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Light touch contact improves pain-evoked postural instability during quiet standing

Rogerio P. Hirata[*1], Steffan W. Christensen[1], Simone Agger[2], Mikkel Svindt[2], Nicklas Røssner[2], Jesper Abildgaard[2], Nicolas Vuillerme[3], Thomas Graven-Nielsen[4]

[1] SMI, Department of Health Science and Technology, Aalborg University, Aalborg, Denmark.

[2] Department of Health Science and Technology, Aalborg University, Aalborg, Denmark.

[3] Univ. Grenoble Alpes, AGEIS, La Tronche, France & Institut Universitaire de France

[4] Center for Neuroplasticity and Pain (CNAP), SMI, Department of Health Science and Technology, Aalborg University, Aalborg, Denmark.

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*** Corresponding author:**

Associate Professor Rogerio Pessoto Hirata, Ph.D.
Center for Sensory Motor Interaction (SMI), Department of Health Science and Technology,
Aalborg University,
9220 Aalborg E, Denmark
Phone: +45 9940 9838
Fax: +45 9815 4008
E-mail: rirata@hst.aau.dk

Abstract

Objective: To investigate if attention to additional sensory information from the fingertip can improve postural stability during pain, which is known to impair balance.

Methods: In sixteen healthy volunteers, experimental pain was induced by intramuscular injection of hypertonic saline in the right vastus medialis muscle (isotonic saline used as non-painful control, intramuscular injection in the same location). Pain intensity was assessed on an 11-point numeric rating scale (NRS, 0 representing "no pain" and 10 "maximum pain"). Subjects were asked to stand as still as possible on a force plate for 40s with eyes closed. Their postural stability was quantified by the area and velocity of center of pressure (CoP) displacement. The CoP was recorded with and without pain, during 2 different conditions: (i) no touch, and (ii) while the subjects were asked to lightly touched a curtain with their right index finger and focus their attention on keeping it as still as possible.

Results: Hypertonic injections induced higher NRS scores compared with control injections ($P<0.05$). During the hypertonic injection condition, the CoP area and velocity in both directions, increased during no touch compared with the light touch condition ($P<0.05$). No differences were found during light touch between hypertonic and isotonic injection conditions. Although experimental knee-related pain impaired postural stability, lightly touching a curtain with the fingertip decreased postural sway during painful conditions.

Conclusion: Providing additional sensory information while pain patients are performing balance exercises may improve postural stability, and increase the quality of exercise, consequent rehabilitation protocols and clinical outcomes.

Key words: knee pain, attention, balance, falls, light touch

1. Introduction

Pain impairs postural stability in young individuals (1-3). Previously it has been proposed that pain disrupts proprioceptive information from the affected area (4) which may impair postural stability (5).

The control of bipedal posture demands cognitive process specially of sensory information presented (6). In order to generate accurate muscular responses while standing, the central nervous system utilizes cognitive resources to process relevant sensory information (vestibular, visual, and proprioceptive), to estimate the body position over time and generate appropriate muscle contractions for balance stability (7). The amount of cognitive resources for which balance control and all other stimuli and tasks competes is limited (8) which poses a special challenge for chronic pain patients which often present some degree of cognitive impairment (9). When competition for cognitive resources take place during balance tasks, young individuals prioritize body stability over performance of secondary tasks (10-12). However it is unknown if presence of pain will affect the integration processing of the sensory input used to control body stability.

Additional sensory information applied to the side of the head, neck, side of the trunk and fingertips plays an important role on balance stability (13). When a relevant supplementary sensory information is presented, healthy subjects decreases body sway while standing quietly probably by directing the subjects' attention to the effects of their movements (14). Similar reduction in body sway was also observed in individuals with balance problems such as Parkinson's disease (15), peripheral neuropathy (16), vestibular loss (17) and lesion on the anterior cruciate ligament (18) [(for a review, please refer to (19)]. Furthermore, the increased body sway during quiet standing caused by deprivation of visual information and lower limb

muscular fatigue is mitigated if subjects are asked to keep the fingertip as still as possible while lightly touching an external object (20). In that situation, the touch per se does not provide mechanical support for balance enhancement, although the supplementary haptic information seems to be useful for balance control enhancement (21). Additionally, lightly touching a surface provoked changes in the primary somatosensory cortex, mainly characterized by a complex modulation of the somatosensory evoked potentials after electrical stimulation of the median nerve (22). However, it is still an open question if young subjects suffering with pain are also able to use light touch information to reduce body sway. Indeed, health young subjects without lightly touching a surface and under experimental painful conditions showed larger body sway and delayed muscle activation onset during pain compared with pain free conditions (23-28).

The aim of the present study was to investigate how extra haptic information and pain affects quiet standing balance in young healthy individuals. It was hypothesized that conditions where supplementary haptic information is presented simultaneously with a painful stimulus will reduce body sway during quiet standing compared with control conditions.

2. Methods

2.1 Subjects

Eighteen healthy male subjects participated in this study. The inclusion criteria was healthy men and women in the age between 18-50 years. Exclusion criteria were neurological, musculoskeletal or mental illnesses along with a history of previous or ongoing painful conditions and currently use of medications such as analgesics and anti-inflammatory drugs. The sample size was based on a previous study (25) to detect at least 20% difference in body sway parameters between pain and control conditions (type I error at 5% and power of 80%). A

convenience sample of subjects was recruited at the university campus. Each subject was given a detailed verbal explanation of the experiment and signed an informed consent statement. The study was conducted in accordance with the Helsinki Declaration and was approved by the local Ethics Committee (N- 20120077).

2.2 Experimental pain

In a comfortable seated position subjects were given an intramuscular injection of hypertonic saline (1 mL, 5.8 %) into the right vastus medialis muscle, 5 cm proximal and 5 cm medial to the medial corner of the patella, while isotonic saline (1 mL, 0.9 %) was used a control injection (25). This model was chosen based on previous findings of larger effects on postural stability (larger body sway) when injections into the vastus medialis muscle and biceps femoris muscle were compared (25). Ultrasound imaging (Logiq S7 Expert with a ML6-15L transducer, GE Health Care) was used to determine the depth and location of the injection site. Immediately after the injections, subjects were asked if they were ready for the task and following a positive answer, they assumed the testing position. The time interval between injections was approximately 30 minutes.

A numeric rating scale (NRS) with 11 points was used to assess pain intensity ranging from “no pain” (0) to “max pain imaginable” (10). NRS scores were collected before and after every trial when the CoP was measured and the average NRS score was used for further analysis. Subjects had to be pain free (defined as NRS = 0) for at least 10 minutes prior the next trial started.

2.3 Experimental design

All conditions and injections order were randomized (nine subjects received first the isotonic injection). Participants were blinded to the type of injection received. The experiment included nine trials completed in a single session. The test trials consisted of one familiarization trial and four experimental trials (performed for both types of injection): (i) prior to injection (baseline) for each no touch and light touch conditions, (ii) immediately after the injection (painful or control saline) for each no touch and light touch conditions. In total, the experiment lasted approximately one hour.

2.4 No touch and Light touch conditions

In all trials, subjects were asked to stand as still as possible on a force platform (Plux Biosignals S.A, Arruda dos Vinhos, Portugal) with eyes closed for 40 s while blindfolded during two conditions assigned randomly across all trials (i) no touch, and (ii) light touch on a curtain with their right index finger and keeping it as still as possible (29). Subjects performed the task blindfolded since a previous study have shown the contribution of visual information for controlling posture positively correlated to level of pain in patients with chronic knee pain (30).

Between the two experimental conditions, subjects were asked to remove the blindfold and sit down for approx. 30 seconds. Foot position was marked with tape for consistency during recordings. The midline on the force platform was used to assure that feet were placed together, one in each half of the force platform. The elbow on the dominant side was flexed at 90 degrees and the forearm held parallel to the horizontal plane during all trials and conditions. The palm of the hand was positioned in a vertical position in relation to the floor with a straight wrist while the other arm was positioned naturally along the body (during both light touch and no touch conditions).

During the light touch condition, a curtain (0.282 kg, 200 * 220 cm) was hanging (only supported at the top and not touching the floor) in front of the subject, in a distance where the index finger of the dominant hand lightly touched the sheet and from this point it was moved an extra 8 cm towards the subject. The subjects were asked to keep the curtain as still as possible during the light touch condition. One assessor was placed on each side of the subject to provide reassurance and to prevent any risk of participants losing their balance. During the no touching condition, the subject was instructed to stand on the platform without touching the curtain.

2.5 Postural stability measurements

Ground reaction forces were recorded and extracted for the 40 seconds during each condition on the force platform and sampled at 1 kHz (Opensignals v. 1.2.8). The reaction force signals were filtered (Butterworth, 2nd order with zero lag and low pass frequency of 15Hz). After filtering, 5 seconds were removed both from the start and from the end of the measurement for each condition to eliminate artifacts due to filtering process. Furthermore, the center of pressure (CoP) position was estimated from the filtered data and the CoP sway area and velocity (both medial-lateral and anterior-posterior direction) were extracted via principal component analysis and 95% confidence interval for ellipse calculation (31).

2.6 Statistical analysis

Normality of the distribution was tested by Q-Q plots for all variables and non-parametric tests were used in case normality was not present. The NRS scores following saline injections were analyzed with the non-parametric Friedman analysis of variance (ANOVA) and Wilcoxon matched pair test corrected with Bonferroni was used as post-hoc. The CoP area and velocity of

both medial-lateral and anterior-posterior direction were analysed via a parametric 3-way repeated measurement ANOVA with time (baseline and injection), saline (hypertonic and isotonic) and condition (no touch and light touch) as main factors.

It was assessed: (i) if supplementary haptic (light touch) information improved CoP compared with no touch conditions; (ii) if hypertonic (painful) and isotonic (non-painful) injection affected CoP area compared with baseline (prior injection) conditions; and (iii) if supplementary haptic information improved CoP parameters during pain compared with no touch conditions.

In case of significant factors or interactions in the main ANOVA, a post-hoc test with multiple comparisons correction (Bonferroni) was applied. Significance was set at P-values less than 0.05. All results are presented as mean ± standard error of the mean (SEM).

3. **Results**

3.1 Subjects and experimental pain intensity

Eighteen healthy male subjects were included in the analysis (mean ± SEM: age 23.8±0.7 years, height 182.4±2.2 cm and weight 76.2 ± 2.5 kg). The NRS scores elicited by the hypertonic saline injection during both conditions were significantly higher than both isotonic saline conditions (isotonic injection and no touch condition: 0.81 ± 0.27, isotonic injection and light touch condition: 0.42± 0.16, hypertonic injection and no touch condition: 3.92± 0.37, hypertonic injection and light touch condition: 4.00 ± 0.43; Friedman: Chi Sqr(3) = 38.1, $P < 0.001$, Wilcoxon: $P < 0.05$).

3.2 Effect of light touch on postural stability

In Table 1, the complete results of the ANOVA are presented for all CoP variables. The ANOVA of the CoP area and velocity in both directions demonstrated a significant effect on the main factor *condition* (no touch vs light touch) with decreased values during the light touch compared with no touch conditions (ANOVA: $F(1,17) > 13.5$, $P < 0.002$, Bonferroni all $P < 0.05$, Fig 1). Additionally, the interaction between time, saline and condition indicated that, during baseline the CoP area (ANOVA: $F(1, 17) = 9.7$, $P = 0.006$, Fig 2) and velocity in the anterior-posterior direction (ANOVA: $F(1, 17) = 4.6$, $P = 0.04$, Fig 2) during light touch condition was smaller prior to isotonic saline injection compared with no touch condition (area: Bonferroni: $P = 0.001$; velocity anterior-posterior: Bonferroni: $P < 0.001$). For the velocity in the medial-lateral direction, the interaction between time, saline and condition (ANOVA: $F(1, 17) = 5.3$, $P = 0.03$, Fig 2) indicated significant reduction prior both isotonic and hypertonic saline injection during light touch condition compared with no touch condition (prior isotonic: Bonferroni: $P < 0.001$; prior hypertonic: Bonferroni: $P = 0.03$).

3.3 Effect of pain on postural stability

The factor *saline* indicated that CoP velocity in the anterior-posterior direction was higher during hypertonic saline conditions (1.20 ± 0.43 cm/s) compared with isotonic saline condition (1.10 ± 0.31 cm/s, ANOVA: $F(1,17) = 5.8$, $P = 0.03$). The ANOVA for the CoP area showed significant interaction between *time, saline and condition* (ANOVA: $F(1, 17) = 9.7$, $P = 0.006$, Fig 2). Comparing the no touch conditions within the factor *time* (baseline vs injection), the CoP area increased during hypertonic saline (painful) condition compared with its respective baseline (prior hypertonic saline and no touch) condition (Bonferroni: $P = 0.03$, Fig 2). For the no touch condition, the CoP velocity in both directions were significantly higher during hypertonic saline

condition compared with isotonic condition (interaction between *time, saline and condition*; medial-lateral direction: ANOVA: F(1,17) = 5.4, P = 0.03, Bonferroni: P = 0.009; anterior-posterior direction: ANOVA: F(1, 17) = 4.6, P = 0.04, Bonferroni: P = 0.008)..

3.4 Effect of light touch condition during painful conditions

The ANOVA for CoP area demonstrated significant interaction between time, saline and condition (ANOVA: F(1, 17) = 9.7, P = 0.006). During hypertonic injections (painful), the CoP area decreased during the light touch condition compared with the no touch condition (Bonferroni: P = 0.004, Fig 2). The ANOVA for CoP velocity in the medial-lateral direction demonstrated significant interaction between time, saline and condition (ANOVA: F(1, 17) = 5.4, P = 0.03). During hypertonic injections, the CoP velocity in the medial-lateral direction decreased during the light touch condition compared with the no touch condition (Bonferroni: P = 0.01, Fig 2). For the velocity in the anterior-posterior direction, a significant interaction between time, saline and condition (ANOVA: F(1, 17) = 4.6, P = 0.04) indicated that during hypertonic injections, the CoP velocity in the anterior-posterior direction decreased during the light touch condition compared with the no touch condition (Bonferroni: P = 0.04, Fig 2).

4. Discussion

The present study is the first to investigate whether postural impairments, due to experimental muscle pain, can be minimized by providing additional haptic sensory information from the fingertip. Although pain impaired balance performance, lightly touching a curtain allowed the subjects to improve their postural sway during pain.

4.1 Baseline differences and effect of light touch during pain-free conditions

Comparing baseline values during the no touch condition, subjects showed significantly smaller CoP area prior to hypertonic saline compared with the condition prior to isotonic saline. This difference in baseline measurements might be related to the natural variability of postural control in humans (32), since CoP measurements using force plates during postural tasks are considered to be reliable (33). Aiming to minimize the effect of such variability, a baseline condition was always performed prior to each injection condition for statistical comparisons. As demonstrated previously (21, 34-41), the light touch condition improved balance performance (smaller CoP area and lower velocity in both directions) in pain-free conditions. This indicates that healthy subjects, while having eyes closed, are able to efficiently use the additional haptic information to improve balance stability (42).

4.2 Effects of experimental pain on postural stability

The hypertonic saline injection induced significantly higher pain intensity, during both no touch and light touch conditions, when compared with the isotonic saline injection. In line with previous studies (24, 26, 27), our results showed that experimental pain close to the knee joint impaired balance, as evidenced by increased: (i) CoP area during pain compared with baseline conditions and (ii) CoP velocity in both medial-lateral and anterior-posterior direction during the pain without touch compared with the isotonic injection condition without touch. A possible explanation is that experimental pain impairs sensory-motor interaction mechanisms, altering the motor output of relevant postural muscles (43), and therefore impairs balance control during quiet standing. For example, Matre et al. (4) showed that experimental pain, applied to the

tibialis anterior and soleus muscles, impaired proprioception at the ankle joint (measured by repositioning tasks) in healthy individuals. Furthermore, simultaneous painful stimulation of both the tibialis anterior and medial gastrocnemius muscles, lead to failure of the motor system in maintaining the muscular strategy similar to conditions without pain, therefore impairing balance stability (23).

4.3 Effects of light touch on balance impairments due to experimental pain

When the subjects were asked to lightly touch the curtain and focus their attention on keeping it as still as possible, the balance impairments due to pain were significantly reduced by improvements in the CoP area and velocity in both directions. If experimental lower limb pain impairs sensory-motor mechanisms (24, 27), balance improvements observed during light touch trials suggest that young healthy adults are able to efficiently use extra haptic information to improve their bipedal stability (42) and to mitigate the sensory-motor impairments due to pain (44). This seems to show a remarkable capacity of the postural control system to dynamically reweight the contribution of all available sensory information in order to preserve and/or optimize balance control (45) even in presence of experimental pain, which is known to impair balance stability and proprioceptive information from nearby joints (4). However, reorganizing the different sensory inputs to optimize balance is a costly cognitive process for the central nervous system (6), even for healthy individuals (42, 46-48). Such cognitive cost has additionally been reported to increase when postural control is compromised by individual factors, e.g. injuries (49), fatigue (50) and aging (51). This costly process suggests that a significant amount of cognitive resources must be allocated to maintain postural stability when sensory inputs are reorganized and balance stability is jeopardized. Even though the present study did not measure

any cortical activation during the task, there is strong evidence that, in pain free states, the addition of supplementary haptic information significantly alters the activation pattern of the somatosensory cortex during similar balance tasks (22). This reorganization has previously been related to activation of the prefrontal cortex (52, 53), which is mainly responsible for controlling cognitive process of attention (54). It is not clear if similar cortical reorganization might also be achieved during conditions with pain and light touch in the present study neither to which extent the subjects directed their attention to the curtain movement (14). However, the improvement of balance control observed when additional haptic information was provided suggests that higher centers might have, to a certain degree, re-weighted the sensory information inputs (such as nociception and haptic) to enhance balance stability (42). This is in line with previous studies showing that young individuals prioritize balance stability during conditions of postural threat (55), such as during pain. Indeed, the cognitive processing of pain (56, 57) competes for the limited attentional resources, impairing performance in motor tasks (57). Therefore, a complementary explanation for the balance impairments during experimental pain in the present study, is that the cognitive processing of the experimental pain also acted as a distraction, disrupting the attention of the subject from the current task (quiet standing) and therefore increasing postural sway (57). However, during the pain with touch task, the cognitive processing of pain (58) would have to compete with the processing of supplementary haptic information (while attempting to keep the curtain as still as possible) potentially lessening its overall impact on balance (22, 50, 59).

Altogether, it is suggested that healthy young individuals, under the effect of experimental pain, were able to utilize additional haptic information to reorganize their balance and improve their postural stability during bipedal posture. Future studies are needed to clarify the extent to which

the presence of pain affects cognitive load and thereby the integration of the sensory input from the fingers.

5. Conclusion

This is the first evidence that balance impairments, due to experimental pain, in an otherwise young healthy system, can be significantly decreased by providing extra haptic information from the index finger. The results of this study reinforce the possibility of improving postural stability in pain patients by including instructions to maintain the fingertip lightly touching an external surface during balance rehabilitation routines.

Conflict of interest statement: The authors declare that there is no conflict of interest in regards to this study.

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Figure Legends

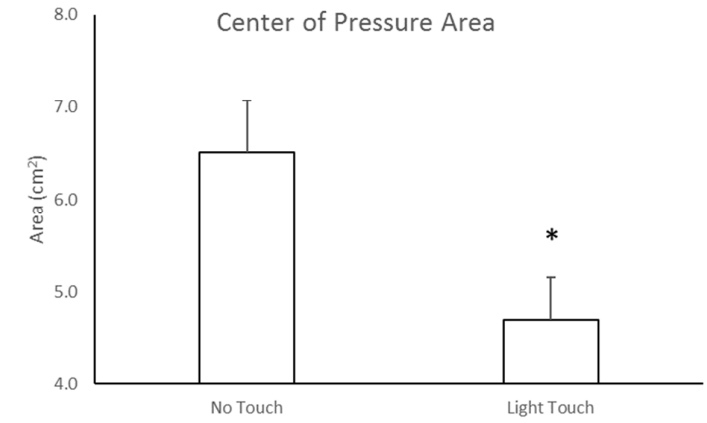
Figure 1. Mean (± SEM, N = 18) center of pressure (CoP) area (A) and velocity in both medial-lateral (B) and anterior-posterior (C) directions during both no touch and light touch conditions. Decreased CoP parameters during light touch condition compared no touch condition (*, Bonferroni: $P < 0.05$). The data is pooled between *saline and time* factors to show the difference within the factor *condition* (Bonferroni: all $P < 0.002$).

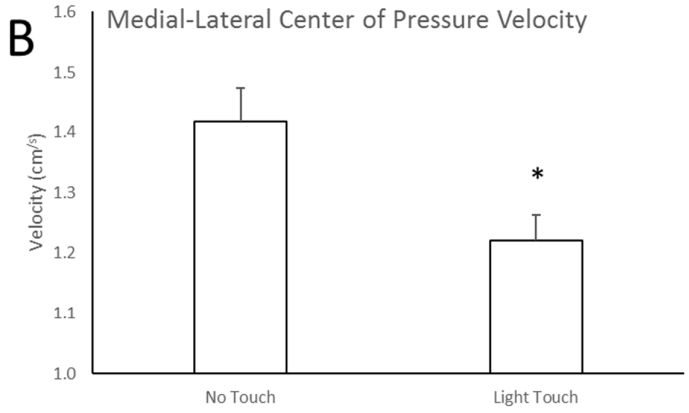
Figure 2. Mean (± SEM, N = 18) center of pressure (CoP) area and velocity and both medial-lateral and anterior-posterior directions during both no touch and light touch conditions following isotonic (non-painful) and hypertonic (painful) saline injections. The CoP areaincreased during hypertonic saline injection and no touch condition compared with baseline and no touch condition (#, Bonferroni: P = 0.003). The CoP velocity in both direction increased duringhypertonic injection and no touch condition compared with isotonic injection and no touch condition (*, Bonferroni: both $P < 0.009$). The CoP area decreased during baseline and hypertonic injection condition compared with baseline and isotonic injection condition (§, Bonferroni: P = 0.04). Additionally, when comparing no tough with light touch conditions, CoP area and velocity in both directions decreased during the light touch condition during baseline prior isotonic injection (¤, Bonferroni: all $P < 0.001$). The CoP velocity in the medial-lateral direction prior hypertonic injection conditions decreased during light touch condition compared with no touch condition (£, Bonferroni: $P < 0.03$). The CoP area and velocity in both direction decreased during the light touch condition and hypertonic saline injection compared with the condition with no touch and hypertonic injection, (¥, Bonferroni: all $P < 0.04$).

Authorship

All authors have 1) substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; 2) drafting the article or revising it critically for important intellectual content; 3) final approval of the version to be published.

FIGURE 1


Center of Pressure Area
Area (cm²)
8.0
7.0
6.0
5.0
4.0
*
No Touch
Light Touch


B
Medial-Lateral Center of Pressure Velocity
Velocity (cm/s)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
*
No Touch
Light Touch

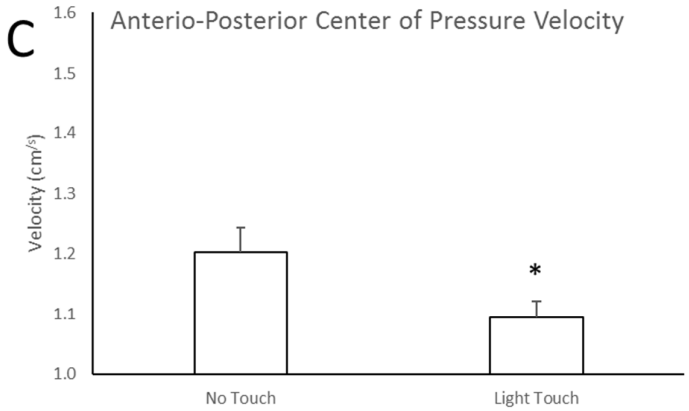

C
Anterio-Posterior Center of Pressure Velocity
Velocity (cm/s)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
*
No Touch
Light Touch

FIGURE 2

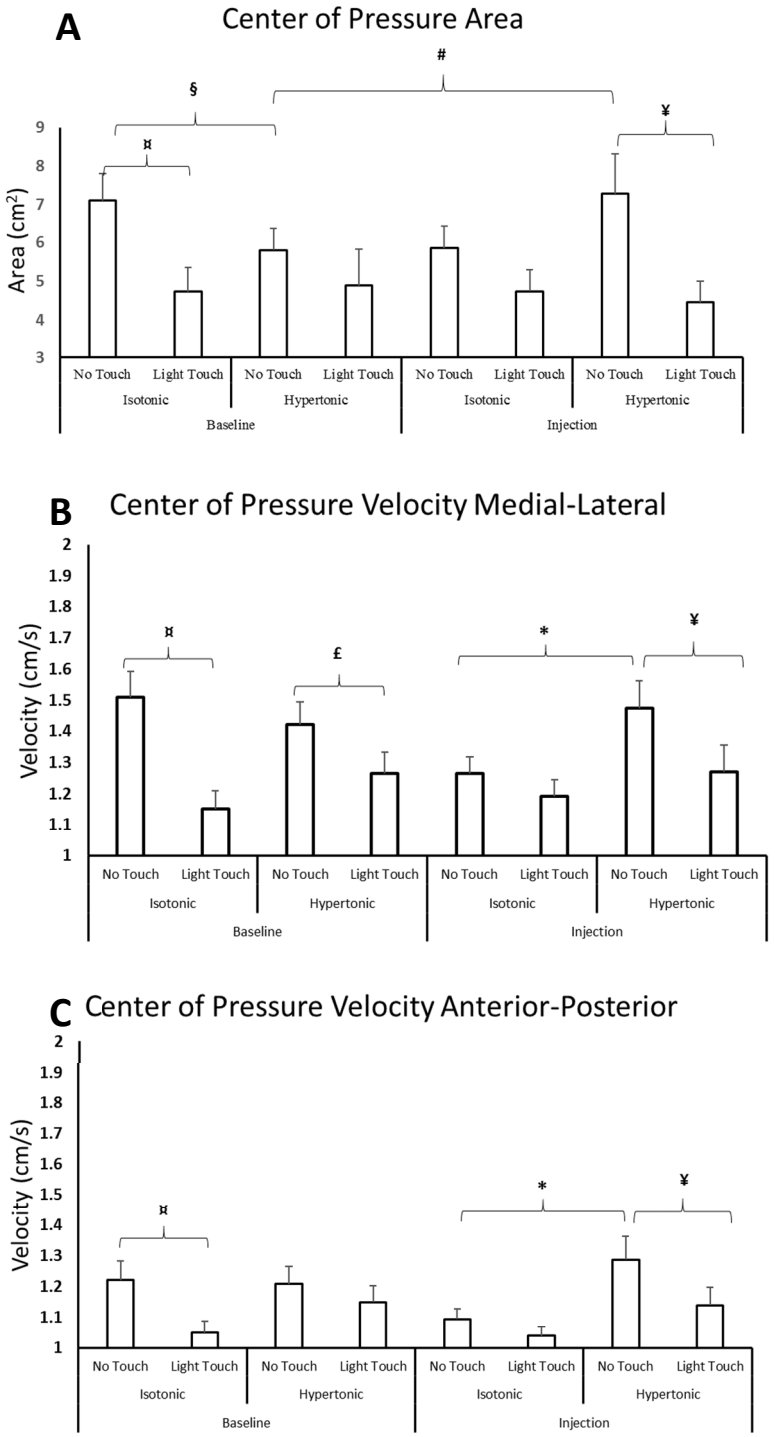

A
Center of Pressure Area
Area (cm²)
9
8
7
6
5
4
3
¤
§
#
¥
No Touch
Light Touch
Isotonic
Hypertonic
Baseline
Injection
B
Center of Pressure Velocity Medial-Lateral
Velocity (cm/s)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
¤
£
*
¥
C
Center of Pressure Velocity Anterior-Posterior
Velocity (cm/s)

Table 1: Summary of the 3-way Repeated Measurement ANOVA results for the Center of Pressure (CoP) variables (n = 18).

	P-Values for factors and interactions						
Center of Pressure variables	time	saline	condition	time*saline	time*condition	saline*condition	time*saline*condition
Area	0.9	0.99	**0.002**	0.16	0.60	0.88	**0.006**
Velocity Medial-Lateral	0.42	0.13	**<0.001**	0.08	0.06	0.37	**0.03**
Velocity Anterior-Posterior	0.65	**0.03**	**<0.001**	0.85	0.79	0.77	**0.04**

P-values for the 3-way Repeated Measurement ANOVA for the center of pressure (CoP) variables area and velocity in both directions (medial-lateral and anterior-posterior). Significant p-values (< 0.05) are highlighted in **bold** for all factors *time*, *saline*, condition, and respective interactions.