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Standard values of the upper body posture in female adults

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Manuscripts

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3 33 **Abstract**

4 34 **Objective:** Classifications of posture deviations are possible when compared to standard
5 35 values. Standard values have been published for healthy male adults but are not known for
6 36 female adults.

7 37 **Design:** Observational study.

8 38 **Setting:** Institute of Occupational Medicine, Social Medicine and Environmental Medicine,
9 39 Goethe-University Frankfurt/Main.

10 40 **Participants:** 106 female healthy volunteers (21 - 30 years old; 25.1 ± 2.7 years) were
11 41 included. Their body weight ranged from 46-106 kg (\bar{O} 60.3 ± 7.9 kg), the heights from 1.53
12 42 to 1.82 m (1.69 ± 0.06 m), and the body mass index ranged from 16.9 kg/m^2 to 37.6 kg/m^2
13 43 ($21.1 \pm 2.6 \text{ kg/m}^2$).

14 44 **Outcome measures:** A three-dimensional back scan was performed to quantify the upper
15 45 back posture while habitual standing. The tolerance regions and the confidence interval were
16 46 calculated. Group differences were tested by using the Wilcoxon-Mann-Whitney-U-test.

17 47 **Results:** The spinal column was marginally twisted to the left. The angle in the thoracic spine
18 48 area is larger than that in the lumbar region. Consequently, a more kyphotic posture can be
19 49 observed in the sagittal plane. The habitual posture is slightly scoliotic with a rotational
20 50 component (scapular depression right, right scapula marginally more dorsally, high state of
21 51 pelvic right, iliac right further rotated anteriorly).

22 52 **Conclusions:** Healthy young women have an almost ideally balanced posture with minimal
23 53 ventral body inclination and a marginal scoliotic deviation. The comparison to equivalent data
24 54 of young males shows only marginal differences in the upper body posture. These values
25 55 allow a comparison of other studies for control and patient data, and may serve as orientation
26 56 in both clinical practice and scientific studies.

27 57

28 58 Key words: body posture, back scan, standard value, female subjects

59 **Strengths and limitations of this study**

- 60 • One strength of this study is the large number of only female participants of the same
61 age (21-30 years).
- 62 • Quantitative analysis of the upper back by using a videorasterstereographic approach.
- 63 • One limitation of the study is the measuring of the upper body posture only in
64 habitual standing position and not while moving.
- 65 • Furthermore, external influences of the occupational environment were not assessed
66 which might influence the body posture.

68 **Introduction**

69 Various subjective and objective methods quantify and analyze the body posture, especially
70 the spinal posture. All methods aim to evaluate the degree of deformity in the diagnosis and
71 treatment of spinal deformities like scoliosis¹⁻⁴.

72 Quantitative analytical methods enable the diagnosis of spinal curvature deviations and/or
73 control the therapeutical effects. The methods vary by their technical complexity and clinical
74 applicability. Roentgenograms or computed tomography scans are frequently used for the
75 diagnosis of bone structure deformities, while ultrasound, inclinometer, thermal infrared
76 imaging, scoliometer or video raster stereography more often establish postural measurements
77⁵⁻¹⁰. X-ray based methods rarely may cause cancer or sperm cell mutations after repeated
78 exposure but still are the gold standard in diagnosis and follow-up of body posture deviations
79¹¹⁻¹⁴.

80 Video raster stereography has recently been evaluated as an alternative method to measure
81 and quantify vertebral column posture and its deformities^{7 8 15-18}. Guidelines of orthopedic
82 rehabilitation in Germany also recommended a follow-up check but do not specify the

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3 83 methods¹⁹. The three-dimensional back scan measures the body geometry between the 7th
4
5 84 cervical vertebra and the gluteal cleft, it has high intraclass correlation coefficients for its
6
7 85 measurements and good Cronbach's Alpha values for intra- and interday reliability for all
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9 86 spine parameters^{17 18 20 21}. Furthermore, inter tester reliability is high¹⁷.

10
11 87 A three-dimensional surface contour image of the back appears suitable to determine vertebral
12
13 88 column deformities, but also to quantify the effect of e.g. orthopedic shoe insoles on the body
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15 89 posture^{22 23}. In addition, 3D images are used to give an insight into muscular imbalances
16
17 90 (kyphotic / lordotic deviations, differences in waist contours, rotation in the shoulder or
18
19 91 pelvis) and to control the effects and therapeutic success of muscle training in primary,
20
21 92 secondary and tertiary prevention^{24 25}.

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24 93 Due to the changing workplace environment with its increase in digital work, ever more
25
26 94 employees work in a sitting position. Both in the workplace and in the household, this leads to
27
28 95 a steady decrease in physical stress on the body. This lack of exercise consequently results in
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30 96 the fast development of muscular imbalances as well as an increase in the number of persons
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32 97 with back pain, as estimated for Germany at 20 million people²⁰. Back pain complaints can
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34 98 also lead to disability or early retirement due to musculoskeletal disorders. Even more
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36 99 frequently, rehabilitation is required to restore the capacity to work in their original
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39 100 occupation.

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41 101 Early signs of postural disorder e.g. musculoskeletal disorders should be detected after the
42
43 102 development of subjective symptoms, and treated appropriately; in order to assess both
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45 103 diagnosis and treatment effects, quantitative classification criteria are necessary for normal
46
47 104 posture and deviations hereof. These "deviations" should be quantified, e.g. in the form of
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49 105 (parametric or non-parametric) percentiles, similar to the Z- or T-scores of bone density²⁶.
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52 106 However, standard or reference values of body posture currently are lacking for healthy
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54 107 female subjects; reference values of the upper body posture for healthy men are published

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3 108 recently²⁷. Also, classifications of the severity of posture deviations are only possible with
4
5 109 quantifiable deviations from standard or reference values.
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9 111 Since standard values for the posture of healthy persons are lacking, this study aims to define
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11 112 reference values for the upper body posture in healthy women aged 21 - 30 years measured by
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13 113 a three dimensional back scan. These values and their variances define tolerance ranges of
14
15 114 upper body posture and can be used to categorize the results of other (orthopaedic) studies.
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17 115 Investigating a homogeneous group of subjects eliminate constitutional, habitual and
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19 116 degenerative changes that could increase both tolerance range and confidence interval²⁸⁻³¹.
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24 119 **Methods**

25 120 **Subjects**

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31 121 106 female volunteers between 21 and 30 years old (25.1 ± 2.7 years) participated in this
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33 122 study. Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the height from 1.53 to 1.82
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35 123 m (1.69 ± 0.06 m), and the body mass index ranged from 16.9 kg/m^2 to 37.6 kg/m^2 (21.1 ± 2.6
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37 124 kg/m^2). According to the WHO weight classification³² 6.6% of the participants were
38
39 125 underweight ($\text{BMI} < 18.5 \text{ kg/m}^2$), 87.8% of the participants had a normal BMI (18.5 to 24.9
40
41 126 kg/m^2), 4.7% were overweight ($\text{BMI} 25$ to 29.9 kg/m^2) and 0.9% had obesity I° ($\text{BMI} 30$ -
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43 127 34.9 kg/m^2).
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46 128 All subjects were healthy and free of musculoskeletal complaints. With the help of a
47
48 129 questionnaire temporomandibular system disorders were excluded³³ 95.3% of the subjects
49
50 130 reported to be right-handed and 4.7% were left-handed. 72.6% of the participants were
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52 131 students, 27.4% were employees in different occupations (dentists, physicians, teachers, office
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54 132 workers).
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3 133 All subjects were informed about the study design before giving written informed consent.
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5 134 The study was approved by the local medical ethics committee of the medical faculty
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7 135 (Goethe-University Frankfurt; No. 303/16).
8

9 136

11 137 **Measurement system**

13 138 A three-dimensional back scan was performed to quantify the upper back posture while
14
15 139 standing, using the back scan system "MiniRot Kombi" (ABW GmbH,
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17 140 Frickenhausen/Germany).

19
20 141 In this system a projector forms a stripe pattern on the persons bare back; this stripe pattern
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22 142 was captured by a LCD camera from a defined angle. In this way the back surface was
23
24 143 represented as a phase picture which was analyzed by an integrated software program
25
26 144 reconstructing the 3D image. For calibration of the phase pictures all test persons were
27
28 145 marked at six defined, standardized anatomical locations (Fig. 1) indicating underlying bone
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30 146 structures. One measurement lasts approx. 2 seconds. Artifacts may be caused by different
31
32 147 patient placements or movements during the scan, i.e. the projection of the stripe pattern on
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34 148 the back, and thus have to be avoided. To measure the body posture, three repeat
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36 149 measurements were taken within 2 minutes.
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39 150

41 151 Fig. 1

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46 153 The six anatomical landmarks allow the calculation of three-dimensional parameters (Fig. 1)
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48 154 which include information about rotational movements in the shoulder and pelvic area and the
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50 155 shape of the spine (lordotic, kyphotic and/or scoliotic posture).

52 156 During a movement sequence 15 photos were taken. The maximum picture frequency of the
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54 157 MiniRot Kombi system is more than 50 frames/sec with a spatial resolution of 1/100 mm. The
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56 158 calculation of the three-dimensional coordinates of the back surface is performed by
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3 159 triangulation. The system error is specified as <1 mm (manufacturer information), the
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5 160 reproducibility is limited by the calculations of the upper body posture defined by markers
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7 161 directly on the skin (<0.5 mm).
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11 163 **Body scans**

13 164 The subjects stood barefoot in their habitual body and jaw posture about 90 cm in front of the
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15 165 back scan apparatus. The arms were hanging loosely; the subjects looked horizontally fixing
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17 166 the opposite wall.
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22 168 **Evaluation Parameter**

24 169 The three-dimensional back scan was split into three components to quantify the following
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26 170 parameters: spinal area (markers on C7 and L3), shoulder area (markers at the top of the
27
28 171 left/right scapula) and pelvis area (markers on the left/right spina iliaca posterior superior
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30 [SIPS]). The marker positions are shown in Figure 1 and a list and the appropriate explanation
31 172 of the spine parameters are shown in ²⁷.
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37 175 **Statistical evaluation**

39 176 The data evaluation was carried out using BIAS (Version 11.0) (Epsilon Verlag, Darmstadt,
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41 177 Germany). With the initial Kolmogorov-Smirnov-Test the normal distribution can only partly
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43 178 rejected, so that either parametrical tolerance regions or non-parametrical tolerance regions
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45 179 were calculated which were defined by the upper and lower limit for 95% of all values
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47 180 (approximately corresponding with +2s values). These values have been found in about 95%
48
49 181 of the examined subjects. Within this tolerance range all values are considered as normal so
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51 182 that the tolerance ranges estimate the central part of 95% of the value of the measured subject
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53 183 population.
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3 184 Furthermore, the two-sided 95% confidence interval was calculated and indicated the range of
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5 185 the mean or median value – depending on the distribution quality – and showed the
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7 186 "accuracy" of these values. For testing group differences, the t-test or the Wilcoxon-Mann-
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9 187 Whitney-U-test was used.

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16 190 **Results**

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18 191 The constitutional parameters "body weight" and "BMI" were not normally distributed, only
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20 192 the constitutional parameter "body height" was normally distributed. The median of the body
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22 193 weight was 60 kg (tolerance range 49.0 to 77.28 kg; confidence interval 57 to 62 kg). For the
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24 194 BMI a median of 20.7 kg/m² was calculated, with a corresponding tolerance range from 17.99
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26 195 to 27.2 kg/m² and a confidence interval from 20.3 to 21.3 kg/m². For the body height a mean
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28 196 value of 1.69 m was calculated with a tolerance range between 1.57 and 1.82 m and a
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30 197 confidence interval of 1.68 to 1.70 m.

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33 198 The lack of handedness as a relevant parameter has been tested in advance by the t-test and
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35 199 the Wilcoxon-Mann-Whitney-U-test. All parameters were not significantly different ($p \geq$
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37 200 0.05).

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41 202 From the back scan values the posture of an average healthy female person was calculated
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43 203 (tab. 1). On average the subjects are standing slightly inclined in the anterior line of 3.31°
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45 204 (tolerance range 8.12° ventrally to 1.5° dorsally; confidence range 3.78° to the left to 2.85° to
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47 205 the right).

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50 206 Laterally, a minimal deviation of the frontal trunk of 0.43° to the left was seen, the confidence
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52 207 interval (0.18° right – 0.67° left) included the perpendicular position, the tolerance interval
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54 208 ranged from 2.91° to the left and to 2.06° to the right. Compensatory, the axial deviation (as
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56 209 inclination between upper body and pelvis) was slightly tilted to the right (0.21°) with a

210 tolerance range of approx. $\pm 4.5^\circ$ and a confidence interval of $<1^\circ$ (0.25° left and 0.66° right).

211 This implied that there are no obvious differences in the inclination between the upper and
212 lower body.

213 The angle of the thoracic bend was calculated from the distance between the vertebra
214 prominens and the kyphosis apex and indicated the deviation from the perpendicular line. The
215 median angle was 13.9° confirming the expected thoracic kyphosis. Here, wider variations
216 were indicated by the tolerance range of 6.49° or 21.31° , and a confidence interval varying
217 from 13.19° to 14.62° . The lumbar bending angle describes the deviation of the distance
218 between the lordosis- and kyphosis apex. As compared to the thoracic bend, similar variations
219 of the tolerance value and the confidence intervals were seen in the lumbar region, with a
220 bending angle of 13.17° (tolerance value 7.83° to 23.06° ; confidence interval 11.90° to
221 14.25°).

222 Measurement of the lateral deviation showed a right-sided inclination of the median line by
223 3.92° when connecting the points VP and the center of the pelvic markers. Both the tolerance
224 range (0.50° respectively 7.33°) as well as the confidence interval ($3.59^\circ/4.25^\circ$) indicated a
225 right-sided deviation.

226 The rotation of the spinal column is a torsion marker of the spinal column and can be
227 measured from the spinous processes of the vertebrae. In our analysis, a negative value
228 indicates a rotation to the left and a positive value to the right. The median rotation was 4.66° ,
229 with a tolerance range between 2.04° and 12.92° , and a confidence interval between 4.18° and
230 5.29° . Consequently, on average a right sided spinal rotation was found.

231 The next two parameters, the kyphosis and lordosis angle have a mean or a median of 51.66°
232 and 46.29° , with a substantial tolerance range of approximately $\pm 25^\circ$ and a confidence
233 interval of about $\pm 2^\circ$.

234 Shoulder parameters are valid indicators for upper body posture (tab. 1), too. The lower
235 scapula spinae were measured from the fixed markers; the scapula distance values as indicator

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3 236 of the variability of the upper body was 150.56 mm, with a tolerance range of 110.51 – 190.60
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5 237 mm, and a confidence limit of 146.68 – 154.43 mm. The scapular height (deviation from the
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7 238 horizontal line) refers to a slightly lower left shoulder blade (by 1.28°), whereas the upper and
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9 239 lower limit of the range markers were -22.36° and 19.81°, so that the left shoulder blade is
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11 240 more caudally in the lower limit and more cranially in the upper limit. The same variation is
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13 241 shown by the data of the confidence interval, with values of -3.32 (left scapula higher) – 0.76
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15 242 ° (right scapula higher).

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17 243 The shoulder markers illustrated a right shoulder being slightly further dorsal by 3.06°, with a
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19 244 tolerance range of -3.26° to 9.37° and a confidence interval of 2.44° to 3.67°. Only minor
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21 245 differences between the left and right shoulder blade angle were seen, with the right shoulder
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23 246 2.6° (median) more caudally.

24
25 247 Table 1 compiles the pelvis parameters. The distance for the spina iliaca posterior superior
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27 248 markers refers to the pelvic width, which on average is 99.56 mm (tolerance range 74.76 to
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29 249 122.37 mm, confidence interval 97.17 and 101.96 mm).

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31 250 The deviation of the pelvic height (in degrees) from the horizontal plane is very low. Both
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33 251 differences in pelvic height (in mm) and deviations from the horizontal line (in degrees)
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35 252 indicate a slightly higher position of the right pelvic side of approx. 1° or 1 mm (Tab. 4). The
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37 253 same applies to the pelvis torsion and rotation, so that the right iliac marker is rotated
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39 254 posteriorly and simultaneously tilted further ventral (mean pelvis torsion: 0.24 °; mean pelvic
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41 255 rotation: 2.2°).

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51 52 259 **Discussion**

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54 260 This paper presents normal values and normal ranges (tolerance and confidence interval) for
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56 261 the body posture of healthy young females from different occupations. Height, weight and

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3 262 body mass index (BMI) of the participants are comparable to average young German female
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5 263 persons^{34 35}. These parameters were measured by Mensink et al.³⁴ in over 7000 adults from
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7 264 the general German population. The age-matched female group was 3.20 cm smaller, 4.92 kg
8
9 265 heavier and thus also had a BMI 2.58 kg/m² higher in comparison to our values. Similar
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11 266 findings have been reported by the German Federal Statistical Office in 2011 for the survey
12
13 267 year of 2009³⁵, which correlate even better to our results than the findings of Mensink et al.³⁴.
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15 268 Data for height, weight and BMI, obtained to assess the prevalence of obesity in Germany
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17 269 between 1985 and 2002³⁶ in 1504 female volunteers (25-29 years) show that the subjects in
18
19 270 our study are marginal taller, lighter and have a lower BMI.
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21
22 271 87.8% of the participants in this study have a normal BMI, 22.3% more than Mensink et al.³⁴
23
24 272 found for 18-29 year old women. The relation of overweight with social status is well known;
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26 273 this confounder of obesity is seen by the data from Mensink et al.³⁴ who proved that 36.9%
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28 274 women with a high social status suffered from overweight and 16.4% from obesity. Helmert
29
30 275 et al.³⁶ calculated similar data with the equivalent household income; 31.8% of the people in
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32 276 the 4th and 5th quintile (low income) suffer from overweight and 7.8% from obesity. Thus the
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34 277 different BMI values likely are explained by the selection of many participants from the
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36 278 students of the School of Dentistry in our university, with a high social status (72.6%).
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39 279 The back scan values indicate a characteristic posture of young females. Only small
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41 280 deviations from an ideal perpendicular position are noted; the marginally ventral tilt of the
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43 281 trunk, the lateral deviation and rotation of the spine, shoulder and pelvis were very small. The
44
45 282 posture is marginally scoliotic (the ventral trunk tilts marginally to the left side, the scapula is
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47 283 higher on the left side, the pelvis is slightly elevated on the right side) with an expected
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49 284 rotatory component (a lumbar right tilt to compensate for the left tilted ventral trunk, a slight
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51 285 twist of the processus spinosus to the right, the right scapula marginally more dorsal, the SIPS
52
53 286 of the right iliac bone rotated anteriorly) (Tab. 1). The spinal curve, defined by the thoracic
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55 287 and lumbar bending angle and the kyphosis and lordosis angle, indicates that the angle in the
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3 288 thoracic spine area is marginally larger than that in the lumbar region (Tab. 1), and
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5 289 consequently a slight kyphotic posture in the sagittal plane can be observed.

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7 290 Handedness has no influence on these parameters, which should be expected from the
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9 291 observed symmetry. However, since 95.3% of the participants were right-handed no firm
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11 292 conclusions can be drawn for left handed people. Also, whether an influence of the dominated
12
13 293 leg³⁷ exists on the posture of the present investigation can't be answered. Appropriate test
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15 294 methods for the determination of these components should be used in further studies.

16
17 295 A gender comparison for young healthy women and men²⁷ shows only marginal differences
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19 296 in the upper body posture. Both studies used the same measuring system and data evaluation
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21 297 and thus allow a direct comparison of the values. Although the female upper body appears
22
23 298 narrower and more delicate due to the weaker muscular shoulder girdle and the smaller chest,
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25 299 the ratio between chest and shoulder width is the same³⁸.

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27
28 300 The anatomical and constitutional differences are confirmed by the present data. In terms of
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30 301 the width of the shoulders, the fixed scapular landmarks indicate a larger distance of 2.9 cm in
31
32 302 men than in women (Table 1). In contrast, men have a smaller pelvis calculated from the SIPS
33
34 303 markers (6 mm difference). This results in a wider shoulder than pelvis distance by 8.5 cm in
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36 304 men, but only 5.0 cm in women, confirming and quantifying the well-known gender-specific
37
38 305 anatomical differences.

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40
41 306 In addition to these constitutional differences, differences in the lordotic and kyphotic angles
42
43 307 are calculated from the spinal column parameters. Thus, women have an average kyphotic
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45 308 angle of 52°, men of 46°; the lordosis angle is 46° for women and 31° for men. Thus, the
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47 309 spinal curvature in the thoracic and lumbar spine area is more pronounced in women than in
48
49 310 men. The difference in the lordosis angle is about 15° greater than in the case of the kyphotic
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51 311 angle with approximately 6°, however, men have an approximately 15° greater thoracic
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53 312 kyphosis angle than lumbar lordosis angle in contrast to a 6° difference of women.
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3 313 Consequently, men have a larger kyphosis in the thoracic spine, with a corresponding lower
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5 314 lumbar lordosis.
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7 315 Liu et al.³⁹ tried to define standard parameters of cervical spine alignment and range of
8
9 316 motion related to age, sex, and cervical disc. These results underline the more pronounced
10
11 317 thoracic kyphosis in women. The greater lumbar lordosis of the females can be traced back to
12
13 318 sex differences in the pelvic shape. The wider female pelvic basin requires a larger angle
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15 319 between the pelvic bones and a larger and lower pelvic transverse diameter. Thus, the
16
17 320 pronounced female pelvic tilt leads to a larger lumbar lordosis, which consequently causes a
18
19 321 compensatory thoracic hyperkyphosis; these (different) compensations are seen above the
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21 322 pelvic position in both sexes³⁸. This different position of the lumbar spine also affects the
22
23 323 extent of the movement in the flexion-extension testing of the trunk. The total task-specific
24
25 324 hip motion ranges, as measured from erect standing to the maximum flexion, were higher in
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27 325 females than in males⁴⁰.
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31 326 Furthermore, the same authors report that female chronic low back pain patients had higher
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33 327 regional hip and trunk motion ranges than male patients⁴¹. The question, why women have a
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35 328 larger lordosis angle currently is unanswered. An extensive literature search in PubMed and
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37 329 other data bases did not retrieve a published hypothesis. An explanation of physiological
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39 330 differences, however, has been forwarded to comparable sex differences in pelvic anatomy for
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41 331 rodents, and has been related to sexual behavior in these animals. Guinea pigs show
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43 332 hormonally controlled, gender related reproductive behaviour: male guinea pigs show a
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45 333 distinct sexual approach consisting of body raising, intromission and ejaculation, and female
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47 334 guinea pigs respond with a corresponding conceiving position of a predominantly lordotic
48
49 335 lumbar posture^{42 43}. At least for this species the observed anatomical differences may
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51 336 translate directly into an apt reproductive behaviour. The pelvis itself has the same position in
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53 337 both sexes in a relaxed posture, and is positioned almost horizontally.
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3 338 No similar explanation exists for differences in the shoulder region parameters; the right
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5 339 shoulder is positioned more caudal in both sexes, but women have “deeper” shoulders
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7 340 (increased scapular angle right/left).

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9 341 All other parameters are nearly identical between men and women, with the differences
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11 342 smaller than the margin of error of our measurement, and thus have no clinical relevance.

12
13 343 The three-dimensional back scan is a fast, non-contact method to quantitate the body posture,
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15 344 and is suitable for measuring body postures in healthy persons and patients. It can quantify
16
17 345 pathologic positions like scoliosis, kyphosis, leg length differences and functional movement
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19 346 disorders, as well as improvements obtained by medical treatments. The chances and
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21 347 limitations of the measurement system and procedure⁴⁴⁻⁵⁰ has already been discussed by
22
23 348 Ohlendorf et al.^{27 51}. In the future, this method may allow to grade postural deviances, e.g. by
24
25 349 a grading system using the tolerance ranges for men and women, as has been done for bone
26
27 350 densitometry in the t- and z-scales²⁶.

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32 33 352 **Conclusion**

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35 353 Video raster stereography is a method to quantitatively measure the human three-dimensional
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37 354 back surface. Healthy young women have an almost ideally balanced posture with minimal
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39 355 ventral body inclination and a marginal scoliotic deviation. In comparison to age-matched
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41 356 men women have only small differences in upper body posture, with nearly identical normal
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43 357 values. These values allow a comparison of other studies for control and patient data, and may
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45 358 serve as orientation in both clinical practice and scientific studies. Further studies should
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47 359 expand this method to quantify age-related changes in body posture, as well as quantitative
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49 360 assessments of postural changes in relevant orthopedic diseases, and improvements by
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51 361 therapeutic interventions.

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4

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6
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8 367 DO, FV, DC, SS, OG and SJ made substantial contributions to the conception and design of
9
10 368 the manuscript, DO, FV and DC made substantial contributions to the construction of the
11
12 369 measurement protocol and AH and DO has been involved in the statistical data analysis. All
13
14 370 authors have read and approved the final manuscript.

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16
17 372 *b. competing interests*

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559 **Tables**

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561 Tab. 1 Spine, shoulder and pelvis parameter: mean value, median, tolerance regions (upper and lower limit),
 562 confidence interval (left and right limit). *Italic data are non-parametrical values.*

	Mean value/ median	tolerance range lower limit	tolerance range upper limit	confidence interval left limit	confidence interval right limit
Spine parameter					
Trunk length D (mm)	461.31	412.95	509.67	456.64	465.99
Trunk length S (mm)	509.52	458.88	560.15	504.62	514.41
Sagittal trunk decline (°)	-3.31	-8.12	1.5	-3.78	-2.85
Frontal trunk decline (°)	-0.43	-2.91	2.06	-0.67	-0.18
Axis decline (°)	0.21	-4.45	4.86	-0.25	0.66
Thoracic bending angle (°)	13.9	6.49	21.31	13.19	14.62
<i>Lumbar bending angle (°)</i>	<i>13.17</i>	<i>7.83</i>	<i>23.06</i>	<i>11.9</i>	<i>14.25</i>
Standard deviation lateral deviation (mm)	3.92	0.5	7.33	3.59	4.25
<i>Maximal lateral deviation (mm)</i>	<i>-5.35</i>	<i>-12.8</i>	<i>12.38</i>	<i>-5.76</i>	<i>-0.89</i>
<i>Standard deviation rotation (°)</i>	<i>4.66</i>	<i>2.04</i>	<i>12.92</i>	<i>4.18</i>	<i>5.29</i>
<i>Maximal rotation (°)</i>	<i>9.2</i>	<i>-9</i>	<i>37.48</i>	<i>8</i>	<i>10.76</i>
Kyphosis angle (°)	51.66	27.91	74.42	49.37	53.96
Lordosis angle (°)	46.29	21.66	70.92	43.91	48.67
Shoulder parameter					
Scapular distance (mm)	150.56	110.51	190.6	146.68	154.43
Scapular height (°)	-1.28	-22.36	19.81	-3.32	0.76
Scapular rotation (°)	3.06	-3.26	9.37	2.44	3.67
Scapular angle left (°)	28.54	16.49	62.74	27.36	30.74
Scapula angle right (°)	31.17	10.61	73	27.2	34.62
Pelvis parameter					
Pelvis distance (mm)	99.56	74.76	124.37	97.17	101.96
Pelvis height (°)	0.76	-4.29	5.81	0.28	1.25
Pelvis height (mm)	1.34	-7.33	10.01	0.5	2.18
Pelvis torsion (°)	0.24	-6.89	7.36	-0.45	0.93
Pelvis rotation (°)	2.2	-5.72	7.34	1.49	2.76

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565 **Figure legend**

566 Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-
 567 dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens
 568 (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right,
 569 D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS)
 570 right, F: Sacrum-point (cranial beginning of the gluteal cleft).
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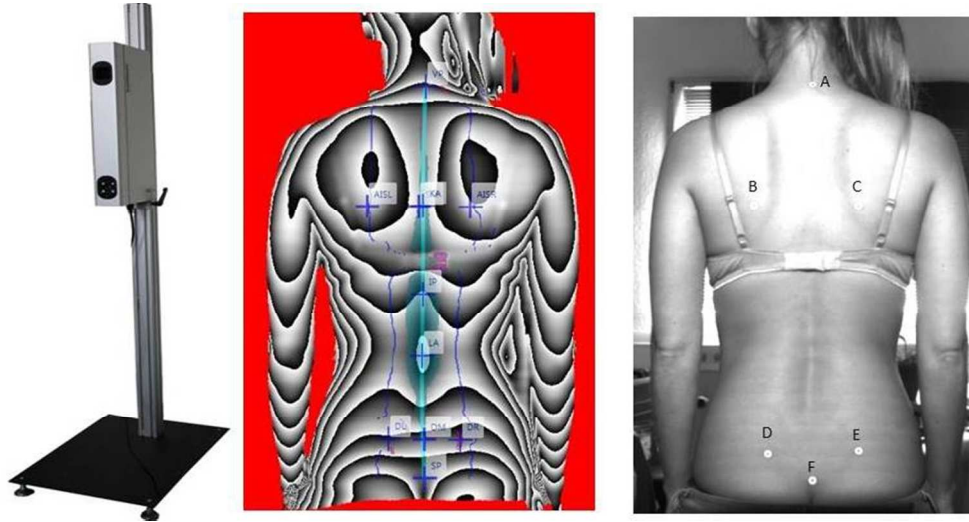


Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

248x128mm (96 x 96 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

	Item No	Recommendation	Pages
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	4,6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(b) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	n/a
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	8
		(b) Describe any methods used to examine subgroups and interactions	n/a
		(c) Explain how missing data were addressed	n/a
		(d) If applicable, explain how loss to follow-up was addressed	n/a
		(e) Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8-9
		(b) Indicate number of participants with missing data for each variable of interest	n/a
		(c) Summarise follow-up time (eg, average and total amount)	n/a
Outcome data	15*	Report numbers of outcome events or summary measures over time	9-11
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-11
		(b) Report category boundaries when continuous variables were categorized	9-11
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	11-14

		analyses, results from similar studies, and other relevant evidence	
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.

n/a = not applicable

Since the study investigated healthy young women in an observational study these parts of the STROBE-criteria are not applicable.

BMJ Open

Standard values of the upper body posture in healthy young female adults, reference values for pathological changes

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Keywords:	body posture, back scan, standard value, female subjects

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9 4 Ohlendorf D^{1*}, Fisch V¹, Doerry C¹, Schamberger S², Oremek G¹, Ackermann H³, Schulze J¹
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34 **Abstract**

35 **Objective:** Classifications of posture deviations are only possible compared to standard
36 values. However, standard values have been published for healthy male adults but not for
37 female adults.

38 **Design:** Observational study.

39 **Setting:** Institute of Occupational Medicine, Social Medicine and Environmental Medicine,
40 Goethe-University Frankfurt/Main.

41 **Participants:** 106 female healthy volunteers (21 - 30 years old; 25.1 ± 2.7 years) were
42 included. Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the heights from 1.53 to
43 1.82 m (1.69 ± 0.06 m), and the body mass index from 16.9 kg/m^2 to 37.6 kg/m^2 (21.1 ± 2.6
44 kg/m^2).

45 **Outcome measures:** A three-dimensional back scan was performed to measure the upper
46 back posture in habitual standing. The tolerance ranges and confidence interval were
47 calculated. Group differences were tested by the Wilcoxon-Mann-Whitney-U-test.

48 **Results:** In normal posture the spinal column was marginally twisted to the left and the
49 vertebrae were marginally rotated to the right. The kyphosis angle is larger than the lumbar
50 angle. Consequently, a more kyphotic posture is observed in the sagittal plane. The habitual
51 posture is slightly scoliotic with a rotational component (scapular depression right, right
52 scapula marginally more dorsally, high state of pelvic right, iliac right further rotated
53 anteriorly).

54 **Conclusions:** Healthy young women have an almost ideally balanced posture with minimal
55 ventral body inclination and a marginal scoliotic deviation. Compared to young males,
56 women show only marginal differences in the upper body posture. These values allow a
57 comparison to other studies, both for control and patient data, and may serve as guideline in
58 both clinical practice and scientific studies.

59

60 Key words: body posture, back scan, standard value, female subjects

61 **Strengths and limitations of this study**

- 62 • Strength: large number of healthy young female participants aged 21-30 years.
- 63 • Strength: Videoraster-stereographic quantitative analysis of the upper back posture.
- 64 • Limitation: measurement of the upper body posture only in habitual standing position,
65 not while moving.
- 66 • Limitation: external influences (occupational environment) were not assessed which
67 might influence the body posture.

69 **Introduction**

70 Various subjective and objective methods to quantify and analyze the body posture have been
71 used, especially for the spinal posture. All prior methods tried to evaluate deformity in the
72 diagnosis and treatment of spinal diseases like scoliosis¹⁻⁴.

73 Quantitative analytical methods enable the diagnosis of spinal curvature deviations and/or
74 control the therapeutic effects. The methods vary by their technical complexity and clinical
75 applicability. Roentgenograms or computed tomography scans are frequently used for bone
76 structure deformities, while ultrasound, inclinometer, thermal infrared imaging, scoliometer or
77 video raster stereography are established postural measurement methods⁵⁻¹⁰. X-ray based
78 methods despite their mutagenic potential still are the gold standard in diagnosis and follow-
79 up of body posture deviations¹¹⁻¹⁴.

80 Video raster stereography has recently been evaluated as an alternative method to quantify
81 vertebral column posture and its deformities^{7 8 15-18}. Guidelines for orthopedic rehabilitation
82 in Germany also recommend a follow-up check but do not specify the methods¹⁹. The three-
83 dimensional back scan measures the body geometry between the 7th cervical vertebra and

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3 84 the gluteal cleft, it has high intraclass correlation coefficients and good Cronbach's Alpha
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5 85 values for intra- and interday reliability for all spine parameters ^{17 18 20 21}. Furthermore, inter
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7 86 tester reliability is high ¹⁷.

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9 87 A three-dimensional surface contour image of the back appears suitable to determine vertebral
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11 88 column deformities, but also to quantify the effect of e.g. orthopedic shoe insoles on the body
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13 89 posture ^{22 23}. In addition, 3D images can quantify muscular imbalances (kyphotic / lordotic
14
15 90 deviations, differences in waist contours, rotation in the shoulder or pelvis) and control the
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17 91 therapeutic success of muscle training in primary, secondary and tertiary prevention ^{24 25}.

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19 92 Due to the changing workplace environment with its increase in digital work, ever more
20
21 93 employees work in a sitting position. Both in the workplace and in the household, this leads to
22
23 94 a steady decrease of physical stress on the body. This lack of exercise may result in the
24
25 95 development of muscular imbalances and increasing numbers of persons with back pain,
26
27 96 currently estimated at 20 million people for Germany ²⁰. Back pain complaints due to
28
29 97 musculoskeletal disorders can lead to disability or early retirement. Even more frequently,
30
31 98 rehabilitation is required to restore the capacity to work in their original occupation.

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33 99 Early signs of postural disorder e.g. musculoskeletal imbalances should be detected when
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35 100 subjective symptoms have developed, and treated appropriately; in order to assess both
36
37 101 diagnosis and treatment effects, quantitative classification criteria are necessary for deviations
38
39 102 from normal posture. These deviations should be quantified, e.g. in the form of (parametric or
40
41 103 non-parametric) percentiles, similar to the Z- or T-scores of bone density ²⁶. However, no
42
43 104 standard or reference values for body posture currently are published for healthy female
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45 105 subjects; reference values of the upper body posture for healthy men have been published
46
47 106 only recently ²⁷. Also, classifications of the severity of posture deviations are only possible
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49 107 when deviations from standard or reference values are quantified.
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3 109 This study measures the upper body posture in healthy women aged 21 - 30 years by a three
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5 110 dimensional back scan to provide standard values for the posture of young healthy women.
6
7 111 These values and their variances define the normal upper body posture and its variability and
8
9 112 may be used to categorize the results of other (orthopaedic) studies. Investigating a
10
11 113 homogeneous group of subjects eliminate constitutional, habitual and degenerative changes
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13 114 that could increase both tolerance ranges and confidence intervals²⁸⁻³¹.
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117 **Methods**

118 **Subjects**

119 106 female volunteers between 21 and 30 years (25.1 ± 2.7 years) participated in this study.
120 Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the height from 1.53 to 1.82 m
121 (1.69 ± 0.06 m), and the body mass index ranged from 16.9 kg/m^2 to 37.6 kg/m^2 (21.1 ± 2.6
122 kg/m^2). 6% of the participants were underweight (BMI $< 18.5 \text{ kg/m}^2$), 87.8% of the
123 participants had a normal BMI (18.5 to 24.9 kg/m^2), 4.7% were overweight (BMI 25 to 29.9
124 kg/m^2) and 0.9% had obesity I° (BMI 30 - 34.9 kg/m^2) according to the WHO weight
125 classification³².

126 All subjects were healthy and free of musculoskeletal complaints and therefore no patient
127 were involved. Using a questionnaire temporomandibular system disorders were excluded³³ ;
128 95.3% of the subjects reported to be right-handed and 4.7% were left-handed. 72.6% of the
129 participants were students, 27.4% employees in different occupations (dentists, physicians,
130 teachers, office workers).

131 All volunteers were informed about the study design before giving written informed consent.
132 The study was approved by the local medical ethics committee of the medical faculty
133 (Goethe-University Frankfurt; No. 303/16).

134

135 **Measurement system**

136 A three-dimensional back scan was performed to quantify the upper back posture while
137 standing, using the back scan system "MiniRot Kombi" (ABW GmbH,
138 Frickenhausen/Germany).

139 In this system a projector forms a stripe pattern on the persons bare back; this stripe pattern is
140 captured by a LCD camera from a defined angle. One measurement lasts approx. 2 seconds.

141 In this way the back surface is represented as a phase picture which is analyzed by an
142 integrated software program reconstructing the 3D image. For calibration of the phase
143 pictures all test persons are marked at six defined, standardized anatomical locations (Fig. 1)
144 indicating underlying bone structures. These allow the calculation of three-dimensional
145 parameters (Fig. 1) with information about rotational movements in the shoulder and pelvic
146 area and the shape of the spine (lordotic, kyphotic and/or scoliotic posture). Artifacts may be
147 caused by different marker placements or movements during the scan, i.e. the projection of
148 the stripe pattern on the back, and thus have to be avoided. To measure the body posture,
149 three repeat measurements are taken within 2 minutes.

150

151 Fig. 1

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153

154 During a movement sequence 15 photos were taken. The maximum picture frequency of the
155 MiniRot Kombi system is more than 50 frames/sec with a spatial resolution of 1/100 mm. The
156 calculation of the three-dimensional coordinates of the back surface is performed by
157 triangulation. The system error is specified as <1 mm (manufacturer information), the
158 reproducibility is limited by the calculations of the upper body posture defined by markers
159 directly on the skin (<0.5 mm).

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3 161 **Body scans**

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5 162 The subjects stood barefoot in their habitual body and jaw posture about 90 cm in front of the
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7 163 back scan apparatus. The arms were hanging loosely; the subjects looked horizontally fixing
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9 164 the opposite wall.

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13 166 **Evaluation Parameter**

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15 167 From the three-dimensional back scan three components were quantified: spinal area (markers
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17 168 on C7 and L5), shoulder area (markers at the top of the left/right scapula) and pelvis area
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19 169 (markers on the left/right spina iliaca posterior superior [SIPS]). The marker positions are
20
21 170 shown in Figure 1, the spine parameters are selected and calculated as described in ²⁷.

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25 172 **Statistical evaluation**

26
27 173 All calculations were carried out using BIAS (Version 11.0) (Epsilon Verlag, Darmstadt,
28
29 174 Germany). Parameter distribution was tested by the Kolmogorov-Smirnov-Test indicating
30
31 175 only partially normal distribution; parametrical or non-parametrical tolerance regions were
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33 176 calculated as defined by the upper and lower limit for 95% of all values (+2 SD values),
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35 177 being found in > 95% of the examined subjects. Values within this range are considered
36
37 178 "normal".

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39 179 Furthermore, the two-sided 95% confidence interval was calculated and indicated the range of
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41 180 the mean or median value – depending on the distribution quality – and showed the
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43 181 "accuracy" of these values. For group differences, the t-test or the Wilcoxon-Mann-Whitney-
44
45 182 U-test was used.

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51 185 **Results**

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3 186 Only the constitutional parameter “body height” was normally distributed, whereas “body
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5 187 weight” and “BMI” were not. The median body weight was 60 kg (tolerance range 49.0 to
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7 188 77.28 kg; confidence interval 57 to 62 kg). For the BMI a median of 20.7 kg/m² was
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9 189 calculated, with a corresponding tolerance range from 17.99 to 27.2 kg/m² and a confidence
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11 190 interval from 20.3 to 21.3 kg/m². For the body height a mean value of 1.69 m was calculated
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13 191 with a tolerance range between 1.57 and 1.82 m and a confidence interval of 1.68 to 1.70 m.

14
15 192 Handedness as a relevant parameter had been refused in advance by the t-test and the
16
17 193 Wilcoxon-Mann-Whitney-U-test. All parameters were not significantly different ($p \geq 0.05$).

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19 194 From the back scan values the posture of an average healthy female person was calculated
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21 195 (tab. 1). On average the subjects are standing slightly inclined in the anterior line of 3.31°
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23 196 (tolerance range 8.12° ventrally to 1.50° dorsally; confidence range 3.78° to the left to 2.85°
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25 197 to the right).

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27 198 Laterally, a minimal deviation of the frontal trunk of 0.43° to the left was seen, the confidence
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29 199 interval (0.18° right – 0.67° left) included the perpendicular position; the tolerance interval
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31 200 ranged from 2.91° to the left to 2.06° to the right. In compensation the axial deviation
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33 201 (inclination between upper body and pelvis) was slightly tilted to the right (0.21°) with a
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35 202 tolerance range of $\pm 4.5^\circ$ and a confidence interval of $< 1^\circ$ (0.25° left and 0.66° right). This
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37 203 implied that there are no obvious differences in the inclination between the upper and lower
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39 204 body.

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41 205 The angle of the thoracic bend was calculated from the distance between the vertebra
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43 206 prominens (VP) and the kyphosis apex and indicated the deviation from the perpendicular
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45 207 line. The median angle was 13.9° confirming the expected thoracic kyphosis. Here, wider
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47 208 variations were seen with a tolerance range from 6.49° to 21.31°, and a confidence interval
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49 209 varying from 13.19° to 14.62°. The lumbar bending angle describes the deviation of the
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51 210 distance between the lordosis and kyphosis apex. As compared to the thoracic bend, similar
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53 211 variations of the tolerance value and the confidence intervals were seen in the lumbar region,
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212 with a bending angle of 13.17° (tolerance value 7.83° to 23.06°; confidence interval 11.90° to
213 14.25°).

214 Measurement of the lateral deviation showed a right-sided inclination of the median line by
215 3.92° when connecting the points VP and the center of the pelvic markers. Both the tolerance
216 range (0.50° and 7.33° respectively), as well as the confidence interval (3.59°/4.25°) indicated
217 a right-sided deviation.

218 The rotation of the spinal column is a marker of the spinal column torsion and can be
219 measured from the spinal processes. In our analysis, a negative value indicates a rotation to
220 the left and a positive value to the right. The median rotation was 4.66°, with a tolerance
221 range between 2.04° and 12.92°, and a confidence interval between 4.18° and 5.29°.

222 Consequently, on average a right sided spinal rotation was found.

223 The kyphosis and lordosis angle have a mean or a median of 51.66° and 46.29°, with a
224 substantial tolerance range of approximately $\pm 25^\circ$ and a confidence interval of about $\pm 2^\circ$.

225 Shoulder parameters are valid indicators for upper body posture (tab. 1), too. The lower
226 scapular spinae were measured by fixed markers; the interscapular distance as indicator of the
227 variability of the upper body was 150.56 mm, with a tolerance range of 110.51 – 190.60 mm,
228 and a confidence limit of 146.68 – 154.43 mm. The scapular height (deviation from the
229 horizontal line) refers to a slightly lower left shoulder blade (by 1.28°), whereas the upper and
230 lower limit of the range markers were -22.36° and 19.81°, so that the left shoulder blade is
231 more caudally in the lower limit and more cranially in the upper limit. The same variation is
232 shown by the data of the confidence interval, with values of -3.32 (left scapula higher) – 0.76
233 ° (right scapula higher).

234 The shoulder markers illustrated a right shoulder being slightly further dorsal by 3.06°, with a
235 tolerance range of -3.26° to 9.37° and a confidence interval of 2.44° to 3.67°. Only minor
236 differences were seen between the left and right shoulder blade angles, with the right shoulder
237 2.6° (median) more caudally.

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3 238 Table 1 also compiles the pelvic parameters. The distance for the spina iliaca posterior
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5 239 superior markers refers to the pelvic width, which on average is 99.56 mm (tolerance range
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7 240 74.76 to 122.37 mm, confidence interval 97.17 and 101.96 mm).

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9 241 The deviation of the pelvic height (in degrees) from the horizontal plane is very low. Both
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11 242 differences in pelvic height (in mm) and deviations from the horizontal line (in degrees)
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13 243 indicate a slightly higher position of the right pelvis by approx. 1° or 1 mm (Tab. 4). The
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15 244 same applies to the pelvic torsion and rotation, so that the right iliac marker is rotated
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17 245 posteriorly and simultaneously tilted further ventral (mean pelvis torsion: 0.24 °; mean pelvic
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19 246 rotation: 2.2°).

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23
24 248 Tab. 1

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27 28 250 **Discussion**

29
30 251 This paper presents normal values and normal ranges including tolerance and confidence
31
32 252 intervals for the body posture of healthy young females. Height, weight and body mass index
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34 253 (BMI) of the participants are comparable to average young German female persons^{34 35}, as
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36 254 measured by Mensink et al.³⁴ in over 7000 adults from the general German population. The
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38 255 age-matched female group from Mensink et al.³⁴ was 3.20 cm smaller, 4.92 kg heavier and
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40 256 thus also had a slightly higher BMI by 2.58 kg/m² as compared to our values. Similar findings
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42 257 have been reported by the German Federal Statistical Office in 2011 for 2009³⁵, which
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44 258 correlate even better to our results.³⁴ Data for height, weight and BMI, obtained to assess the
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46 259 prevalence of obesity in Germany between 1985 and 2002³⁶ in 1504 female volunteers (25-
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48 260 29 years) show that the subjects in our study are marginal taller, lighter and have a lower
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50 261 BMI.

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3 262 In this context, however, it should be borne in mind that this study mainly involved students
4 263 and university employees with the same lifestyle, with values slightly differing from the
5 264 general population, and a likely overrepresentation of participants with a high social status.
6 265 87.8% of the participants in this study have a normal BMI, 22.3% more than Mensink et al.³⁴
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9 266 found for 18-29 year old women. The relation of overweight with social status is well known;
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11 267 this confounder is also seen by the data from Mensink et al.³⁴; 36.9% of women with a low
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13 268 social status were overweight, 16.4% obese as compared to 18.7% overweight and 4.4%
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15 269 obese women with a high social status. Helmert et al.³⁶ calculated similar data using the
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17 270 equivalent household income; thus the different BMI values likely are explained by the
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19 271 participant selection preferentially from the students of the School of Dentistry in our
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21 272 university, with a high social status.
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24 273 The back scan values indicate a characteristic posture of young females. Only small
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26 274 deviations from an ideal perpendicular position are noted; the ventral tilt of the trunk, the
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28 275 lateral deviation and rotation of the spine, shoulder and pelvis were very small. The posture is
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30 276 marginally scoliotic (the ventral trunk tilts marginally to the left side, the scapula is higher on
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32 277 the left side, the pelvis slightly elevated on the right side) with an expected rotatory
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34 278 component (a lumbar right tilt to compensate for the left tilted ventral trunk, a slight twist of
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36 279 the processus spinosus to the right, the right scapula marginally more dorsal, the SIPS of the
37
38 280 right iliac bone rotated anteriorly) (Tab. 1). The spinal curve, defined by the thoracic and
39
40 281 lumbar bending angle and the kyphosis and lordosis angle, indicates that the angle in the
41
42 282 thoracic spine area is marginally larger than that in the lumbar region (Tab. 1), and a slightly
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44 283 kyphotic posture in the sagittal plane can be observed.
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47 284 Handedness has no influence on these parameters, which should be expected from the
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49 285 observed symmetry. However, since 95.3% of the participants were right-handed no firm
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51 286 conclusions can be drawn for left handed people. Also, whether an influence of the dominant
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53 287 leg³⁷ exists on the posture cannot be answered by our results. Appropriate test methods for
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55 288 the determination of these components should be used in further studies.
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3 289 A gender comparison ²⁷ shows only marginal differences in the upper body posture. Both
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5 290 studies used the same measurement system and data evaluation and thus allow a direct
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7 291 comparison of the values. Although the female upper body appears narrower and more
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9 292 delicate due to the weaker muscular shoulder girdle and the smaller chest, the ratio between
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11 293 chest and shoulder width is the same ³⁸.

13 294 The anatomical and constitutional differences are confirmed by the present data. In terms of
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15 295 the shoulder width, the fixed scapular landmarks indicate a larger distance of 2.9 cm in men
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17 296 than in women (Table 1). In contrast, men have a smaller pelvis calculated from the SIPS
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19 297 markers (6 mm difference) which results in a wider shoulder than pelvis distance by 8.5 cm in
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21 298 men, but only 5.0 cm in women, confirming and quantifying the well-known gender-specific
22
23 299 anatomical differences.

26 300 In addition to these constitutional differences, differences in the lordotic and kyphotic angles
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28 301 are calculated from the spinal column parameters. Thus, women have an average kyphotic
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30 302 angle of 52°, men of 46°; the lordosis angle is 46° for women and 31° for men. Thus, the
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32 303 spinal curvature in the thoracic and lumbar spine area is more pronounced in women than in
33
34 304 men. The difference in the lordosis angle between the sexes is about 15° and in the case of the
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36 305 kyphotic angle with approximately 6°, however, men have an approximately 15° greater
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38 306 thoracic kyphosis angle than lumbar lordosis angle in contrast to a 6° difference of women.
39
40 307 Consequently, the kyphosis angle is larger than the lordosis angle in both sexes, women are in
41
42 308 a more balanced posture due to the smaller difference between the two angles.

45 309 Liu et al. ³⁹ tried to define standard parameters of cervical spine alignment and range of
46
47 310 motion related to age, sex, and cervical disc. These results underline the more pronounced
48
49 311 thoracal kyphosis in women. The greater lumbar lordosis of the females can be traced back to
50
51 312 sex differences in the pelvic shape: The wider pelvic blades of the female pelvis have a larger
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53 313 angle between the pubic branches, a larger transverse pelvic diameter and are lower. Thus, the
54
55 314 pronounced female pelvic tilt leads to a larger lumbar lordosis. Consequently, a larger lumbar
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3 315 lordosis causes a thoracal hyperkyphosis. These (different) compensations are seen in the
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5 316 pelvic position in both sexes³⁸. This position of the lumbar spine also affects the extent of the
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7 317 movement in the flexion-extension testing of the trunk. The total task-specific hip motion
8
9 318 ranges as measured from erect standing to the maximum flection were higher in females than
10
11 319 in males⁴⁰.

12
13 320 Furthermore, the same authors report that female chronic low back pain patients had higher
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15 321 regional hip and trunk motion ranges than male patients⁴¹. Why women have a larger lordosis
16
17 322 angle currently is unknown. An extensive literature search in PubMed and other data bases
18
19 323 did not retrieve any published hypothesis. An explanation of physiological differences,
20
21 324 however, has been forwarded to comparable sex differences in the pelvic anatomy for rodents
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23 325 and has been related to sexual behavior in these animals. Guinea pigs show hormonally
24
25 326 controlled, gender related reproductive behaviour: male guinea pigs show a distinct sexual
26
27 327 approach consisting of body raising, intromission and ejaculation, and female guinea pigs
28
29 328 respond with a corresponding conceiving position of a predominantly lordotic lumbar posture
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31 329^{42 43}. At least for this species the observed anatomical differences may translate directly into
32
33 330 an apt reproductive behaviour. In both species, the pelvis itself has the same position in both
34
35 331 sexes in a relaxed posture, and is positioned almost horizontally.

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37 332 No similar explanation exists for differences in the shoulder region parameters either; the
38
39 333 right shoulder is positioned more caudal in both sexes, but women have “deeper” shoulders
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41 334 (increased scapular angle right/left).

42
43 335 All other positional parameters are nearly identical between men and women, with the
44
45 336 differences being smaller than the margin of error, and likely have no clinical relevance.

46
47 337 The three-dimensional back scan is a fast, non-contact method to quantify the body posture
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49 338 and is suitable for measuring body postures in both healthy persons and patients. It can
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51 339 quantify pathologic positions like scoliosis, kyphosis, leg length differences and functional
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53 340 movement disorders, as well as improvements by medical treatment. The chances and
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3 341 limitations of the measurement system and procedure ⁴⁴⁻⁵⁰ has already been discussed by
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5 342 Ohlendorf et al. ^{27 51}. In the future, this method may allow to grade postural deviations, e.g. by
6
7 343 a grading system using the tolerance ranges for men and women, as has been done for bone
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9 344 densitometry in the t- and z-scales ²⁶.

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11 345

12 13 346 **Conclusion**

14
15 347 Video raster stereography is a method to quantitatively measure the human three-dimensional
16
17 348 back surface. Healthy young women have an almost ideally balanced posture with minimal
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19 349 ventral body inclination and a marginal scoliotic deviation. In comparison to men women
20
21 350 have only small differences in upper body posture, with nearly identical normal values. These
22
23 351 values allow a quantitative comparison with other studies for control and patient data, and
24
25 352 may serve as an orientation in both clinical practice and scientific studies. Further studies
26
27 353 could expand this method to age-related changes in body posture, quantitative assessments of
28
29 354 postural changes in relevant diseases, and improvements by therapeutic interventions.

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39
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41 42 359 *a. contributorship statement*

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44
45 361 the manuscript, DO, VF and CD made substantial contributions to the construction of the
46
47 362 measurement protocol and HA and DO have been involved in the statistical data analysis. All
48
49 363 authors have read and approved the final manuscript.

50 364

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53 366 The authors declare that they have no conflict of interest.

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55 367

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2
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4 370

5
6 371 *d. data sharing statement*

7 372 No additional data available.

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552 **Tables**

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554 Tab. 1 Spine, shoulder and pelvis parameter: mean value, median, tolerance regions (upper and lower limit),
555 confidence interval (left and right limit). Italic data are non-parametrical values.

	Mean value/ median	tolerance range lower limit	tolerance range upper limit	confidence interval left limit	confidence interval right limit
Spine parameter					
Trunk length D (mm)	461.31	412.95	509.67	456.64	465.99
Trunk length S (mm)	509.52	458.88	560.15	504.62	514.41
Sagittal trunk decline (°)	-3.31	-8.12	1.5	-3.78	-2.85
Frontal trunk decline (°)	-0.43	-2.91	2.06	-0.67	-0.18

Axis decline (°)	0.21	-4.45	4.86	-0.25	0.66
Thoracic bending angle (°)	13.9	6.49	21.31	13.19	14.62
<i>Lumbar bending angle (°)</i>	<i>13.17</i>	<i>7.83</i>	<i>23.06</i>	<i>11.9</i>	<i>14.25</i>
Standard deviation lateral deviation (mm)	3.92	0.5	7.33	3.59	4.25
<i>Maximal lateral deviation (mm)</i>	<i>-5.35</i>	<i>-12.8</i>	<i>12.38</i>	<i>-5.76</i>	<i>-0.89</i>
<i>Standard deviation rotation (°)</i>	<i>4.66</i>	<i>2.04</i>	<i>12.92</i>	<i>4.18</i>	<i>5.29</i>
<i>Maximal rotation (°)</i>	<i>9.2</i>	<i>-9</i>	<i>37.48</i>	<i>8</i>	<i>10.76</i>
Kyphosis angle (°)	51.66	27.91	74.42	49.37	53.96
Lordosis angle (°)	46.29	21.66	70.92	43.91	48.67
Shoulder parameter					
Scapular distance (mm)	150.56	110.51	190.6	146.68	154.43
Scapular height (°)	-1.28	-22.36	19.81	-3.32	0.76
Scapular rotation (°)	3.06	-3.26	9.37	2.44	3.67
Scapular angle left (°)	28.54	16.49	62.74	27.36	30.74
Scapula angle right (°)	31.17	10.61	73	27.2	34.62
Pelvis parameter					
Pelvis distance (mm)	99.56	74.76	124.37	97.17	101.96
Pelvis height (°)	0.76	-4.29	5.81	0.28	1.25
Pelvis height (mm)	1.34	-7.33	10.01	0.5	2.18
Pelvis torsion (°)	0.24	-6.89	7.36	-0.45	0.93
Pelvis rotation (°)	2.2	-5.72	7.34	1.49	2.76

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560 Figure legend

561 Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-
 562 dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens
 563 (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right,
 564 D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS)
 565 right, F: Sacrum-point (cranial beginning of the gluteal cleft).
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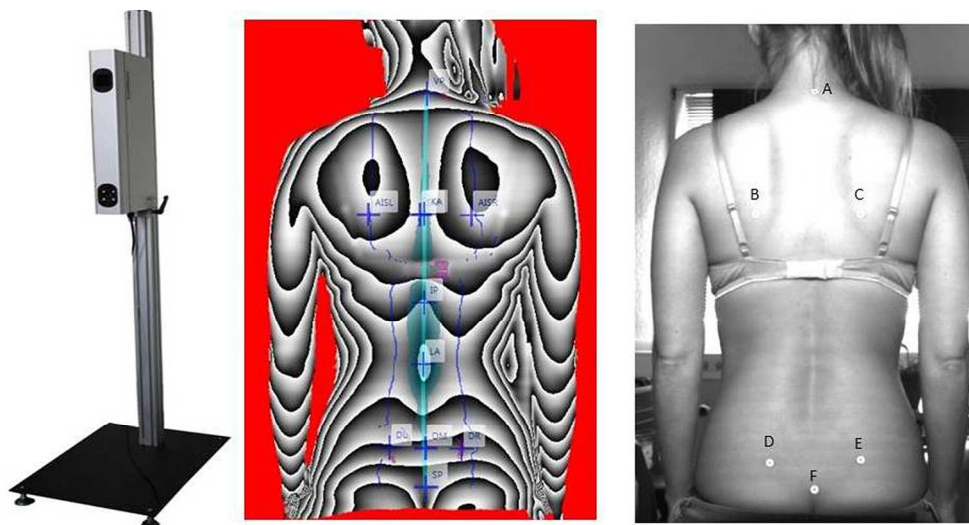


Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

199x103mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

	Item No	Recommendation	Pages
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	4,6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(b) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	n/a
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	8
		(b) Describe any methods used to examine subgroups and interactions	n/a
		(c) Explain how missing data were addressed	n/a
		(d) If applicable, explain how loss to follow-up was addressed	n/a
		(e) Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8-9
		(b) Indicate number of participants with missing data for each variable of interest	n/a
		(c) Summarise follow-up time (eg, average and total amount)	n/a
Outcome data	15*	Report numbers of outcome events or summary measures over time	9-11
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-11
		(b) Report category boundaries when continuous variables were categorized	9-11
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	11-14

		analyses, results from similar studies, and other relevant evidence	
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.

n/a = not applicable

Since the study investigated healthy young women in an observational study these parts of the STROBE-criteria are not applicable.

BMJ Open

Standard reference values of the upper body posture in healthy young female adults in Germany: an observational study

Journal:	<i>BMJ Open</i>
Manuscript ID	bmjopen-2018-022236.R2
Article Type:	Research
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Primary Subject Heading:	Rehabilitation medicine
Secondary Subject Heading:	Rehabilitation medicine
Keywords:	body posture, back scan, standard value, female subjects

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Manuscripts

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9 4 Ohlendorf D^{1*}, Fisch V¹, Doerry C¹, Schamberger S², Oremek G¹, Ackermann H³, Schulze J¹
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34 **Abstract**

35 **Objective:** Classifications of posture deviations are only possible compared to standard
36 values. However, standard values have been published for healthy male adults but not for
37 female adults.

38 **Design:** Observational study.

39 **Setting:** Institute of Occupational Medicine, Social Medicine and Environmental Medicine,
40 Goethe-University Frankfurt/Main.

41 **Participants:** 106 female healthy volunteers (21 - 30 years old; 25.1 ± 2.7 years) were
42 included. Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the heights from 1.53 to
43 1.82 m (1.69 ± 0.06 m), and the body mass index from 16.9 kg/m^2 to 37.6 kg/m^2 (21.1 ± 2.6
44 kg/m^2).

45 **Outcome measures:** A three-dimensional back scan was performed to measure the upper
46 back posture in habitual standing. The tolerance ranges and confidence interval were
47 calculated. Group differences were tested by the Wilcoxon-Mann-Whitney-U-test.

48 **Results:** In normal posture the spinal column was marginally twisted to the left and the
49 vertebrae were marginally rotated to the right. The kyphosis angle is larger than the lumbar
50 angle. Consequently, a more kyphotic posture is observed in the sagittal plane. The habitual
51 posture is slightly scoliotic with a rotational component (scapular depression right, right
52 scapula marginally more dorsally, high state of pelvic right, iliac right further rotated
53 anteriorly).

54 **Conclusions:** Healthy young women have an almost ideally balanced posture with minimal
55 ventral body inclination and a marginal scoliotic deviation. Compared to young males,
56 women show only marginal differences in the upper body posture. These values allow a
57 comparison to other studies, both for control and patient data, and may serve as guideline in
58 both clinical practice and scientific studies.

59

60 Key words: body posture, back scan, standard value, female subjects

61 **Strengths and limitations of this study**

- 62 • Strength: large number of healthy young female participants aged 21-30 years.
- 63 • Strength: Videoraster-stereographic quantitative analysis of the upper back posture.
- 64 • Limitation: measurement of the upper body posture only in habitual standing position,
65 not while moving.
- 66 • Limitation: external influences (occupational environment) were not assessed which
67 might influence the body posture.

69 **Introduction**

70 Various subjective and objective methods to quantify and analyze the body posture have been
71 used, especially for the spinal posture. All prior methods tried to evaluate deformity in the
72 diagnosis and treatment of spinal diseases like scoliosis¹⁻⁴.

73 Quantitative analytical methods enable the diagnosis of spinal curvature deviations and/or
74 control the therapeutic effects. The methods vary by their technical complexity and clinical
75 applicability. Roentgenograms or computed tomography scans are frequently used for bone
76 structure deformities, while ultrasound, inclinometer, thermal infrared imaging, scoliometer or
77 video raster stereography are established postural measurement methods⁵⁻¹⁰. X-ray based
78 methods despite their mutagenic potential still are the gold standard in diagnosis and follow-
79 up of body posture deviations¹¹⁻¹⁴.

80 Video raster stereography has recently been evaluated as an alternative method to quantify
81 vertebral column posture and its deformities^{7 8 15-18}. Guidelines for orthopedic rehabilitation
82 in Germany also recommend a follow-up check but do not specify the methods¹⁹. The three-
83 dimensional back scan measures the body geometry between the 7th cervical vertebra and

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3 84 the gluteal cleft, it has high intraclass correlation coefficients and good Cronbach's Alpha
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5 85 values for intra- and interday reliability for all spine parameters ^{17 18 20 21}. Furthermore, inter
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7 86 tester reliability is high ¹⁷.

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9 87 A three-dimensional surface contour image of the back appears suitable to determine vertebral
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11 88 column deformities, but also to quantify the effect of e.g. orthopedic shoe insoles on the body
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13 89 posture ^{22 23}. In addition, 3D images can quantify muscular imbalances (kyphotic / lordotic
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15 90 deviations, differences in waist contours, rotation in the shoulder or pelvis) and control the
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17 91 therapeutic success of muscle training in primary, secondary and tertiary prevention ^{24 25}.

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19 92 Due to the changing workplace environment with its increase in digital work, ever more
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21 93 employees work in a sitting position. Both in the workplace and in the household, this leads to
22
23 94 a steady decrease of physical stress on the body. This lack of exercise may result in the
24
25 95 development of muscular imbalances and increasing numbers of persons with back pain,
26
27 96 currently estimated at 20 million people for Germany ²⁰. Back pain complaints due to
28
29 97 musculoskeletal disorders can lead to disability or early retirement. Even more frequently,
30
31 98 rehabilitation is required to restore the capacity to work in their original occupation.

32
33 99 Early signs of postural disorder e.g. musculoskeletal imbalances should be detected when
34
35 100 subjective symptoms have developed, and treated appropriately; in order to assess both
36
37 101 diagnosis and treatment effects, quantitative classification criteria are necessary for deviations
38
39 102 from normal posture. These deviations should be quantified, e.g. in the form of (parametric or
40
41 103 non-parametric) percentiles, similar to the Z- or T-scores of bone density ²⁶. However, no
42
43 104 standard or reference values for body posture currently are published for healthy female
44
45 105 subjects; reference values of the upper body posture for healthy men have been published
46
47 106 only recently ²⁷. Also, classifications of the severity of posture deviations are only possible
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49 107 when deviations from standard or reference values are quantified.

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3 109 This study measures the upper body posture in healthy women aged 21 - 30 years by a three
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5 110 dimensional back scan to provide standard values for the posture of young healthy women.
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7 111 These values and their variances define the normal upper body posture and its variability and
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9 112 may be used to categorize the results of other (orthopaedic) studies. Investigating a
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11 113 homogeneous group of subjects eliminate constitutional, habitual and degenerative changes
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13 114 that could increase both tolerance ranges and confidence intervals²⁸⁻³¹.
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117 **Methods**

118 **Subjects and Public Involvement**

119 106 female volunteers between 21 and 30 years (25.1 ± 2.7 years) participated in this study.
120 Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the height from 1.53 to 1.82 m
121 (1.69 ± 0.06 m), and the body mass index ranged from 16.9 kg/m^2 to 37.6 kg/m^2 (21.1 ± 2.6
122 kg/m^2). 6% of the participants were underweight (BMI $< 18.5 \text{ kg/m}^2$), 87.8% of the
123 participants had a normal BMI (18.5 to 24.9 kg/m^2), 4.7% were overweight (BMI 25 to 29.9
124 kg/m^2) and 0.9% had obesity I° (BMI 30 - 34.9 kg/m^2) according to the WHO weight
125 classification³².

126 All subjects were healthy and free of musculoskeletal complaints and therefore no patient
127 were involved. Using a questionnaire temporomandibular system disorders were excluded³³ ;
128 95.3% of the subjects reported to be right-handed and 4.7% were left-handed. 72.6% of the
129 participants were students, 27.4% employees in different occupations (dentists, physicians,
130 teachers, office workers).

131 No patients were involved. All volunteers were healthy (no patients involved) and informed
132 about the study design before giving written informed consent. The study was approved by
133 the local medical ethics committee of the medical faculty (Goethe-University Frankfurt; No.
134 303/16).

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5 136 **Measurement system**

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7 137 A three-dimensional back scan was performed to quantify the upper back posture while
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9 138 standing, using the back scan system "MiniRot Kombi" (ABW GmbH,
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11 139 Frickenhausen/Germany).

12
13 140 In this system a projector forms a stripe pattern on the persons bare back; this stripe pattern is
14
15 141 captured by a LCD camera from a defined angle. One measurement lasts approx. 2 seconds.
16
17 142 In this way the back surface is represented as a phase picture which is analyzed by an
18
19 143 integrated software program reconstructing the 3D image. For calibration of the phase
20
21 144 pictures all test persons are marked at six defined, standardized anatomical locations (Fig. 1)
22
23 145 indicating underlying bone structures. These allow the calculation of three-dimensional
24
25 146 parameters (Fig. 1) with information about rotational movements in the shoulder and pelvic
26
27 147 area and the shape of the spine (lordotic, kyphotic and/or scoliotic posture). Artifacts may be
28
29 148 caused by different marker placements or movements during the scan, i.e. the projection of
30
31 149 the stripe pattern on the back, and thus have to be avoided. To measure the body posture,
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33 150 three repeat measurements are taken within 2 minutes.
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38
39 152 Fig. 1

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45 155 During a movement sequence 15 photos were taken. The maximum picture frequency of the
46
47 156 MiniRot Kombi system is more than 50 frames/sec with a spatial resolution of 1/100 mm. The
48
49 157 calculation of the three-dimensional coordinates of the back surface is performed by
50
51 158 triangulation. The system error is specified as <1 mm (manufacturer information), the
52
53 159 reproducibility is limited by the calculations of the upper body posture defined by markers
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55 160 directly on the skin (<0.5 mm).
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5 162 **Body scans**6
7 163 The subjects stood barefoot in their habitual body and jaw posture about 90 cm in front of the
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9 164 back scan apparatus. The arms were hanging loosely; the subjects looked horizontally fixing
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11 165 the opposite wall.
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16 167 **Evaluation Parameter**17
18 168 From the three-dimensional back scan three components were quantified: spinal area (markers
19
20 169 on C7 and L5), shoulder area (markers at the top of the left/right scapula) and pelvis area
21
22 170 (markers on the left/right spina iliaca posterior superior [SIPS]). The marker positions are
23
24 171 shown in Figure 1, the spine parameters are selected and calculated as described in ²⁷.
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29 173 **Statistical evaluation**30
31 174 All calculations were carried out using BIAS (Version 11.0) (Epsilon Verlag, Darmstadt,
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33 175 Germany). Parameter distribution was tested by the Kolmogorov-Smirnov-Test indicating
34
35 176 only partially normal distribution; parametrical or non-parametrical tolerance regions were
36
37 177 calculated as defined by the upper and lower limit for 95% of all values (+2 SD values),
38
39 178 being found in > 95% of the examined subjects. Values within this range are considered
40
41 179 "normal".
4243
44 180 Furthermore, the two-sided 95% confidence interval was calculated and indicated the range of
45
46 181 the mean or median value – depending on the distribution quality – and showed the
47
48 182 "accuracy" of these values. For group differences, the t-test or the Wilcoxon-Mann-Whitney-
49
50 183 U-test was used.
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54 18555
56
57 186 **Results**

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3 187 Only the constitutional parameter “body height” was normally distributed, whereas “body
4
5 188 weight” and “BMI” were not. The median body weight was 60 kg (tolerance range 49.0 to
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7 189 77.28 kg; confidence interval 57 to 62 kg). For the BMI a median of 20.7 kg/m² was
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9 190 calculated, with a corresponding tolerance range from 17.99 to 27.2 kg/m² and a confidence
10
11 191 interval from 20.3 to 21.3 kg/m². For the body height a mean value of 1.69 m was calculated
12
13 192 with a tolerance range between 1.57 and 1.82 m and a confidence interval of 1.68 to 1.70 m.

14
15 193 Handedness as a relevant parameter had been refused in advance by the t-test and the
16
17 194 Wilcoxon-Mann-Whitney-U-test. All parameters were not significantly different ($p \geq 0.05$).

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19 195 From the back scan values the posture of an average healthy female person was calculated
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21 196 (tab. 1). On average the subjects are standing slightly inclined in the anterior line of 3.31°
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23 197 (tolerance range 8.12° ventrally to 1.50° dorsally; confidence range 3.78° to the left to 2.85°
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25 198 to the right).

26
27 199 Laterally, a minimal deviation of the frontal trunk of 0.43° to the left was seen, the confidence
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29 200 interval (0.18° right – 0.67° left) included the perpendicular position; the tolerance interval
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31 201 ranged from 2.91° to the left to 2.06° to the right. In compensation the axial deviation
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33 202 (inclination between upper body and pelvis) was slightly tilted to the right (0.21°) with a
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35 203 tolerance range of $\pm 4.5^\circ$ and a confidence interval of $< 1^\circ$ (0.25° left and 0.66° right). This
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37 204 implied that there are no obvious differences in the inclination between the upper and lower
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39 205 body.

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41 206 The angle of the thoracic bend was calculated from the distance between the vertebra
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43 207 prominens (VP) and the kyphosis apex and indicated the deviation from the perpendicular
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45 208 line. The median angle was 13.9° confirming the expected thoracic kyphosis. Here, wider
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47 209 variations were seen with a tolerance range from 6.49° to 21.31°, and a confidence interval
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49 210 varying from 13.19° to 14.62°. The lumbar bending angle describes the deviation of the
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51 211 distance between the lordosis and kyphosis apex. As compared to the thoracic bend, similar
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53 212 variations of the tolerance value and the confidence intervals were seen in the lumbar region,
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213 with a bending angle of 13.17° (tolerance value 7.83° to 23.06° ; confidence interval 11.90° to
214 14.25°).

215 Measurement of the lateral deviation showed a right-sided inclination of the median line by
216 3.92° when connecting the points VP and the center of the pelvic markers. Both the tolerance
217 range (0.50° and 7.33° respectively), as well as the confidence interval ($3.59^\circ/4.25^\circ$) indicated
218 a right-sided deviation.

219 The rotation of the spinal column is a marker of the spinal column torsion and can be
220 measured from the spinal processes. In our analysis, a negative value indicates a rotation to
221 the left and a positive value to the right. The median rotation was 4.66° , with a tolerance
222 range between 2.04° and 12.92° , and a confidence interval between 4.18° and 5.29° .
223 Consequently, on average a right sided spinal rotation was found.

224 The kyphosis and lordosis angle have a mean or a median of 51.66° and 46.29° , with a
225 substantial tolerance range of approximately $\pm 25^\circ$ and a confidence interval of about $\pm 2^\circ$.

226 Shoulder parameters are valid indicators for upper body posture (tab. 1), too. The lower
227 scapular spinae were measured by fixed markers; the interscapular distance as indicator of the
228 variability of the upper body was 150.56 mm, with a tolerance range of $110.51 - 190.60$ mm,
229 and a confidence limit of $146.68 - 154.43$ mm. The scapular height (deviation from the
230 horizontal line) refers to a slightly lower left shoulder blade (by 1.28°), whereas the upper and
231 lower limit of the range markers were -22.36° and 19.81° , so that the left shoulder blade is
232 more caudally in the lower limit and more cranially in the upper limit. The same variation is
233 shown by the data of the confidence interval, with values of -3.32 (left scapula higher) – 0.76
234 $^\circ$ (right scapula higher).

235 The shoulder markers illustrated a right shoulder being slightly further dorsal by 3.06° , with a
236 tolerance range of -3.26° to 9.37° and a confidence interval of 2.44° to 3.67° . Only minor
237 differences were seen between the left and right shoulder blade angles, with the right shoulder
238 2.6° (median) more caudally.

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3 239 Table 1 also compiles the pelvic parameters. The distance for the spina iliaca posterior
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5 240 superior markers refers to the pelvic width, which on average is 99.56 mm (tolerance range
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7 241 74.76 to 122.37 mm, confidence interval 97.17 and 101.96 mm).

8
9 242 The deviation of the pelvic height (in degrees) from the horizontal plane is very low. Both
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11 243 differences in pelvic height (in mm) and deviations from the horizontal line (in degrees)
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13 244 indicate a slightly higher position of the right pelvis by approx. 1° or 1 mm (Tab. 4). The
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15 245 same applies to the pelvic torsion and rotation, so that the right iliac marker is rotated
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17 246 posteriorly and simultaneously tilted further ventral (mean pelvis torsion: 0.24 °; mean pelvic
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19 247 rotation: 2.2°).

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23
24 249 Tab. 1

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27 28 251 **Discussion**

29
30 252 This paper presents normal values and normal ranges including tolerance and confidence
31
32 253 intervals for the body posture of healthy young females. Height, weight and body mass index
33
34 254 (BMI) of the participants are comparable to average young German female persons^{34 35}, as
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36 255 measured by Mensink et al.³⁴ in over 7000 adults from the general German population. The
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38 256 age-matched female group from Mensink et al.³⁴ was 3.20 cm smaller, 4.92 kg heavier and
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40 257 thus also had a slightly higher BMI by 2.58 kg/m² as compared to our values. Similar findings
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42 258 have been reported by the German Federal Statistical Office in 2011 for 2009³⁵, which
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44 259 correlate even better to our results.³⁴ Data for height, weight and BMI, obtained to assess the
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46 260 prevalence of obesity in Germany between 1985 and 2002³⁶ in 1504 female volunteers (25-
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48 261 29 years) show that the subjects in our study are marginal taller, lighter and have a lower
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52 262 BMI.

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3 263 In this context, however, it should be borne in mind that this study mainly involved students
4 264 and university employees with the same lifestyle, with values slightly differing from the
5 265 general population, and a likely overrepresentation of participants with a high social status.
6 266 87.8% of the participants in this study have a normal BMI, 22.3% more than Mensink et al.³⁴
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8
9 267 found for 18-29 year old women. The relation of overweight with social status is well known;
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11 268 this confounder is also seen by the data from Mensink et al.³⁴; 36.9% of women with a low
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13 269 social status were overweight, 16.4% obese as compared to 18.7% overweight and 4.4%
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15 270 obese women with a high social status. Helmert et al.³⁶ calculated similar data using the
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17 271 equivalent household income; thus the different BMI values likely are explained by the
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19 272 participant selection preferentially from the students of the School of Dentistry in our
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21 273 university, with a high social status.
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24 274 The back scan values indicate a characteristic posture of young females. Only small
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26 275 deviations from an ideal perpendicular position are noted; the ventral tilt of the trunk, the
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28 276 lateral deviation and rotation of the spine, shoulder and pelvis were very small. The posture is
29
30 277 marginally scoliotic (the ventral trunk tilts marginally to the left side, the scapula is higher on
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32 278 the left side, the pelvis slightly elevated on the right side) with an expected rotatory
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34 279 component (a lumbar right tilt to compensate for the left tilted ventral trunk, a slight twist of
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36 280 the processus spinosus to the right, the right scapula marginally more dorsal, the SIPS of the
37
38 281 right iliac bone rotated anteriorly) (Tab. 1). The spinal curve, defined by the thoracic and
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40 282 lumbar bending angle and the kyphosis and lordosis angle, indicates that the angle in the
41
42 283 thoracic spine area is marginally larger than that in the lumbar region (Tab. 1), and a slightly
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44 284 kyphotic posture in the sagittal plane can be observed.
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47 285 Handedness has no influence on these parameters, which should be expected from the
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49 286 observed symmetry. However, since 95.3% of the participants were right-handed no firm
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51 287 conclusions can be drawn for left handed people. Also, whether an influence of the dominant
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53 288 leg³⁷ exists on the posture cannot be answered by our results. Appropriate test methods for
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55 289 the determination of these components should be used in further studies.
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3 290 A gender comparison ²⁷ shows only marginal differences in the upper body posture. Both
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5 291 studies used the same measurement system and data evaluation and thus allow a direct
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7 292 comparison of the values. Although the female upper body appears narrower and more
8
9 293 delicate due to the weaker muscular shoulder girdle and the smaller chest, the ratio between
10
11 294 chest and shoulder width is the same ³⁸.

13 295 The anatomical and constitutional differences are confirmed by the present data. In terms of
14
15 296 the shoulder width, the fixed scapular landmarks indicate a larger distance of 2.9 cm in men
16
17 297 than in women (Table 1). In contrast, men have a smaller pelvis calculated from the SIPS
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19 298 markers (6 mm difference) which results in a wider shoulder than pelvis distance by 8.5 cm in
20
21 299 men, but only 5.0 cm in women, confirming and quantifying the well-known gender-specific
22
23 300 anatomical differences.

26 301 In addition to these constitutional differences, differences in the lordotic and kyphotic angles
27
28 302 are calculated from the spinal column parameters. Thus, women have an average kyphotic
29
30 303 angle of 52°, men of 46°; the lordosis angle is 46° for women and 31° for men. Thus, the
31
32 304 spinal curvature in the thoracic and lumbar spine area is more pronounced in women than in
33
34 305 men. The difference in the lordosis angle between the sexes is about 15° and in the case of the
35
36 306 kyphotic angle with approximately 6°, however, men have an approximately 15° greater
37
38 307 thoracic kyphosis angle than lumbar lordosis angle in contrast to a 6° difference of women.
39
40 308 Consequently, the kyphosis angle is larger than the lordosis angle in both sexes, women are in
41
42 309 a more balanced posture due to the smaller difference between the two angles.

45 310 Liu et al. ³⁹ tried to define standard parameters of cervical spine alignment and range of
46
47 311 motion related to age, sex, and cervical disc. These results underline the more pronounced
48
49 312 thoracal kyphosis in women. The greater lumbar lordosis of the females can be traced back to
50
51 313 sex differences in the pelvic shape: The wider pelvic blades of the female pelvis have a larger
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53 314 angle between the pubic branches, a larger transverse pelvic diameter and are lower. Thus, the
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55 315 pronounced female pelvic tilt leads to a larger lumbar lordosis. Consequently, a larger lumbar
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3 316 lordosis causes a thoracal hyperkyphosis. These (different) compensations are seen in the
4
5 317 pelvic position in both sexes³⁸. This position of the lumbar spine also affects the extent of the
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7 318 movement in the flexion-extension testing of the trunk. The total task-specific hip motion
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9 319 ranges as measured from erect standing to the maximum flection were higher in females than
10
11 320 in males⁴⁰.

12
13 321 Furthermore, the same authors report that female chronic low back pain patients had higher
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15 322 regional hip and trunk motion ranges than male patients⁴¹. Why women have a larger lordosis
16
17 323 angle currently is unknown. An extensive literature search in PubMed and other data bases
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19 324 did not retrieve any published hypothesis. An explanation of physiological differences,
20
21 325 however, has been forwarded to comparable sex differences in the pelvic anatomy for rodents
22
23 326 and has been related to sexual behavior in these animals. Guinea pigs show hormonally
24
25 327 controlled, gender related reproductive behaviour: male guinea pigs show a distinct sexual
26
27 328 approach consisting of body raising, intromission and ejaculation, and female guinea pigs
28
29 329 respond with a corresponding conceiving position of a predominantly lordotic lumbar posture
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31 330^{42 43}. At least for this species the observed anatomical differences may translate directly into
32
33 331 an apt reproductive behaviour. In both species, the pelvis itself has the same position in both
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35 332 sexes in a relaxed posture, and is positioned almost horizontally.

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37 333 No similar explanation exists for differences in the shoulder region parameters either; the
38
39 334 right shoulder is positioned more caudal in both sexes, but women have “deeper” shoulders
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41 335 (increased scapular angle right/left).

42
43 336 All other positional parameters are nearly identical between men and women, with the
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45 337 differences being smaller than the margin of error, and likely have no clinical relevance.

46
47 338 The three-dimensional back scan is a fast, non-contact method to quantify the body posture
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49 339 and is suitable for measuring body postures in both healthy persons and patients. It can
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51 340 quantify pathologic positions like scoliosis, kyphosis, leg length differences and functional
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53 341 movement disorders, as well as improvements by medical treatment. The chances and
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3 342 limitations of the measurement system and procedure ⁴⁴⁻⁵⁰ has already been discussed by
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5 343 Ohlendorf et al. ^{27 51}. In the future, this method may allow to grade postural deviations, e.g. by
6
7 344 a grading system using the tolerance ranges for men and women, as has been done for bone
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9 345 densitometry in the t- and z-scales ²⁶.

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11 346

12 13 347 **Conclusion**

14
15 348 Video raster stereography is a method to quantitatively measure the human three-dimensional
16
17 349 back surface. Healthy young women have an almost ideally balanced posture with minimal
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19 350 ventral body inclination and a marginal scoliotic deviation. In comparison to men women
20
21 351 have only small differences in upper body posture, with nearly identical normal values. These
22
23 352 values allow a quantitative comparison with other studies for control and patient data, and
24
25 353 may serve as an orientation in both clinical practice and scientific studies. Further studies
26
27 354 could expand this method to age-related changes in body posture, quantitative assessments of
28
29 355 postural changes in relevant diseases, and improvements by therapeutic interventions.

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38
39
40 359

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46
47 363 measurement protocol and HA and DO have been involved in the statistical data analysis. All
48
49 364 authors have read and approved the final manuscript.

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51 365

52 366 *b. competing interests*

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55 368

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371

372 *d. data sharing statement*

373 No additional data available.

374

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553 **Tables**

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555 Tab. 1 Spine, shoulder and pelvis parameter: mean value, median, tolerance regions (upper and lower limit),
556 confidence interval (left and right limit). Italic data are non-parametrical values.

	Mean value/ median	tolerance range lower limit	tolerance range upper limit	confidence interval left limit	confidence interval right limit
Spine parameter					
Trunk length D (mm)	461.31	412.95	509.67	456.64	465.99
Trunk length S (mm)	509.52	458.88	560.15	504.62	514.41
Sagittal trunk decline (°)	-3.31	-8.12	1.5	-3.78	-2.85
Frontal trunk decline (°)	-0.43	-2.91	2.06	-0.67	-0.18

Axis decline (°)	0.21	-4.45	4.86	-0.25	0.66
Thoracic bending angle (°)	13.9	6.49	21.31	13.19	14.62
Lumbar bending angle (°)	13.17	7.83	23.06	11.9	14.25
Standard deviation lateral deviation (mm)	3.92	0.5	7.33	3.59	4.25
Maximal lateral deviation (mm)	-5.35	-12.8	12.38	-5.76	-0.89
Standard deviation rotation (°)	4.66	2.04	12.92	4.18	5.29
Maximal rotation (°)	9.2	-9	37.48	8	10.76
Kyphosis angle (°)	51.66	27.91	74.42	49.37	53.96
Lordosis angle (°)	46.29	21.66	70.92	43.91	48.67
Shoulder parameter					
Scapular distance (mm)	150.56	110.51	190.6	146.68	154.43
Scapular height (°)	-1.28	-22.36	19.81	-3.32	0.76
Scapular rotation (°)	3.06	-3.26	9.37	2.44	3.67
Scapular angle left (°)	28.54	16.49	62.74	27.36	30.74
Scapula angle right (°)	31.17	10.61	73	27.2	34.62
Pelvis parameter					
Pelvis distance (mm)	99.56	74.76	124.37	97.17	101.96
Pelvis height (°)	0.76	-4.29	5.81	0.28	1.25
Pelvis height (mm)	1.34	-7.33	10.01	0.5	2.18
Pelvis torsion (°)	0.24	-6.89	7.36	-0.45	0.93
Pelvis rotation (°)	2.2	-5.72	7.34	1.49	2.76

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561 Figure legend

562 Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-
 563 dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens
 564 (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right,
 565 D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS)
 566 right, F: Sacrum-point (cranial beginning of the gluteal cleft).

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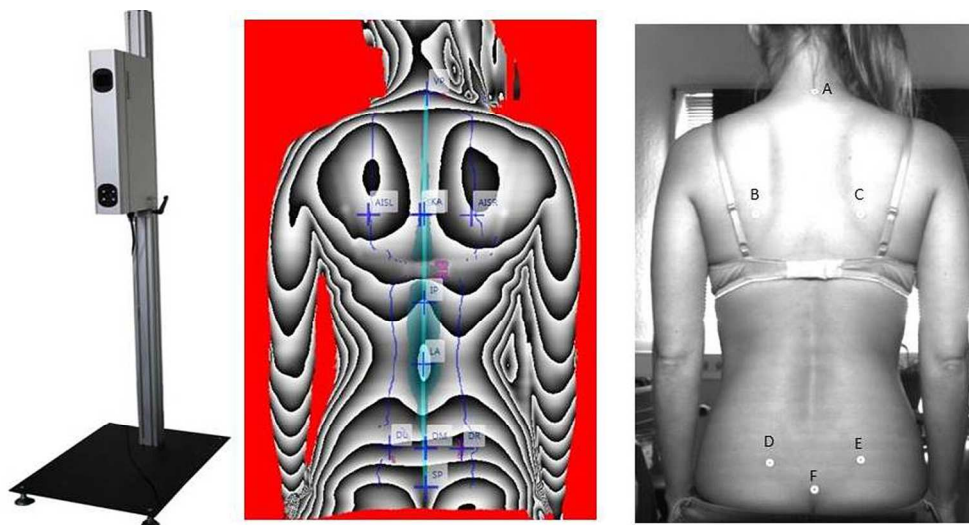


Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

199x103mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of *cohort studies*

	Item No	Recommendation	Pages
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	4,6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(b) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	n/a
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	8
		(b) Describe any methods used to examine subgroups and interactions	n/a
		(c) Explain how missing data were addressed	n/a
		(d) If applicable, explain how loss to follow-up was addressed	n/a
		(e) Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8-9
		(b) Indicate number of participants with missing data for each variable of interest	n/a
		(c) Summarise follow-up time (eg, average and total amount)	n/a
Outcome data	15*	Report numbers of outcome events or summary measures over time	9-11
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-11
		(b) Report category boundaries when continuous variables were categorized	9-11
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	11-14

		analyses, results from similar studies, and other relevant evidence	
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at <http://www.strobe-statement.org>.

n/a = not applicable

Since the study investigated healthy young women in an observational study these parts of the STROBE-criteria are not applicable.