extended the knee at an angular velocity of 5°/s [24] with a sampling rate of 100 Hz. The subjects were instructed to press a stop button when they felt that the sensation of stretch changed to pain, which instantaneously stopped the lever arm. This was defined as the stretch tolerance [8, 22]. The Biodex system has a minimum detectable change (MDC95%) of 1.2° (range of motion) and 0.0 Nm (passive resistive torque) as calculated based upon the standard error of measurement (SEM) reported by Drouin et al. [25].

Muscle activity during the passive knee extension motion was recorded with a Noraxon Desktop DTS Wireless Surface EMG amplifier (Noraxon U.S.A. Inc., Scottsdale, AZ, USA). Following appropriate skin preparation, surface electrodes (Noraxon Dual EMG Gel Electrodes; Noraxon U.S.A. Inc., Scottsdale, AZ, USA) were placed on the muscle bellies, parallel to the muscle fibres on the M. Biceps femoris, M. Semimembranosus, and M. Semitendinosus in accordance with SENIAM guidelines [26]. A reference electrode was placed on the antero-superior aspect of the tibia [1]. Measurements were documented using video recordings (Logitech HD pro Webcam C920; Logitech International S.A, Romanel-sur-Morges, Switzerland) with a sampling rate of 30 frames per second (1080px). EMG activity was quantified as the root mean square (RMS) amplitude over the period from initiation of extension until movement was stopped in accordance with previous procedures [22, 27, 28]. EMG data and video recordings were digitally synchronized by placing digital time markers on the first and last frame in which movement of the lever arm on the Biodex could be identified. Using this method, the range of motion and passive resistive torque data were synchronised to within 1/30 of a second of the EMG data. EMG data were collected using a sampling rate of 1500 Hz and the signals were filtered with a 6th order Butterworth pass-band filter 20–500 Hz [29], and RMS (50 ms window) values were calculated for each measurement [1, 24]. MR 3.8 software (Noraxon U.S.A. Inc., Scottsdale, AZ, USA) was used for both synchronisation and analysis.

The first measurement served as a pre-stretch baseline, the second measurement as a post-stretch measurement and the third measurement was the post-pain measurement. To reduce potential confounders in relation to group differences in stretch tolerance, the effect of stretching was first examined and compared between groups before the tonic pain was induced in the pain group.

Following the pre-stretch measurement, both groups underwent a static stretch protocol consisting of two bouts of 30-s constant-angle static stretching of the knee flexors with a 1-min rest between bouts. Subjects were instructed to keep the limb relaxed as the lower leg was passively moved towards extension. Each movement was stopped when the subjects felt that the sensation of stretch changed to pain, which was defined as the stretch tolerance. This position was then kept constant for 30 s. Following the stretch protocol, the post-stretch measurement was performed, following the same procedures as at baseline. Finally, only subjects in the pain group were instructed to immerse their non-dominant hand into a container with circulating water at 1 °C–4 °C and keep it there for 2 min. They were instructed to immerse it to wrist-level and keep the hand open. During this part of the study, both groups were seated in the Biodex. Water temperature was controlled using a digital thermometer (Electronic Temperature Ltd. 810–930; Electronic Temperature Instruments Ltd., Worthing, UK) and a water pump (Aquadistri Aqua-Power 200–200 l; Aquadistri UK Ltd, Great Gransden, Cambridgeshire, UK) was used to circulate the water,

preventing local warming [30]. The subjects rated the cold-induced pain intensity on a 0–10 numerical rating scale (NRS) where 0 was defined as "no pain" and 10 as "maximal pain" [17]. Following this procedure, the participants extracted their hand out of the water. The post-pain measurement was then performed 30 s later to minimize the likelihood of pain-induced distraction on the measurement [31]. All data (muscle activity, passive resistive torque and range of motion) were extracted for analysis when all measurements had been performed. Therefore, both the participant and researcher were blind to the results of all measurements.

The data were analysed using SPSS 23 (SPSS Inc., Chicago, IL, USA). To explore the homogeneity between the two groups, physical characteristics of the participants and pre-stretch range of motion were examined using independent samples *t*-tests, between groups difference in hand dominance was assessed by Fisher's Exact test and normality of the data were assessed by the Shapiro-Wilks test. Pre-stretch between-groups differences in range of motion, muscle activity and passive resistive torque were examined using One Way analysis of variance (ANOVA). Univariate Analysis of Covariance (ANCOVA) was used to examine the post-stretch between-groups differences in range of motion, muscle activity and passive resistive torque. The pre-stretch values served as the covariate following verification of the homogeneity of regression assumption to account for the potential issue of collinearity and for potential between-groups pre-test or post-stretch differences. Post-pain Between-group differences in range of motion, muscle activity and passive resistive torque were examined with the post-stretching values serving as the covariate following verification of the homogeneity of regression assumption. Cohen's d was used to calculate effect size. Within-group differences in range of motion, passive resistive torque and muscle activity were analysed using paired samples *t*-tests. An alpha level of 0.05 was defined for the statistical significance of all the tests.

3 Results

Due to technical failure, post-pain measurement data was lost for $n=1$ subject in the pain group. Due to this, a post-pain intention-to-treat analysis was performed using data from the post-stretch measurement for that subject. Therefore, a full dataset for 34 subjects (17 in each group) was available for data analysis.

Participant characteristics are summarized in Table 1. No significant between group differences were found in demographic or physical characteristic variables ($p>0.05$) (Table 1). Mean pain intensity (NRS) after the cold pressor test was 6.8 ± 0.9 (95% CI 6.27–7.26).

Table 1: Demographic and Physical characteristics of the participants shown as mean group values ± SD.

	Pain ($n=17$)	Control ($n=17$)	*p*-Value	Total ($n=34$)
Age (years)	25.7 ± 5.5	25.0 ± 5.1	0.701	25.5 ± 5.4
Height (cm)	181.8 ± 5.4	181.8 ± 5.7	0.976	181.6 ± 5.5
Weight (kg)	82.5 ± 11.9	75.9 ± 8.7	0.075	79.5 ± 10.7
BMI (kg/m^2)	25.0 ± 3.8	22.4 ± 1.9	0.052	24.2 ± 3.1
Hand dominance	R (14/17)	R (16/17)	0.601	R 30/34
MET score (W/kg)	46.0 ± 7.4	45.2 ± 6.9	0.746	46.0 ± 7.0

Hand dominance is indicated as the ratio between left and right-handed individuals. MET: Metabolic Equivalent of Task score and BMI = body mass index.

3.1 Between-groups comparisons

The ANCOVA showed significantly increased post-pain knee extension range of motion in the pain group compared with the control group ($F=4{,}706$ (1, 32), $p=0.038$) with an observed power = 0.6 and an effect size (d) = −0.83. The ANCOVA showed no additional between-groups differences in range of motion ($F<0.605$ (1, 32), $p>0.442$) (Fig. 3).

The ANCOVA showed no between-groups differences in muscle activity ($p>0.162$) or passive resistive torque ($p>0.091$) during the passive knee extension motions (Fig. 5).

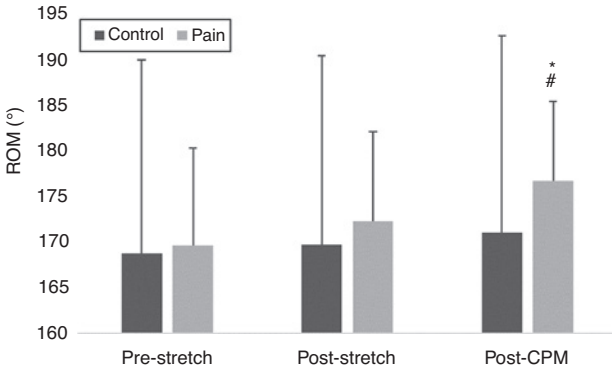

Fig. 3: Mean ± SD of range of motion (in degrees) in the passive knee extension measured pre-stretch, post-stretch and post-pain for the control and pain group. *Between-groups difference Post-pain ($p=0.038$). #Within-group post-stretch – post-pain difference for the pain group ($p=0.003$).

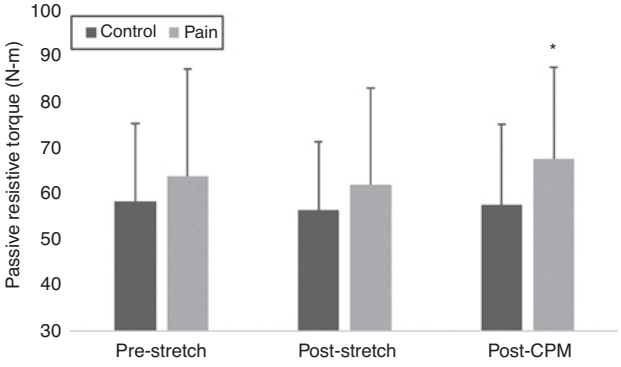

Fig. 4: Mean ± SD of passive resistive torque (N-m) in the passive knee extension measured pre-stretch, post-stretch and post-pain for the control and pain group. *Within-group post-stretch – post pain difference in the pain group ($p > 0.001$).

3.2 Within-Groups comparisons

A significant within-group post-stretch – post-pain difference in range of motion was found for the pain group ($p = 0.003$) but not the control group ($p > 0.1$). No additional within-group differences in range of motion were found ($p > 0.2$) (Fig. 3).

For passive resistive torque, a significant within-group post-stretch – post pain increase was found in the pain group ($p > 0.001$). No additional within-group differences in passive resistive torque ($p > 0.3$) or muscle activity ($p > 0.07$) were found (Figs. 4 and 5).

4 Discussion

This is the first study to investigate the role of a remote, painful stimulus on passive joint range of movement following stretching. The main findings of this study demonstrate that by engaging the endogenous pain inhibitory systems after stretching, a significant between-groups increase in passive knee extension range of motion and within-groups increase in passive resistive torque is found without any apparent changes in muscle activity.

Bishop & George (2017) showed that range of motion measures was associated with average pain sensitivity ratings thus further indicating that sensory perception may be an important mechanism during stretching. However, they were unable to exclude potential changes in muscle activity due to an absence of electromyographic data. [11] The present results support previous findings indicating that an increase in stretch tolerance following stretching is not related to a reduction in muscle activity [28], implicating mechanisms other than the intrinsic

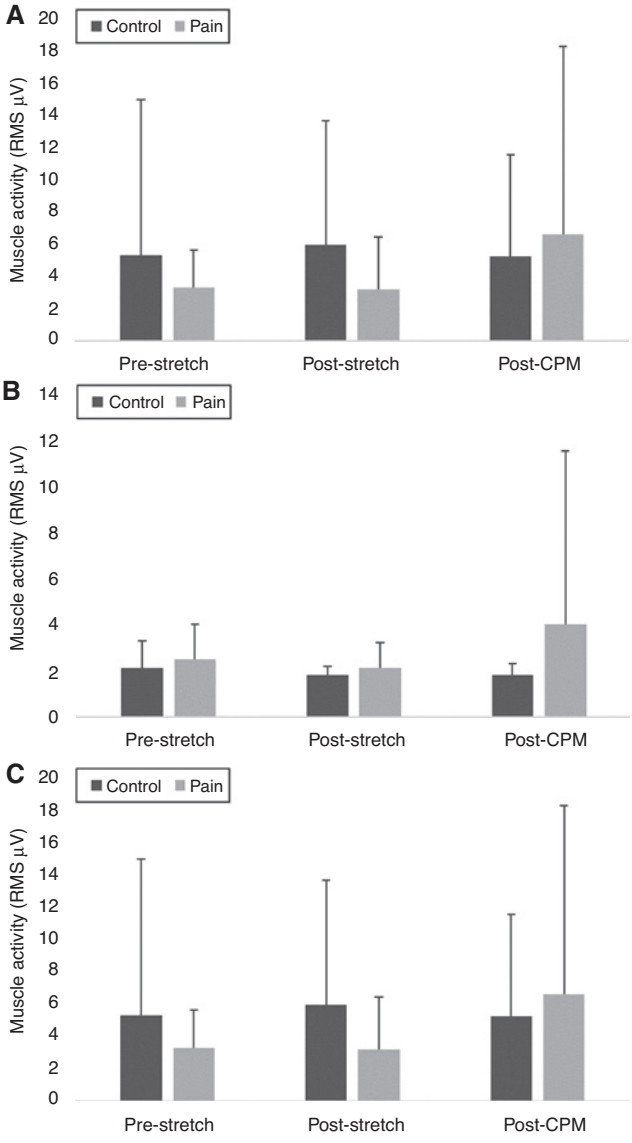

Fig. 5: Mean ± SD of muscle activity (RMS uV) in the passive knee extension measured pre-stretch, post-stretch and post-pain for the control and pain group for the Biceps femoris muscle (A), the Semitendinosus muscle (B) and the Semimembranosus muscle (C).

mechanical properties of the muscle-tendon unit. This may imply that the increased, pain-free passive range of motion seen here is related to an upwards shift of the stretch-pain threshold, e.g. stretch tolerance.

Supraspinally-mediated endogenous pain modulation has significance for both the perception of pain [32] and the intensity of pain via descending inhibition of nociceptive signals from the peripheral nervous system [33]. By engaging this mechanism, e.g. by using the cold pressor test, is known to decrease pain sensitivity and thereby increasing the tolerance to pain [16, 17]. The current findings, therefore, indicate that perceived pain

has a significant role in pain-free range of motion following stretching.

Stretching is a common part of exercise and rehabilitation; it is recommended for increasing joint range of motion and injury prevention [34] and is generally recommended as part of a pre-exercise warm-up regime [35]. Although an increase in intramuscular temperature has been shown to decrease muscular stiffness [14], it remains unclear how and if an increase in intramuscular temperature following physical activity affects joint range of motion [14]. In light of the current findings, it is interesting to note that physical activity has been shown to reduce pain sensitivity in a similar manner as a painful conditioning stimulus [36]. Exercise-induced analgesia has been related with brainstem-mediated modulation of endogenous opioid and non-opioid systems [37] but given the parallels which have been drawn between this phenomenon and the effectiveness of conditioned pain modulation (CPM) [38], it is possible that this relates to a reduction in the sensitivity to stretch. This is similar to the current findings and may lead to an increase in the tolerance to stretch. Further studies to investigate whether exercise-induced activation of the pain inhibitory system results in similar findings is warranted.

Furthermore, stretch exercises are commonly used in clinical settings as part of the rehabilitation strategies for patients with chronic musculoskeletal pain [12]. However, chronic pain patients often have impaired pain inhibition [32] as a result of reduced efficiency of central pain inhibitory systems [17, 39]. Although speculative, this may indicate that people with chronic musculoskeletal pain, may respond differently to a stretching protocol than healthy individuals as the present results seem to support the hypothesis that observed changes in flexibility are at least sometimes a manifestation of pain sensitivity.

It has been shown that endogenous pain inhibitory mechanisms can have both a pro- and antinociceptive effect [40] which may account for the variation in post-pain joint range of motion observed in this study. Also, cognitive attentional factors (e.g. distraction) can alter perceived pain intensity and it has been suggested that the CPM effect is, at least partly, due to cognitive attention manipulation [16]. However, the same authors concluded that separate physiological mechanisms underlie distraction and the CPM effect [16]. With this in mind, this study was designed so that the post-pain passive knee extension range of motion measurements were first conducted 30-s after the hand had been removed from the ice water.

The results of this study indicate that the significant post-pain increase in passive knee extension range of motion was a result of supraspinally mediated endogenous pain inhibition, which increased the stretch tolerance following stretching. This implies that central pain mechanisms can to some extent modulate joint range of motion following stretching, supporting the doubts recently put forward [5, 7, 28] regarding the acute increase in post-stretch joint range of motion being a result of changes in the mechanical properties of the muscle-tendon unit. Given that fact that the increase in range of motion following stretching is strongly related to stretch tolerance [10], the influence of endogenous pain inhibitory mechanisms on stretch tolerance reported in this study supports the hypothesis that an increase in stretch tolerance depends on an analgesic effect, resulting in greater tolerance to passive tension.

4.1 Methodologic considerations

The manual synchronisation of SEMG and range of motion data using visual inspection from a video recording resulted in a systematic bias that might have influenced the results regarding muscle activity during passive knee extension range of motion. It is therefore recommended, that future studies utilize digital synchronisation to eliminate this potential bias. Although the limitations of manual synchronisation were inherent to the experimental design, all procedures were identical for all subjects, and the findings were in line with that of similar studies [41, 42].

A tonic, nociceptive cold stimulus has consistently been shown to modulate the sensitivity of central pain mechanism in experimental and clinical studies [33, 43]. This study did, however, not confirm the presence or magnitude of the response by e.g. assessing the pain sensitivity at remote sites. Future studies should include such measurements in the protocol to confirm the role of these mechanisms.

5 Conclusion

This is the first study to demonstrate a link between the tolerance to stretch and endogenous inhibitory pain mechanisms. The findings may have implications for clinical practice as they indicate that pain, regardless of changes in mechanical properties can influence range of motion in healthy individuals. The current results warrant further investigations of endogenous pain inhibitory mechanisms effect on muscle stretches on joint range of motion in different chronic pain states.

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Conflict of interest: Authors state no conflict of interest.

Informed consent: Informed consent has been obtained from all individuals included in this study.

Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the local ethical committee (N-20160019).

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