The relationship between pain and proprioception among individuals with rotator cuff-related shoulder pain

ABSTRACT

Background: Individuals with rotator cuff-related shoulder pain (RCRSP) have altered proprioception. The relationship between shoulder pain and proprioception is not well understood.

Purpose: Investigate the relationship between shoulder pain and proprioception.

Study design: Cross-sectional comparative study.

Methods: Twenty-two participants with RCRSP (mean age 27.6 ± 4.8 years) and 22 matched pain-free participants (23.4 ± 2.5 years) performed two upper limb active joint position sense (AJPS) tests: (1) the Upper Limb Proprioception Reaching Test (PRO-Reach; reaching towards 7 targets) in centimetres (cm) and (2) Biodex System™ at 90% of maximum internal rotation in degrees (°). Participants performed three memorization and three reproduction trials blindfolded. The proprioception error (PE) is the difference between the memorized and estimation trials. Pain levels were captured pre- and post-evaluation (11-point Likert Numerical Pain Rating Scale). Relationships between PE and pain were investigated using independent *t*-tests and Spearman rank correlations.

Results: 22.7% RCRSP participants indicated an increase in pain following the PRO-Reach ($\bar{X}$ increase of 1.4 ± 1.5 points), while 59% did so with the Biodex ($\bar{X}$ increase of 2.3 ± 1.8 points), reflecting a clinically important increase in pain. Weak to moderate correlations between pain and PEs were found with the Biodex ($r = .39 - .53$) and weak correlations with the PRO-Reach ($r = -.26 - .38$). Concerning PEs, no significant differences were found between groups with the Biodex ($p = .32$, effect size d=-.31 [-.90 − .29]). The RCRSP participants demonstrated lower PEs with the PRO-Reach in elevation compared to pain-free participants (global $\bar{X} = 4.6 \pm 1.2$cm vs 5.5 ± 1.5cm; Superior 3.8 ± 2.1cm vs $5.7 \pm$

2.9cm; Superior-Lateral Non-Dominant targets 4.3 $\pm$ 2.2cm vs 6.1 $\pm$ 2.8cm) (p = .02 to .05, effect size d = .72 to .74 [.12 $-$1.3]).

Conclusions: Individuals with RCRSP demonstrated better upper limb proprioception in elevation, suggesting a change to interoception (sensory reweighting) in the presence of pain.

Level of evidence: Level III cross-sectional diagnostic study.

Key words: Joint position sense, Biodex System, Upper Limb Proprioception Reaching Test, Interoception

INTRODUCTION

Our sense of body perception, or proprioception [1], is an integral part of how we interact with our surroundings. Understood to be our sixth somatosensory sense [2], proprioception guides our movements while contributing to our protection from injury through neuromuscular feedforward (preparatory) and feedback (reactive) mechanisms [3]. It is theorized that a change in proprioception following an injury can be due to a change in the processing of proprioceptive information by the central nervous system (CNS) [4], a loss of function of peripheral proprioceptors [1], a disruption in proprioceptive signalling as a result of trauma [5], the activation of local nociceptors, or a combination thereof [6].

Despite this neurophysiological rationale as to the influence of pain on the sense of proprioception, the current literature remains conflicting [6]. Changes to proprioception in the presence of pain have been noted across various joints including the ankle [7], knee [8], as well as the lumbar [5] and cervical [9] spines. However, other individual investigations involving the knee [10], lumbar spine [11] and the shoulder [12] describe no change to proprioception in the presence of pain. The developing understanding of shoulder proprioception contributes to the convoluted nature of this topic, as proprioception deficits appear to differ across various shoulder pathologies, such as instabilities [13], osteoarthritis [14], rotator cuff dysfunctions [15] and in post-operative shoulders [14, 16]. Moreover, the noted shoulder proprioception deficits are inconsistent across the sub-categories of proprioception [6].

A review evaluated the effects of pain on shoulder proprioception and reported mixed results across the various sub-categories [6]. Notably, a moderate level of evidence for the impairment of kinesthesia (sense of movement), a lower level of evidence for an altered sense of force and inconsistent levels of evidence involving joint position sense (JPS - spatial positioning). Passive joint position sense (PJPS) was described as likely unaffected by pain and the results are opposing regarding active joint position sense (AJPS) [6]. The aggregate of the evidence at this time suggests a contradictory

understanding of how the presence of shoulder pain influences proprioception, more specifically, upper limb JPS. This is an important area of study as it is unclear how the senses of pain and proprioception could influence each other during the rehabilitation of upper limb pathologies in a clinical setting.

As it is difficult to uncouple AJPS from our understanding of motor control [17], recent research has been moving away from evaluating AJPS at a single joint, towards appreciating the multisensory representation of an entire limb in space [18]. There is growing support for understanding proprioception ability of an entire limb [19] through limb-centered reference frames. [20]. Considering the proprioception acuity of an entire limb instead of a single joint, also increases the ecological validity, or resemblance to real-life function [21], of evaluating upper limb proprioception in a clinical setting.

For this reason, this study aims to investigate the relationship between pain and upper limb proprioception by comparing individuals affected by a rotator cuff-related shoulder pain (RCRSP) to healthy matched controls. Participants will partake in two active upper limb proprioception outcome measures: (1) the newly developed Upper Limb Proprioception Reaching Test (PRO-Reach) and (2) an AJPS protocol in internal rotation (IR) using an isokinetic dynamometer (Biodex Systems).

We hypothesized that participants affected by RCRSP would demonstrate a worse AJPS (higher proprioceptive error - PE) with both the Biodex and the PRO-Reach ($p \leq .05$). We further theorized a strong correlation (r values $\geq .707$) between PE and the reported shoulder pain of the RCRSP participants [22] as well as a between the PE of the two outcomes (PRO-Reach & Biodex), as they are both evaluate upper limb AJPS.

METHODS

Study Design

A cross-sectional, matched-control design.

Participants

Twenty-two individuals with a clinical diagnosis of RCRSP were recruited through a convenience sampling at the XXX from June to December 2019. Men and women were considered if they were between the ages of 18 and 35, and respected the inclusion and exclusion criteria (Table 1). A younger population experiencing RCRSP was selected for this study so as to avoid age as a potential confounding variable. It has been suggested that proprioception acuity can decline during the ageing process [23-25]. The clinical eligibility criteria for individuals affected by RCRSP has been previously outlined by Dubé and colleagues [26]. A positive cluster of criteria 3, 4 and 5 was required for inclusion.

Table 1 Eligibility criteria for RCRSP group

Inclusion criteria	Exclusion criteria
1. Between the ages of 18 and 35 2. Symptoms > 3 months 3. Presence of a painful arc 4. Presence of a positive Neer sign or Hawkin's Kennedy test 5. Presence of pain when resisting humeral external rotation or abduction, or positive Jobe test	1. Clinical signs of massive rotator cuff tears (grow weakness in the absence of pain [positive lag sign])[27] 2. Other shoulder disorders, for example, frozen shoulder, severe osteoarthritis, fracture and dislocation 3. Symptomatic cervical spine pathology 4. Presence of significant comorbidities (i.e., neurological disorders, rheumatoid arthritis) 5. Previous shoulder surgery 6. Corticosteroid injection in the past 6 weeks

Eligibility criteria for men and women affected by a rotator cuff-related shoulder pain (RCRSP), as outlined by Dubé and colleagues [26]. A positive cluster of criteria 3, 4 and 5 was required for inclusion in this study.

Twenty-two pain-free participants were recruited as matched controls with the following variables: age, gender, and dominance. The RCRSP population was recruited first, and the healthy control population matched, to ensure an equal number of male and females, and left and right-handed individuals in each group. Also ensuring the continuous data (age) of the matched-controls were within one standard deviation of the RCRSP population mean for that demographic variable. A convenience sample of healthy individuals was recruited through posters and e-mail distribution lists as well as face-to-face communication at XXX. Men and women, between the ages of 18 and 35 without any diagnosed upper limb neuro-musculoskeletal disorders within the last two years were recruited. Participants were eligible if they reported no musculoskeletal injuries to the upper limbs or cervical spine within the past two years and had no other major health concerns. Matched-control participants were excluded if they presented with pain, or any neurological, vestibular or circulatory symptoms. All participants gave informed consent voluntarily to participate in this study.

This study was approved by the Ethical Committee XXX and XXX. All methods were performed in accordance with the relevant guidelines and regulations as outlined by the Declaration of Helsinki (1964).

Proprioception outcomes

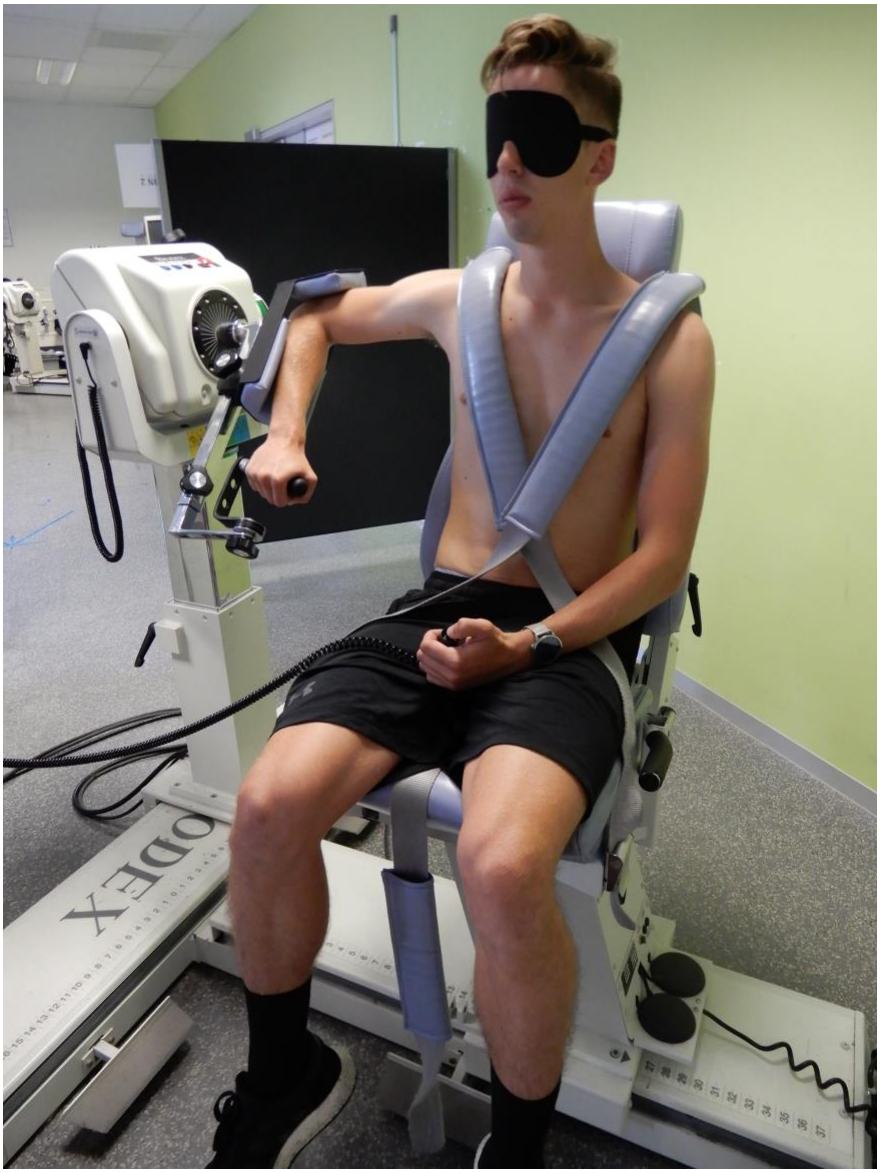
Upper limb AJPS was measured using an isokinetic dynamometer (Biodex) as well as the Upper Limb Proprioception Reaching Test (PRO-Reach). Although there is no accepted "Gold Standard" for measuring upper limb proprioception [28, 29], a recent review [30] has suggested that the isokinetic dynamometer supports the highest reliability for measuring shoulder JPS (a weighted average intra-session ICC = 0.92 $\pm$ 0.07) [30]. Recent psychometric testing of the PRO-Reach has suggested an overall good level of intra-rater reliability (ICC = 0.77) [31]. For the purpose of this study, A lower PE indicates better shoulder proprioception.

AJPS Biodex

The Biodex Systems IV (Biodex Multi-Joint System IV; Biodex Medical Systems, Inc., Shirley, NY, USA) was used at XXX and the Biodex Systems III was used at the XXX. The Biodex Systems manufacturer confirmed no differences existed between the two models for the measurement of upper limb proprioception. Before testing, the Biodex Systems were calibrated according to the manufacturer's guidelines. Pilot testing with a healthy population (n=40) within our motor control laboratory in XXX, suggests that the evaluation of AJPS with 90% of maximum IR supports excellent intra-session (between trials) reliability and (ICC = .86 (95%CI [.65 − .93]) and good inter-session reliability (48-hours apart) (ICC = .66 (95%CI [.34 − .82]).

All tests were performed on the dominant (matched-controls) or pathological shoulders (RCRSP). Participants were seated and secured with pelvic and torso straps. The glenohumeral joint was positioned at 90° abduction, 0° of rotation with the elbow in 90° flexion. The maximal (max) active ROM for IR was measured with the Biodex, and 90% of their max ROM was used as their relative target angle. Relative target angles were used to theoretically represent the same stretching of the soft tissues, activating the mechanoreceptors to the same degree for each participant. A familiarization trial (75% of max IR) was conducted. Participants were blindfolded and received an on/off button to stop the movement of the Biodex arm (Figure 1).

Figure 1 Laboratory installation for the evaluation of joint position sense of the shoulder using the Biodex Systems outcome



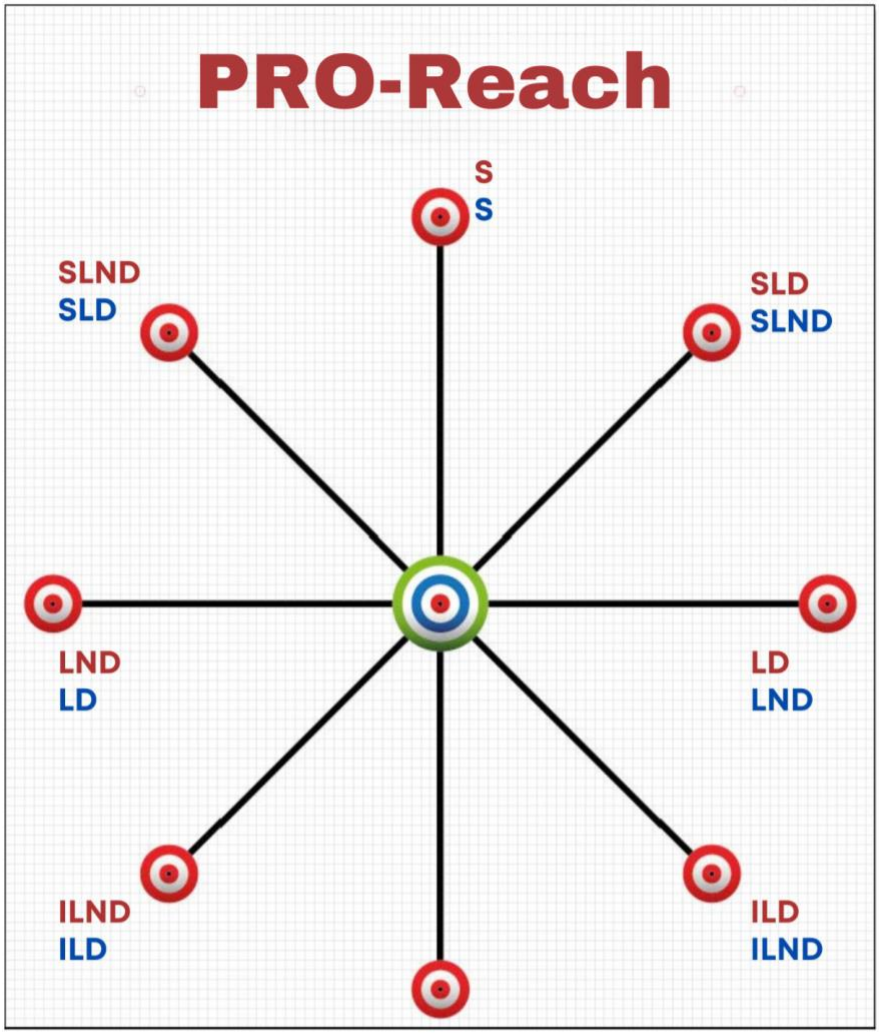
During the evaluation, the upper limb was actively assisted to the target angle, because of the weight of the Biodex arm (12 lbs) [32]. Once they reached their target, they had to "Hold" the position by contracting their shoulder muscles isometrically (five seconds), and memorize this position. Instructions included: “Ready, Go, Hold, Relax”. Participants then had to actively move their arm to the target angle, and click the on/off button when reached. The speed of the movement was set to 300°/second, allowing participants to choose their angular velocity. The PE was assessed as the difference between their relative target and reproduced target angle in degrees (Appendix I).

AJPS PRO-Reach

The PRO-Reach uses a plasticized poster (90 cm in length and 110 cm in height), printed on a grid pattern of 1 cm squared, for the ease of measurement of the PE. The poster is mounted on a wall with double-sided magnetic strips (ProMAG® Magnetic Tape; Marietta, OH, USA), to adjust to the height of the participant. The PRO-Reach uses stickers (0.6 cm round colour-coded, manually numbered 1-3) for the three reaching trials per target, and a standardized evaluation form (Appendix II) with instructions (Appendix III). Each participant is told that the purpose is to "evaluate your ability to reproduce movements in space" and is instructed to "memorize the position of your arm in space".

A total of seven targets in a star formation is used and the targets are named according to the direction of movement of the dominant shoulder (Figure 2). For example, the left-side of the PRO-Reach is dominant for left-handed participants, and the right-side of the PRO-Reach represents non-dominant (ND) cross-body movements, and vice-versa for right-handed participants. The targets are therefore named: superior (S), superior-lateral dominant (SLD) and non-dominant (SLND), lateral-dominant (LD) and non-dominant (SLND) and inferior-lateral dominant (ILD) and non-dominant (ILND). The (S) target is used to evaluate the reaching movements for both right and left-handed participants. During the evaluation, each participant was evaluated on 21 reaching movements in total, 7 targets with 3 reaching trials each. An evaluation of all 7 targets takes an estimated 25-30 minutes, including instructions, with each target taking less than 5 minutes to evaluate individually.

Figure 2 Upper Limb Proprioception Reaching Test



Direction of movement according to dominance

RIGHT-handed

LEFT-handed

S = Superior
SLD / ND = Superior Lateral Dominant / Non-Dominant
LD / ND = Lateral Dominant / Non-Dominant
ILD / ND = Inferior Lateral Dominant / Non-Dominant

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178 The participant performed three memorization trials, where they reached with their
179 eyes open towards an indicated target. Once their index finger reached the center of the
180 target, they would close their eyes and memorize their position in space for 5 seconds.
181 Following the memorization trials, they would promptly apply a blindfold with their
182 non-dominant hand, and immediately perform three reproduction reaching trials

towards the target (used to measure the PEs) (Figure 3). No feedback or corrections are given during testing. After each reproduction reaching trial, the evaluator placed a numbered sticker (1 through 3) immediately above the nail of the index finger, without making contact. One target is evaluated at a time. The evaluator used a retractable fabric sewing measuring tape (Fabric Tailor Cloth Craft Measurement Tape) to measure from the center of the target, to the center of the sticker, representing the "proprioception error" (PE) in cm. For the purpose of this study, upper limb "proprioception acuity" [33] is the reaching accuracy of the participant during the reproduction movement towards a target.

Figure 3 Upper limb reaching movement towards the superior target of the PRO-Reach tool

Symptoms and Disability

The *Quick* Disability of the Arm, Shoulder, or Hand questionnaire (*Quick*DASH; score ranges from 0 [no disability] to 100 [most severe disability]) questionnaire [34] was utilized to assess upper limb symptoms and disability for both populations. The *Quick*DASH is valid in French [35] and Dutch [36] and is highly reliable (ICC = 0.91) [37]. The minimal clinically important difference (MCID) is 12.85 points (sensitivity 79%, specificity 75%) [37], which was used as our threshold to ensure a symptom-free population with our matched controls.

Pain Levels

Pain levels were assessed using the 11-point Numerical Pain Rating Scale (NPRS), where 0 represents "no pain" and 10 represents "worst pain imaginable." The French and Dutch versions are considered to be moderately reliable (ICC range 0.74–0.76) [38], and a change of two points is deemed to be clinically important [39].

Handedness

Handedness was determined by asking "Which arm do you use to throw a ball?". If the answer was both or ambiguous, the Edinburgh Handedness Inventory questionnaire - Short Form [40] was issued. This questionnaire has been unofficially translated into Dutch for the use of this study (A.M.C).

Evaluators

Two evaluators were used for this study. One evaluator in XXX performed the evaluations with the healthy participants and one evaluator in XXX with the participants affected by RCRSP. The two evaluators underwent two days of practice and familiarization training with the PRO-Reach tool and Biodex Systems. Pilot inter-rater evaluations (48-hours apart) of five graduate students not directly involved in the

study, revealed good reliability of the PRO-Reach with an intraclass correlation coefficient (ICC) of 0.87 (95% confidence intervals [CI] .67 – .95], $p < .001$) and with the Biodex Systems, evaluating AJPS at 90% of the participants' maximum internal rotation (ICC = 0.77 [95% *CI: .60 – .87*] $p < .001$).

Data Analysis

Descriptive statistics (means [$\bar{X}$] and standard deviations [SDs]) were used for all outcomes. Parametric testing was used, as the data was normally distributed and homogenous (Shapiro-Wilk test and the Kolmogorov-Smirnov's tests). Baseline demographics were used for comparability of groups (Independent *t*-test / chi-square tests). All data was tested to for distributional assumptions for the inferential statistical analyses.

Independent *t*-tests compared the two groups concerning all variables. Correlation analysis was used for the two proprioception outcomes; AJPS with the Biodex (AJPS score IR 90%) and the PRO-Reach global mean score (the average of the mean PEs of each target, for a resultant global PE). Effect size is reported through a Cohen's *d* measure (Cohen's $d = (x_1 - x_2) / \sqrt{(s_1^2 + s_2^2)/2}$) with associated confidence intervals (CIs), where a *d* of 0.2 or less is considered to be a small effect size, a *d* of 0.5 is considered to be a medium effect size, and 0.8 or larger is considered to be a large effect size [41]. A positive Cohen's *d* value indicates that both proprioception and pain either increase or decrease together, whereas a negative value suggests one variable increases as the other one decreases.

Correlational analysis was also used between pain levels of the RCRSP population and their PE for both outcomes. Pearson correlation coefficients were used as all variables were normally distributed. The Pearson correlation coefficient (*r*) was categorized as weak ($\leq .499$), moderate ($.50 - .707$), or strong ($\geq .707$) [42].

All analyses were performed using the Statistical Package for Social Sciences (SPSS), version 25 (Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.) for Mac software, with all α values set to 0.05.

Research biases were minimized throughout the study design, recruitment, data collection and analysis phases by coding participant data, applying randomization to all outcomes, having a collaborative and transparent approach to all aspects of the scientific process and declaring no conflicts of interest by all researchers involved.

Sample Size

Sample size was estimated based on the variability of pilot data from measuring AJPS with the Biodex in IR (mean group I: 4.0°; mean group II: 3.6°; standard deviation: 1.8°) (G*Power 3.1.9.7) effect size: 0.8, $\alpha = 0.05$, power $(1-\beta) = 0.90$, requiring a minimum of 20 participants per group.

RESULTS

Forty-four participants were recruited and evaluated for this study, 22 individuals affected by RCRSP and 22 matched pain-free individuals. There was no missing data from our evaluations.

Baseline demographics

Both groups are comparable with all baseline demographics, except for pain and *Quick*DASH scores (Table 2).

Table 2 Baseline Demographics

	Pain-free Population (n=22)	Population affected by RCRSP (n=22)	Independent t-Test or Chi-Squared test
Age ($\bar{X} \pm$SD) years	23.4 ± 2.5	27.6 ± 4.8	p = .06
Gender (%) Male / Female	M:40.9% F: 59.1%	M:40.9% F: 59.1%	p = 1.0
Height (cm) ($\bar{X} \pm$SD)	170 ± 10	170 ± 10	p = .40
Weight (kg) ($\bar{X} \pm$SD)	63.9 ± 12.1	68.9 ± 8.7	p = .90
Dominance (%) Right/Left	R: 81.8% L: 18.2%	R: 81.8% L: 18.2%	p = 1.0
Affected shoulder R/L	n/a	12/10	n/a
Length of symptoms (months) (mean / median / quartiles)	n/a	Mean: 40.2 Median: 36.0 IQR-Q1: 15.3 IQR-Q2: 44.8 IQR-Q3: 60.0 IRQ-Q4: 120.0	n/a
***Quick*DASH score**	0.1 ± 0.62	29.7 ± 10.6	p <.001*
Pain at baseline (/ 10) †	0	3.4 ± 1.6	p <.001*

Means and standard deviations ($\bar{X} \pm$SD) of baseline characteristics of the participants.
RCRSP = Rotator cuff-related shoulder pain, M = male, F = female, R = Right, L = Left, n/a = not applicable, $\bar{X}$ = mean, SD = standard deviation, IQR = quartiles (1st, 2nd, 3rd and 4th), QuickDASH = Abbreviated version of the Disabilities of the Arm, Shoulder and Hand Questionnaire.
QuickDASH; score ranges from 0 [no disability] to 100 [most severe disability]) questionnaire.

(*) Statistically significant results.

(†) Based on the verbally reported values using the 11-point Numerical Pain Rating Scale (NPRS), (0 being no pain at all, 10 being the worst pain of your life).

Reported levels of pain

Among the RCRSP population (n=22), 11 participants (50%) reported pain pre-PRO-Reach ($\bar{X}$ pain levels: 1.41 points) and 16 participants (72.7%) reported pain post-PRO-Reach ($\bar{X}$ pain levels: 2.77 points). Pre-Biodex, six participants (27.3%) reported pain ($\bar{X}$ pain levels: 1.82 points) and 19 participants (86.4%) reported pain post-Biodex ($\bar{X}$ pain levels: 4.1 points). The RCRSP population demonstrated a clinically important increase of 2.28 points in pain post-Biodex (Table 3). Rest periods of up to 30 minutes were permitted between evaluations, to return to baseline pain levels. The duration of pain demonstrated weak correlations to the overall PEs (global means) of the PRO-Reach and Biodex, (r range from −.001 to −.276).

Table 3 Reported levels of pain among the population affected by rotator cuff-related shoulder pain

	Pre-evaluation	Post-evaluation	Change in pain level
PRO-Reach ($\bar{X} \pm$ SD)	1.41 $\pm$ 1.74	2.77 $\pm$ 2.09	
Median	**0.5**	**2**	
IRQ-Q1	0	1	**1.36** $\pm$ 1.50
IRQ-Q2	0.5	2	
IRQ-Q3	2	4	
IRQ-Q4	6	7	
Biodex ($\bar{X} \pm$ SD)	1.82 $\pm$ 1.65	4.1 $\pm$ 2.24	
Median	**2**	**3**	
IRQ-Q1	0.25	2	**2.28*** $\pm$ 1.84
IRQ-Q2	2	3	
IRQ-Q3	2.75	4	
IRQ-Q4	6	9	

AJPS = active joint position sense

PRO-Reach = Upper Limb Proprioception Reaching Test

$\bar{X}$ = mean, SD = standard deviation, median & IQR = quartiles (1st, 2nd, 3rd and 4th)

Pain levels were assessed using the 11-point Numerical Pain Rating Scale (NPRS), where 0 represents "no pain" and 10 represents "worst pain imaginable." A change of two points using the NPRS scale is deemed to be clinically important (*).

Correlations Between Pain and Proprioception with RCRSP Population

No statistically significant correlations between pain levels (pre or post) and the PE from the AJPS Biodex evaluation were identified (p range .24 – .29). A weak correlation (r=.39 p=.008) was found between the duration of pain symptoms in months and the reported post-evaluation pain levels.

Weak correlations were found between post-PRO-Reach pain and the PEs of the [S] target (r=– .337, p=.025) and the [SLND] target (r=– .369, p=.014). Moreover, weak correlations (r range – .23 to .28) were identified with the PRO-Reach PEs (global means) of the other targets, with regards to pain intensity and duration in months.

Proprioception Outcomes

Descriptive statistics with associated independent t-test and effect sizes for both upper limb proprioception outcomes are presented in Table 4.

Table 4 Descriptive statistics of upper limb proprioception (active joint position sense) and reported pain levels

	Pain-free Population (n=22)	**Population affected by RCRSP (n=22)**	***t*-test level of significance Cohen's *d* [CI]**
PRO-Reach ($\bar{X}\pm$ SD) cm			
Superior **[S]**	5.7 ± 2.9	3.8 ± 2.1	p=.02* d=.74 [.12 –1.3]

Superior Lateral Dominant **[SLD]**	4.6 ± 1.8	5.1 ± 2.5	*p*=.50 *d*=-.21 [-.79 −.34]
Lateral Dominant **[LD]**	5.0 ± 2.2	3.7 ± 2.0	*p*=.05* *d*=.60 [-.01 −1.2]
Inferior Lateral Dominant **[ILD]**	6.5 ± 2.7	5.2 ± 2.3	p=.08 *d*=.54 [-.06 −1.1]
Superior Lateral Non-Dominant **[SLND]**	6.1 ± 2.8	4.3 ± 2.2	*p*=.02* *d*=.72 [.11 −1.3]
Lateral Non-Dominant **[LND]**	3.8 ± 1.8	4.1 ± 1.9	*p*=.57 *d*=-.17 [-.76 − .42]
Inferior Lateral Non-Dominant **[ILND]**	6.6 ± 2.9	5.6 ± 3.1	*p*=.25 *d*=.35 [-.25 −.95]
Global mean **[7 targets]**	5.5 ± 1.5	4.6 ± 1.2	*p*=.02* *d*=.72 [1.0 −1.3]
Mean pain level pre-PRO-Reach evaluation (/10)	0	1.4 ± 1.7 Median = 0.5 IRQ-Q1 = 0 IRQ-Q2 = 0.5 IRQ-Q3 = 2 IRQ-Q4 = 6	*p*=<.001* *d*=1.1 [.5 −1.8]
Mean pain level post-PRO-Reach evaluation (/10)	0	2.8 ± 2.1 Median = 2 IRQ-Q1 = 1 IRQ-Q2 = 2 IRQ-Q3 = 4 IRQ-Q4 = 7	*p*=<.001* *d*=1.9 [1.2 – 2.6]
Biodex ($\bar{X}$ ± SD) °			
90% of maximum IR (Global mean)	4.0 ± 1.8	4.8 ± 2.7	*p*=.32 *d*=-.31 [-.90 −.29]
Mean pain level pre Biodex evaluation (/10)	0	1.8 ± 1.7 Median = 2 IRQ-Q1 = 1 IRQ-Q2 = 2	*p*=<.001* *d*=1.6 [.87 − 2.2]

		IRQ-Q3 = 4 IRQ-Q4 = 7	
Mean pain level post Biodex evaluation (/10)	0	4.1 ± 2.2 Median = 3 IRQ-Q1 = 2 IRQ-Q2 = 3 IRQ-Q3 = 4 IRQ-Q4 = 9	*p*=<.001* *d*=2.1 [1.4 – 2.9]

(*) Statistically significant results.

PRO-Reach = Upper Limb Proprioception Reaching Test

$\bar{X}$ = mean, SD = standard deviation, median & IQR = quartiles (1st, 2nd, 3rd and 4th)

IR = internal rotation

Effect size was established using Cohen's d measure with associated confidence intervals [CI], to evaluate the difference between the two groups.

Pain levels were assessed using the 11-point Numerical Pain Rating Scale (NPRS), where 0 represents "no pain" and 10 represents "worst pain imaginable."

Biodex

No statistically significant differences between the two populations were found with the Biodex (pain-free participants 4.1 ± 1.7°; RCRSP participants 4.8 ± 2.7°; *p*=.32, *d*=-.31 [-.90 −.29]).

PRO-Reach

No statistically significant differences were identified between the two populations, except for the superior [S] target, superior-lateral non-dominant [SLND] target and the global mean PE; where the RCRSP population had lower mean PE scores (4.6 ± 1.2 cm) compared to the pain-free population (5.5 ± 1.5 cm) (*p*=.02, *d*=.72 [1.0 −1.3]).

Weak correlations were identified between the PRO-Reach (individual targets or global mean) and the AJPS Biodex (r ranging from -0.19 to 0.20, p=.07—.90).

DISCUSSION

Proprioception deficits have been documented among several populations affected by shoulder pathologies, including individuals with RCRSP [15]. What remains unclear is how the presence of pain influences upper limb proprioception among this population. This knowledge is important because shoulder proprioception rehabilitation is often included in treatment plans for RCRSP without adequate evidence that it relates to pain.

We hypothesized that the presence of pain could contribute towards proprioceptive deficits captured through upper limb AJPS reproduction tasks. The results of our study do not support this, since we did not observe better proprioception in pain-free matched controls compared to the RCRSP population. Interestingly, the RCRSP population demonstrated better proprioception with the reaching tasks in elevation towards the (S) and (SLND) targets of the PRO-Reach, suggesting a possible heightened sense of proprioception when experiencing chronic pain. Indeed, our RCRSP population can be described as experiencing chronic pain, as the median duration of their symptoms was 36 months.

Prior research examining the relationship between shoulder proprioception, pain intensity and functional disability among individuals with RCRSP has presented with inconsistent results [6, 43, 44]. Certain studies have indicated decreased proprioception acuity [45, 46], while others have not detected substantial differences when comparing individuals with RCRSP to a healthy population [6, 47]. These findings suggest that impaired proprioception may not be a consistent feature of individuals affected by RCRSP [46].

Our results can be partially understood when considering a probable change to sensory interoception and motor adaptations of the CNS in the presence of pain. Interoception is the process by which the body senses, interprets, integrates and regulates signals from within itself [47]. It has been suggested that pain changes the sensory-mechanical feedback loop and cortical reorganization [5], and that there may be an accompanying reweighting of proprioceptive inputs [5]. This could alter how we prioritize proprioception and adapt different motor control strategies to avoid further pain or injury [5]. A study by Dupuis and colleagues [48] suggested altered shoulder kinematics and motor adaptations during experimentally induced shoulder pain. Their pain group demonstrated different inter-joint coordination strategies, significant motor adaptations and an increased EMG activity of the trapezius muscle during a reaching task. Their work proposed a change to central motor planning, which incorporates proprioception, in the presence of pain.

Furthermore, persistent nociception stimulation could lead to an enhanced activation of the sympathetic nervous system [49]. As a result, this impacts the activation and rate of discharge of localized muscle spindles [50] and arguably neighbouring proprioceptors. It is therefore possible that a prolonged exposure to nociception stimulation could heighten the localized sense of proprioception, which was captured through the active reaching tasks of the PRO-Reach in elevation. We could be seeing this heightened sense of proprioception in elevation only, as these reaching movements are causing stretching of soft tissues. It is well known that the deformation of soft tissues elicits increased mechanoreceptor activity, causing an augmented localized sense of proprioception [51]. Previous research supports that load and angle have a meaningful impact on JPS of the shoulder, as decreased PEs have been noted at higher angles of shoulder elevation [51, 52]. Although this is a plausible explanation, little continues to be known about the peripheral changes or the cortical reorganization of somatosensory senses in the presence of pain, in particular proprioception [6, 53].

This reasoning could also explain why we did not observe a difference in proprioception between our two populations with the IR movements with the Biodex.

Firstly, we employed a relative target angle, arguably not attaining as much of a stretch response and stimulation to localized mechanoreceptors as seen with the PRO-Reach. Also, the evaluation with the Biodex was tested in a seated position and involved the glenohumeral joint with one degree of freedom, acknowledging that this method is evaluating shoulder movement only. The PRO-Reach involved movements of the entire upper limb as well as a trunk lean during reaching in standing, soliciting a greater deformation of bodily tissues and activation of associated mechanoreceptors. As we found weak correlations between the proprioception variables of the PRO-Reach and Biodex, there is a probability that they examine different aspects and areas of proprioception acuity. It is also interesting to note that we are not the first study to suggest no change in JPS with internal or external rotation movements between a population with shoulder pain and matched controls [6, 54]. Perhaps evaluating JPS with rotational movements is not the optimal method for detecting a change in shoulder proprioception, particularly with a RCRSP population.

Another significant aspect to highlight is the possibility of different shoulder pathologies presenting with different proprioception adaptations, suggesting a certain specificity to proprioception deficits [55]. This unclear relationship between pain and proprioception has not only been documented among the upper limb and shoulder, but also among other joints including the lumbar spine [56], cervical spine [57], knee [8] and ankle [7].

Future studies should investigate how senses are influenced by one another, including among pain-free and pathological populations. What makes this line of inquiry challenging is that proprioception may be the least well-measured of all the contributing senses to central motor planning [58]. To clarify the relationship between pain and proprioception, researchers require psychometrically established proprioception outcome measures [30], a better understanding of the various sub-categories of proprioception and consistent testing among different pathologies. At this time, we simply do not know if pain increases, decreases or does not affect proprioception acuity [6, 11] and what the associated causes or consequences might be.

Clinical Implications

- There is support for a relationship between pain and proprioception, but the magnitude and directionality has yet to be determined;
- It is possible that an improved sense of proprioception among the RCRSP population could reflect a protective mechanism to avoid further injury;
- The PRO-Reach tool did not significantly increase post-evaluation pain levels. It may be a feasible way of measuring a change in proprioception acuity over time with a population experiencing upper limb pain.

Strengths and limitations

Our study used two psychometrically tested upper limb AJPS outcomes to investigate the influence of pain on proprioception. To continue the conversation about pain and proprioception, several limitations need to be recognized.

Firstly, we strongly recommend that this study be repeated with different populations affected by diagnoses or injuries involving the neck, shoulder, elbow or distal arm, for example. This will help to establish if an injured area of the upper limb does in fact influence the proprioception acuity of the entire limb. Secondly, the relatively lower levels of reported pain and disability through the DASH scores by the RCRSP group needs to be acknowledged. Higher reported pain and disability levels could alter, or contradict, the results of this study. It would be interesting to investigate if higher pain levels would influence proprioception, and if so, in which direction. Another avenue worth exploring is the possibility of experimentally induced shoulder pain, where a pain-free population could act as their own control. Albeit, a recent study reported no change to PJPS or kinesthesia in the presence of experimentally-induced shoulder pain [12]. Thirdly, a stronger study design would have included a single evaluator for all participants. Although inter-rater reliability for the two outcomes were good to excellent (ICC ranges .67 – .95), it is difficult to rule out evaluator measurement error for the differences we are seeing between our two populations. Lastly, it is prudent to consider the influence of dominance when evaluating upper limb proprioception.

Acknowledging that 45% (10/22) of the RCRSP group had injured their non-dominant limb, it would have been worth evaluating both upper limbs for both populations. This could have allowed us to identify if dominance was a potential confounding variable. That being said, the association between upper limb proprioception and dominance is unclear at this time. Some studies report better proprioception acuity with the dominant limb [59], some with the non-dominant limb [19, 60], and others reporting no effect [52, 61, 62] suggesting that comparison between limbs may be misleading [63].

CONCLUSION

Our investigation into the relationship between pain and upper limb proprioception suggests that a young adult population affected by chronic rotator cuff-related shoulder pain may have better proprioception acuity in elevation compared to their healthy counterparts. Further investigation with this population is strongly encouraged as the association between pain and active joint position sense has been predominantly weak. In addition, as none of our proprioception variables with the PRO-Reach or Biodex demonstrated strong associations, our two proprioception outcomes may quantify different proprioception variables altogether. Our findings are contradictory to our initial hypothesis as well as the trends in current research, which suggest a worsening of proprioception in the presence of pain.

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Ethical Approval

This study was approved by XXX and XXX. All methods were performed in accordance with the relevant guidelines and regulations as outlined by the Declaration of Helsinki (1964).

Conflict of interest statement

There are no competing interests to declare at this time. No conflict of interest exists from any of the authors involved in this paper.

Author contributions

All named authors have made a significant and substantial contribution to all aspects of the study. Each of the named authors provided a meaningful contribution to the conception, design, execution and interpretation of the study data in addition to writing, drafting and revising the paper itself. This paper is submitted with the agreement and approval of all authors.

Availability of data materials

All authors consent to all data being openly public and accessible.

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