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ABSTRACT

Fibromyalgia (FM) is a chronic pain syndrome, characterised by several symptoms. One of the most prevalent symptoms in FM is balance impairment that compromise the autonomy, function and per-formance status of patients.

Purpose: The main objective of the present study was to evaluate the effect of sensory stimulation provided by the use of a low additional thickness of 0.8 mm placed under the great toes bilaterally on the centre of pressure (CoP) measures in patients with FM. It was hypothesised that postural ability would change with a low focal additional thickness used to compute these measures.

Materials and Method: Twenty-four patients with FM voluntarily participated in this study. Postural performance during quiet standing was investigated through the CoP displacements recorded using a force-plate. Sensory stimulation was provided by a small additional thickness of 0.8 mm placed under the great toe bilaterally and two conditions were compared: additional thickness 0 (control) and 0.8 mm.

Results: An improvement of body balance through spatial parameters with sensory cutaneous stimula-tion applied under the great toe bilaterally were observed in patients with FM. Our results showed a significant decrease of surface area and mean speed of CoP, associated to a significant decrease of variance of speed. An additional observation is that sagittal (Y) mean position of the CoP gets more anterior (þ 5 mm) relative to control condition.

Conclusion: These findings brings new clinical perspectives in the development of intervention strat-egies in the management of patients with FM and balance disorders, completing validated thera-peutic strategies.

Introduction

Fibromyalgia (FM) is a chronic pain syndrome with an unknown aetiology. FM is characterised by widespread pain, tender points, fatigue, sleep disturbance and mood disorders (Wolfe et al. 2010). The most prevalent symptoms in FM are low back pain, headaches, arthritis diseases, muscle spasms and balance impairment (Bellato et al. 2012). All these clinical symptoms compromise the autonomy, function and performance status of patients with FM. Some evidence has supported central nervous system (CNS) dysfunction as a possible aetiology of FM. These patients suffer from chronic pain conditions characterised by altered nociceptive processing. These alterations manifest as altered descending pain inhibition (Arendt-Nielsen et al. 2010) with extended hypersensitivity (Kosek and Ordeberg 2000). In this context, these patients would then be considered to have a combination of nociceptive and nociplastic contributors to their pain (Kosek et al. 2016). Systematic hypertonia is frequently associated with these neuro-functional pathologies, which are characterised by a lowering of pain thresholds (Banic et al. 2004) and muscular response (Kleinrensink et al. 1994).

Balance or postural stability is a complex task that involves the rapid and dynamic integration of multiple sensory, motor and cognitive inputs to execute appropriate neuromuscular activity needed to maintain balance (Horak 2006). Peripheral and/or central mechanisms of postural control may be affected in patients with FM (Jones et al. 2009), leading to a greater risk and frequency of falls (Jones et al. 2009). Alteration of postural control has a negative impact on endurance, muscle strength, flexibility, and coordination (Muto et al. 2015). Indeed, patients with FM showed higher postural oscillation than those exhibited by healthy control group (Trevisan et al. 2017). They presented some difficulties in the goal of maintaining centre of pressure (CoP) inside base of support, and it was proposed that motor behaviour

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adapts to chronic painful conditions with changes in the mechanical behaviour such as modified movement and stiffness, in order to protect from further pain (Hodges and Tucker 2011). Pain, possibly causes a pre-synaptic inhibition of muscle afferents, also disturbs the central modulation of proprioceptive spindles of muscles, causes prolonged latencies by decreasing muscle spindle feedback. It leads to changes in the timing of postural adjustments, increase postural sway and decrease the control of muscles (Ruhe et al. 2012; Moseley and Hodges 2005). These changes seem beneficial in the short-term, but holds potential long-term consequences due to factors such as increased load, decreased movement and decreased variability (Hodges and Tucker 2011). Consequently, patients with FM exhibit higher levels of sedentary lifestyles with higher levels of inactivity (Giannotti et al. 2014). Some authors (Galli et al. 2011) suggested that therapeutic remediation of balance problems should focus on assisting people in the facilitating of somesthesic system and strengthening the muscles in order to improve the processes responsible for standing, avoiding risks of falling (Galli et al. 2011).

The human foot is the direct interface between the body and the ground, and could be considered as a sensory structure (Viseux 2020) that provides somatosensory feedback and contributes to balance control (Kavounoudias et al. 1998, 2001). The increased distribution of cutaneous afferents in the toes compared with the heel (Viseux 2020) may reflect the postural significance of feedback from the toes in regard to the control of standing balance (Viseux 2020). Since tactile plantar sensations are important for maintaining upright balance, specific sole stimulation could exert a significant effect on postural control. Some authors have used focal additional thicknesses to facilitate cutaneous sensory feedback from the foot (Janin and Dupui 2009; Wang et al. 2016; Viseux et al. 2019a). For example, an anterior bar of small thickness (3 mm) placed behind the metatarsal heads of the feet induced a significant displacement of the CoP in the sagittal plane (Janin and Toussaint 2005). In the same way, a mechanical facilitation of sensation that was produced with a coin-shaped piece of aluminium placed approximately at the junction of the anterior third and posterior two thirds of the plantar sole caused a decrease in the velocity and amplitude of movement of the CoP (Wang et al. 2016). In addition to these postural reactions induced by additional thicknesses placed under both feet, Janin and Dupui (2009) showed that an additional thickness (3 mm) placed under the medial part of the right foot induced a shift of the CoP in the sagittal plane towards the left, and conversely when the same additional thickness was placed under the medial part of the left foot. Furthermore, Forth and Layne (2007) stimulated the lateral aspect of the foot sole using a 3 mm thick mechanical stimulus. Based on surface electromyography, they showed that the low mechanical stimulus induced increased activation of the plantar flexor musculature and suggested that their small depression of the lateral aspect of the plantar surface stimulated both type I and II cutaneous mechanoreceptors units. Recently, an interaction between CoP parameters and different additional thickness placed under all the toes (Viseux et al. 2018) or under the great toe (Viseux et al. 2019b) was described and allowed to determine an optimal thickness of 0.8 mm. A significant change of balance was obtained with the lowest additional thickness of 0.8 mm even through the contact forces induced by this small thickness were probably too small to mechanically stabilise the body. Less than one millimetre placed under the great toe bilaterally provided significant neurosensory cues but not mechanical support and was enough to improve postural ability in healthy subjects. All of these results support that low mechanical stimulation of the plantar surface of the foot can enhance neuromuscular activity (Fallon et al. 2005; Nakajima et al. 2006; Forth and Layne 2007) and induce specific and predictable postural reactions (Janin and Toussaint 2005; Forth and Layne 2007; Janin and Dupui 2009). They underline the importance of rehabilitation treatments based on a bottom-up approach in which the role of cutaneous sensory facilitation of the feet is of great importance.

Given the above, the main objective of the present study was to evaluate the effect of sensory stimulation provided by the use of a low additional thickness of 0.8 mm placed under the great toe bilaterally on the CoP measures in patients with FM. It was hypothesised that postural ability would change with a low focal additional thickness of 0.8 mm used to compute these measures.

Material and methods

Population

Twenty-four patients with FM (age = 50 years ± 10 years, height = 1.63 m ± 0.07 m, weight = 70 kg ± 16 kg) voluntarily participated in this study and gave their informed consent to the experimental procedure. All patients were examined at the Pain Management Unit at the General Hospital. Only women were included in this study as more than 80% of patients with FM are females (Wolfe et al. 1995). A diagnosis of fibromyalgia was confirmed by a doctor using the screening criteria established by the American College of Rheumatology (ACR) in 2010 (Wolfe et al. 2010). The ACR 2010 criteria are pooled to give an 0-31 fibromyalgia symptoms score, and only patients with a score of $\geq$13 were included. Exclusion criteria for all participants were: diagnosed psychiatric disorder, neurological, musculoskeletal or vestibular pathology, injury, or uncorrected reduced vision.

Ethics

The study was approved by the local ethical board and conducted according to the declaration of Helsinki.

Material

Postural oscillations were recorded for each participant using a force plate (AFP/APE85, 40 Hz/16-bit, Win-posturo®, Médicapteurs©, France) and analysed with the software (v; 1.8, Win-posturo®) coupled to the force plate. The force plate measured 530 mm × 460 mm × 35 mm and was equipped with three pressure gauges (hysteresis <0.2%).

Balance condition

Static conditions are used when testing postural control, and postural tests are done in a bipedal stance. Participants stood upright on the platform, lowered arms, barefoot, with heels 2 cm apart and feet angled apart at 30°. Foot position was marked on the platform and repeated between both conditions. So, in this normalised position, the centre of sustentation polygon was located on the sagittal axis of the platform at a known distance to the rear from the electrical centre of the platform. According to the International Society for Posture and Gait Research (Bologna, Italy 2009), data was collected over 30 s with a sampling frequency of 40 Hz (Scoppa et al. 2013). Platform calibration coefficients were reset before each participant, then an average of three consecutive measurements were performed (Pinsault and Vuillerme 2009). Subject's task was to stand as still as possible during the trial (Zok et al. 2008). Two randomised conditions were compared: additional thicknesses under the great toe (TUGT) 0 (control) and 0.8 mm. TUGT were made of a rigid polyester resin and with an ovular form. They had a width of 28 mm and a length of 35 mm (Figure 1). The hardness was 60 Shore A, and the density was 250 kg/m3. TUGT were placed under the plantar surface of great toe of both feet. There was no time to adapt to different conditions. In order to avoid phenomenon of habituation of the plantar cutaneous mechanoreceptors, a two-minute period of seated rest separated each recording (Forth and Layne 2007).

Postural parameters

Postural performance during quiet standing was investigated through the CoP displacements recorded using a force-plate. Under each condition, five variables were computed from the CoP displacements: (i) the surface area of CoP excursions; (ii) the frontal (X) mean position of the CoP, (iii) the sagittal (Y) mean position of the CoP, (iv) the mean speed, and (v) the variance of speed of the CoP.

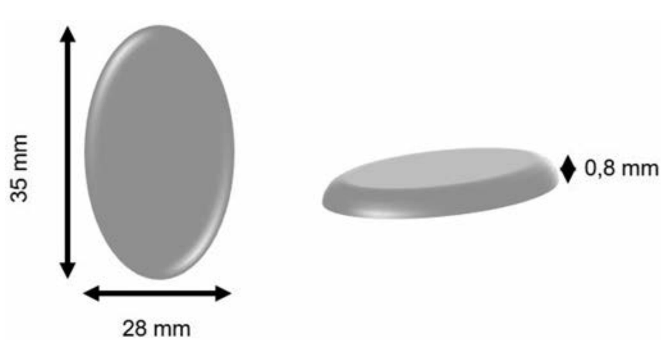

Figure 1. TUGT were made of a rigid polyester resin and with an ovular form. The hardness was 60 Shore A, and the density was 250 kg/m^3.They had a width of 28 mm, a length of 35 mm and a thick of 0.8 mm. TUGT were placed under the plantar surface of great toe of both feet. TUGT: Thickness under Great Toe.

Surface area of CoP

The surface area (in mm^2) represents 90% of the instantaneous positions of the CoP included within the confidence ellipse, eliminating the extreme points (Ruhe et al. 2013). It is an index of the effectiveness of the tonic postural system in keeping the CoM closer to the intermediate position of balance (Cultrera et al. 2010). This variable measures the accuracy with which the postural system locates the subject in its environment, and represents a global measure that allows it to estimate overall postural performance: the smaller the surface, the better the performance (Asseman et al. 2004).

Mean speed of CoP

The mean speed (in mm.s^{-1}) represents the total distance covered by CoP divided by the duration of the sampled period. It reflects the efficiency of the postural control system (the smaller the velocity, the better the postural control) (Paillard and Noé 2015) while characterising the neuromuscular activity required to maintain balance (Paillard and Noé 2006). It has been considered as the measurement with the greatest reliability among trials (Duarte and Freitas 2010) and constitutes a good index of the amount of activity required to maintain stability (Geurts et al. 1993). CoP speed are considered as the most sensitive parameter in comparing individuals from different age groups and with different neurological diseases (Prieto et al. 1996; Masani et al. 2014) and play a major role in the feedforward mechanisms of the postural control system during quiet stance (Vseteckova and Drey 2013).

Variance of speed

The variance of speed (in mm/s) indicates the standard deviation of speed of the CoP and was calculated according to the following formula:

$$Var\ Speed = \sqrt{\left(\frac{\Sigma\left(\left(\sqrt{(Dx)^2 + (Dy)^2} * f - v_{(mean)}\right)^2\right)}{f * t}\right)},$$

Dx and Dy represent the difference of x and y between two successive points of the statokinesigram; f is the sampling frequency; $v_{(mean)}$ is the mean of speed; t is the duration of acquisition. Noted that the statokinesigram records the successive sampled positions of the CoP in relation to a frame of reference whose origin is located at the barycenter of sustentation polygon.

It expresses the relationship between accelerations and decelerations during oscillations: the higher the variance, the greater is the discomfort and the energic loss to the patient (Cultrera et al. 2010). It was believed that variance of speed of CoP displacement is related to the energy used to achieve postural stabilisation, namely leg muscle activity (Wang et al. 2006). The link between the shift of CoP and leg muscle activity has been shown by several authors (Amiridis et al. 2003; Jonsson et al. 2005; Wang et al. 2006): decrease in variance of speed indicated less energy needed to maintain postural stability.

Note that these CoP measures are widely employed in clinical practice to assess individual's postural control capacities during an unperturbed stance (Paillard and Noé 2015).

Statistical analysis

Statistical analysis was performed using SPSS statistics software. A Wilcoxon signed-rank test was performed for each dependent variable (Table 1) since the Shapiro-Wilk test revealed that some of the distributions were not normal and proved impossible to normalise. For all analyses, the threshold of significance was $p < 0.05$.

Table 1. Postural results and p value of the Wilcoxon signed-rank test.

Postural parameters	Control	TUGT 0.8	p
Surface of CoP (mm^2)	**231 ± 201**	**170 ± 132**	**0.003**
X (Mean frontal position of CoP, mm)	−4 ± 9	−6 ± 8	0.133
Y (Mean sagittal position of CoP, mm)	**−38 ± 16**	**−33 ± 17**	**0.0005**
Mean variance of speed of CoP (mm/s)	**46 ± 16**	**42 ± 17**	**0.02**
Mean of speed of CoP (mm/s)	**13 ± 5**	**11 ± 4**	**0.0005**

Means and standard deviations of postural parameters for both condition. p Values of the Wilcoxon signed-rank test for the postural parameters, the significant ones are in bold letters.

Results

As shown in Figure 2, a difference with TUGT 0.8 mm compared to control condition was observed for four of the five dependent variables: the surface of CoP excursions, the mean speed of the CoP, the variance of speed of CoP, and the sagittal (Y) mean position of the CoP. The area of CoP showed a significative (p = 0.003) decrease of about 30% (from 218 to 155mm^2) with TUGT 0.8 mm. The mean speed of CoP showed a significative ($p = 0.0005$) decrease of about 15% (from 13 to 11 mm/s). The mean sagittal (Y) CoP position corresponds to the relative position of the CoP relative to the centre of support polygon on the anteroposterior axis. The results showed a significative ($p = 0.0005$) more anterior mean position, approximately 5 mm, of the CoP with TUGT compared to the control condition.

Discussion

This study provides evidence that a low local additional thickness of 0.8 mm placed under the great toe bilaterally has an effect on the CoP measures used to assess static balance ability during unperturbed stance. Our results suggest that a very small additional thickness is sufficient to change

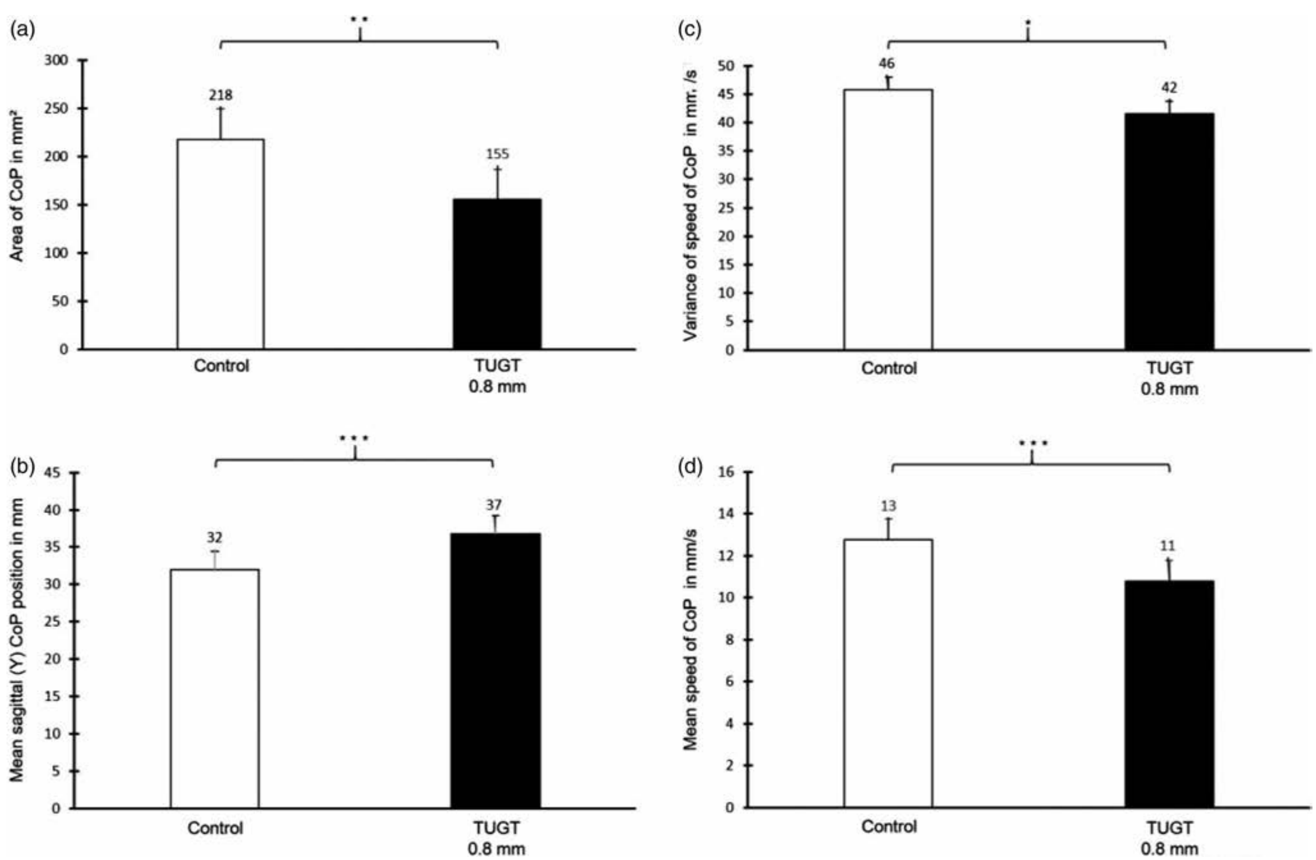

Figure 2. (a) Area of CoP (mm^2) for all conditions. Error bars represent the standard error. The ** denotes a statistically difference with $p = 0.003$. CoP: Centre of Pressure; Control: Control condition (0 mm); TUGT: Thickness under Great Toes (0.8 mm). (b) Mean sagittal (Y) CoP position (mm) for all conditions. Error bars represent the standard error. The *** denotes a statistically difference with p = 0.0005. CoP: Centre of Pressure; Control: Control condition (0 mm); TUGT: Thickness under Great Toes (0.8 mm). (c) Variance of speed of CoP (mm/s) for all conditions. Error bars represent the standard error. The * denotes a statistically difference with $p = 0.02$. CoP: Centre of Pressure; Control: Control condition (0 mm); TUGT: Thickness under Great Toes (0.8 mm). (d) Mean speed of CoP (mm/s) for all conditions. Error bars represent the standard error. The *** denotes a statistically difference with $p = 0.0005$. CoP: Centre of Pressure; Control: Control condition (0 mm); TUGT: Thickness under Great Toes (0.8 mm).

CoP measures. These postural reactions are consistent with previous reports that used mechanical stimulation of the plantar sole (Viseux et al. 2018, 2019b) to promote cutaneous sensory facilitation, and could assist in changing the balance ability in patients with FM.

Effects on postural control

The major finding concerning postural control is an improvement of body balance through spatial parameters with plantar mechanical stimulation, which confirms our hypothesis. A very small additional thickness of 0.8 mm, placed under the great toe bilaterally, are sufficient to change CoP measures, and to improve postural performance during quiet upright stance with higher stability (decrease of surface area and mean speed of CoP) (Asseman et al. 2004; Paillard and Noé 2015) and lower energy cost (decrease of variance of speed) (Cultrera et al. 2010). An additional observation is that sagittal (Y) mean position of the CoP gets more anterior (+5 mm) relative to control condition.

Area of CoP

Studies showed an area of CoP around 130 mm^2 in healthy subjects (Trevisan et al. 2017; Viseux et al. 2018). In patients with FM, area of CoP was about 228 mm^2 (Trevisan et al. 2017), which represents an increase of about 75%. According to Trevisan et al. (2017), our results showed a similar increase with a value of 218 mm^2.

The large area of postural sway in the control condition could reflect the ineffectiveness of postural control and deficits in fine tuning movements that may be related to poor use of somatosensory information (Wang et al. 2016). This speculation is consistent with previous findings that demonstrate CoP shifts larger than the normal ellipse area when somatosensory feedback is delayed peripherally (Horak and MacPherson 1996). The activation of plantar cutaneous receptors largely depends on the speed and amplitude of the body sway during standing (Mouchnino et al. 2019). Large sways during standing correspond to a self-generated functional behaviour to release skin compression. Cortical source and EMG analyses showed that large sways were preceded by (i) activation of cortical areas known to be engaged in motor planning (i.e., supplementary motor area and dorsolateral prefrontal cortex) and (ii) by ankle muscle activations (Mouchnino et al. 2019). Large body sways could play a sensory function for balance control, especially in subjects with impaired plantar cutaneous feedback. By contrast, one could assume that reduced postural sway area in the stimulation condition may reflect increased somatosensory feedback in the postural control loop and accurate detection of the spatial representation of body posture in this condition.

Mean speed of CoP

In terms of the mean speed of CoP, significant differences between the stimulation and control condition were observed. The mean speed was significantly decreased in the stimulation condition. These results are consistent with previous studies (Maurer et al. 2001; Horak and MacPherson 1996). Postural control systems rely notably on velocity information (Morasso and Schieppati 1999; Masani et al. 2003). During quiet stance, the postural control systems might adopt a control strategy relying significantly on body sway velocity information, and modulating the muscle activity in an anticipatory manner (Masani et al. 2003). Worsening of postural stability with FM happens due to increasing body sway velocity, which is, most probably, reflecting decline in the neural processing (Wilder et al. 1996), and impaired muscle function (Klaver-Krol 2017), especially to postural muscles (Elert et al. 2001). Body sway velocity increase, represent a substantial danger to overall postural stability. Therefore, the decrease in the body sway velocity, characterised by a decrease in the speed of CoP, could be a good indicator of better postural stability (Paillard and Noé 2015), and might further serve as an indicator of progressive changes in physical functioning (Vseteckova and Drey 2013).

Sagittal (y) mean position

The contraction of agonist muscles as well as the co-contraction of antagonistic muscle pairs is employed by the CNS in voluntary motor tasks. Anticipatory strategies often govern muscle contraction and co-contraction of the lower extremities when postural stability is threatened. Ankle muscle contractions produce counteracting forces through plantar flexion and dorsi-flexion in response to balance challenges (Borg et al. 2007). Muscle activities at the ankle joint correlate with the behaviour of CoP (Borg et al. 2007). The CoP is a widely-used indicator of neuromuscular control while standing (Winter et al. 1990), and is closely proportional to the moment about the ankle joint that is generated by the musculoskeletal system governing the ankle (Winter et al. 1990**;** Borg et al. 2007). Our findings indicate a forward displacement (+ 5 mm) of the mean position of the CoP, induced by TUGT. Therefore, we can suggest that this modification of the mean position of the CoP, in particular in the sagittal plane induces a modulation of the muscular activities and could promote an increase in stiffness at the ankle by co-contraction of sufficient amplitude and thus neutralise destabilising disturbances and minimising body sway (Kim and Hwang 2018).

Variance of speed

Variance of speed allows to evaluate if the corrective intervention is more or less effective. A subject in balance moves slowly and has low variance of speed, while patient with altered posture has a non-fluid movement and a higher variance. The return of CoP parameters to normal values after correction indicates the effectiveness of the correction on condition that variance of speed remains low, otherwise the compensation leads to higher energetic expenditure which is of no benefit to the patient. Our results indicate a significant decrease in the surface of CoP associated with a significative decrease in the speed of CoP with TUGT 0.8 mm. This goes in the direction of improving postural stability (Asseman et al. 2004; Paillard and Noé 2015). This improvement could be induced by an adapted modulation of the stiffness of the ankle in relation with the change in the mean position of the CoP. In addition, the significative decrease in the variance of the speed which indicates a reduction in the energetic cost (Cultrera et al. 2010), underlines the effectiveness of cutaneous sensory facilitation by the use of TUGT in the improvement of postural control.

Clinical interest

Since patients displaying larger CoP area and sway speed are identified as having greater balance impairment (Phu et al. 2019), decrease of surface area, mean speed and variance of speed of CoP may reflect a better postural control system efficiency (Asseman et al. 2004; Paillard and Noé 2015) with a reduced energy cost (Wang et al. 2006). During the great toe stimulation condition, participants showed a general tendency to move the CoP at a lower velocity over a smaller area. Inappropriate or defective information from any of the sensory systems (i.e., visual, vestibular, and somatosensory receptors) can result in instability due to a mismatch between incoming sensory signals (Bloem et al. 2002). Thus, the CNS has to compensate this mismatched information from sensory receptors to correctly functioning receptors where, according to Pyykko et al. (1990), the most important source of somatosensory information comes from plantar mechanoreceptors, being the most important site when balance is perturbed (Stal et al. 2003). In this way, the addition of a small thickness under the toes facilitated the tactile cutaneous sensation and reduced the individual's postural sway (Viseux et al. 2018, 2019b). In fact, plantar cutaneous afferents play a role in stabilising the feet, providing an additional source of sensory input that enhances the detection of movement and controlling small amplitude body sway (Kavounoudias et al. 1998, 1999). Because integration of information from all sensory systems appears to be impaired in FM population, it is relevant for clinicians such as podiatrist to include sensory stimulation. FM patients exhibited a generalised non-modality-specific increase in pain sensitivity and a further increase in sensitivity to pressure pain (Kosek et al. 1996). In this context, this study brings interesting clinical perspectives to improve balance in patients with FM. Neurophysiological studies showed a very low perceptual threshold (less than 0.5 mN) (Inglis et al. 2002) for all cutaneous mechanoreceptors and that potentials from this skin receptors have been obtained by low intensity mechanical stimuli such as displacements of the order of 0.001 μm (Bolanowski and Zwislocki 1984). Light-touch from the great toe allowed the activation of this cutaneous mechanoreceptors, and induced by low additional thickness, (i) provided significant no painfully somatosensory cues and (ii) induce attenuated postural sway. Compared to the no touch condition, an additional sensory stimulus stemming from light-touch would lead to a stabilising effect on postural sway (Viseux et al. 2018, 2019b). Our results suggested that cutaneous mechanoreceptors of the great toe, especially the most superficial ones (Macefield et al. 1990; Inglis et al. 2002) were activated by the lowest additional thickness and seem to be consistent with sensory hypothesis and earliest reports using light-touch, which showed an improvement in postural performance (Jeka and Lackner 1994).

Limitations

There are potential limitations when interpreting the observations reported in this paper. First, although this study showed significant effects of low cutaneous mechanical stimulation placed under the great toe bilaterally on static balance, it would be necessary to consider these effects on dynamic balance. Both static and dynamic conditions are often used to test postural control (Paillard and Noé 2015). Indeed, dynamic balance is considered more challenging because it requires the ability to maintain equilibrium during a transition from a dynamic to a static state (Ross and Guskiewicz 2004). For patients with FM, it seemed more prudent to realise postural tests in static conditions even if dynamic conditions are more discriminating in terms of postural control (Tomomitsu et al. 2013).

Secondly, given the linear relationship between pain intensity and postural sway speed (Lihavainen et al. 2010; Ruhe et al. 2011), it will be interesting to investigate whether COP excursions of FM patients are also influenced by pain severity and pain duration. Previous research has already demonstrated a linear relationship between the magnitude of CoP excursions and the perceived pain intensity in patients suffering from chronic low back pain (Ruhe et al. 2011) or neck pain (Ruhe et al. 2013). However, we do not know if this relationship is also observed in patients with FM.

Finally, even though there is some evidence that higher CoP sway parameters are associated with a higher risk of falling, especially in the elderly (Horak et al. 1989; Maki et al. 1991), our results did not include elderly participants and therefore cannot be generalised to that population.

Conclusion

Postural ability has been assessed using CoP parameters in patients with FM, and our results showed an improvement of body balance through spatial parameters with sensory cutaneous stimulation applied under the great toe bilaterally. These findings emphasise that cutaneous information arising from the great toe plays an important role in balance and postural control. A very small additional thickness of 0.8 mm, placed under the great toe bilaterally, are sufficient to change CoP measures, and to improve postural performance during quiet upright stance with higher stability in patients with FM. It would be interesting to consider in future investigations to understand the complex neurophysiological mechanisms underlying these postural reactions.

Taken together, these results bring new clinical perspectives in the development of intervention strategies to improve the quality of plantar cutaneous feedback (i.e., customised postural insoles) (Figure 3) and seems to be an interesting and promising way in the management of patients with FM and balance disorders, completing validated therapeutic strategies.

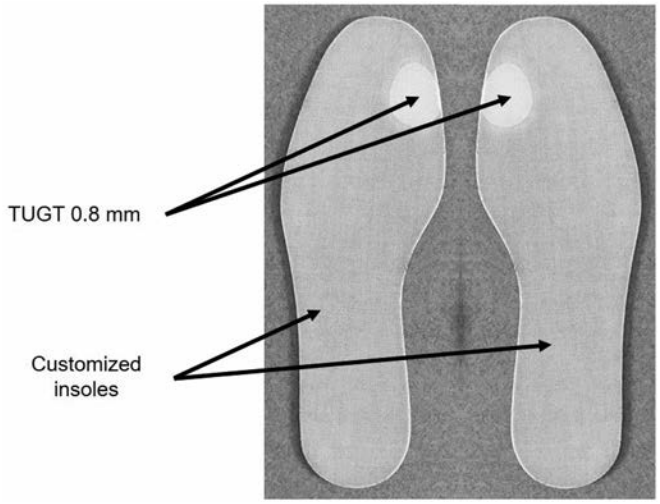

Figure 3. Example of customised postural insoles. The insoles were made of a rigid polyester resin. The hardness was 60 Shore A, and the density was 250 kg/m^3. They had a thickness of 1 mm and their size of the insoles is adapted to the size of the subject's feet. TUGT are inserted in both insoles and positioned exactly under the great toes. TUGT: Thickness under Great Toe.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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