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The effects of pain and a secondary task on postural sway during standing

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ABSTRACT

Background: Pain impairs available cognitive resources and somatosensory information, but its effects on postural control during standing are inconclusive. The aim of this study was to investigate whether postural sway is affected by the presence of pain and a secondary task during standing.
Methods: Sixteen healthy subjects stood as quiet as possible at a tandem stance for 30s on a force platform at different conditions regarding the presence of pain and a secondary task. Subjects received painful stimulations on the right upper arm or lower leg according to a relative pain threshold [pain 7 out 10 on a Visual Analog Scale (VAS) - 0 representing "no pain" and 10 "worst pain imaginable"] using a computer pressurized cuff. The secondary task consisted of pointing to a target using a head-mounted laser-pointer as visual feedback. Center of Pressure (COP) sway area, velocity, mean frequency and sample entropy were calculated from force platform measures.
Findings: Compared to no painful condition, pain intensity (leg: VAS = 7; arm VAS = 7.4) increased following cuff pressure conditions ($P < .01$). Pain at the leg decreased COP area ($P < .05$), increased COP velocity ($P < .05$), mean frequency ($P < .05$) and sample entropy ($P < .05$) compared with baseline condition regardless the completion of the secondary task. During condition with pain at the leg, completion of the secondary task reduced COP velocity ($P < .001$) compared with condition without secondary task.
Interpretation: Pain in the arm did not affect postural sway. Rather, postural adaptations seem dependent on the location of pain as pain in the lower leg affected postural sway. The completion of a secondary task affected postural sway measurements and reduced the effect of leg pain on postural sway. Future treatment interventions could benefit from dual-task paradigm during balance training aiming to improve postural control in patients suffering from chronic pain.

1. Introduction

Maintenance of posture relies on accurate sensory information (Winter, 1995). It has been suggested that pain impairs

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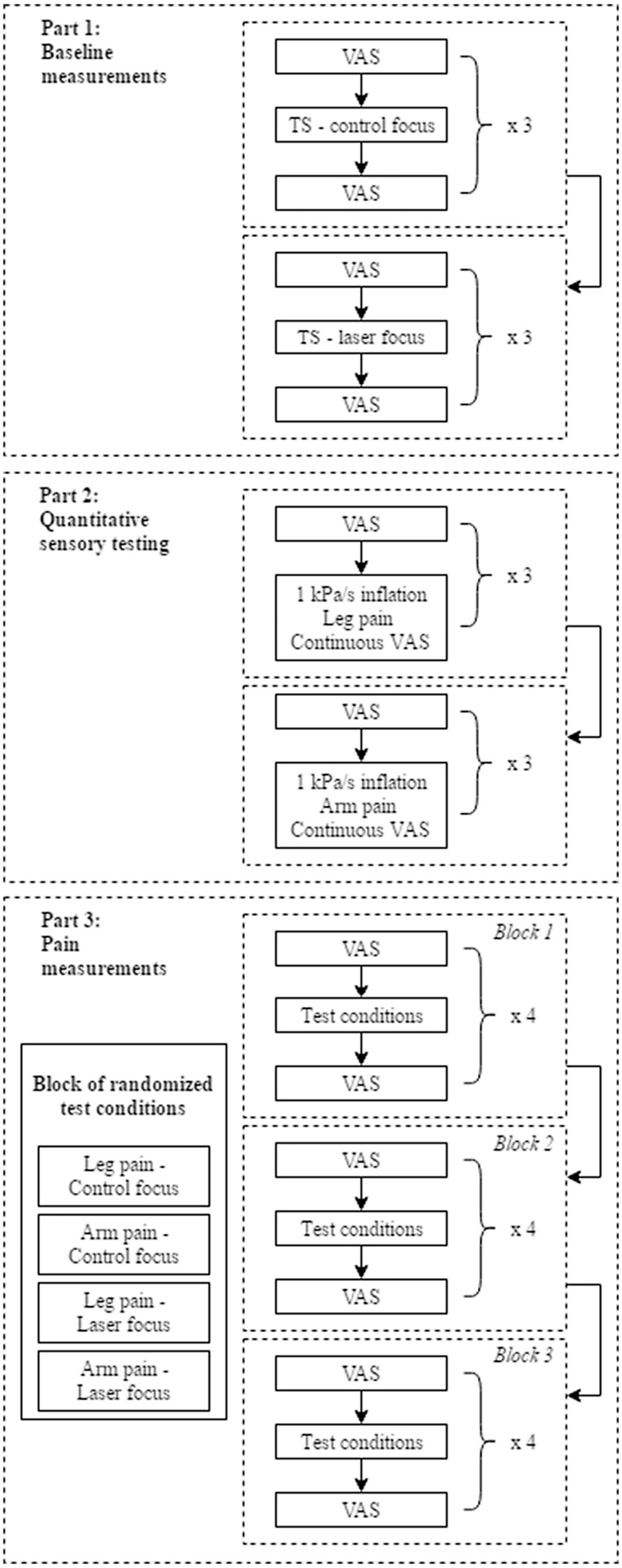


(caption on next page)

Fig. 1. Subjects first performed baseline postural sway measurements without any experimental pain during tandem stance (TS). Subsequently, pressure that elicited pain corresponding to an intensity of 7 cm on a visual analogue scale (VAS) was assessed using cuff algometry. This pressure was used to inflict experimental pain on either the arm or leg in a standard (control focus) and during the completion of a secondary task (laser focus) condition.

proprioceptive information from the affected area (Matre, Arendt-Neilsen, & Knardahl, 2002). Thus, it is possible that inaccurate sensory information from painful areas plays an important role in the impairments observed in postural sway both in young (Hirata, Arendt-Nielsen, & Graven-Nielsen, 2010; Hirata, Arendt-Nielsen, Shiozawa, & Graven-Nielsen, 2012; Hirata, Ervilha, Arendt-Nielsen, & Graven-Nielsen, 2011) and elderly subjects (Hirata et al., 2013; Hirata et al., 2019) with increased falls risk (Blyth, Cumming, Mitchell, & Wang, 2007; Foley, Lord, Srikanth, Cooley, & Jones, 2006; O'Loughlin, Robitaille, Boivin, & Suissa, 1993). However, one important factor usually neglected in previous studies evaluating postural sway during pain is the cognitive threat value of the pain stimulus (Crombez, Eccleston, Baeyens, & Eelen, 1998). In fact, pain disrupts attention and worsens task performance, especially while performing complex tasks (Moore, Keogh, & Eccleston, 2013) by imposing a cognitive load that decreases cognitive resources available for the primary task (Eccleston & Crombez, 1999). Crombez et al. (1998) suggested that a painful stimulus is automatically evaluated for its possible threat value and, if sufficient threat is perceived, attention is redirected from the primary task to the object of threat (Crombez et al., 1998). This may explain the reduced accuracy of relevant sensory information under painful situations (Matre et al., 2002; Matre, Sinkjaer, Svensson, & Arendt-Nielsen, 1998).

Although the underlying strength in attention disruption due to pain and its effects on balance is not fully understood yet, attention disruption due to pain would, for example, be relevant for rehabilitation programs for pain patients with high risk of fall accidents. Compared to proprioceptive and vestibular sensory information, the visual sensory information seems to have a greater contribution for postural sway during painful conditions (Hirata et al., 2013; Pradels, Pradon, Hlavackova, Diot, & Vuillerme, 2013). Similar findings were found in healthy subjects, where application of painful stimuli to the plantar surface of both feet and depriving subjects of visual feedback impaired postural sway, however when visual feedback was available, this effect was negated (Matre et al., 1998). Secondary tasks providing feedback may possibly provide reliable sensory information (Taube, Leukel, & Gollhofer, 2008; Vuillerme, Nougier, & Prieur, 2001) or act to distract the attention away from the painful stimulation (Hirata et al., 2018), attenuating the negative effect of pain on postural sway. Providing visual information of the head position has shown to improve postural sway in healthy subjects (Taube et al., 2008) and help to overcome freezes of gait problems in Parkinson patients (Van Gerpen, Rucker, Matthews, & Saucier, 2012). Additional studies have also shown that limiting available attention to focus on the pain stimulation, by focusing on a secondary task, reduces perceived pain (Brewer & Karoly, 1989) and improves postural sway(Hirata et al., 2018). For example, touching a curtain while focusing on not moving it, improved postural sway during experimental leg pain (Hirata et al., 2018). However, it is unclear if the concurrent completion of a secondary task involving visual information of the head position also negates the deleterious effect of pain on postural sway, as it has been shown with haptic feedback (Hirata et al., 2018).

Therefore, the aim of the present study is to investigate the effect of painful stimulation of the lower leg and upper arm on postural sway with or without the completion of a secondary task. We hypothesize that i) pain impairs postural sway only when applied to the lower leg, ii) the completion of a secondary task improves postural sway, and iii) leg pain does not impair postural sway while performing a secondary task.

2. Methods

Sixteen subjects (10 males) with mean ± 1SD age, mass and height of 23.0 ± 1.6 years old, 71 ± 13 kg and 1.74 ± 0.09 m, respectively, and with no pain, neural or mental deficits participated in this study. This sample size was based on our previous study that also manipulated the available sensory feedback during pain in quiet standing tasks (Hirata et al., 2018). Therefore, 16 subjects would be necessary to detect, during painful conditions, a minimum difference in the COP sway area of 40% (effect size = 0.87, power = 0.95 and alpha-level = 0.05) when comparing condition with vs without additional sensory information.

2.1. Procedure

The present study was carried out using a within subjects cross-over design. The study consisted of three parts (see Fig. 1):

Part 1: Baseline measurements where subjects performed three 30-s trials with no cuff algometry and no secondary task (control focus), and three 30-s trials with no cuff algometry but with a secondary task (laser focus).

Part 2: Pain threshold assessment to determine the pressure corresponding to 7 cm on a visual analogue scale (VAS7) as previous studies have shown impaired postural sway using similar pain intensities (2,7). The individual adjusted pressure secured that all subjects had the same relative pain intensity. These pressure values were used to perform pneumatic cuff algometry corresponding to VAS7 to induce pain in dominant leg or right arm during 30s in condition of the third part of the experiment.

Part 3: Subjects were asked to stand in a tandem stance (30 s) at the following conditions: 1) leg pain, 2) arm pain, 3) leg pain and secondary task and 4) arm pain and secondary task. These four conditions were grouped in a block, which was performed three times. Pauses of 60 s and 120 s were given between trials and blocks, respectively. The order of the conditions was randomized across trials. During this third part of the study cuff-inflation time from 0 kPa to individual-adjusted pressure was 2 s. The participants were asked to only discontinue the pressure application if they were to withdraw the experiment, otherwise the pressure was sustained for the entire 30 s of each painful condition.

In the conditions with no secondary task, subjects were asked to “stand as quiet as possible while focusing on the circle on the wall in front of you”. In the secondary task condition, subjects were asked to “stand as quiet as possible while focusing on keeping a laser pointer within the circle position on the wall in front of you” and received visual information of the head position. The laser-pointer was fixed to the subject's head and was adjusted to follow subjects' line of sight before each trial (see Fig. 2). The head often moves independent from the center of mass and its movement variability usually does not relates to the movement variability of the center of mass while controlling standing posture (Park, Schoner, & Scholz, 2012), therefore, the rational for mounting the laser pointer in the head was to provide visual information of the head position in the secondary task.

2.2. Setup

A force platform (Metitur Good Balance System©, Finland), sampled at 50 Hz, was placed two meters from a wall. A circle (d = 0.05 m) was placed on the wall at the height of 1.8 m above the floor. All subjects wore a laser-pointer mounted on an elastic band helmet and a pneumatic cuff on the lower dominant leg through all trials unless otherwise stated. Subjects stood in a tandem stance (feet in heel-to-toe position with dominant leg placed rear) which was replicated across trials and with arms at their sides. Subjects were instructed not to move from this position during trials. Trials were cancelled and repeated if position changed (Fig. 2). A video camera (DSC-HX10V, SONY) recorded the laser focus condition performance at 25 Hz (640 × 480 pixels) for later analysis.

Pressure corresponding to 7 cm on a visual analogue scale (VAS) was averaged across three trials using pneumatic cuff algometry for the dominant leg and right arm for use in part three (Fig. 1). Subjects stood in a tandem stance when assessing leg and arm pain tolerance. Sixty-second breaks were provided between trials. The cuff was wrapped around the widest part of the dominant lower leg (25) or the upper right arm (26). Pressure was inflated at 1 kPa/s for maximally 100 s. Subjects rated pain on a digital VAS throughout every trial. When reaching VAS7, subjects terminated inflation by using a hand-held pressure release button. Pneumatic cuff algometry was performed using a computer-controlled pneumatic cuff algometry setup (27). The setup consisted of a 13 cm wide single chamber pneumatic cuff (VBM, Germany) and an air compressor (JUN-AIR International A/S, Denmark) connected to an electric-pneumatic converter (ITV2030, SMC Corp., Japan) controlled by a data acquisitioning card (PCI 6024E, National Instruments, USA) (27). Several safety precautions were taken. The pressure limit was 100 kPa and could be released from a stationary release button, hand-held release button and from the computer software. Pain was assessed using a digital 10 cm visual analogue scale (Aalborg University, Denmark). Zero cm was defined as “no pain” and 10 cm was defined as “worst pain imaginable”. Subjects started rating when pressure went from non-painful to painful (VAS > 0 cm). For the baseline trials, pain was assessed before and after each trial. During part three, pain was assessed three times, before cuff inflation, after cuff inflation and after 30 s tandem stance.

2.3. Data analysis

The center of pressure (COP) data from the force platform was filtered digitally with a low-pass filter and a 20 Hz cut-off frequency. The amount of postural sway and the speed of the sway were quantified from the COP data with the variables 95% prediction ellipse COP area and resultant mean COP velocity (Duarte, 2015). The median frequency of the CoP displacement was calculated by the Welch periodogram method with a resolution of 0.039 Hz for both medial-lateral and anterior-posterior direction of the COP. The resultant COP frequency was calculated as the weighted mean of the anterior-posterior and medial-lateral COP directions, with the weights

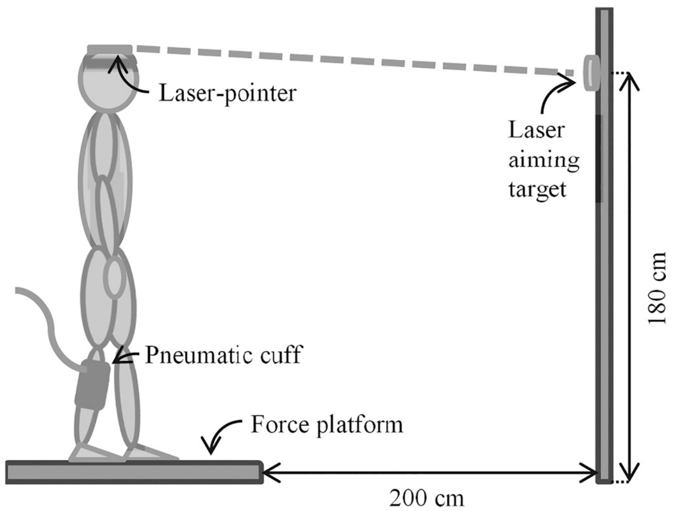


Fig. 2. Subjects stood in a tandem stance on a force platform with the dominant leg rear and arms hanging loose. A laser-pointer was mounted using an elastic helmet and oriented so that the laser pointed on a circular target, when subjects looked straight ahead. The cuff position alternated between upper right arm and lower dominant leg.

defined by the respective power's signal (Duarte & Zatsiorsky, 2002). Sample entropy was calculated (values for r set to 0.20 and m set to 2) for both medial-lateral and anterior-posterior direction of the COP (Duarte & Sternad, 2008). The resultant COP sample entropy was calculated as the average value between both directions. All analyses were performed using a custom script written in Matlab (MATLAB and Statistics Toolbox Release 2017b, The MathWorks, Inc., Natick, Massachusetts, United States). The Video data displaying laser displacements were analyzed using a custom script written in Python (Python Software Foundation. Python Language Reference, version 3.5.2). The script marked the circle and tracked the middle pixel of the laser-point for each frame and then the total displacement of the laser was computed. Laser focus condition performance was quantified as total laser displacement and number of frames where the laser-pointer was within the circle and defined as successful frame percentage.

Results are presented as mean and standard deviation. Two-way repeated measure ANOVA with Pain (baseline×arm pain×leg pain) and Laser (no laser×with laser) as factors were applied to determine differences in the investigated COP variables. A Bonferroni post hoc test, with correction for multiple comparisons, was applied when appropriate. A Friedman ANOVA was applied to the VAS data and laser performance variables (baseline×arm pain×leg pain). A Bonferroni adjusted Wilcoxon matched pairs post hoc was performed following non-parametric tests when appropriate. Results were considered statically significant when $P < .05$.

3. Results

Pain intensity increased following pneumatic cuff algometry (Table 1, χ^2.(16, 2) = 26.00, $P < .01$) in both leg and arm pain conditions compared to baseline measurements (Wilcoxon: adjusted $P < .01$). No difference in pain intensity between arm and leg pain conditions was found (Wilcoxon: adjusted $P > .17$), see Table 1. Laser performance data was only available for 14 of the 16 subjects. No differences between baseline, arm pain and leg pain conditions were found for total laser displacement (χ^2 (14, 2) = 0.43, $P > .81$). Subjects showed lower successful frame percentage in the leg pain condition compared with baseline condition (χ^2 (14, 2) = 9.42, $P < .01$, Wilcoxon, adjusted $P < .01$).

Representative COP excursion plots during the different conditions are presented in Fig. 3.

A main effect of factor Pain was found for the COP area (ANOVA: F(1, 15) = 11.84, $P < .01$, Fig. 4A) with larger values during baseline measurements compared with both painful conditions (Bonferroni: all $P < .05$).

A main effect of Pain was found for the COP sample entropy (ANOVA: F(1, 15) = 13.19, $P < .001$), with lower values in the baseline measurements (Mean ± 1 SD: 0.19 ± 0.04) compared with condition with pain (i) in the arm (0.23 ± 0.04, Bonferroni: $P = .001$) and (ii) in the leg (0.22 ± 0.04, Bonferroni: $P = .002$). A main effect of Laser was found in the COP sample entropy with lower values during the condition with laser (0.20 ± 0.04, Bonferroni: $P = .035$) compared with the condition without laser (0.23 ± 0.04).

A main effect in the factor Pain was also found in the COP velocity (ANOVA: F(1, 15) = 28.33, $P < .001$, Fig. 4B) with larger velocities during leg pain condition compared with both other conditions (Bonferroni, all $P < .05$). A main effect of factor Laser was also found in the COP velocity (ANOVA: F(1, 15) = 28.33, $P < .001$, Fig. 4b) with larger velocities during no laser condition compared with laser condition (Bonferroni: P < .001). A significant interaction between Pain×Laser was found for the COP velocity (ANOVA: F (2, 15) = 5.76, $P = .008$, Fig. 4B). Within each condition (baseline, arm pain and leg pain), the COP velocity was smaller at the condition with laser compared with no laser condition (Baseline, P < .001; Arm Pain, $P = .003$; Leg Pain, P < .001). During no laser condition, leg pain induced larger COP velocity compared with both baseline (Bonferroni, $P = .009$) and arm pain (Bonferroni, $P = .001$) conditions.

A significant effect for the main factor Pain was found for the mean resultant COP frequency (ANOVA: F(1, 15) = 4.46, $P = .005$, Fig. 4c) with smaller values during the baseline condition compared with both painful conditions (Bonferroni: all P < .05). The main effect Laser was significant for the mean resultant COP frequency (ANOVA: F(1,15) = 10.97, $P = .005$, Fig. 4c) with larger frequency during the no laser conditions (Bonferroni: P = .005). There was a significant interaction between the main factors Pain*Laser (ANOVA: F(2, 15) = 3.96, $P = .03$, Fig. 4C) where the mean resultant COP frequency were larger during the no laser and leg pain condition compared with: (i) no laser and baseline condition (Bonferroni: $P = .02$), and (ii) with laser and leg pain condition (Bonferroni: P = .001).

4. Discussion

Our initial hypotheses were only partially confirmed: i) it's not clear that pain impaired postural sway: the COP area variable decreased in the conditions with pain at the arm and at the leg (contrary to expected) but both COP velocity and COP mean frequency variables increased in the condition with pain at the leg compared with baseline, ii) the completion of a secondary task (laser focus condition) improves postural sway: the COP area variable was smaller during the laser focus condition compared with no laser

Table 1
Mean ± 1 SD pain intensity (visual analogue scale) and performance in laser focus condition during tandem stance during the three pain conditions (baseline, arm pain and leg pain).

Variables	Baseline	Arm pain	Leg pain
Visual Analogue Scale (cm)	0 ± 0	7.4 ± 0.5*	7.0 ± 0.7*
Total Laser Displacement (mm)	2377 ± 606	2414 ± 887	2516 ± 842
Successful Frame Percentage (%)	95.3 ± 5.2	94.3 ± 6.1	92.8 ± 6.9*

* Denotes a significant difference from the baseline condition ($P < .01$).

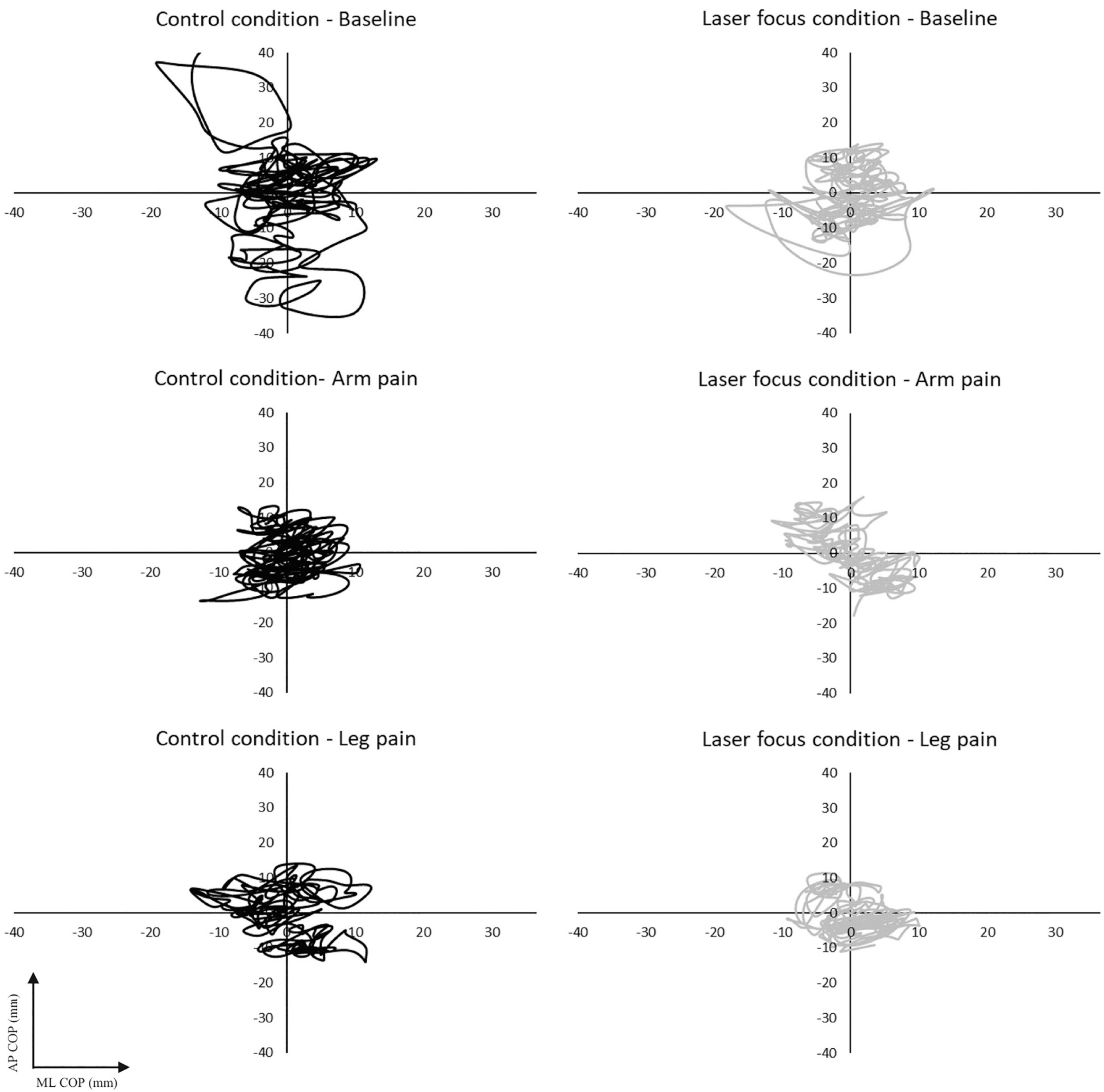


Fig. 3. Examples of COP trajectories during baseline, arm and leg pain without or with laser focus conditions for a representative subject during 30-s tandem stance.

condition, and iii) leg pain didn't impair postural swaywhile performing a secondary (laser focus condition) task: a difference in the COP velocity variable between the pain condition at the leg and the other pain conditions was found only when there was no secondary task (control condition). These effects are discussed next.

4.1. The effects of pain on postural sway

Pain affected postural sway in a nontrivial way: in the conditions with pain in relation to the conditions with no pain, COP area decreased, but COP velocity and COP mean frequency increased. These apparently contradictory results preclude the classification of the effect of pain in a dichotomic, and simplistic, impairment or improvement. These results may be explained using the abstract concept for the control of posture during standing as the control of an inverted pendulum (Caron, Faure, & Brenière, 1997) with an agonist/antagonist pair of actuators (muscles). In such abstraction, a feasible response to mitigate an unpredictable perturbation to the system's sway would be a simultaneous activation of the agonist/antagonist actuators (co-contraction) (Fitzpatrick, Gorman, Burke, & Gandevia, 1992), which would increase the apparent stiffness of the system resulting in a smaller and quicker displacement of the pendulum after a perturbation (Winter, Patla, Rietdyk, & Ishac, 2001). With continuous unpredictable perturbations, the control of an inverted pendulum, by increased apparent stiffness, would result in a smaller area, but increased velocity and frequency of the pendulum displacement, a scenario analogous to the present results when pain was induced into the subjects. The increased sample entropy observed during painful conditions compared with baseline condition may support the co-contraction strategy proposed elsewhere (Fino, Nussbaum, & Brolinson, 2016). So, we conjecture that the subjects in this study might have used a co-contraction response during the pain conditions; however, further experiments have to be conducted to elucidate this question.

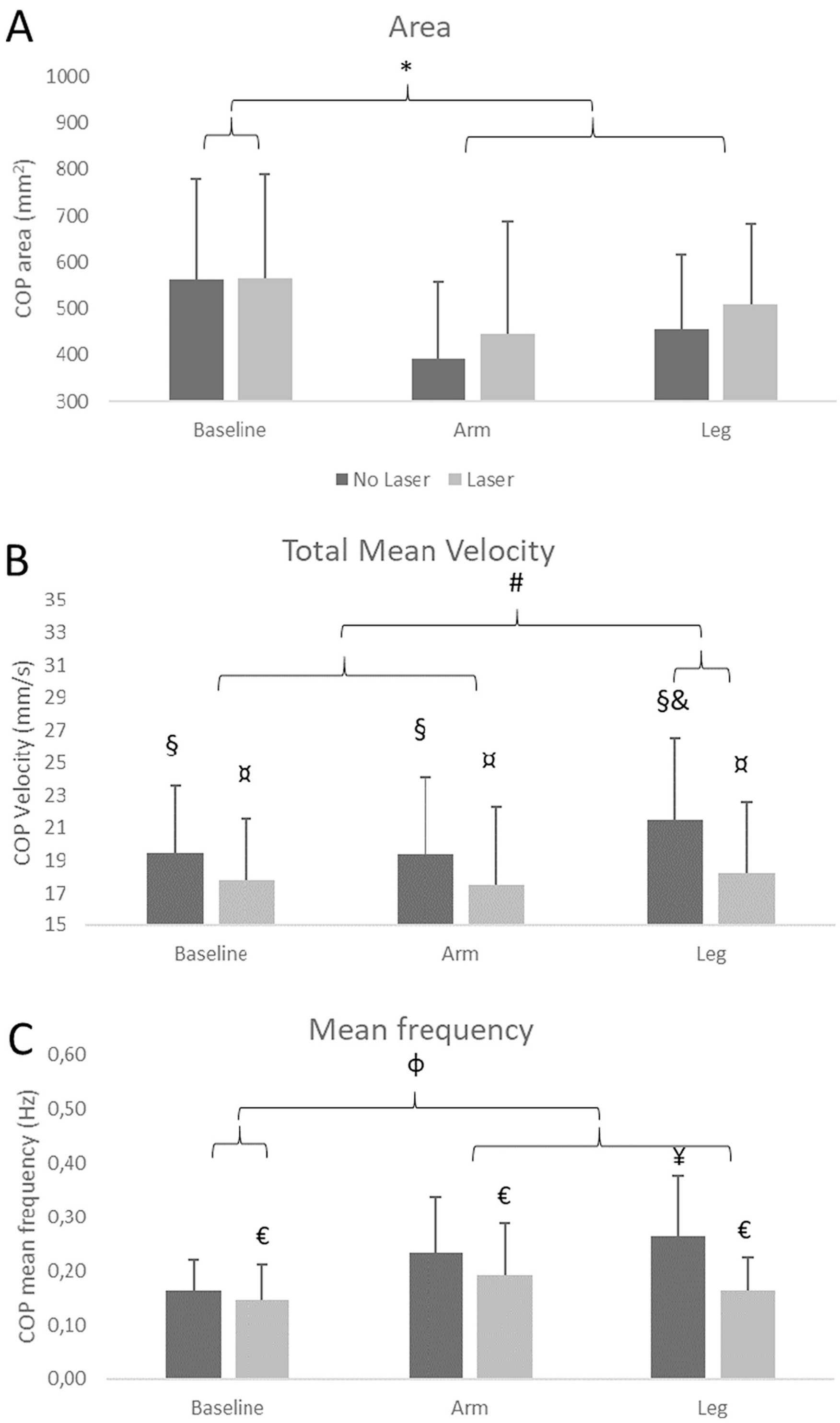
The present study found changes in postural sway following leg pain, supporting previous studies also showing reduced COP area (Suda et al., 2019) and increased COP velocity (Hirata et al., 2011) compared with pain free conditions. Additionally, arm pain did not alter postural sway in present study. For example, no difference in postural sway has been found with and without hand pain (Corbeil, Blouin, & Teasdale, 2004; Pradels et al., 2013), suggesting that pain in areas not involved in postural control has a minimal influence on postural sway.

Pain reduces proprioceptive feedback accuracy from the inflicted muscles (Matre et al., 1998; Matre et al., 2002) which has been related to impaired postural sway (Hirata et al., 2013; Hirata et al., 2019). A possible reason for changes in postural sway observed in the present study could be that pain reduced proprioceptive accuracy from the lower leg (Matre et al., 1998; Matre et al., 2002) leading to a biased estimation of whole-body position in space (Corbeil et al., 2004; Pradels et al., 2013). A possible confounder is that cuff high pressure might have caused ischemia, leading to loss of sensory information. However, it has been shown that ischemic blocking by cuffing for less than 10 min does not induce sensory loss, neither the oxygen deficiency in the lower leg muscles due to a short period ischemic condition seems to affect postural sway (Demura, Yamaji, Kitabayashi, Yamada, & Uchiyama, 2008), indicating that the present results are likely due to pain rather than sensory alterations caused by cuffing alone. Even if ischemia was present, completion of the secondary task was still able to mitigate the negative effects of cuffing, further substantiating the positive effects of dual-task paradigms to improve postural sway during painful conditions (Hirata et al., 2018). Similar to present study, previous studies also failed to show any negative effect of arm pain on postural sway (Corbeil et al., 2004; Pradels et al., 2013). Possibly, pain influences postural sway via sensorimotor mechanisms rather than via the utilization, by the perception of pain, of cognitive resources necessary to maintain postural control (Corbeil et al., 2004). It may also be speculated that arm pain did not pose the same threat to postural sway as leg pain and therefore did not capture a significant amount of attention (Crombez et al., 1998). In line with this results, Cluff, Gharib, and Balasubramaniam (2010) showed that postural dynamics were not affected by asking the subject to perform a cognitive task irrelevant (arithmetic task) for both postural and secondary tasks. In our study, the arm pain condition might be understood as an irrelevant cognitive task since it was not applied to structures directly related to postural control. Therefore, the healthy subjects in this study seems to present a robust postural control to secondary cognitive demands (Dault, Geurts, Mulder, & Duysens, 2001a) even in the presence of pain. Since it was not the aim of the study, a performance task for the arm was not included, making it impossible to evaluate if the effect of pain on an arm task is similar to the effect of leg pain on postural sway. However, Huysmans, Hoozemans, van der Beek, de Looze, and van Dieen (2010) showed impaired performance of an arm tracking task in subjects with neck and upper extremity pain attributing these findings to impaired proprioception.

However, from the ecological approach to perception and action (Stoffregen, Pagulayan, Bardy, & Hettinger, 2000; Stoffregen, Smart, Bardy, & Pagulayan, 1999) the control of posture is modulated to assure the performance of the secondary task and minimize the effort for controlling posture itself (Stoffregen et al., 1999). This framework makes no appeal to information processing such as sensory feedback for controlling posture, instead, the relevance of the available information is stablished according to the extent that such information would facilitate the performance of the secondary task. This important framework is also discussed in the sections below as an alternative explanation of the current results. From the ecological approach to perception and action perspective (Stoffregen et al., 1999; Stoffregen et al., 2000), one may argue that pain represents a threat to the system (Legrain et al., 2012), making the performance of a secondary task more challenging and less predictable. That would impose additional constraints for controlling posture, and requiring a more restricted (smaller COP area) and less predictable (increased COP sample entropy) postural sway for the accomplishment of the secondary task (Prado, Stoffregen, & Duarte, 2007).

4.2. The effects of a secondary task on postural sway

The laser focus condition improved postural sway in the present study. Previous studies have shown improvements in postural sway following a concurrent secondary task compared to attentional tasks only (Hirata et al., 2018; Morioka, Hiyamizu, & Yagi, 2005;



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Polskaia, Richer, Dionne, & Lajoie, 2015). Focusing the attention on a point external to the body usually facilitates automatic processes related to postural control, therefore enhancing postural sway (Polskaia et al., 2015) whereas the contrary (impairments in postural sway) is usually found when attention is focused in body parts (such as the hand, head or chest) (Wulf, 2013). However, it is also

Fig. 4. Results are presented as mean ± 1SD. (A) COP area, (B) COP velocity and (C) COP median frequency. * denotes larger area during baseline compared with both pain conditions (main effect Pain). # denotes larger total mean velocity during leg pain condition compared with both arm pain and baseline conditions (main effect Pain). § denotes larger total mean velocity during no laser condition compared with laser condition (main effect Laser). ¤ denotes smaller total mean velocity during with laser condition compared with no laser conditions (interaction Pain*Laser). & denotes larger total mean velocity during no laser and leg pain condition compared with baseline (interaction Pain*Laser) and arm during no laser conditions (interaction Pain*Laser). ϕ denotes smaller mean resultant COP frequency values during the baseline condition compared with both painful conditions (main effect Pain). € denotes larger resultant COP frequency during the no laser conditions compared with laser condition (main effect Laser). ¥ denotes larger resultant COP frequency during the no laser and leg pain condition compared with (interaction Pain*Laser) no laser and baseline condition and (ii) with laser and leg pain condition.

possible that previous studies used secondary tasks that simultaneously provided subjects with sensory feedback (Hirata et al., 2018; Morioka et al., 2005; Polskaia et al., 2015) similar to the purpose of this study. Hence, the completion of a secondary task could have provided additional spatial information and improved postural sway by sensory re-weighting, i.e. increasing weighting of visual while decreasing weighting of proprioceptive feedback to maintain optimal postural control (Pradels et al., 2013; Taube et al., 2008; Vuillerme et al., 2001). It is important to notice that the laser beam provided information about the head motion, which often moves independent from the center of mass during quiet standing (Park et al., 2012). However, from the ecological approach to perception and action perspective, whether participants interpreted visible motion of the laser beam as "feedback" might be speculative. Balasubramaniam, Riley, and Turvey (2000) asked the subjects to hold a laser pointer and keep its beam within a defined area. Although the subjects maintained the performance of the secondary task during different postural tasks, adaptation were observed in the postural strategy. From the ecological approach to perception and action perspective, the secondary task of "stand as quiet as possible while focusing on keeping a laser pointer within the circle position on the wall in front of you" applied in this study might have imposed constraints for the postural control task. In order to facilitate the success of the secondary task in the new constrained environment, postural sway was intentionally reduced (Chen & Stoffregen, 2012; Stoffregen et al., 1999; Stoffregen et al., 2000).

4.3. The effects of a secondary task on postural sway during leg pain

Impaired postural sway during leg pain in both laser conditions was expected as pain impairs proprioception (Matre et al., 1998; Matre et al., 2002) and reduces available cognitive resources for maintaining postural sway (Crombez et al., 1998; Eccleston & Crombez, 1999; Moore et al., 2013). Surprisingly, during the laser focus condition and leg pain, the postural sway velocity returned to values similar to the non-painful condition. One possible explanation is that by adding the secondary task, a competition for the limited attention resources was established in the high centers of the central nervous system (Dault, Geurts, Mulder, & Duysens, 2001b) where the task of standing quiet, maintaining the laser within the target, and interpretation of the nociception input from the leg likely compete for the limited attentional resources (Crombez et al., 1998; Eccleston & Crombez, 1999; Moore et al., 2013). The laser focus condition may have reduced the attention directed towards the painful stimuli (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002) and postural control, as it was evident by the improved postural sway and worsened performance in the laser aiming task (Table 1). Impaired postural sway during leg pain in the control focus condition could be a result of a stimulus-driven unintentional capture of attention (Legrain et al., 2009), as the interpretation of a painful stimuli demands attention. The attention selection could switch to an intentional, goal-directed attention, when providing subjects with a secondary task (Legrain et al., 2009), indicating that arm pain did not pose an attention disruptive threat (Crombez et al., 1998). However, postural control was still prioritized over the laser task performance as a decrease in successful frame percentage was evident during leg pain compared with baseline and arm pain condition (Table 1), supporting the posture first principle (Andersson et al., 2002). Another possible explanation is that the sensory re-weighting of visual feedback from the laser-pointer compensated the biased proprioceptive feedback from the painful leg (Hirata et al., 2010; Pradels et al., 2013). Similarly, Hirata et al. (2013) showed that obese knee osteoarthritis patients had a larger and faster sway during eyes-closed compared to eyes-open conditions, indicating that visual feedback attenuated the effect of biased sensory feedback from leg pain. As indicated previously, from the ecological approach to perception and action perspective (Chen & Stoffregen, 2012; Stoffregen et al., 1999; Stoffregen et al., 2000), the laser condition might have imposed new constraints for the postural task, and, for completing the secondary task of keeping the laser beam inside the designed target during leg pain, postural sway velocity was intentionally decreased.

5. Conclusion

The results suggest that pain alone does not affect postural sway, since pain in the arm did not impair any postural sway measurements. Rather, postural impairments seem dependent on the location of pain as pain in the lower leg increased postural sway velocity. The completion of the secondary task improved postural sway measurements and reduced the effect of leg pain on postural sway. Future treatment interventions could benefit from dual-task paradigm during balance training aiming to improve postural control in patients suffering from chronic pain.

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Ethics approval

This study was done in accordance with the Helsinki Declaration and approved by the local Ethics Committee (N-20120077).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Availability of data and material

Not applicable.

Code availability

Not applicable.

Figures in print

Black and white.

Authors' contributions

All authors have contributed significantly to the manuscript. All authors took part in data acquisitioning, discussed the results, commented on the manuscript and concurred with the content of the final version of the manuscript.

Declaration of Competing Interest

The authors declare no conflict of interest.

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