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Original Article

A study of interdependence of geometry of the nuchal neck triangle and cervical spine line in the habitual and straightened postures

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ABSTRACT

Introduction: The paper shows the mutual dependencies of height and angles of the neck triangle and selected points of the spine for straightened and habitual postures with the use of a non-contact optical tool. A group of 39 healthy, adult volunteers participated in the study, which was conducted in Warsaw, Poland. Results show relationships between the habitual posture in the sagittal plane, the angle of the triangle between the cervical and upper thoracic kyphosis and the vertical line defined by spine points C7/Th1.
Methods: Measurement system based on photogrammetry was used for spatial determination of specific points. Specially designed non-invasive markers were used. The presented paper shows a new approach for analysis of the geometry of the upper part of the human musculoskeletal system with the use of optical systems in biomedical applications.
Results: Results are presented as series of 14 defined parameters and calculated for habitual and straighten postures. Results were analyzed as a values of correlation coefficients and significance level.
Discussion: An analysis of measurements results based on a triangle represented by three points: two outermost points of the superior nuchal line of the skull and the C7 point are presented. This approach allow to characterize individual positioning of the head in space and is sensitive to many changes in the musculoskeletal system – i.e. the individual way of "standing up straight".

1. Introduction

The human posture and the entire musculoskeletal system are centered around the spine, which is the vertical axis of the body. This complex mechanical system, with a high level of stiffness and plasticity, automatically adjusts the tension of many postural muscles to balance the body.[1] The spine, as the central column of the trunk, is composed of interconnected segments characterized by different heights of vertebral bodies and intervertebral disc thickness. Each segment also has a different range of motion. In the neutral position, viewed from the front and back, the backbone appears straight if the shoulder line and the upper edge of the sacrum are positioned horizontally and parallel to each other. Viewed from the side (sagittal plane), the spine exhibits the physiological curvatures known as: lordosis – forward curvature, and kyphosis – backward curvature. According to Kapandji,[2] the curvatures compensate each other. An example is the cervical curvature, the angle value of which is directly proportional to the depth of the thoracic curvature.

The cervical segment of the spine, connected to the thoracic vertebrae, supports the head and forms the backbone of the neck. It is the most flexible section of the spine, ensuring appropriate orientation of the head. Normally, the head is in perfect balance when the line of sight is set horizontally, and the layers of muscles of the back of the neck (extensor muscles) are stronger than the flexors.[2,3] The functional complexity of the cervical spine is illustrated by the multiplicity of muscle connections; from deeply localized suboccipital muscles, the movements of which are synchronized with the movements of the eyes (the so-called suboccipital "star"), or the upper part of the ilio-costalis muscle, to the more superficially located splenius, levator scapulae and trapezius muscles.[4]

Diagnosis of disorders of the cervical segments, an area associated with an elevated risk of pain, is initially performed by clinical examination; however, the decisive method for diagnosing a pathological condition is radiological or magnetic

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resonance imaging.[5,6] The Cobb angle can be determined in a similar manner. It provides information about changes of the thoracic curvature (chest hyperkyphosis). In most cases, radiological imaging in the AP plane is used to collect necessary data. To estimate the angle of thoracic kyphosis, an inclinometer can also be used. Its arms are placed on the previously designated points on the skin corresponding to the spinous processes of Th2/Th3 and Th11/Th12 (e.g. Debrunner kyphometer).[7] Designated bone points on the examined person's body are also used in 3D systems and to assess the potential of selected shoulder girdle muscles (EMG) to influence changes in the posture of the human body.[8]

There are few reports on evaluating the position of the cervical spine – the most movable and delicate part of the vertebral column. In normal conditions, the vertical position of the head and the slender shape of the human neck are perceived as an aesthetic value. In terms of pathology, the spatial position of the head and cervical spine could be a reflection of trauma, degenerative changes or overuse syndromes associated with an asthenic posture, the cumulative reflection of emotions in the body or the result of long hours in front of a computer.[2,4,9] A visually shorter neck often results from anterior positioning of the human head (FHP – forward head posture) associated with shoulder elevation, changes in the upper thoracic kyphosis angle and lumbar lordosis angle. This type of silhouette is typical for people with hyperkyphosis or the elderly with significant osteoarthritis or osteoporosis. Therefore, mutual analysis of the parameters of the cervical posture and head positioning, taking into account their relationship to the parameters of the thoracic and lumbar spine, has a significant clinical value in the diagnosis of postural abnormalities. This paper, based on a study performed on a random group of healthy volunteers, presents the correlation between selected parameters describing above-mentioned parts of the body.

2. Methods

Determination of human postures in clinical practice is usually done using a contact method. The measurement is performed by a person with appropriate qualifications and skills for determining the adequate places on patient's body (i.e. palpation measurement). This is done using generally accepted measuring instruments, such as scoliometers, inclinometers and plurimeters. The disadvantage of this method is the inability to determine an actual value of the position of the vertebrae, degree of rotation, angles and curves for normal human postures, i.e. standing, relaxed posture and so on. It is also impossible to determine the changes that occur over time as a result of the body's natural mechanical activity (including the so-called mobility of normal posture resulting from physiological changes taking place in the human body).

The only way to precisely determine the current position of the characteristic points of the human skeleton is radiology. This approach has significant drawbacks: a long time to carry out a single measurement, impossibility of sufficient analysis of postural changes over time (due to natural physiology and human physical activity). Moreover, radiological imaging is invasive, and can have a detrimental effect on the body (i.e. cumulative effect of the negative effects of ionizing radiation). Non-contact (e.g. optical) methods are free of these disadvantages.

Optical measurement methods supported by computer analysis are well-known tools in the described field. The following types of them are commonly encountered in literature: moiré and fringe projection methods[10–12] and photogrammetric methods.[13–16] The first group, moiré and fringe projection methods, don't require applying any markers to the patient's body. As a result, the measurement is independent of the influence of individual factors of the person performing the measurement. The disadvantage of this method is the ambiguity of the determination of characteristic skeleton points, which are calculated only on the basis of 3D data representing the body surface. This disadvantage can be eliminated by using measurement markers applied onto the patient's body, e.g. in the form of small balls which contrast with the background, mounted on pins[17] or markers applied with pens directly onto the patient's skin.[10]

The measurement system used in this study permitted non-invasive measurement allowing to determine the spatial position (3D) of the measured points: the position of the spinous processes of the C7, Th1, Th6, Th7, L/S and S1 vertebrae, the position of the superior scapular angles, and the outermost points of the superior nuchal line of the skull.

The study involved a group of 39 adult persons, volunteers, ranging in age from 18 to 28. The measurement was performed for two postures: habitual (relaxed, spontaneous) and straightened. However the straightened posture was not defined by the Authors, was assumed individually by each subject, this type of posture can be found in literature as "actively corrected"[2] and can be adopted in practice as well.[19] The measurement for each posture was performed twice at short intervals, to confirm the stability of the adopted position of the body.

The measurement system used by the Authors is based on a widely known technique of photogrammetric registration of stereoscopic images (stereopairs) using devices with high resolution imagers (Fig. 1). In this role, cameras equipped with CMOS imaging sensors, APS-C format with a resolution of approx. 16 million pixels, equipped with optics with a focal length of 30 mm were used. Both cameras were mutually synchronized. The cameras were located symmetrically to the z-axis, and the base of the stereoscopic set-up was 350 mm. Images were recorded in the camera' native raw format (RAW-type) and subsequently converted to grayscale on the basis of stored image data, using specialized software (Adobe Lightroom). The prepared images were analyzed with an application created specifically for this study (in C++) that uses OpenCV libraries.

The measuring points were marked using special markers glued to the skin of the subject's body, in the form of a circle with a diameter of ϕ*10 mm*, black edges and a white central field (approx. ϕ*3 mm*). As a result, it was possible to quickly and unambiguously determine the center of the marker. The measurement system was prepared for a distance of approx. *1500 mm*. The area of calibrated measurement space, approx. $600 \times 1200 \times 500$ *mm* (x, y, z), was calibrated using a standard test chart (checkered black and white square with a side of 50×50 *mm*). On the basis of two images of a stereopair, the position of measuring points was determined in the form of coordinates (p_x, p_y, p_z).

Subjects with markers affixed onto their body were placed within the designated, calibrated measurement space, with their back directed to the lenses of the photogrammetric measuring

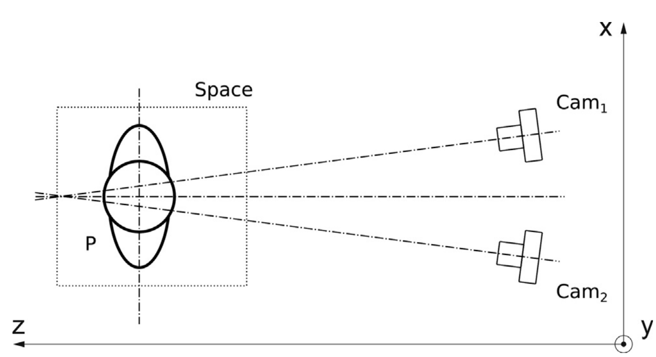

Fig. 1. Measurement set-up. Coordinates x, z as on the axes, y-axis is perpendicular to the drawing plane. Space – calibrated measuring space (as described in text), P – examined person under measurement, Cam_1, Cam_2 – photogrammetric stereopair.

system. All subjects were dressed in underwear that did not interfere with the location of the applied markers. After having their hair lifted up, the subjects put on tight bathing caps (silicone). Markers corresponding to the position of the outermost points of the superior nuchal line of the skull were applied to the surface of the cap.

3. Results

On the basis of collected photogrammetric data, the location of selected characteristic points in a 3D space was determined. These points were as follows: the outermost points of the superior nuchal line of the skull – Oc_L (left), Oc_R (right); the spinous processes of vertebrae – C7, Th1, Th6, Th7, L/S, S1; the position of superior scapular angles – ScU_L (left), ScU_R (right). These points are illustrated in Fig. 2a-b.

Based on these points, for each subject we determined the vectors that were subsequently used for further analysis of the results:

$$\overline{Oc} = Oc_L - Oc_R \quad (1.1)$$

$$\overline{ScU} = ScU_L - ScU_R \quad (1.2)$$

$$\overline{CT} = C7 - Th1 \quad (1.3)$$

$$\overline{LS} = L/S - S1 \quad (1.4)$$

$$\overline{TT} = Th6 - Th7 \quad (1.5)$$

$$\overline{TL} = Th12 - L1 \quad (1.6)$$

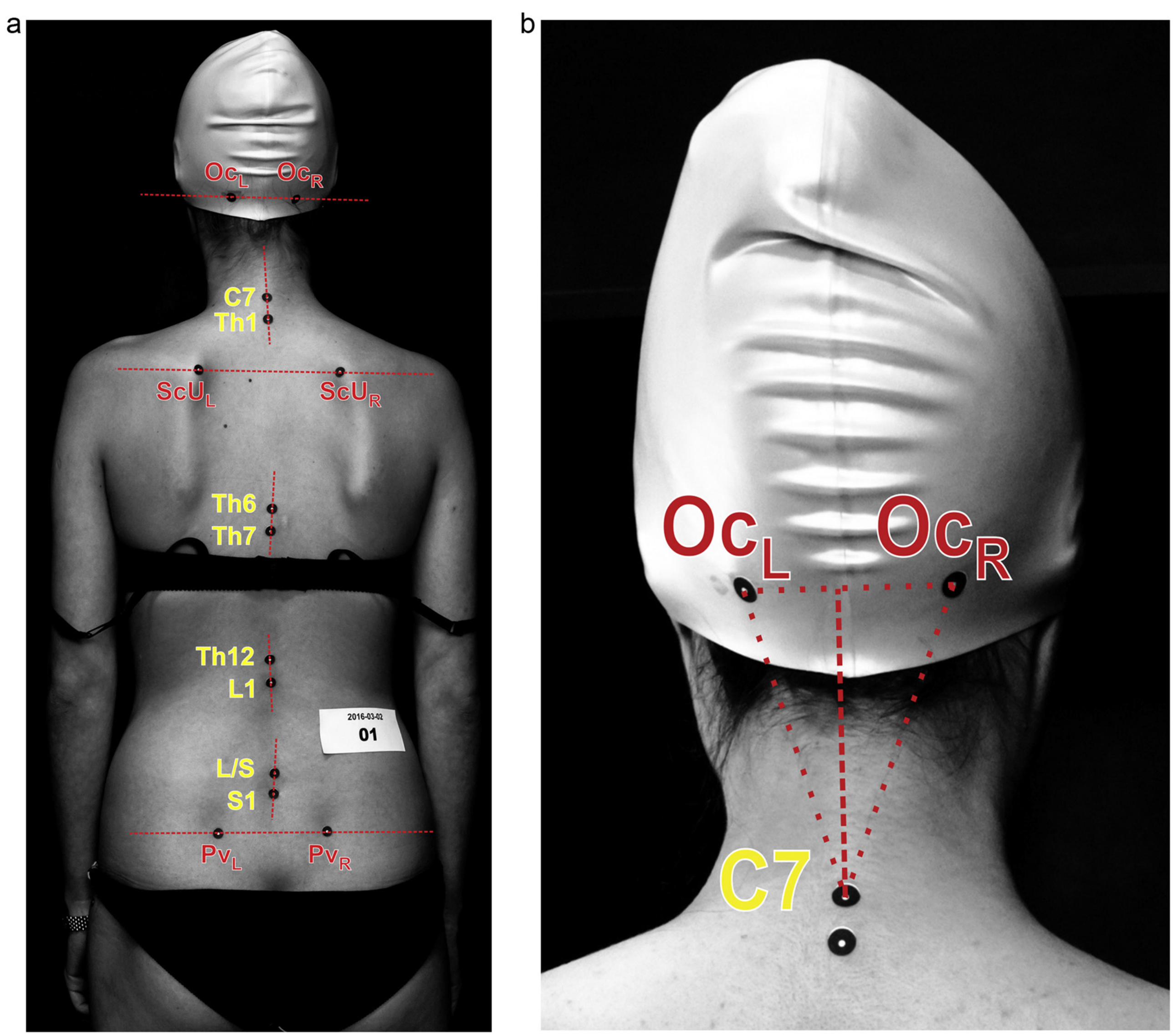

Fig. 2. In Fig. 2a. a set of points marked on the subject's body is shown, along with a visualization of calculated parameters as in the Formulas (1.1)–(1.7). In Fig. 2b. the calculated vector $\overline{OcC7}$ (height of the triangle Oc_LOc_RC7) is shown. *Note*: In Fig. 2a. markers corresponding to both ScL points (angulus inferior scapulae) were removed for clarity.

$$\overline{P}_v = Pv_L - Pv_R \qquad (1.7)$$

Additionally, we defined the vector $\overline{OcC7}$, which corresponds to the height of the triangle $Oc_L Oc_R C7$ taken from the apex C7. We also determined the vector $\overline{Vt}$, indicating verticality. We subsequently defined five parameters that define the geometry of the cervical triangle:

$$P_1 = 90 - \measuredangle_{xy}(\overline{Oc}, \overline{Vt}) \qquad (2.1)$$

$$P_2 = ||\overline{OcC7}|| \qquad (2.2)$$

$$P_3 = \measuredangle_{yz}(OcC7, Vt) \qquad (2.3)$$

$$P_4 = 90 - \measuredangle_{xz}(OcC7, Vt) \qquad (2.4)$$

$$P_5 = ||\overline{Oc_R C7}|| - ||\overline{Oc_R C7}|| \qquad (2.5)$$

These parameters were correlated with successive ones, describing the geometry of the anatomical back:

$$P_6 = 180 - \measuredangle\left(CT, TT\right) \qquad (3.1)$$

$$P_7 = \measuredangle\left(CT, Vt\right) \qquad (3.2)$$

$$P_8 = 180 - \measuredangle\left(TL, LS\right) \qquad (3.3)$$

$$P_9 = 90 - \measuredangle\left(ScU, \mathrm{Vt}\right) \qquad (3.4)$$

$$P_{10} = 90 - \measuredangle\left(ScL, Vt\right) \qquad (3.5)$$

$$P_{11} = 90 - \measuredangle\left(Pv, Vt\right) \qquad (3.6)$$

$$P_{12} = \measuredangle_{XZ}\left(ScU, ScL\right) \qquad (3.7)$$

$$P_{13} = \measuredangle_{XZ}\left(ScL, Pv\right) \qquad (3.8)$$

$$P_{14} = \measuredangle\left(TT, Vt\right) \qquad (3.9)$$

Fig. 3 presents in graphical form the results of the distribution of values of parameters *P_1–P_7*. The parameters *P_1 P_3, P_4, P_6* and *P_7* describing the angular relationship between calculated values are given in degrees, whereas *P_2* and *P_5*, which describe the distance between calculated values, are given in mm. Other parameters (i.e., *P_8–P_{14}*) have been omitted in Fig. 3, because the results presented

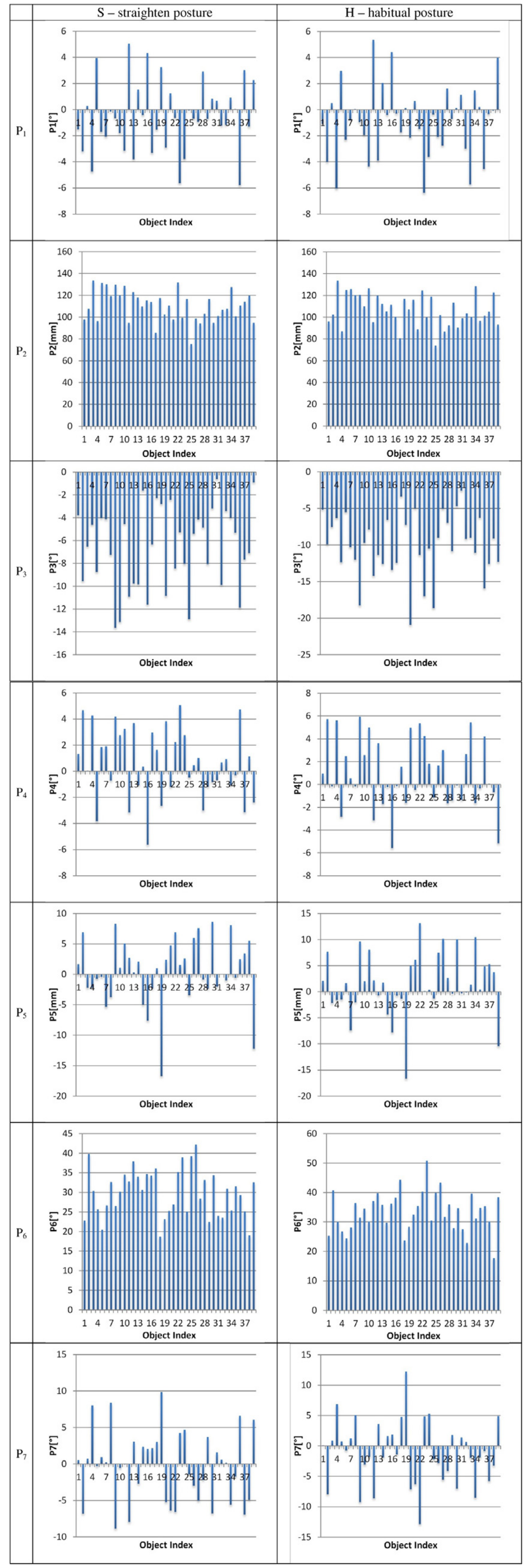

Fig. 3. Graphs show the results obtained for the series of parameters from *P_1* to *P_7* calculated using the Formulas (2.1)–(2.5) and (3.1)–(3.2) for both postures used in the tests: habitual and straightened.

below show a lack of interdependence with the parameters determined for the cervical region (i.e., P_1–P_5).

The distribution of all parameters was tested using the Shapiro-Wilk test,[17] confirming that they have an approximately normal distribution. Subsequently, parameters P_1–P_5 were correlated to the other parameters using the r-Pearson correlation[18] to give the results presented in Table 1.

After Cohen,[17] the following assessment of correlation strength was adopted: $0.1 < |r| < 0.3$–low correlation, $0.3 < |r| < 0.5$–average/moderate correlation, $|r| > 0.5$–high/strong correlation, summarized in Table 1. The correlation results indicate that in the case of the habitual posture, the parameters from P_2–P_3 correlate in an inversely proportional manner with parameter P_6, and correlation strength is at least medium. Conversely, the same parameters correlate in a directly proportional manner with parameter P_7, and correlation strength is also at least medium. In the case of the straightened posture, we observed a correlation with parameters P_3 and P_7 in the range of low to medium.

4. Discussion

This study analyzed the interrelationships between the cervical segment of the spine with the thoracic and lumbar segments in two postures (habitual and straightened).

In the studied group of volunteers, the results showed changes in the height h of the cervical triangle (defined as the vector $Oc'C7$ and represented by the parameter P_3) coexisting with the change of the angle between segments C7/Th1 and Th6/Th7 (parameters P_6 and P_7, respectively), but only in the habitual posture; in other words, the individual way of maintaining a relaxed upright posture while expending the smallest possible amount of energy. A correlation value of $r = -0.36$, with a significance of $p = 0.026$, indicates the inverse relationship between the triangle's height and the angle of the upper thoracic kyphosis. In other words, as the head is extended forward, this angle becomes greater. In the straightened posture, i.e. when postural muscles are activated, the correlation value was $r = -0.27$, with a significance of $p = 0.09$. There was no correlation between the height h of the cervical triangle and the thoracolumbar transition (Th12/L1) or lumbar lordosis (L5/S1).

In contrast, strong relationships were shown in the habitual posture in the sagittal plane between the angle of the cervical triangle and the upper thoracic kyphosis angle ($r = -0.38$, $p = 0.02$ for the correlation parameters P_3 and P_6) and the vertical line determined in relation to the C7/Th1 segment ($r = 0.45$, $p = 0.00$ for the correlation between parameters P_3 and P_7). In the straightened posture, a slight correlation was shown between the angle of the triangle and the vertical line determined in respect to the C7/Th1 vector ($r = 0.29$, $p = 0.08$ for the correlation between parameters P_2 and P_7).

Rating posture using the stereometry system allows assessment of the angle between the segment connecting Oc_L and Oc_R (line between the outermost points of the superior nuchal line) and the line of the superior scapular angles. In the studied group, a correlation value of $r = -0.27$, $p = 0.09$ for the correlation between parameters P_2 and P_6 was shown only in the straightened posture.

In conclusion, these results clearly indicate an inverse correlation to the one assumed as normal between the cervical lordosis angle (P_3) and the angle of the upper thoracic kyphosis (P_6, P_7) in the test subjects in the habitual posture only. The obtained data may indicate postural deficits specific to persons exhibiting protracted positioning of the head. Simultaneously, these results indicate a need to continue the project with the use of the presented system.

5. Conclusions

The obtained results prove that photogrammetry-based optical measurement systems are useful for determination of the physiological aspects of human posture and anatomy. The optical set-up allowed us to examine changes in the geometry of selected points of the spine and position of the skull in relation to different body postures (in this case, habitual and straightened ones).

In this work, the analysis was based on a triangle represented by three points: two outermost points of the superior nuchal line of the skull and the C7 point. This approach allowed us to characterize individual positioning of the head in space and is sensitive to many changes in the musculoskeletal system – i.e. the individual way of "standing up straight".

The research presented in this work should be treated as a pilot study. Further clinical tests performed on a wider group of patients, differing in age, body mass, social group, occupation, injuries etc., are necessary to confirm the correctness of the proposed assumptions

Table 1
Results of correlation of P_1-P_5 factors with P_6-P_{14}, r – the Pearson correlation coefficient, p – the statistical significance level.

		H – habitual posture					*S – straightened posture*				
		P1	*P2*	*P3*	*P4*	*P5*	*P1*	*P2*	*P3*	*P4*	*P5*
P6	*r*	−0.11	−0.36	−0.38	0.14	0.00	−0.08	−0.27	−0.21	0.15	0.00
	p	0.49	0.03	0.02	0.40	0.51	0.64	0.09	0.20	0.38	0.59
P7	*r*	0.14	0.29	0.45	−0.21	−0.01	0.12	0.19	0.29	−0.20	0.00
	p	0.38	0.08	0.00	0.21	0.33	0.47	0.25	0.07	0.23	0.42
P8	*r*	0.15	−0.26	−0.17	−0.15	−0.01	0.13	−0.22	−0.09	−0.09	−0.01
	p	0.36	0.10	0.30	0.36	0.21	0.43	0.18	0.58	0.60	0.05
P9	*r*	−0.17	0.01	0.11	0.12	0.00	−0.14	−0.18	0.02	0.07	0.00
	p	0.29	0.94	0.52	0.48	0.96	0.39	0.28	0.89	0.67	0.65
P10	*r*	0.07	−0.07	−0.16	0.09	0.01	0.01	0.07	−0.03	0.05	0.01
	p	0.65	0.66	0.32	0.57	0.04	0.96	0.66	0.85	0.78	0.14
P11	*r*	0.10	0.18	−0.09	−0.14	0.00	0.08	0.14	−0.13	−0.15	0.00
	p	0.53	0.27	0.57	0.39	0.83	0.63	0.39	0.44	0.37	0.66
P12	*r*	0.09	0.00	0.05	−0.07	0.00	0.05	−0.12	0.25	−0.01	0.00
	p	0.59	1.00	0.76	0.69	0.75	0.77	0.47	0.13	0.97	0.96
P13	*r*	0.23	−0.16	−0.12	−0.08	0.00	0.21	−0.05	−0.09	−0.13	0.00
	p	0.15	0.33	0.48	0.62	0.54	0.20	0.78	0.60	0.45	0.86
P14	*r*	0.09	0.02	0.26	−0.15	0.00	0.11	−0.07	0.18	−0.12	0.00
	p	0.58	0.91	0.10	0.36	0.39	0.49	0.69	0.26	0.46	0.54

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