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Less Pain, but no changes in maximal inclination angles during an overhead reach task following local anesthetic in patients with ongoing shoulder pain

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ABSTRACT

This multicenter observational study aimed to assess how pain reduction, induced by local anesthesia, affects the relative angular contributions of the shoulder girdle and trunk to the maximal angular performance during a semi-constrained overhead reach task in patients with ongoing shoulder pain. Twenty-nine individuals (age 59.0 SD 12.8 years;16-male) with symptomatic shoulders were administered corticosteroid and lidocaine injections by their attending orthopedic surgeon. Immediately before and after the injections, participants reached for a target on the ceiling ten times as high as possible while their pain levels, shoulder, and trunk movements were recorded. The analysis revealed that there was a significant reduction in pain following the injections. However, there were no significant differences in maximum shoulder and trunk inclination angles between the pre- and post-injection conditions. Notably, there were slight but statistically significant alterations in humeroscapular kinematics during the initial phase of arm elevation following the injections. In conclusion, acute pain relief following local anesthetics is not associated with immediate alterations in maximum shoulder girdle and trunk inclination angles during a semi-constrained overhead reach task in patients with ongoing shoulder pain. However, there are signs of small alterations in humeroscapular kinematics during the initial phase of arm elevation.

1. Introduction

In persistent shoulder pain states, individuals exhibit different movement behaviour when compared to asymptomatic individuals (Lin et al., 2011). Several cross-sectional studies involving various shoulder conditions showed significantly less scapular upward rotation (Ludewig and Cook, 2000; Lukasiewicz et al., 1999), greater scapular asymmetry (McClure et al., 2006), less shoulder range of motion (Ludewig and Cook, 2000) and different trunk movement (Gonçalves et al., 2021) during activities in individuals with shoulder pain. These differences are believed to be functional alterations aimed at relieving the affected shoulder. However, altered movement behavior in persistent pain states is also suggested to have long-term negative consequences, such as secondary or renewed tissue damage, when maintained excessively or inappropriately (Hodges and Smeets, 2015). To achieve effective pain management and improve the quality of life for those with persistent

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shoulder pain states, knowledge about what drives this movement behaviour is therefore essential.

It is generally conisdered that movement behavior in musculoskeletal pain is driven by nociception. For example, in acute tissue damage, excessive loading of the affected tissue usually leads to an immediate increase in pain intensity due to involvement of mechanical sensitive transient receptor potential (TRP) ion-channels of a nociceptor. This pain response may provide individuals with a strong incentive to adapt their movement strategy to reduce potential negative consequences for the actual tissue state, such as worsening of existing tissue damage or re-injury (Brown et al., 2022; Pastor-Mira et al., 2022). However, the brain also weighs the nociceptive signal in the context of other sensory inputs, such as proprioceptive and vestibular information, as well as environmental cues, such as visual and auditory stimuli (Ongaro and Kaptchuk, 2019). Moreover, prior experiences also play a role, as the brain learns from previous pain experiences and adapt its response accordingly (Mansour et al., 2014). Compared with acute pain, movement behavior in persistent pain thus seems to be part of a more complex interaction between physiological, psychological and environmental factors (Simons et al., 2014). It is therefore unclear to what extent movement behavior in persistent shoulder pain can still be primarily attributed to nociception.

One method to determine the influence of nociception on movement behavior is the use of lidocaine by local injection. Lidocaine reduces the conduction velocity of nociceptors by blocking specifically involved mechanosensitive TRP ion-channels (Kankel et al., 2012). Only a limited number of studies have specifically examined the reduction of nocisensor input by lidocaine on motor behaviour in persistent shoulder pain states (Ettinger et al., 2017; Kolk et al., 2016). Both studies found significant differences in scapular kinematics after a bolus of local anesthetics was injected into the subacromial-subdeltoid bursa.

However, arm movements were restricted to 120 degrees elevation, only measurements of the scapula were considered and the requested activities did not relate to tasks in daily life. Thus, additional knowledge on the influence of nociception – through shoulder pain reduction using lidocaine by local injection – on shoulder and trunk movement behavior in daily life/tasks for effective pain management in shoulder pain patients is still warranted.

The aim of this study was to determine the influence of immediate nociceptive pain-relief on the relative angular contributions of the shoulder girdle and trunk to the maximal angular performance of a semi-constrained reaching task by patients with persistent shoulder pain. To meet this aim, we conducted a multi-center observational study and compared shoulder and trunk kinematics within a sample of patients with various shoulder conditions during an overhead reach task immediately before and after a bolus of local anesthetic administered as part of best practice orthopedic care.

2. Methods

2.1. Participants

Twenty-nine patients (13 males/16 females, mean age: 59.0 SD 12.8 years; mean body height: 173.9 SD 10.6 cm; mean body mass: 82.2 SD 16.1 kg), with various shoulder conditions recruited from the outpatient clinics of four cooperating hospitals (i.e. Amphia, Breda/Oosterhout; OLVG, Amsterdam; Spaarne Gasthuis, Haarlem; Bergman Clinics, Naarden) participated in this multicentre observational study. Patients were eligible when they 1) had ongoing shoulder pain (i.e. > 6 weeks), 2) were indicated by the attending orthopedic surgeon for injection therapy as best practice orthopedic care, in either the subacromial-subdeltoid bursal space (SASD), the glenohumeral joint (GHJ), the acromioclavicular joint (ACJ), or a combination of these sites, 3) experienced increasing pain with high arm elevations, and 4) demonstrated no structural deformities that could potentially obstruct their range of motion, or prevented them to lift their arm.

This study was approved by the Scientific Ethical Review Board (VCWE) of the Vrije Universiteit Amsterdam (VCWE-2020-131R1) the Netherlands, and by the participating hospitals' Ethics Advisory Boards. All participants provided written consent after being informed about the study aims, procedure and risks, prior to their participation. Measurements were conducted in the outpatient shoulder clinics of the four participating hospitals, between March 2021 and October 2021.

2.2. Procedure and data acquisition

As part of the standard clinical examination, participants were instructed to perform ten consecutive forward arm elevations with their affected arm, reaching as high as possible to a red dot on the ceiling directly above them, immediately before and 5 min after they were administered a local bolus of corticosteroids and lidocaine by the attending orthopedic surgeon as part of their planned treatment. For intra-articular injections into ACJ, a mixture of 1 ml triamcinolone acetonide (Kenacort) and 1 ml lidocaine was used, while for injections into SASD and GHJ, a mixture of 1 ml triamcinolone acetonide with 2 to 4 ml lidocaine was applied. Participants sat upright on a stool in a standardized position with their hands on their knees and the backs of their heels on the edge of a tape on the floor **[**Fig. 1**]** . Participants were allowed to complete the movement at their own pace. Pain intensity was measured with a Verbal Pain Rating Scale-11 (VPRS-11) (0 = no pain, 10 = worst pain imaginable) (Michener et al., 2011), immediately before starting and after completing each task, and when pointing their finger at the dot on the ceiling. Prior to the execution of the tasks, patients were asked to score their expectations about the pain-reducing effect of the injection on a Verbal Numerical Rating Scale-11 (VNRS-11) (0 = no pain-reducing effect expected, 10 = maximal pain-reducing effect expected). The degree of perceived threat of 1) worsening of existing tissue damage, and 2) increase in pain from performing the task was measured for both conditions with a Verbal Numerical Rating Scale-11 (VNRS-11) (0 = no threat, 10 = highest imaginable threat) directly after completion of the task, to contextualize the kinematic output.

Kinematic data of the shoulder and trunk segments were obtained with four wireless inertial measurement unit (IMU) sensors (Xsens DOT, Xsens Technologies B.V. Enschede, The Netherlands), collecting 3D inertial sensor data with a sample frequency of 60 Hz.

Prior to the clinical assessment, the IMU sensors were mounted with double-sided tape to the participants' sternum, acromion, upper arm and pelvis following the recommendations outlined by Höglund e.a. 2021. (Höglund et al., 2021) Acromion sensor displacement due to deltoideus contraction was checked with humeroscapular abduction and avoided as much as possible when mounting the sensor. Magnetic field mapping was performed to calibrate the IMU's magnetometers.

2.3. Data processing

First the unprocessed output from the Xsens DOT sensors, presented as quaternions, served as the input for the Madgwick orientation filter. This procedure was conducted to determine the orientations of each IMU sensor, using MATLAB (R2022a Update 2, version 9.12.0, The Mathworks Inc, Natick, MA, USA) (Madgwick, 2010). The filter gain (ß) was set to 0.041 providing optimal performance (Madgwick, 2010). To convert these IMU orientations into a one-dimensional inclination angle between all segments (i.e. trunk, scapula, humerus) involved in the reach task, a helical angle approach was used (Blankevoort et al., 1990). Therefore, joint orientations, expressing the distal segments relative to the proximal (e.g. humerus relative to sternum), were calculated. These were expressed to the first static sample (t_0) in which the patient was positioned in a neutral pose, i.e. sitting upright on a stool with their arms alongside and their elbows 90 degrees flexed forward. Then thoracohumeral, humeroscapular, scapulothoracic and sternopelvic inclination angles were calculated (Blankevoort et al., 1990). Finally, nonlinear functional time normalisation was used to normalized the time

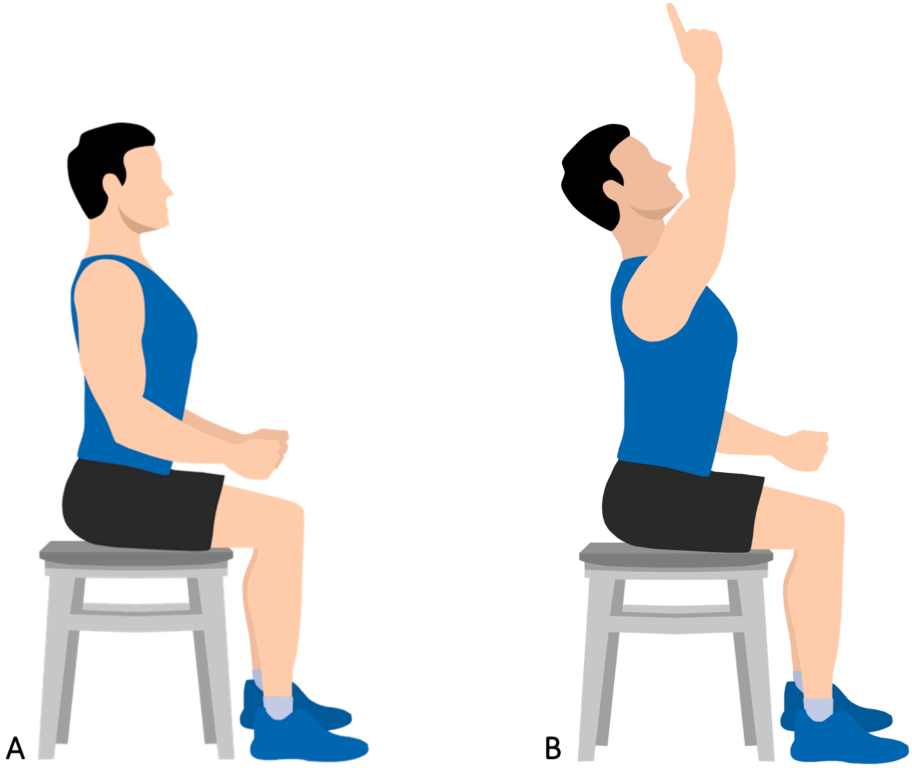

Fig. 1. The starting position of the participant prior to raising their arm (A) and end position of their arm after reaching for the dot on the ceiling (B).

from 0 % to 100 % to be able to perform a Statistical Non-Parametric Mapping (SnPM) analysis (Ramsay and Silverman, 2005).

2.4. Statistical analysis

To determine the difference between the pain intensity before and after the injection therapy, a Generalized Estimating Equations (GEE) analysis using the exchangeable working correlation structure was conducted (Lumley et al., 2022). Normality was tested with a Q-Q plot, Shapiro-Wilk and the Jarque-Bera test, revealing that the data was not normally distributed. Generalized Estimating Equations (GEE) analysis was selected for its ability to provide valid standard errors for parameter estimates regardless of data distribution, and for its general efficiency over paired t-tests in managing correlated responses. This is a more powerful statistical test because it uses all available data points rather than just means, as with a paired *t*-test. Within the GEE-model participants were considered as a random factor to account for the within participant dependence of the consecutive arm movements. Pre- and post-injection conditions were added as categorical predictor. Pain intensity scores were added as the continuous outcome variable. Alpha was set at 0.05. R (R Core Team, version 4.2.0, 2022, Vienna, Austria) and R package 'gee' (version 4.13–23) were used to perform the analysis (Lumley et al., 2022; Team, 2022) and R packages 'ggplot2′ (version 3.3.6) and 'ggeffects' (version 1.1.2) were used to design the graphs (Lüdecke, 2018; Team, 2022; Wickham, 2016) as reported in the results.

Descriptive statistics were used to represent pre-trial expectations about the pain-reducing effect, and perceived threat of worsening existing tissue damage and increased pain due to performing the overhead reach task.

To compare pre-injection with post-injection shoulder and trunk kinematics, a one-dimensional hierarchical (two-level) random effect analysis with the SnPM (version 0.4.2) methodology was used (Nichols and Holmes, 2002). Thoracohumeral, humeroscapular, scapulothoracic and sternopelvic inclination angles were added to the model as continuous outcome variables. Pre- and post-injection conditions were added as categorical predictors. The first level consisted of performing a within-subject linear regression analysis to establish the regression coefficient (ß1) for each point in time, representing the differences between both conditions per participant. The second level consisted of subjecting ß1 to a non-parametric two-tailed one-sample *t*-test, accounting for the non-normal distribution of normalized timeseries data. SnPM is based on probability density functions (PDF) that include the label permutation procedure. This procedure comprises of assigning labels to the original data followed by a random permutation of the labels. The *t*-test statistics were calculated in the form of SnPM {t} trajectories for each permutation. The critical threshold of the SnPM {t} was determined and ensures that only 5 % of all permutations exceed the critical threshold of the SnPM {t} (Pataky et al., 2015). Eventually, the probability value (p) was determined for each supra- and infra-threshold region where the SnPM {t} exceeded the critical threshold (Pataky et al., 2015). Alpha was set at 0.05. SnPM analyses were performed for each of the outcome variables separately using PyCharm version 2022.1.3 (JetBrains s.r.o., Prague, Czech Republic) running the Python language (version 3.8.3.) (van Rossum et al., 2009) with the 'spm1d' package of the open-source code (https://www.spm1d.org) (Nichols and Holmes, 2002; Pataky, 2021, 2012).

3. RESULTS

3.1. Pain reduction

In 29 participants, 16 SASDs, 4 GHJs, 7 ACJs, 1 combination of all three sites, and 1 combination of SASD and GHJ were injected. Prior to the injection, the participants' expectations about the pain-reducing effect of the injection were 7.1 (SD=2.4) out of 11 (0 = no pain-reducing effect expected, 10 = maximal pain-reducing effect expected). Two participants were excluded from analysis due to lack of pain reduction following local anesthesia. The remaining participants (n = 27) demonstrated a statistically significant lower maximal pain intensity during the reach task in the post-injection condition (M=3.1; 95

%CI [2.4, 3.8]) compared to the pre-injection condition (M=6.1; 95 %CI [5.3, 6.8]) **[**Fig. 2**]**.

3.2. Perceived threat during task performance

Participants' degree of perceived threat of 1) worsening of existing tissue damage, and 2) increase in pain from performing the task were both very low to nonexistent before and after the injection **[**Table 1**]**.

3.3. Shoulder and trunk inclination angles

There were no statistically significant differences in any of the maximum inclination angles between the pre- and post-injection conditions **[**Table 2**]**.

Statistically significant differences in scapulohumeral kinematics were observerd for the intitial phase of arm elevation within range of 8.3 % to 20.4 % ($p = 0.005$), with smaller inclination angles for the post-injection condition **[**Fig. 3 **C]**. No statistically significant differences were found for the thoracohumeral, scapulothoracic inclination angles or the sternopelvic kinematics **[**Fig. 3 A, B and D**]**.

4. DISCUSSION

The objective of this observational study was to determine the influence of immediate nociceptive pain-relief on the relative angular contributions of the shoulder girdle and trunk to the maximal angular performance of a semi-constrained reaching task by patients with persistent shoulder pain. Assuming that participants' current state of movement behaviour was affected by pain, we figured that their movement behaviour would change after pain relief, presumably to their pre-pain state. Contrary to what we anticipated, our results did not show that immediate pain relief was associated with significant alterations in maximum thoracohumeral, scapulothoracic and humeroscapular and trunk inclination angles when reaching for an overhead target. However, during the initial phase of arm elevation, there was a small but statistically significant different decrease in humeroscapular

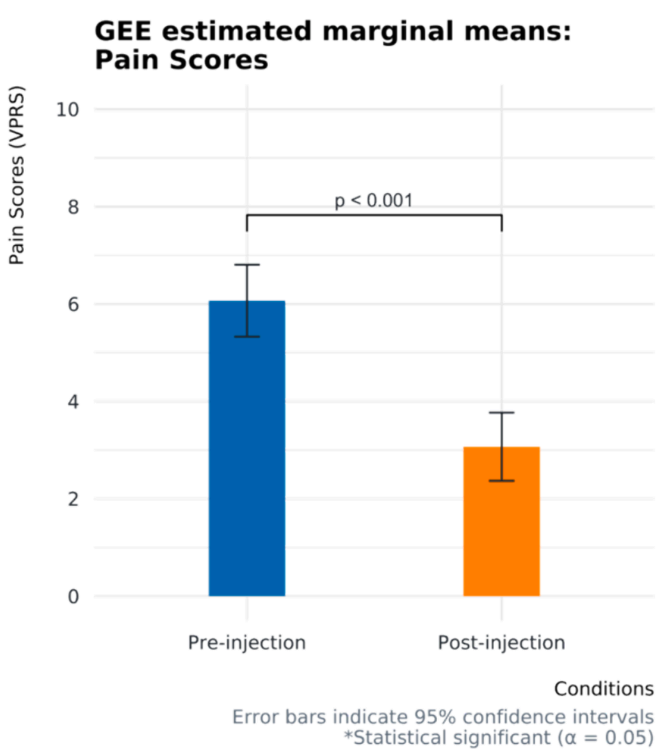

Fig. 2. Mean maximal pain intensity (VPRS-11) per condition.

Table 1
Means and standard deviations for the degree of perceived threat of worsening existing tissue damage and increase in pain from performing the task.

(VNRS-11)	Pre-injection		Post-injection	
	Mean	(SD)	Mean	(SD)
Threat of worsening of existing tissue damage from performing the task	0.8	(2.0)	0.3	(1.5)
Threat of increase in pain from performing the task	1.9	(2.9)	0.9	(1.7)

VNRS-11 = Verbal Numeric Rating Scale-11, 0 = no threat, 10 = highest threat imaginable.

Table 2
SnPM means and bootstrapped 95% CI maximum shoulder girdle and trunk inclination angles (degrees), per condition.

Helical angle		Pre-injection		Post-injection	
		Mean	95 %CI	Mean	95 %CI
Shoulder	Thoracohumeral	163	[157, 168]	161	[156, 168]
	Scapulothoracic	102	[93, 110]	99	[91, 108]
	Humeroscapular	123	[113, 134]	121	[111, 131]
Trunk	Sternopelvic	29	[25, 34]	29	[24, 33]

inclination angles in the post-injection condition.

A possible explanation for the lack of significant alterations in maximum inclination angles after injection is the presence of residual pain. Pain had not been completely subsided in any participant after the injection, except for one. This suggests that other pain mechanisms were involved in most participants, which were not affected by the injected lidocaine, such as nociception of other damaged shoulder tissue, or central sensitization of pain, but may be responsible for the persistence of movement behavior.

Another possibility is that the immediate reduction of long-term pain is a weaker incentive to make immediate rigorous changes in movement behavior, as opposed to the induction of acute pain due to tissue injury (Hodges and Smeets, 2015). The brain processes and integrates nociceptive signals with other sensory and environmental inputs, as well as previous experiences, to evaluate the potential consequences of possible actions and to determine whether the physical integrity of the musculoskeletal system is further threatened. In our study, participants did not perceive the performance of the task or the pain increase experienced during the task as threatening. Furthermore, regardless of their performance during the task, participants were able to reach the overhead target despite experiencing pain beforehand. Therefore, significantly altering trunk and shoulder contributions following pain reduction may not have been a priority during the task, as it does not provide them with a direct benefit. This could also explain why some studies found that individuals with chronic pain continued to exhibit altered movement behavior in the long-term after pain relief (A. et al., 1996; Hodges and Richardson, 1996; MacDonald et al., 2009).

The SnPM analysis uncovered a minor but statistically significant decline in humeroscapular inclination angles in the initial phase of arm elevation after the injection, indicating a relative slower arm elevation. Interestingly, the injection seemed to have a consistent impact on shoulder movements, as a similar alteration, although not statistically significant, was observed in scapulohumeral and thoracohumeral movements, but not in the trunk. This phenomenon could indicate a careful exploration of the altered sensory state in the shoulder following the injection. The nervous system requires time to fully acknowledge and integrate the absence of pain caused by the injection, (Flor, 2003; Woolf, 2011)(Flor, 2003; Woolf, 2011) leading to gradual adjustment of movements to accommodate changes in sensory feedback (Shadmehr et al., 2010).

Few aspects of this study need further consideration. First, we used

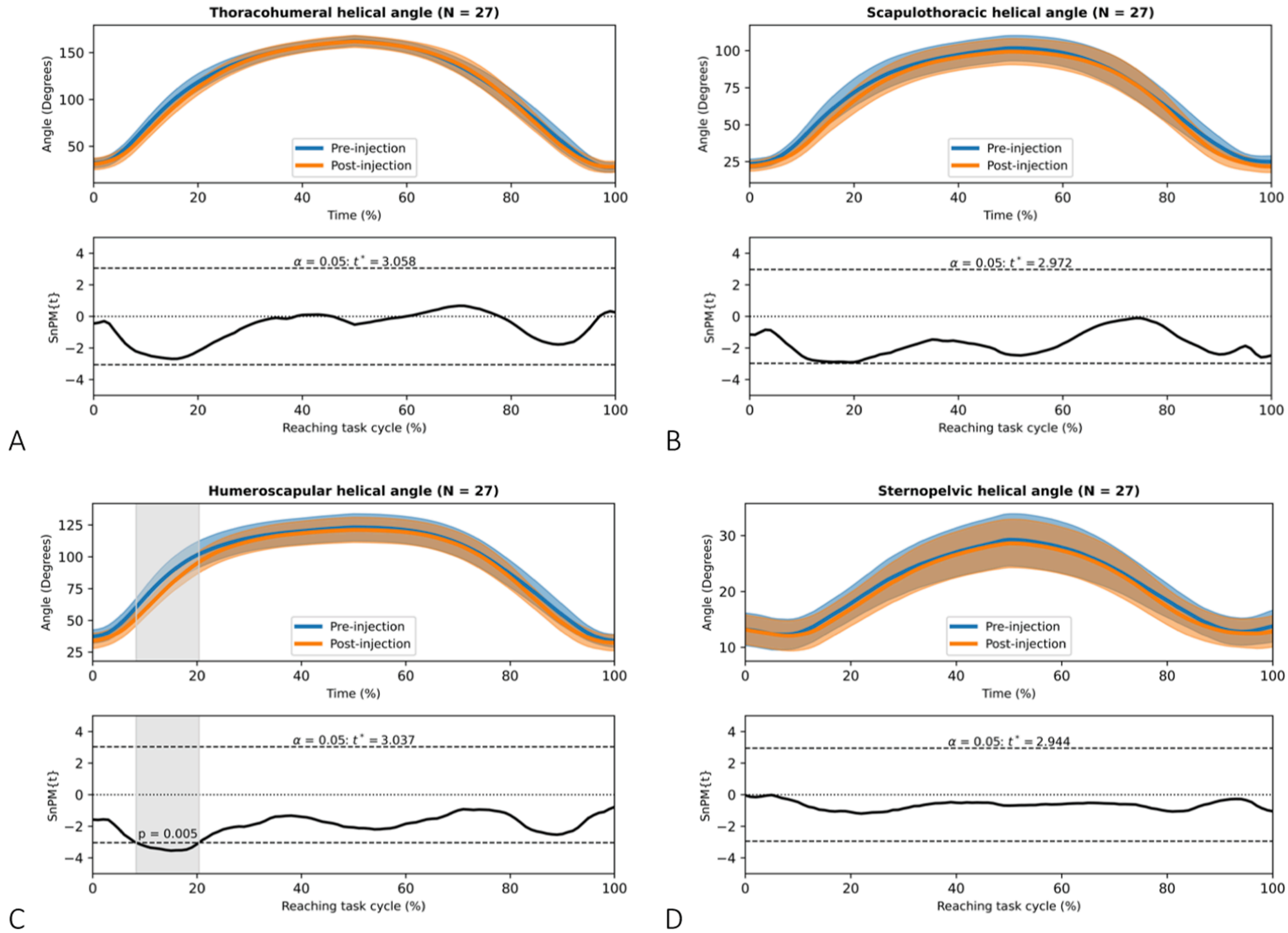

Fig. 3. Statistical non-Parametric Mapping (SnMP) results of shoulder and trunk kinematics (degrees) of the reach task within the normalized time domain (%). Mean (solid line) and 95% confidence intervals (shaded band) of pre-injection in blue and post-injection in orange are presented for A) 1-dimensional thoracohumeral inclination angles, B) 1-dimensional scapulothoracic inclination angles, C) 1-dimensional humeroscapular inclination angles, and D) 1-dimensional sternopelvic inclination angles. Shaded grey areas indicate significant differences. The Solid black line represents the t statistic continuum. The striped black lines represent the critical thresholds of the SnPM {t}.

helical angles to express the angular inclination contribution of the involved segments to the reach task, instead of Euler decompositions. As the procedure of deriving helical angles using IMU's does not require an extensive calibration process, data collection is less time-consuming and more efficient. However, helical angles are complementary angles and do not provide as detailed three-dimensional information as Euler decompositions. This limited our ability to identify possible clinically relevant inter- and intra-individual differences in the three-dimensional course of the movement trajectories, as was done in some previous studies (Ettinger et al., 2017; Kolk et al., 2016). Nevertheless, our focus was on exploring differences between pre- and post-injection conditions, rather than establishing clinically relevant angles. Furthermore, the exploratory and observational nature of this trial necessitates minimal patient burden and interference with the orthopedic surgeon's actions. This makes the use of helical angles suitable for our study purpose and compatible with the study design. (Lin et al., 2011; Ludewig and Reynolds, 2009; Lukasiewicz et al., 1999; McClure et al., 2006).

Finally, previous research has shown that positive expectations can significantly contribute to placebo analgesia (Nakamura et al., 2012; Pascalis et al., 2002). To determine whether this effect may be present in our study, we used a VNRS-11 to measure the patient's expected pain reduction prior to the injectiontherapy. Although not formally validated, this measurement method appears to be face valid. For example, the Credibility/Expectancy questionnaire uses items with a 9-point numerical rating scale to measure patients' expectations of symptom improvement (Devilly and Borkovec, 2000). In our study, the participants' expectations regarding the expected pain-reducing effect of the injection were 7.1 out of 11 (0 = no pain-reducing effect expected, 10 = maximal pain-reducing effect expected), indicating that a placebo-effect might be involved. The analgesic effect attributable solely to nociceptor blockade by the administered infiltrate may therefore be overestimated.

In summary, regardless the analgesic mechanism, this observational study shows that acute pain relief following local anaesthetics is not associated with immediate alterations of maximal shoulder and trunk inclination angles when reaching for an overhead target in patients with ongoing shoulder pain. These findings suggest that nociceptive pain, although present in patients with persistent shoulder pain, has little influence on the organisation of inclination contributions of the shoulder and trunk when performing a feasible overhead reaching task. Further research is needed to fully understand the mechanisms underlying these effects and to identify the most effective interventions for different types of shoulder pain and individuals.

CRediT authorship contribution statement

N.E. D'hondt: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **A.J.R. Leenen:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **H. Kiers:** Writing – review & editing. **M.J.M. Hoozemans:** Writing – review & editing, Supervision, Methodology. **T.D. Alta:** Writing – review & editing, Writing – original draft, Resources, Investigation. **M.P.J. van den Bekerom:** Writing – review & editing, Writing – original draft, Resources, Investigation. **M.P.J. van de Borne:** Writing – review & editing, Writing – original draft, Resources, Investigation. **M.P.J. van der List:** Writing – review & editing, Writing – original draft, Resources, Investigation. **H.E.J. Veeger:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Declaration of competing interest

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

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Statement of Institutional Review Board or Ethics Committee approval of the study protocol

This study was approved by the Scientific Ethical Review Board (VCWE) of the Vrije Universiteit Amsterdam (VCWE-2020-131) the Netherlands, and by the local medical ethics advisory boards of 1) Amphia Ziekenhuis, Breda/Oosterhout; 2) OLVG Amsterdam, 3) Spaarne Gasthuis, Haarlem; and 4) Bergman Clinics, Naarden, the Netherlands.

Financial Disclosure and Conflict of Interest

We affirm that we have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as disclosed and cited in the manuscript. Any other conflict of interest (i.e., personal associations or involvement as a director, officer, or expert witness) is also disclosed and cited in the manuscript.

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