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CAN A THIN MECHANICAL STIMULATION ON THE PLANTAR ARCH AFFECT ON THE HEAD MOBILITY?

ABSTRACT

Background: Successfully controlling head posture demands the integration of sensory information arising from different receptors. Of particular interest is the influence of feet mechanoreceptors on the control of head position in space. Here we therefore ask whether a thin, plantar insert can modify the Range of Motion (RoM) of the head. Of our further interest is testing for whether changes in RoM depend on the foot site where the insoles are positioned.

Methods: Twenty-four healthy subjects were randomly assigned to either experimental or control group. A plantar insole with a half-moon shape (1.5 mm thick) was used to stimulate the feet mechanoreceptors. For both groups, the head RoM in each of the three anatomical planes was assessed before and after participants walked for 15 minutes at 4 km/h on the treadmill. This procedure was applied four times for subjects in the experimental group: for each trial subjects walked with a plantar insole placed at a specific, foot location. Changes in head RoM were assessed through a symmetry index, accounting for differences in movement direction.

Results: In the control group, no pre-post differences in the symmetry index were observed for the sagittal, frontal and horizontal planes. Similarly, for the intervention group, ANOVA did not reveal both main and interaction effects of time and insole position on the symmetry index for the three planes of movement.

Conclusion: Our results did not evidence any effect of a 1.5-mm thick mechanical stimulus on the head mobility, regardless of where the insole was placed.

INTRODUCTION

The cervical spine is a complex structure, converging inputs from the somatosensory and vestibular systems to finely control the head position in space (Kiper, et al., 2020). Control of head position is crucial for the smooth coordination of head-eyes movements and for maintaining specific body postures (Hadjidimitrakis , 2020), as evidenced by a recent review highlighting the impact of the head position on the respiratory system, cervical muscle activity, proprioception, ability to maintain balance and neck pain (Szczygieł, et al., 2020). The dependence of stability scores (Carrick, et al., 2020) and tongue strength (Paris-Alemany, et al., 2021) on the head posture further attests the functional relevance of preserving the integrity of the cervical spine.

Successfully controlling head posture demands however the integration of sensory information arising from different receptors. Of particular interest is the influence of feet mechanoreceptors on head-eye posture coordination. Kavounoudias et al. (1998), for instance, observed that mechanical stimulation of specific foot regions affected the direction of body sways during standing, with sways being typically directed away from the site of stimulation. Corroborating this observation, the perception of sway has been shown to be directed laterally, towards the foot where vibration was applied to the plantar arch (Roll, et al., 2002). The association between feet stimulation and postural responses has been documented also in dynamic conditions, with postural reactions being affected by the proprioceptive input of the feet during gait (Kennedy & Inglis, 2002; Perry, et al., 2000). In addition to affecting head posture, the application of mechanical stimulus to the feet sole has been shown to affect the ocular organization. Foisy et al.

(2015), for example, documented a significant effect of the presence of a thin, mechanical insole on the ocular convergence. In particular, stimulation of the medial arch and of the lateral arch seems to respectively induce ocular divergence and convergence. Finally, head posture has also been shown to affect the near point convergence (Giffard, et al., 2018). Considering that head-eye coordination demands the appropriate control of neck muscles (Corneil, et al., 2002; Peterson, et al., 1985; Peterson, 2004), collectively, these pieces of evidence suggest the cervical mobility may be affected by mechanical stimulation of the feet sole.

In this study we therefore ask whether small, thin insoles may acutely affect the cervical mobility. We specifically ask whether, with respect to controls, subjects wearing small insoles can move their head over a greater range of motion in the three, anatomical planes. Of further concern is whether such dependence is affected by the foot site where the insoles are positioned. If voluntary control of head posture is affected by passive, mechanical stimulation of foot sole, we expect to observe greater range of motion values for the group of subjects undergoing stimulation, regardless of where the insoles are positioned.

METHODS

Subjects

Twenty-four healthy subjects were enrolled for the study and were randomly assigned to either of two groups, after providing written, informed consent. Twelve subjects composed the control group (range values; age: 21-35 years; body mass: 46-85 kg; height: 151-182 cm), whereas the remaining 12 participants were assigned to the experimental group (age: 21-31 years; body mass: 53-88 kg; height: 164-189 cm). A plantar insole with a half-moon shape

(60 mm diameter; 15 mm thick; Figure 1*A*) was used to stimulate mechanoreceptors of both feet of subjects in the experimental group. None of the participants reported the presence of scoliosis, hyperlordosis, hyperkyphosis of the spine and of the lower limbs, neurological diseases or musculoskeletal injuries within the preceding 6 months. Also, the right leg was the dominant leg for all participants. The experimental procedures conformed to the Declaration of Helsinki and were approved by the institutional ethics committee of the University of Turin, number of protocol 451939.

Experimental Protocol

Prior to commencing data collection, participants were instructed to stand upright, with arms relaxed alongside the body and eyes open looking forward (reference position). During standing, participants were asked to move their head as much as possible along each of the three anatomical planes. At their preferred speed, subjects moved their head into maximal flexion and then maximal extension, rested for at least 5 s and then repeated the procedure for the frontal plane (flexion to the left and then to the right) and the horizontal plane (rotation to the left and then to the right). Only one trial per direction was collected, given the high repeatability reported for the range of motion (RoM) values of head movements (Wang, et al., 2018). Moreover, head movements were executed in the upright stance because previous studies have shown that range of motion estimates obtained are more reliable in upright stance than in the seated position (Strimpakos, et al., 2005; Strimpakos, 2011).

A different number of head movement trials were conducted for the different groups. For the control group, two trials were applied, one before and one after subjects walked for 15 min on a treadmill (Reharunner 02/51; Chinesport, Udine, Italy) at a constant 4 km/h speed (Alessandria & Gollin, 2020). For the experimental group, four blocks of two trials each were applied. The first trial was collected before and the second trial was collected after participants walked for 15 minutes at 4 km/h on the same treadmill with the plantar insole. The 15 min walking was sought to ensure subjects adapted to the presence of the mechanical stimuli, potentially increasing its presumed efficiency (Alessandria & Gollin, 2020). For each block, the plantar insoles were positioned in both shoes, at one of four, specific combinations, with insoles inserted (Figure 1*B*; (Alessandria & Gollin, 2020)): 1) laterally under the right and left feet; 2) laterally under the right and medially under the left foot; 3) medially under the right and laterally under the left foot; 4) medially under the right and left feet. The order with which the insoles were positioned was random and 15 min of rest between blocks were considered.

Figure 1

Motion analysis system

A set of 12 infrared cameras (Vero 2.2, Vicon system, Oxford, UK) was used to assess the head movements in the three anatomical planes. Ten retroreflecting markers were secured by an expert at specific, anatomical landmarks, based on the model proposed by Rab et al. (2002). Specifically, the head, neck, trunk, and pelvis segments were modelled from markers positioned at the top of the head, the jugular notch, at the S2 and C7 vertebrae and bilaterally at the temporo-zygomatic arch, in front of the tragus, just lateral to the acromion-clavicular joint and at the anterior, superior iliac spine.

The coordinates of each marker were recorded at 100 fps (Nexus 2.9 software, Vicon system, Oxford, UK). Coordinates were labelled in real time and visually inspected throughout the trials to ensure the data collected was of high quality.

Data analysis

Giving our general interest in the lumped movement of the head, we assessed cervical mobility from movements of the head in relation to the trunk segment. First, markers coordinates were low pass filtered to remove high-frequency noise with a Butterworth filter (2nd order, 3 Hz cut-off). Then, unit vectors defining head and trunk segments were computed according to (Rab, et al., 2002).

A custom Matlab script was written to compute joint angles and to extract RoM values for relative, head movements. Cardan angles were computed based on the direction cosine matrix, relating movements of the head to movements of the trunk segment. The X-Y-Z (flexion/extension – right/left flexion– right/left rotation) sequence of rotation was selected so as to minimize the Gimbal lock effect. Prior to computing head angles, the unit vectors defining the head segment in the laboratory reference frame were rotated so that the anterior-posterior, craniocaudal and lateral axes of the head and trunk coincided for the first, acquisition frame.

Values for the head RoM were computed separately for each anatomical plane and movement direction. First we identified the baseline angle, defining the head neutral position in relation to the trunk (cf dashed lines in Figure 2). Then, we computed the maximal angular deviation (α) relative to the baseline angle, in each direction and for each plane of movement. We repeated this procedure for each pair of trials, before and after subjects walked for 15 min over the treadmill (cf. circles and squares in Figure 2, respectively). From the maximal deviation values, we computed the following symmetry index (Carpaneto, et al., 2004):

$$SI = \frac{\alpha_{+} - \alpha_{-}}{\alpha_{+} + \alpha_{-}}$$

where α_{+} denotes maximal absolute deviation in the flexion, right lateral flexion and right axial rotation directions, depending on whether SI was computed for movements in sagittal, frontal or horizontal plane. Conversely, α_{-} corresponds to maximal absolute deviation to the opposite direction in each plane. SI values close to zero indicate subjects moved the head by equal amounts in both directions whereas, for each plane, head movement in a predominant direction would be represented by either negative or positive SI values.

Statistical analysis

Parametric, inferential statistics were applied for pre-post walking assessments after ensuring the distribution of SI values was Gaussian (Shapiro-Wilk test; $P>0.09$ for all cases) and the homogeneity of variance (Bartlett's test; $P>0.21$ for all cases). SI values were assessed separately for each plane of movement and group. Differences in SI values between trials, pre and post 15 min walking, were assessed with the Students, paired t-test for the control group. For the experimental group differences were assessed with two-way, repeated measures ANOVA (2 trials x 4 insole positions). Significant differences were considered at $P<0.05$.

RESULTS

The angles obtained from a single subject in the experimental group before and after the 15 min walking are shown in Figure 2. Positive and negative peaks are observed for both movement directions in each of the three anatomical planes, highlighting the validity of RoM values (circles and squares) computed with respect to the baseline angle (0° for all planes). Similarly, clear profiles for head movements were observed for all participants tested, in both groups.

Figure 2

Subjects in the control group moved their head equally before and after walking for 15 min on the treadmill (Figure 3). Students *t-test* did not reveal statistical differences in SI values for the sagittal (t=1.10; P=0.29; N=12 subjects), frontal (t=-0.59; P=0.57) and horizontal planes (t=0.35; P=0.73), as shown in Figure 3. Similarly, for the intervention group, ANOVA did not reveal a main effect both for time (pre-post 15 min walking; F<0.50; P>0.48; N = 24, 12 subjects x 2 trials) and insole position (F<1.06; P>0.37; N = 48, 12 subjects x 4 insole positions) for the three planes of movement (Figure 4). No interaction effect was observed either, with only a tendency for interaction between time and position for the sagittal plane (F=2.44; P=0.07; N = 96, 12 subjects x 2 trials x 4 insole positions).

Figures 3 and 4

DISCUSSION

The aim of this study was to investigate the effect of a thin, small plantar insole on the cervical mobility, with the insole effect being quantified in terms of differences in the cervical RoM. Statistical analyses did not reveal however a significant time (pre x post) effect in both control and intervention groups, regardless of where the insole was placed for the latter group.

Our study was partly motivated by pieces of evidence relating changes in body posture to the control of head position. Shaghayegh et al. (2016), for instance, reported a significant increase of the cranio-vertebral angle in upright position when compared to the sitting position, suggesting an influence of the lower limb posture on the head position in the sagittal plane. Similarly, Bergmann et al. (2020) observed a significant effect of seat-standing posture on the head position in the sagittal plane while Billiaert et al. (2021) documented changes in head positions between sitting and standing postures exclusively over the lateral axis. Finally, Tecco et al. (2007) demonstrated that an anterior cruciate ligament injury affects the amplitude of EMGs detected from the cervical muscles, influencing the control of the head position in the sagittal plane. The predominant effect of body posture on the head flexion-extension movement is not surprising when considering the biomechanics of the cervical spine. Anderst et al. (2015), indeed, highlighted that the flexion/extension RoM of the cervical spine is less complex compared to lateral bending and axial rotation: indeed, the overall movements of cervical vertebrae occur primarily around an axis perpendicular to the sagittal plane while axial rotation and lateral bending take place around an oscillating axis (called helical axis of motion), due to anatomical constraints imposed by the coupling of vertebral segments~~.~~ Such predominant, sagittal motion has been attributed to the ample RoM of the C5-C6 segment in the sagittal plane (REFs - (Anderst, et al., 2015; Kuo, et al., 2018)).

Notwithstanding the effect of body posture on the head sagittal motion, postural reactions necessary to stabilize the head in space demand movements in the transverse plane. Indeed, during walking, the proprioceptive stimulation of the feet has been suggest to affect the perception of trunk rotation (Gordon, et al., 1995). Accordingly, the observed suppression of the vertical though not of the horizontal vestibulo-ocular reflex has been suggested to posit a mechanism of gaze and head stabilization (Dietrich & Wuehr, 2019). Furthermore, it is worth noting that unilateral vibration of the sternocleidomastoid muscle during stepping-in-place or walking produces a contralateral body turn while unilateral vibration of the dorsal, neck muscles lead to an ipsilateral to body rotation (Bove et al., 2001; 2002). It appears evident that the control of the head on the transverse plane during walking depends on the involvement of both afferent and efferent inputs. Pettorossi & Schieppati (2014), suggest the integration of both inputs which effect depends by necessity of maintenance of the direction of walking. It is likely that these postural, head reactions in the transverse plane are mainly determined by the upper cervical spine (C1 – C2), given that RoM values for this segment (37.5 deg) have been reported to be roughly seven times greater than those for the C2-C7 segment (Salem, et al., 2013). These authors suggest, indeed, that the upper cervical segment has a more crucial role on the orientation and stabilization of the head and of the plane of vision during head rotation when compared to the lower segments.

Considering the effect of the podalic stimulation on the ocular organization (Foisy, et al., 2015) and that the head-eye coordination demands the appropriate control of neck muscles (Corneil, et al., 2002; Peterson, et al., 1985; Peterson, 2004), it would therefore seem plausible to expect that acute changes in the cervical RoM would be affected by the presence of plantar insoles. Based on the evidence just discussed, RoM values in either the sagittal or transverse plane would be expected to change after wearing the plantar insoles for 15 min. Our current results, however, do not support this hypothesis. It could be speculated that there was a tendency for the position of the insoles to affect the head RoM in the sagittal plane. Insoles at position 2 and 3 (Figure 1) would seem to lead to opposite changes in the ability to maximally move the head in the sagittal plane (Figure 4). Increasing the sample size and considering wearing the insoles for a longer period could help identifying the existence of an effect of the stimulation of feet mechanoreceptors on the head RoM.

In the current state of our knowledge, it is not possible to anticipate whether an adaptation greater than 15 minutes could have produced different results. Similar studies aimed at assessing the influence of podalic stimulations similar to ours but thicker (Tramontano, et al., 2019; Foisy & Kapoula, 2017; Foisy, et al., 2015; Janin & Dupui, 2009) were focused on the effect immediately following to the administration of the stimulus, without considering possible postural responses following an adaptation. These studies reported a stimulation effect immediately after introducing the stimulus, which was twice as thick (3 mm) as that considered here. The choice to carry out the tests after 15 minutes is linked to the results of our previous study (Alessandria & Gollin, 2020) which showed significant changes after 15 minutes of adaptation to the treadmill, without a corresponding acute effect. Increasing either the insole thickness or duration along which subjects are exposed to the podalic stimulation could therefore possibly lead to significant changes in head mobility.

CONCLUSIONS

Our results do not evidence any effect of a 1.5-mm thick mechanical stimulus on the head mobility. Only a trend for an effect of stimulus site under the feet sole on the head RoM in the sagittal plane was observed, with stimulation of the right and left side of both feet respectively resulting in opposite changes in head RoM. Reproducing our experimental protocol on a larger sample or increasing the duration of exposure to the feet stimuli would therefore seem advisable.

CLINICAL RELEVANCE

The results of our study do not support the notion that stimulation of the feet proprioceptive inputs affects the cervical RoM and, hence, the cervical symptoms. It seems therefore inappropriate to predominantly rely on the use of plantar insoles when devising therapeutic approaches for treating cervical issues.

At this point of this study, it is seemingly not possible to confirm that a thin mechanical stimulation of the plantar arch is able to modify the proprioceptive inputs of the feet. Indeed, no significant changes were observed in the cervical RoM and, therefore, in any cervical symptoms. Despite this study highlighted interesting topics that can eventually be deepened, our current level of knowledge indicates that we cannot spare the classical therapeutic approaches to treat cervical issues.

QUELLO CHE HA SCRITTO SIMONA VEDO EQUIVALENTE A QUANTO SCRITTO NEL PRIMO PARAGRAFO. NON LASCEREI TUTTI E DUE. VANNO ENTRAMBI BENE SECONDO ME. BISOGNEREBBE SOLO CHIARIRE NEL TESTO CERVICAL SYMPTOMS E CERVICAL ISSUES.

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