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Effects of experimental insoles on body posture, mandibular kinematics and masticatory muscles activity. A pilot study in healthy volunteers

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ABSTRACT

Background: It has been hypothesized that different plantar sensory inputs could influence the whole body posture and dental occlusion but there is a lack of evidence on this possible association. *Objectives:* To investigate the effects of experimental insoles redistributing plantar pressure on body posture, mandibular kinematics and electromyographic (EMG) activity of masticatory muscles on healthy subjects. *Methods:* A pilot study was conducted on 19 healthy volunteers that wore custom-made insoles normalizing the plantar pressure distribution for 2 weeks. Body posture parameters were measured by means of an optoelectronic stereophotogrammetric analysis; mandibular kinematics was analyzed by means of gothic arch tracings; superficial EMG activity of head and neck muscles was performed. Measurements were carried out 10 days before the insertion of the insoles, immediately before the insertion, the day after, 7 and 14 days after, in four different exteroceptive conditions. *Results:* The outcomes of the present study show that insoles do not modify significantly over time the parameters of body posture, SEMG activity of head and neck muscles and mandibular kinematics. *Conclusions:* In this pilot study the experimental insoles did not significantly influence the body posture, the mandibular kinematics and the activity of masticatory muscles during a 14-day follow up period.

1. Introduction

Body posture is a vital non-volitional motor function based on in-born neural mechanisms that can be defined as the position or attitude of the body (Deliagina et al., 2006). Following the so-called "muscle chains" theory, many studies proposed an influence of dental occlusion on body posture (descending chain theory) (Valentino and Melito, 1991; Valentino et al., 1991, 2002; Tardieu et al., 2009; Perinetti et al., 2010). However, this possible influence remains controversial and essentially undemonstrated (Michelotti et al., 2011; Manfredini et al., 2012; Marini et al., 2013a).

The human foot is a biomechanical structure considered as a functional unit that performs static and dynamic functions: it supports the body weight and propels the body forward in walking and running (Ker et al., 1987; Bramble and Lieberman, 2004). These functions involve the counterbalancing of the gravitational load and maintenance of the body equilibrium, that is dynamic in nature (Wright et al., 2012). Since the physiology of the foot seems to contribute to the postural control with great sensitivity (Wright et al., 2012), some authors proposed also the "ascending chain" theory and they postulated that a disturbance at this level or a different plantar sensory input could influence the whole body posture and dental occlusion (Valentino and Melito, 1991; Valentino et al., 1991, 2002; Chinappi and Getzoff, 1994, 1995, 1996). Literature data provide lacking results about the ascending chain theory since no studies tested this theory with an instrument that recorded the body posture in a measurable and repeatable way.

Although there is not scientific evidence regarding this theory, some chiropractors and some dental practitioners suggest to follow this dental-kinesiologic approach (Chinappi and Getzoff, 1995, 1996; Baldini, 2010; Cuccia, 2011; Fournier et al., 2011; Baldini et al., 2012; Silvestrini-Biavati et al., 2013). In addition, the Internet and the mass media contributed to spread these beliefs, inducing patients to increase the requests of simultaneous treatments for their postural and occlusal or dental disorders.

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Fig. 1. Experimental insoles.

Since previous studies demonstrated that custom-made contoured insoles can change the plantar pressure distribution (Chen et al., 2003; Tsung et al., 2004), the aim of the present study was to investigate the effects of experimental insoles providing a different plantar support on the body posture, the mandibular kinematics and on the activity of head and neck muscles; the null hypothesis is that experimental insoles do not modify body posture, mandibular kinematics and muscular activity.

2. Materials and methods

2.1. Subjects

Sixty student volunteers from the School of Medicine of the "Alma Mater Studiorum" University of Bologna, Italy, were recruited through an information campaign using leaflets. An anamnestic questionnaire was administered to all the volunteers. The same dentist and physiatrist initially evaluated the subjects for their eligibility to the study and an orofacial pain specialist carried out temporomandibular disorders (TMD) evaluation. Inclusion criterion was the presence of the complete dentition (except for third molars). Exclusion criteria were history of spine and lower limbs disorders, vestibular system pathology, flat-feet, claw-feet, hallux valgus, signs and symptoms of TMD, chronic diseases, dental prostheses, headaches and/or other neurological disorders, pregnancy, malignancy, clinically proven conditions of asymmetric lower limbs, scoliosis and whiplash injury in the previous 3 years (Marini et al., 2013b). From the initial group of 60 students, 19 subjects (7 males and 12 females, mean age 22 ± 1.33 years) fulfilling the inclusion and exclusion criteria were enrolled for this study. All participants signed an informed consent form, describing the experimental protocol in detail and informing them that the study could be abandoned at any time. Volunteers did not receive any money reward. The study protocol was approved by the local Institutional Review Board and was carried out in accordance with the Declaration of Helsinki.

2.2. Experimental insoles

Custom-modeled full-length insoles providing accommodative support homogeneously redistributing plantar pressure were manufactured for each participant by the same physiatrist, in order to normalize the foot–ground relationship about the trend of vertical forces at the impact, mid-stance and propulsive phase (Chen et al., 2003; Tsung et al., 2004). The insoles were symmetric, made of a viscoelastic material with a regional differentiation in hardness (heel, arch and metatarsus). The minimum height of all insoles was 1 mm and the maximum height varied among subjects with a maximum value of 18 mm (Fig. 1).

The plantar insoles could fit any kind of shoes. The participants wore them all day throughout the entire period of the experiment (14 days) and at each time point of the study for the measurements using the same gym shoes.

2.3. Optoelectronic stereophotogrammetric description

The optoelectronic stereophotogrammetric system automatically digitizes video signals received from infrared camera detectors and elaborates data in order to reconstruct the position of the reference points previously placed on the target (Mikhail et al., 2001).

For this purpose 26 small plastic reflecting spheres (markers) were placed on the subject's skin at given anatomical points of reference: 13 markers were placed on the frontal part of the body in correspondence of nasion apex (NA), right and left lateral poles of the mandibular condyles (TMJ), menton (ME), right end left acromion apex (AA), xiphoid process (XP), right and left anterior superior iliac spines (ASIS), right and left lateral femoral condyles (LFC), right and left lateral malleoli (LM) and 8 markers on the dorsal part in correspondence of spinous processes of C7, T2, T12, L2, S1 and S3 and right and left posterior superior iliac spines (PSIS) as described in a previous work (Marini et al., 2013a) and in the Figs. 2 and 3.

In order to obtain a full description of the upright body posture a stereophotogrammetric analysis system (EL.I.TE, BTS Spa, Milano, Italy) was used. The system consists of 4 infrared light sources and 4 infrared sensitive cameras located in the corners of the square in which the examination is performed and integrates data deriving from reflecting spheres with superficial electromyography (SEMG) device. These items of equipment were synchronized by means of a common gen-lock signal.

The position of the markers was marked on the skin in semi-permanent ink and renewed at each session, in order to be able to reposition them for the follow-up recordings.

2.4. Study design

Measurements were recorded 10 days before the application of the experimental insoles (T0), just before the insertion of the insoles (T1), the day after (T2), 7 and 14 days thereafter (T3 and T4, respectively). Posture and SEMG measurements were performed under four different exteroceptive conditions (ECs): eyes opened, teeth in maximum intercuspation, lips closed (A); eyes closed, teeth in maximum intercuspation, lips closed (B); eyes opened, teeth not in contact (mandibular rest position), lips closed (C); eyes closed, teeth not in contact (mandibular rest position), lips closed (D). Five complete measurements were performed at each recording session. Fig. 4 describes the study design. The biostatistician who performed the statistical analysis was blind to the aim of the study.

2.5. Mandibular kinematics registration

Alginate impressions of both dental arches of all the subjects were taken (Extrude XP and Wash, Kerr, Orange, CA, USA) before starting the study. A dental technician developed plaster casts (Vel-Mix Stone type IV, Panadent, Colton, CA, USA) and built an acrylic device per participants. The maxillary part of the device, anchored to the upper arch by means of two ball hooks between

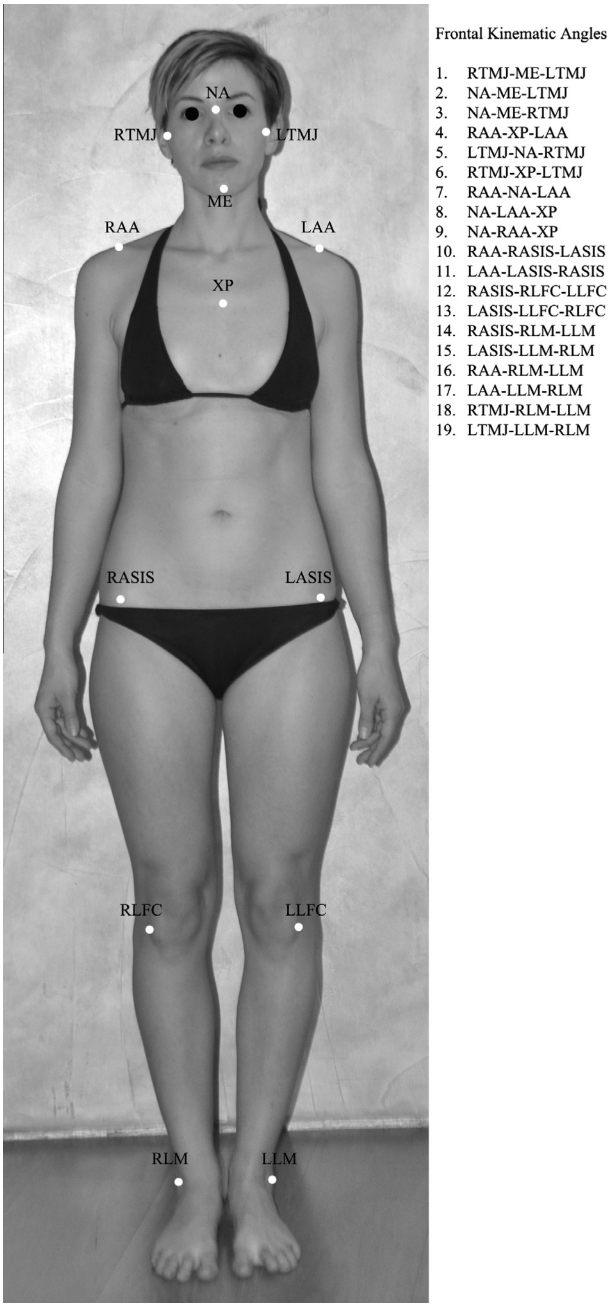

Fig. 2. Frontal body landmarks and angles description.

the bicuspids, covered the palate and had a writing pin inserted in the center of the palatal plate. This pin prevented any contact between opposite teeth during lateral and protrusive excursions. The mandibular device embedded a plate and was anchored by means of 4 ball hooks, two between the bicuspids and two between molars.

The gothic arch tracing resulted from 4 mandibular excursions (protrusion, retrusion, right and left lateral movements) with the maxillary pin writing on the mandibular plate, as previously described (Paixão et al., 2007; Rubel and Hill, 2011).

On the gothic arch tracings 5 points of reference were defined (Fig. 5): the centric position (C), the point of maximum retrusion (R), the point of maximum protrusion (P), the points of maximum right and left excursion (RL and LL). Furthermore on the gothic arch tracing, a perpendicular to R-P through C was traced (A-B). On this tracings 9 measures were performed: the angle between B-C and C-RL segments, the angle between A-C and C-LL segments, the length of the 4 excursions (retrusive, right and left laterotrusive, and protrusive) that are the distance between P-C, R-C, LL-C, RL-C. In addition the distance between C and both mandibular canines was measured in order to control the centric position.

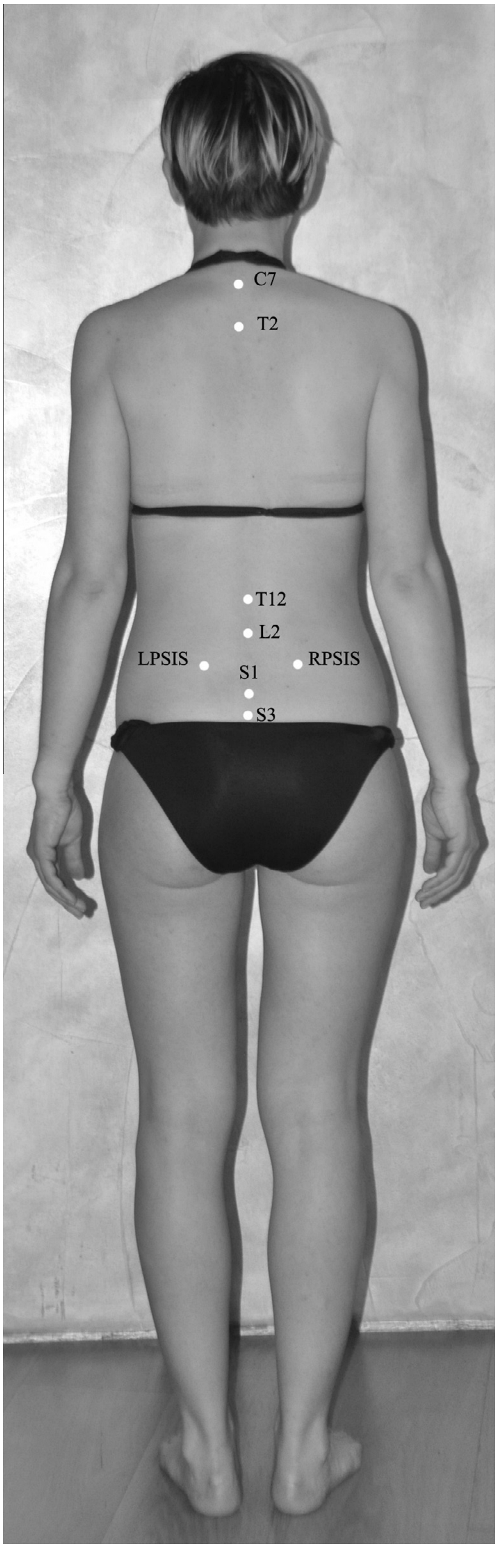

Fig. 3. Dorsal body landmarks description.

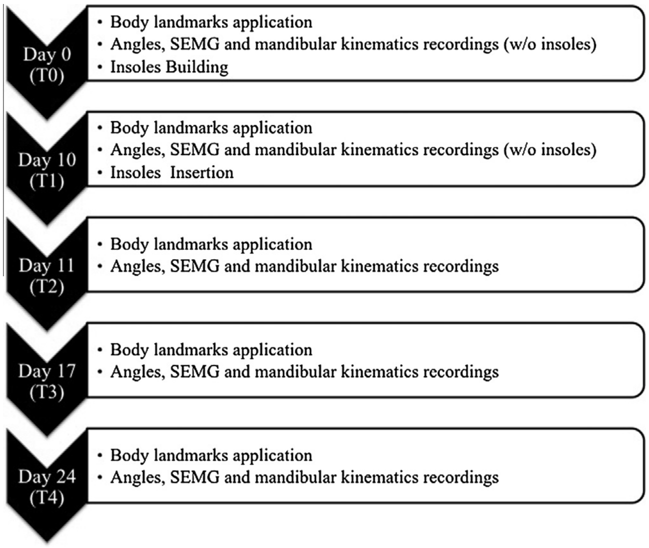

Fig. 4. Study design description.

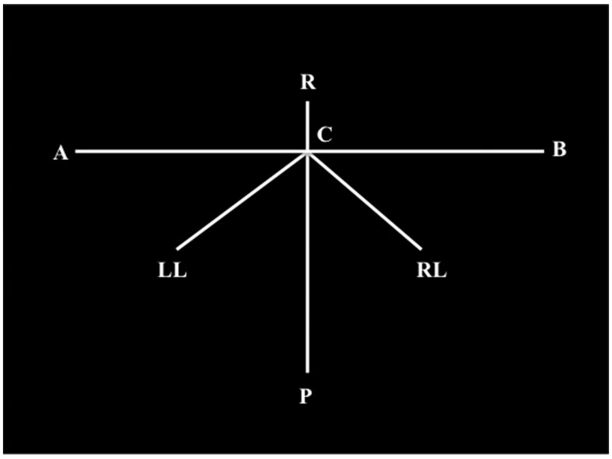

Fig. 5. Gothic arch measurement description.

Five separate arch tracings were performed for each subject at each time point (T0, T1, T2, T3 and T4) and the mean values of each measurement at each time were recorded.

2.6. Posture recordings

The orthostatic body position was recorded 5 times per each EC during each session of the investigation (T0, T1, T2, T3 and T4) with the subject standing in orthostatic posture. The duration of the recordings was 2 s. At each session the mean value of the 5 recordings for each of the 4 ECs was computed. These data were used to calculate a set of 19 frontal morphological angles: (Fig. 1) and 4 sagittal morphological parameters: C7-S3 distance, kyphosis, lordosis and sacral angle. The kyphosis angle was computed between the segment C7-T2 and the segment T12-L2; the lordosis angle was computed between the segment T12-L2 and the segment S1-S3; the sacral angle was computed between a true vertical straight line and a straight line going through the midpoint between anterior superior iliac spines and the midpoint between the posterior superior iliac spines. All angles were digitally calculated by means of the EL.I.TE software on the basis of the position of the reflecting spheres.

Table 1
Influence of experimental insoles on frontal and sagittal angles, mandibular kinematics and muscular activity (results of generalized linear model for repeated measures).

	Parameter (*p*=)	Time (*p*=)	EC (*p*=)
Frontal angles	0.001*	0.588	0.341
Sagittal angles	0.001*	0.047*	0.992
SEMG activity of right muscles	0.001*	0.320	0.001*
SEMG activity of left muscles	0.001*	0.291	0.001*
Gothic arch measurements (normalized data)	0.990	0.990	//

* Statistically significant.

2.7. SEMG recordings

In order to verify a possible influence of the insoles on the activity of masticatory muscles, SEMG evaluations were performed bilaterally on the anterior belly of temporalis muscle and on the central portion of the masseter, of the sternocleidomastoid (SCM) and of the *trapezius descendens* (upper), 5 times for each EC during each session of the study. The electrodes were positioned following the Surface Electromyography for non-invasive assessment of muscles (SENIAM) protocol (Hermens et al., 1999). After skin preparation with ethanol SEMG activity was recorded with a TELEMG 8 channel electromyograph (BTS Spa, Milano, Italy), using standard clip-type adhesive pre-gelled disposable bipolar silver-silver chloride electrodes (MediTrace, Kendall LTP, MA, USA). The diameter of the electrodes was 10 mm, the inter-electrode distance was 22 mm and the input impedance was 1×10^6 Ohm. The EMG signals were recorded and digitized at sampling rate of 1000 Hz. They were pre-amplified and transmitted to the main unit via the telemetry system. The pass band filter of the data logger amplifier was set to obtain a 10–500 Hz bandwidth. In addition the SEMG signals were notch filtered 50 Hz and rectified. A zero-lag forward and backward fourth order Butterworth low-pass filter (6 Hz cut off frequency) has been used to extract the linear envelope from the rectified SEMG signal. At each session the mean value of the 5 recordings for each of the 4 ECs was computed.

2.8. Statistical analysis

A sample size of 19 subjects was chosen for this longitudinal pilot study (Julious, 2005). Kolmogorov–Smirnov test ascertained that the distribution of some parameters was significantly different from the Gaussian. The median and interquartile ranges were used to describe the data. To control the effect of dominance, separate analysis were performed for right and left sides concerning muscles. A generalized linear model for repeated measures was used; for this analysis raw data of gothic arch parameters were transformed in unit of standard deviation (z-value) aiming to control the difference in magnitude of the measures. On the basis of significance of the M Box test, Tamhane (T2) post hoc test was performed. Intra-subject variability was controlled comparing all measurements recorded at T0 and T1 by using Wilcoxon test for paired data. Friedman test was applied in order to verify if the experimental insoles could influence the measured parameters over time and for each EC. When the differences among the time points were statistically significant, post hoc analysis with Wilcoxon test for paired data with a Bonferroni correction applied was carried out in order to test the differences between T1 and each of the other time points. α level was a priori set at 0.05.

A repeatability analysis was performed between data sets collected at T0 and T1 in all ECs using intraclass correlation coefficient (ICC) to quantify random errors. As reported in electronic tables, for frontal and sagittal angles and for SEMG parameters the values

Table 2
Influence of time on frontal morphological angles for exteroceptive condition A (eyes opened, teeth in contact, lips closed). All data are reported as median and interquartile range.

Angle	T1	T2	T3	T4	p=
RTMJ-Menton-LTMJ	72.8(68.6–75.2)	72.2(69.1–74.5)	70.9(67.5–73.6)	73.0(70.2–74.1)	0.368
NA-Menton-LTMJ	58.7(56.9–60.1)	58.2(57.0–59.7)	58.3(56.6–59.7)	57.9(57.1–59.5)	0.911
NA-Menton-RTMJ	58.0(56.1–59.4)	57.2(55.5–58.8)	57.4(54.4–59.7)	57.2(56.0–58.2)	0.623
RAA-XP-LAA	146.2(142.7–156.6)	148.8(140.8–158.9)	147.9(140.6–160.1)	153.6(144.5–158.3)	0.609
LTMJ-NA-RTMJ	76.8(75.1–80.4)	77.8(76.1–80.7)	78.2(72.3–79.6)	77.9(76.6–80.3)	0.397
RTMJ-XP-LTMJ	45.4(43.7–47.3)	46.0(43.9–47.1)	45.9(43.3–47.4)	45.7(43.8–46.7)	0.166
RAA-NA-LAA	69.3(66.4–71.8)	69.7(66.3–72.3)	68.8(64.5–71.5)	69.4(65.5–70.7)	0.328
NA-LAA-XP	54.0(50.2–56.3)	51.2(48.5–55.2)[^]	52.7(49.1–54.6)	52.2(49.1–55.6)	0.002[*]
NA-RAA-XP	56.0(53.2–57.6)	53.5(52.4–58.1)	54.9(53.5–57.2)	55.7(54.2–57.9)	0.543
RAA-RASIS-LASIS	95.2(92.9–96.4)	95.1(93.2–97.2)	95.7(93.2–98.1)	95.7(94.4–96.6)	0.730
LAA-LASIS-RASIS	94.7(93.2–95.7)	95.4(94.5–97.2)	95.2(92.6–96.5)	94.4(93.2–95.4)	0.195
RASIS-RLFC-LLFC	93.5(91.4–95.7)	92.9(91.8–95.5)	93.5(90.6–94.5)	93.6(91.8–94.6)	0.562
LASIS-LLFC-RLFC	92.4(90.9–94.3)	92.5(90.1–94.4)	91.6(89.8–94.2)	91.6(90.9–93.7)	0.852
RASIS-REM-LEM	89.7(89.1–92.3)	90.0(88.7–91.2)	89.3(88.4–90.5)	89.4(88.8–90.4)	0.079
LASIS-LLM-RLM	89.4(88.4–91.2)	90.8(89.6–92.0)	90.5(89.0–91.6)	90.4(89.1–91.8)	0.562
RAA-REM-LLM	91.5(90.5–93.7)	91.8(90.7–92.4)	90.9(90.2–92.1)	90.9(89.9–92.0)	0.167
LAA-LLM-RLM	91.7(89.9–92.3)	92.7(91.2–93.7)	92.1(90.7–92.7)	92.2(91.3–93.4)	0.145
RTMJ-RLM-LLM	87.9(87.1–89.8)	88.2(86.9–88.4)	87.5(86.8–88.5)	87.2(86.6–87.8)	0.163
LTMJ-LLM-REM	87.6(85.9–88.3)	88.5(87.4–89.2)	88.2(86.5–89.0)	88.3(87.2–89.2)	0.175

RTMJ = right temporomandibular joint; RAA = right acromion apex; LTMJ = left temporomandibular joint; NA = nasion apex; XP = xiphoid process; LAA = left acromion apex; RASIS = right anterior posterior iliac spine; LASIS = left anterior posterior iliac spine; RLFC = right lateral femoral condyle; LLFC = left lateral femoral condyle; RLM = right lateral malleolus; LLM = left lateral malleolus.

[*] Significant difference among time points (Friedman test).

[^] Significantly different from T1 (Wilcoxon test).

Table 3
Influence of time on frontal morphological angles for exteroceptive condition B (eyes closed, teeth in contact, lips closed). All data are reported as median and interquartile range.

Angle	T1	T2	T3	T4	p=
RTMJ-Menton-LTMJ	72.6(68.7–75.2)	72.9(69.9–74.9)	71.6(67.2–74.8)	73.0(70.2–74.3)	0.277
NA-Menton-LTMJ	58.9(57.4–59.7)	58.4(57.2–59.6)	58.3(57.2–60.1)	57.7(56.8–58.9)	0.588
NA-Menton-RTMJ	58.4(53.9–59.1)	57.7(55.3–58.9)	58.2(55.1–59.4)	56.9(55.6–58.0)	0.588
RAA-XP-LAA	147.0(145.4–155.9)	148.5(142.2–159.8)	148.2(140.4–161.5)	154.6(146.2–157.5)	0.601
LTMJ-NA-RTMJ	77.4(75.2–80.9)	78.9(75.9–81.0)	76.1(74.0–79.6)	77.9(77.0–79.9)	0.166
RTMJ-XP-LTMJ	45.0(43.6–47.5)	45.9(43.9–47.3)	45.7(43.8–47.4)	45.6(44.0–46.9)	0.454
RAA-NA-LAA	69.0(66.7–71.9)	70.5(67.0–72.8)	68.8(65.4–71.2)	69.2(65.4–71.1)	0.241
NA-LAA-XP	53.9(49.4–56.5)	51.2(48.5–54.8)[^]	52.3(49.0–54.8)[^]	52.5(48.9–55.7)	0.002[*]
NA-RAA-XP	55.1(52.7–58.2)	53.7(52.9–57.8)	55.2(53.2–57.0)	55.2(54.0–57.0)	0.697
RAA-RASIS-LASIS	95.4(93.1–96.6)	95.2(94.1–97.3)	95.7(94.0–98.2)	95.6(94.4–96.8)	0.465
LAA-LASIS-RASIS	94.4(93.3–95.6)	95.5(95.0–96.6)	95.2(92.7–96.3)	94.5(93.3–95.4)	0.044[*]
RASIS-RLFC-LLFC	93.6(91.5–95.5)	93.3(92.0–95.3)	93.5(91.1–94.5)	93.6(92.3–94.7)	0.715
LASIS-LLFC-RLFC	92.2(90.7–94.6)	92.6(89.7–94-2)	91.3(90.4–94.2)	91.8(90.6–93.7)	0.791
RASIS-RLM-LLM	89.8(89.6–92.3)	90.0(88.9–90.8)	89.4(88.5–90.5)	89.5(88.6–90.5)	0.069
LASIS-LLM-RLM	89.5(88.7–91.1)	90.8(89.3–92.0)	90.5(88.7–91.5)	90.4(89.1–91.8)	0.601
RAA-RLM-LLM	91.6(90.5–93.6)	91.8(90.6–92.3)	90.9(90.1–92.2)	90.7(89.5–92.1)	0.312
LAA-LLM-RLM	91.7(89.8–92.4)	92.4(91.1–93.4)	92.1(90.8–92.6)	92.2(91.5–93.4)	0.113
RTMJ-RLM-LLM	87.8(87.0–89.7)	87.9(87.0–88.6)	87.5(86.8–88.8)	87.3(86.2–88.2)	0.254
LTMJ-LLM-RLM	87.6(86.1–88.3)	88.4(87.3–89.3)	88.2(86.4–89.0)	88.2(87.4–89.3)	0.195

RTMJ = right temporomandibular joint; RAA = right acromion apex; LTMJ = left temporomandibular joint; NA = nasion apex; XP = xiphoid process; LAA = left acromion apex; RASIS = right anterior posterior iliac spine; LASIS = left anterior posterior iliac spine; RLFC = right lateral femoral condyle; LLFC = left lateral femoral condyle; RLM = right lateral malleolus; LLM = left lateral malleolus.

[*] Significant difference among time points (Friedman test).

[^] Significantly different from T1 (Wilcoxon test).

of ICC are statistically significant ($p = 0.001$). The high values of ICC guarantee the repeatability of the measurements.

3. Results

No significant differences were observed in any of the analyzed parameters comparing the intrasubject values before the application of the experimental insoles (T0 and T1). The results of the generalized linear model are shown in Table 1. Concerning the frontal morphological parameters no significant differences were observed among the conditions and across the times, but only among the 19 angles ($p = 0.001$). Tables 2–5 report the results of Friedman test showing the influence of time on frontal parameters for all the ECs.

Regarding the sagittal angles, no significant differences were observed among the conditions, but among times ($p = 0.047$) and angles ($p = 0.0001$) according to the generalized linear model; these results were confirmed by Tamhane post hoc tests except for kyphosis and lordosis angles that did not significantly differ. Table 6 reports the influence of time on sagittal parameters for each EC resulting from Friedman test showing significant difference among time points only for lordosis angle in EC C; Wilcoxon test did not find any difference between T1 and any other time point.

Concerning SEMG activity, significant differences were found for muscles and ECs, but not among times both on the right and left sides. Table 7 reports the results of Friedman test showing the influence of time on SEMG activity for each EC. Significant differences were found only for the right temporalis muscle in ECs A, B and C; Wilcoxon test showed significant differences only in EC A between T3 and T1 and between T4 and T1.

Mandibular kinematics analysis revealed no significant differences neither among time points ($p = 0.99$) nor the examined

Table 4
Influence of time on frontal morphological angles for exteroceptive condition C (eyes opened, teeth not in contact, lips closed). All data are reported as median and interquartile range.

Angle	T1	T2	T3	T4	p=
RTMJ-Menton-LTMJ	72.9(68.5–76.0)	73.1(69.6–75.3)	72.4(69.2–74.0)	73.1(70.9–76.0)	0.730
NA-Menton-LTMJ	58.5(56.7–59.5)	59.2(57.1–60.3)	58.9(56.6–60.7)	58.0(56.8–59.4)	0.536
NA-Menton-RTMJ	57.7(54.4–59.1)	57.9(55.3–59.8)	57.7(56.6–59.7)	57.2(55.3–58.7)	0.657
RAA-XP-LAA	146.7(146.0–158.3)	148.4(141.9–157.9)	147.4(139.9–159.6)	154.5(147.4–158.9)	0.373
LTMJ-NA-RTMJ	79.5(75.1–81.2)	77.1(76.2–79.8)	76.9(72.6–81.1)	78.0(76.5–80.3)	0.549
RTMJ-XP-LTMJ	45.6(43.8–47.0)	46.2(43.9–47.7)	45.6(44.0–47.4)	46.1(44.2–47.1)	0.247
RAA-NA-LAA	69.4(66.9–72.0)	70.3(65.9–72.5)	68.8(65.5–72.0)	69.3(66.2–71.2)	0.217
NA-LAA-XP	54.0(50.4–56.6)	51.9(48.5–55.5)[^]	51.5(50.1–55.4)	52.2(49.7–55.8)	0.012[*]
NA-RAA-XP	55.5(52.2–59.0)	54.3(52.2–57.5)	55.5(54.1–57.3)	55.1(54.5–56.1)	0.730
RAA-RASIS-LASIS	95.2(92.9–96.2)	95.2(93.8–97.3)	95.6(93.6–97.8)	95.5(94.7–97.0)	0.281
LAA-LASIS-RASIS	94.6(93.5–95.7)	95.5(94.8–96.7)	95.1(93.1–96.3)	94.5(93.3–95.5)	0.025[*]
RASIS-RLFC-LLFC	93.5(91.5–95.5)	92.8(92.0–95.5)	93.4(91.0–94.5)	93.9(92.9–94.6)	0.465
LASIS-LLFC-RLFC	92.1(91.1–94.3)	92.5(89.4–94.2)	91.2(90.5–94.2)	91.8(90.5–93.2)	0.992
RASIS-RLM-LLM	89.8(89.6–92.2)	89.8(89.0–90.9)	89.3(88.4–90.6)[^]	89.5(89.0–90.6)	0.008[*]
LASIS-LLM-RLM	89.5(88.4–91.1)	91.0(89.2–91.6)	90.4(89.0–91.6)	90.5(89.3–91.8)	0.643
RAA-RLM-LLM	91.6(90.4–94.5)	91.8(90.6–92.2)	90.7(90.2–92.1)	90.6(89.8–92.0)	0.363
LAA-LLM-RLM	91.7(90.4–92.4)	92.5(91.2–93.3)	92.1(91.0–92.6)	92.0(91.4–93.5)	0.213
RTMJ-RLM-LLM	87.8(87.0–89.6)	88.1(87.0–88.7)	87.3(86.8–88.7)	87.2(86.5–88.0)	0.205
LTMJ-LLM-RLM	87.7(86.3–88.4)	88.4(87.4–89.1)	88.1(86.6–89.1)	88.3(87.1–89.5)	0.500

RTMJ = right temporomandibular joint; RAA = right acromion apex; LTMJ = left temporomandibular joint; NA = nasion apex; XP = xiphoid process; LAA = left acromion apex; RASIS = right anterior posterior iliac spine; LASIS = left anterior posterior iliac spine; RLFC = right lateral femoral condyle; LLFC = left lateral femoral condyle; RLM = right lateral malleolus; LLM = left lateral malleolus.

[*] Significant difference among time points (Friedman test).

[^] Significantly different from T1 (Wilcoxon test).

Table 5
Influence of time on frontal morphological angles for exteroceptive condition D (eyes closed, teeth not in contact, lips closed). All data are reported as median and interquartile range.

Angle	T1	T2	T3	T4	*p*=
RTMJ-Menton-LTMJ	72.6(70.0–74.9)	72.7(69.7–74.7)	71.4(68.1–73.6)	72.7(67.8–74.2)	0.345
NA-Menton-LTMJ	57.5(56.5–59.5)	57.6(56.4–59.2)	57.9(55.8–60.1)	56.7(55.5–57.9)	0.141
NA-Menton-RTMJ	57.0(54.5–58.7)	57.1(55.0–59.0)	57.0(54.1–58.9)	55.9(54.5–57.5)	0.363
RAA-XP-LAA	147.6(145.4–156.8)	148.1(140.3–158.6)	148.3(141.4–159.6)	155.3(145.0–157.8)	0.643
LTMJ-NA-RTMJ	78.1(75.2–81.2)	78.3(76.3–80.2)	76.3(72.9–80.7)	78.1(77.2–79.8)	0.274
RTMJ-XP-LTMJ	45.1(43.7–47.3)	45.5(44.0–47.6)	45.8(44.0–47.4)	45.9(44.2–46.7)	0.643
RAA-NA-LAA	69.8(66.3–71.3)	70.3(65.6–72.0)	68.6(65.6–70.8)	68.8(66.1–70.8)	0.643
NA-LAA-XP	54.5(49.2–56.7)	51.8(58.9–55.6)[^]	52.3(50.0–55.5)	52.2(49.6–56.1)	0.010[*]
NA-RAA-XP	55.6(53.0–57.7)	53.8(53.2–58.1)	55.6(53.7–57.4)	55.1(54.1–57.4)	0.382
RAA-RASIS-LASIS	94.8(93.1–96.3)	94.9(93.8–97.5)	95.8(93.7–98.1)	95.7(94.5–96.9)	0.363
LAA-LASIS-RASIS	94.4(93.6–95.8)	95.4(94.6–97.0)	95.1(92.8–96.2)	94.4(93.6–95.1)	0.073
RASIS-RLFC-LLFC	93.6(91.7–95.8)	93.1(91.9–95.6)	93.3(91.3–94.6)	93.9(93.0–94.7)	0.296
LASIS-LLFC-RLFC	92.2(90.7–94.6)	92.6(89.4–94.2)	91.1(90.5–94.5)	92.0(90.8–93.8)	0.776
RASIS-RLM-LLM	89.9(89.3–92.1)	72.7(69.7–74.7)[^]	89.3(88.5–90.4)[^]	89.4(89.0–90.7)	0.001[*]
LASIS-LLM-RLM	89.6(88.6–91.4)	90.8(89.6–91.8)	90.5(88.6–91.6)	90.4(89.5–91.6)	0.518
RAA-RLM-LLM	91.5(90.3–93.3)	92.0(90.6–92.3)	90.8(90.3–92.0)	90.6(89.8–91.9)	0.337
LAA-LLM-RLM	91.8(90.6–92.5)	92.4(91.2–93.2)	92.3(90.8–92.6)	92.3(91.5–93.4)	0.141
RTMJ-RLM-LLM	87.8(87.0–89.5)	88.2(87.0–88.7)	87.5(86.9–88.6)	87.3(86.6–87.8)	0.267
LTMJ-LLM-RLM	87.7(86.6–88.6)	88.3(87.6–89.2)	88.1(86.6–88.9)	88.3(87.1–89.5)	0.337

RTMJ = right temporomandibular joint; RAA = right acromion apex; LTMJ = left temporomandibular joint; NA = nasion apex; XP = xiphoid process; LAA = left acromion apex; RASIS = right anterior posterior iliac spine; LASIS = left anterior posterior iliac spine; RLFC = right lateral femoral condyle; LLFC = left lateral femoral condyle; RLM = right lateral malleolus; LLM = left lateral malleolus.

[*] Significant difference among time points (Friedman test).

[^] Significantly different from T1 (Wilcoxon test).

parameters ($p = 0.99$). Table 8 reports the results of Friedman test for the influence of time on gothic arch tracings.

4. Discussion

The present study presents a new protocol for the evaluation of the possible effects of a different plantar sensory input on body posture changes. In a previous study the same device was used in order to evaluate the effects of an experimental occlusal interference on body posture (Marini et al., 2013a). Since Maeda and coworkers showed that experimental leg length discrepancies can affect body posture and dental occlusion (Maeda et al., 2011), in this investigation custom-made insoles were used in order to verify the postural effects of a standardized plantar support without reproducing a pathological condition performing asymmetrical disturbance.

The integrated system of optoelectronic stereophotogrammetric analysis and SEMG, together with the gothic arch tracing and the study design, represent a consistent way of approaching to this field. The accuracy of the proposed protocol was tested using the generalized cross validatory splines algorithm (GCVC) that is the best known and effective automatic algorithm for smoothing biomechanical data. The test performed has shown that the overall accuracy of the software proposed was superior or similar to GCVC, while the time spent for computation was higher for the latter; moreover the new software is virtually insensible to the number of samples, allowing the computation of the derivatives for short

Table 6
Influence of time on sagittal morphological parameters for all exteroceptive conditions. All data are reported as median and interquartile range.

Angle	EC	T1	T2	T3	T4	*p*=
C7-S3 distance	A	33.8(25.2–42.0)	36.2(21.5–44.0)	33.5(19.9–40.9)	33.9(13.9–40.9)	0.194
	B	34.9(27.2–43.6)	36.3(22.9–45.5)	35.2(20.7–47.3)	32.8(17.0–45.9)	0.312
	C	31.3(17.7–45.1)	37.2(23.0–45.9)	37.3(18.1–44.8)	31.5(15.8–48.2)	0.651
	D	34.9(24.0–47.4)	38.6(18.7–44.5)	33.5(21.7–42.1)	34.8(9.3–44.8)	0.225
Kyphosis	A	43.4(36.5–49.6)	43.2(34.5–47.8)	41.0(33.8–47.2)	40.2(31.6–48.4)	0.518
	B	45.1(35.2–49.3)	42.1(37.1–46.4)	41.1(35.8–48.1)	40.2(31.0–50.1)	0.216
	C	42.6(35.8–51.6)	43.2(38.4–48.1)	40.8(34.3–46.2)	41.9(32.8–48.2)	0.516
	D	42.2(37.2–50.2)	44.5(33.2–48.7)	44.9(33.3–49.9)	42.1(32.0–46.7)	0.341
Lordosis	A	41.5(33.5–50.8)	43.0(34.8–49.3)	41.9(35.9–51.0)	42.0(37.3–51.8)	0.229
	B	42.1(32.6–50.0)	41.7(34.5–47.5)	46.3(38.4–50.8)	42.6(37.7–52.7)	0.061
	C	40.7(33.9–49.7)	43.2(34.5–48.6)	42.4(37.5–51.5)	43.2(38.0–51.0)	0.029*
	D	41.0(34.5–48.9)	42.1(33.0–49.2)	44.2(33.4–49.3)	43.7(39.6–51.0)	0.427
Sacral angle	A	20.1(16.0–27.8)	20.7(15.4–26.0)	21.6(18.2–27.2)	22.5(19.6–27.3)	0.325
	B	20.4(14.9–27.9)	20.6(16.0–25.2)	23.1(18.1–27.6)	21.7(18.7–26.7)	0.092
	C	21.0(15.7–26.7)	19.6(15.6–23.4)	22.6(17.7–27.4)	21.0(19.4–27.1)	0.124
	D	22.7(17.6–26.7)	20.3(16.4–24.5)	21.3(17.1–26.6)	23.1(20.5–26.2)	0.131

EC = exteroceptive condition.
* Significant difference among time points (Friedman test).

Table 7
Influence of time on SEMG parameters (μV) for all exteroceptive conditions. All data are reported as median and interquartile range.

Muscle	EC	T1	T2	T3	T4	*p*=
Right temporalis	A	18.9(12.1–32.7)	23.8(11.3–48.1)	25.3(179–35.8)^	26.8(20.2–47.3)^	0.006*
	B	19.3(12.6–28.0)	20.0(10.7–29.8)	21.5(15.7–28.8)	28.8(14.6–41.0)	0.009*
	C	16.7(8.1–32.9)	7.9(6.5–19.1)	23.8(9.4–33.4)	8.4(7.0–24.0)	0.013*
	D	11.9(10.0–18.8)	10.4(9.7–12.3)	10.6(9.6–13.5)	13.4(10.3–16.5)	0.896
Left temporalis	A	18.4(15.5–30.7)	20.6(15.0–29.7)	26.3(20.5–38.3)	25.4(18.2–34.4)	0.141
	B	20.5(18.6–26.0)	22.3(16.6–28.1)	22.5(16.4–30.0)	24.7(20.0–32.3)	0.073
	C	14.0(7.4–28.3)	9.6(7.2–26.7)	8.2(7.0–15.8)	7.8(7.1–16.3)	0.637
	D	14.3(10.9–20.1)	12.0(10.5–20.4)	11.0(10.5–17.1)	13.8(10.3–18.2)	0.896
Right masseter	A	10.5(9.7–15.6)	13.6(9.5–24.8)	11.6(9.7–18.3)	11.4(9.5–17.4)	0.465
	B	11.4(9.9–17.6)	14.5(10.4–19.5)	10.2(9.2–13.0)	10.4(9.9–18.1)	0.079
	C	12.6(8.7–36.2)	19.8(8.2–33.3)	9.6(6.4–20.5)	13.0(7.9–20.5)	0.549
	D	10.1(9.9–12.7)	9.9(8.9–11.3)	10.0(8.3–12.8)	9.9(8.8–16.7)	0.673
Left masseter	A	10.0(9.7–14.5)	11.8(9.1–22.8)	11.3(10.1–15.7)	10.0(8.9–16.2)	0.730
	B	10.6(9.4–18.7)	10.9(9.8–18.3)	9.7(9.0–13.2)	10.0(9.8–18.3)	0.488
	C	11.4(7.4–39.9)	11.8(6.5–38.7)	24.4(10.0–40.0)	8.8(7.5–18.2)	0.443
	D	10.1(9.0–11.6)	9.8(8.4–10.6)	9.8(7.4–10.4)	9.9(9.4–13.0)	0.551
Right SCM	A	9.6(8.9–10.2)	9.2(7.8–10.0)	9.5(7.7–10.0)	9.1(8.5–9.9)	0.990
	B	9.8(9.0–10.0)	9.9(8.9–10.1)	9.1(7.5–10.0)	9.8(8.9–10.1)	0.328
	C	16.4(11.2–22.2)	16.1(12.0–21.7)	14.8(11.3–19.4)	15.7(10.4–24.0)	0.126
	D	10.0(9.3–10.5)	9.8(8.4–10.2)	9.7(8.4–10.2)	9.7(8.5–10.4)	0.651
Left SCM	A	8.8(8.1–9.7)	9.3(8.0–11.1)	8.9(8.0–9.6)	8.5(7.5–10.0)	0.911
	B	9.5(8.7–10.1)	9.6(8.6–10.1)	9.1(7.8–10.0)	9.1(7.7–10.7)	0.882
	C	12.3(10.6–26.1)	14.9(11.5–18.6)	13.9(11.5–24.3)	18.3(11.3–20.9)	0.671
	D	9.7(9.4–10.3)	9.5(8.9–10.1)	9.8(8.5–10.1)	9.4(8.2–10.3)	0.250
Right trapezius	A	20.6(10.0–45.0)	15.8(10.0–30.9)	31.0(11.4–53.2)	30.2(10.2–54.7)	0.791
	B	20.2(10.4–42.3)	20.8(11.4–36.6)	30.2(13.7–48.9)	20.5(10.0–42.6)	0.822
	C	13.9(9.3–30.3)	13.2(9.6–31.8)	27.3(10.5–49.0)	25.1(10.2–49.6)	0.064
	D	24.0(9.9–27.8)	23.2(9.5–40.5)	30.0(10.8–45.5)	28.8(10.5–49.0)	0.422
Left trapezius	A	18.7(13.5–39.6)	13.2(6.5–27.3)	17.6(4.3–31.2)	11.7(1.8–26.5)	0.116
	B	30.3(13.7–47.1)	12.0(6.1–25.8)	12.9(5.7–28.8)	10.4(3.0–2.7)	0.120
	C	20.3(15.8–34.6)	11.6(4.8–25.0)	15.4(2.5–29.6)	10.0(2.0–25.8)	0.588
	D	25.5(17.9–36.7)	10.6(4.0–24.7)	12.0(2.9–30.8)	11.9(5.0–24.2)	0.609

EC = Exteroceptive condition.
* Significant difference among time points (Friedman test).
^ Significantly different from T1 (Wilcoxon test).

Table 8
Influence of time on gothic arch measurements (mm). All data are reported as median and interquartile range.

Measurement	T1	T2	T3	T4	*p*=
A-C-LL angle	20.2(13.5–25.2)	14.9(3.9–24.3)	15.0(6.7–25.0)	17.7(6.7–24.5)	0.791
B-C-RL angle	21.0(13.7–27.2)	23.5(11.2–28.5)	20.5(10.5–27.0)	19.0(11.5–27.4)	0.312
Protrusion	35.5(32.1–42.8)	35.0(31.2–37.5)	35.3(27.9–38.2)	35.4(32.6–42.6)	0.110
Right laterotrusion	33.4(29.5–36.8)	33.2(28.9–36.4)	31.9(26.8–36.8)	31.9(25.4–37.1)	0.064
Left laterotrusion	37.4(32.6–40.2)	35.9(28.9–40.6)	33.8(27.8–43.4)	32.6(28.5–39.3)	0.126
Retrusion	1.3(0.9–1.6)	1.0(0.7–1.4)	1.2(0.9–1.6)	1.4(1.2–1.6)	0.086
C-Left canine distance	51.5(46.3–55.0)	53.2(49.3–56.7)	57.6(48.9–62.0)	52.9(47.4–59.1)	0.075
C-Right canine distance	56.0(53.2–60.7)	57.8(52.8–62.7)	56.1(53.3–60.6)	56.0(52.8–61.5)	0.177

data records (less than 40 samples) (D'Amico and Ferrigno, 1992). The accuracy of the proposed protocol for the angles measurements was tested in comparison with X-ray measurements (D'Amico and Vallasciani, 1997) and the sagittal angles evaluation, obtained by measuring skin markers resulted stable, since it allows to overcome the differences, due to morphological factors, that emerge with X-ray measurements (Bryant et al., 1989).

In our opinion the great number of data achieved (3300 measurements per subject) strengthen the relevance of the study. In addition the length of follow up (14 days) represents a strength that guarantees the evaluation of a possible adaptation of body posture to perturbations (Perinetti and Contardo, 2009). Moreover, two complete sets of recordings without experimental insoles were carried out (T0 and T1) to have an intra-individual control.

No previous studies investigated the influence of a different sensory plantar input on mandibular kinematics; only few studies investigated the effects of plantar arch perturbations on SEMG activity of masticatory muscles (Valentino and Melito, 1991; Valentino et al., 1991, 2002; Ciuffolo et al., 2006) but without follow up.

The outcomes of the present study suggest that the insertion of full-length viscoelastic plantar insoles that provide plantar pressure redistribution does not induce neither postural changes nor mandibular kinematics modifications in young healthy volunteers.

The generalized linear model does not show significant changes over time for frontal angles, SEMG activity and gothic arch measurements but only for sagittal angles on the limits of statistical significance ($p = 0.047$). The Friedman test performed among time points and post hoc analysis show that no significant long-term changes for both frontal and sagittal angles were found. The only differences emerged between T1 and T2 or T1 and T3, not between T1 and T4. Therefore the significant data found with the generalized linear model have been analyzed with inferential statistics over time showing that they are not experimentally relevant since no significant differences resulted between T1 and T4. A postural adaptation over time could be hypothesized.

The angles analyzed were chosen since they permitted to appreciate possible changes affecting the main joints that could modify body balance.

SEMG activity over time did not show significant changes while the ECs influenced muscle activity significantly. This result could be considered the consequence of the movement of the mandible from rest position to intercuspation in different ECs and is in accordance with the study by Marini et al. (2013a).

Gothic Arch Tracings did not reveal any significant difference over time for all the analyzed parameters. This showed that experimental insoles do not influence mandibular kinematics. Some studies analyzed mandibular kinematics using optoelectronic techniques (Ferrario et al., 2005; Sforza et al., 2010; De Felício et al., 2013); since literature provides evidence supporting the reliability and reproducibility of gothic arch tracing in registering mandibular position (Paixão et al., 2007; Rubel and Hill, 2011; Linsen et al., 2013), in the present investigation it was performed being the authors more confident with this procedure.

The main limitation of the present pilot study is the small sample size; so further investigations with a sample size calculation based on the present data would be needed in order to verify the present results. Moreover a SEMG analysis extended to other groups of muscles would have been useful to evaluate possible modifications in other districts induced by the insoles. Finally, despite the subjects were instructed to wear the insoles all day long, the present protocol did not take into consideration the exact amount of time the feet were in functional contact with the insoles, since the usual activities of the subjects were not registered.

Despite scientific literature lacks methodologically sound studies endorsing the ascending chain theory, the media promote the possibility to treat postural and occlusal impairments on the basis of this theory; consequently, patients increase the request of such treatments.

It is important to remark that the present study evaluated the influence of insoles on body posture and mandibular kinematics in healthy volunteers, so the results could not be transferred to clinical conditions. However the present outcomes should promote new methodologically valid research aiming to investigate possible effects of a plantar disturbance on dental occlusion and body posture. Therefore, further investigations are needed to verify the effects of insoles on clinical conditions and in our opinion until then, practitioners should take a prudent attitude performing clinical treatments based on the "ascending chain" theory since scientific evidence is lacking.

In conclusion, the outcomes of the present longitudinal investigation showed that experimental insoles do not modify body posture, SEMG activity of head and neck muscles, and mandibular kinematics over time in healthy volunteers.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jelekin.2015.02.001.

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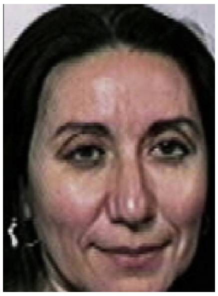

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