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Postural Evaluation in Sports and Sedentary Subjects by Rasterstereographic Back Shape Analysis

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Abstract: Abstract: BackgroundPosture is defined as the position of the body in space, the aim of which is to maintain balance, both in static and dynamic conditions. Our purpose was to study various postural variables involved in postural adaptations of athletes practicing symmetric and asymmetric sports at professional level. **Methods:** Patients include sedentary subjects, competitive athletes practicing symmetrical and asymmetrical sports. Postural evaluation of the three different groups was performed using the rasterstereographic-system Formetric-4D. **Results:** 157 subjects were recruited. From the comparison between subjects playing symmetrical and asymmetrical sports, arises a statistically significant difference on cervical ($p = 0.041$) and lumbar ($p = 0.047$) flèche of Stagnara, with higher values for symmetrical athletes' group. Hemipelvis torsion ($p = 0.031$) and lumbar flèche ($p \leq 0.001$) of Stagnara are higher in symmetrical athletes' group (sedentary). Hemipelvis torsion, cervical and lumbar flèche resulted to be higher among athletes (sedentary) ($p = 0.016$, $p = 0.003$, $p = 0.027$). **Conclusions:** In addition to the competitive sports' medical examination, a screening with rasterstereographic-system Formetric-4D is suggested to all sedentary subjects, without serious skeletal pathologies which want to start athletic activity. Rasterstereographic-system Formetric-4D is also suggested to all athletes practicing sports, with the aim to identify eventual unknown postures, consequent to reiterated repetition of specific movements.

Keywords: Formetric; rasterstereographic system; posture; sport

1. Introduction

Posture is defined as "the position of the body in space and the spatial relationship between the skeletal segments, the aim of which is to maintain balance, both in static and dynamic conditions, to which neurophysiological, biomechanical, psycho-emotional and relational factors contribute, also linked to the evolution of the species" [1]. It is defined as correct when the "deformation is coherent with gravity", that is, when it activates anti-gravity functions with less energy expenditure both during walking and in standing position [1]. The human body functions like a system capable of self-regulation, self-adaptation and self-programming. Based on the information received instant by instant from the external and internal environment, it constantly tries to better maintain a system of perfect homeostasis by means of feed-forward (cortical, subcortical and, once acquired, cerebellar areas) and feedback (subcortical areas) control systems [2,3]. Posture is therefore the result of complex interactions between environmental stimuli and mechanisms that integrate visual, otovestibular, proprioceptive and exteroceptive afferents [4,5]. Any force acting on this system will entail an attitude of compensation with reprogramming of postural system and balance [6]. These compensations, if repeated over time, can be structuralized by the central nervous system, first as functional mnemonic posture mechanisms and subsequently at peripheral level, as real anatomical anomalies [7,8]. This phenomenon, called the motor engram, represents the set of motor experiences memorized by the individual as programming activating the feed-forward system responsible for direct neuro-motor activation. The more a motor action is repeated over time the more it is strengthened, like a neuro-associative conditioning [9].

Sports actions also include motor actions. In particular, different types of sports with repeated stresses on the spine, presenting themselves as motor engrams, can determine not only benefits deriving from muscle training, but also negative influences on the body, which affect postural structure [10,11].

In fact, in subjects who practice these sports at professional level, repeated stresses can lead to postural adaptations of the spine, both functional adaptive and dysfunctional [12].

Rasterstereography is an optical measurement system that provides a reliable method for three-dimensional analysis of the back and reconstruction of spinal deformities without radiation exposure [13,14]. This system allows a three-dimensional reconstruction of spinal posture and pelvic position starting from the analysis of the posterior surface during orthostasis. [15,16].

This radiation-free system provides information that correlates well, on the sagittal plane, with radiographic data and that can be used over time to perform postural analysis and evaluate the effects of therapies [17]. This technique could be used to noninvasively assess the postural characteristics of athletes.

The purpose of the observational study was to study various postural variables involved in postural adaptations of athletes practicing symmetric and asymmetric load sports at professional level. Postural variables related to primary injury prevention were also investigated with respect to a sample of sedentary subjects.

2. Materials and Methods

From January 2018 to January 2020 patients of both sexes were recruited from the Physical Medicine and Rehabilitation out-patient clinic of University Hospital Umberto I in Rome (presentation recruitment). Enrolled patients include sedentary subjects, competitive athletes practicing asymmetrical sports (sports with greater musculoskeletal involvement of one limb or one body side compared to the contralateral) and competitive athletes practicing symmetrical sports (sports with homogeneous involvement of the musculoskeletal system of both body sides). Non-eligible patients were excluded.

This study protocol was developed in accordance with the STROBE guidelines and was approved by the Ethics and Experimental Research Committee of Sapienza University, Rome, Italy (Prot. N° 434/18). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

2.1. Inclusion and Exclusion Criteria

Once having informed participants about the aim of the study, informed consent was obtained from all individual participants enrolled. Among athletes, only subjects which play professional sports with a minimum training frequency of 3 times/week have been recruited; participants must be aged between 18 and 36 years old and should not be previously or actually treated for structural or postural alterations of the spine.

Subjects excluded from the study: athletes presenting at their history of injuries which compromised their sports activity. Before each instrumental evaluation, a specialist physiatric medical examination was performed in order to identify possible problems that could affect the quality of the analysis and that involved the exclusion of the subject from the study (for example lower limb heterometry, polytrauma, severe lower limb trauma, lower limb mal-rotations, etc.)

2.2. Instrumental Evaluation

Postural evaluation of all subjects of the 3 different groups was performed using the rasterstereographic system Formetric-4D (DIERS, International GmbH, Schlangenbad, Germany) (Figure 1). Rasterstereographic-system Formetric-4D ® acquires a postural image through an optical analysis system, with the possibility of graphically representing various problems of clinical nature about objective and qualitative analysis of posture [13–16].

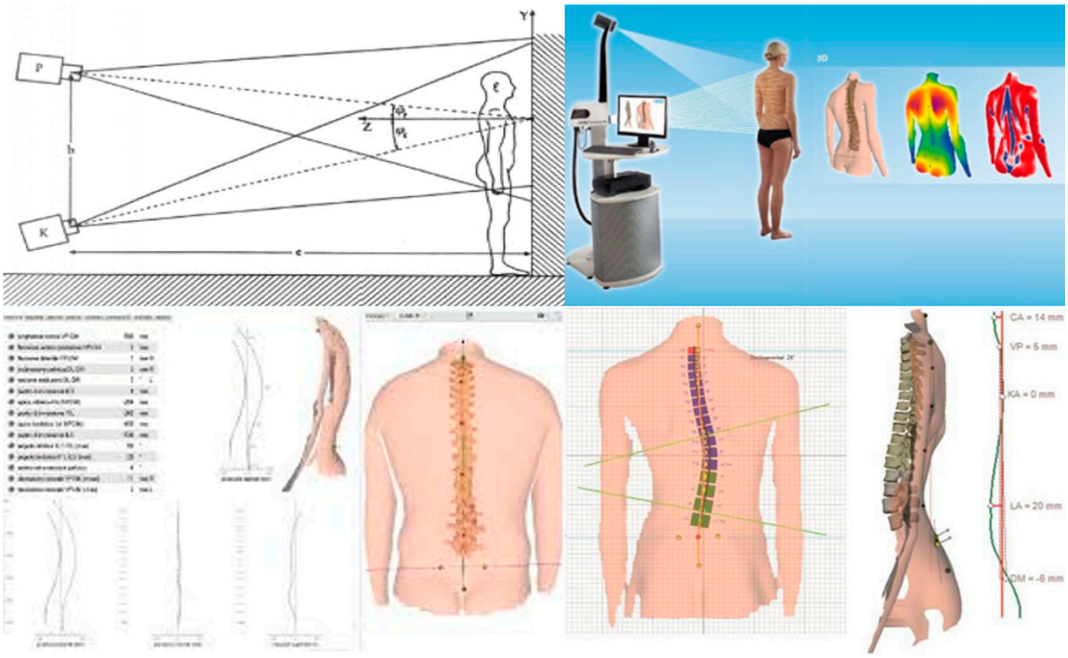

Figure 1. Rasterstereographic-system Formetric-4D.

This device projects onto the patient's back a series of parallel light stripes (raster-image), emitted by a slide projector. A three-dimensional reconstruction of back surface is made with high precision (till 0.01 mm) using triangulation equations by transforming the stripes and their corresponding curvature into a scatter plot. Vertebra prominent (VP) and right (DR) and left (DL) lumbar dimples are specific back surface landmarks that are recognized automatically with a standard deviation of ±1 mm for the purposes of creating a Cartesian coordinate system.

The result of the exam is the average of all images acquired during six second of recording, in order to reduce postural variability and to improve the clinical value of the exam.

In accordance with the recommendations of Guidetti et al. [18], subjects were placed in a standing position, barefoot with their knees extended and their arms left naturally alongside their hips. To standardize subjects' positioning, a horizontal line was drawn on the floor in order to provide a reference for subjects' heels.

2.3. Statistical Analysis

All the variables analyzed did not present a normal distribution; therefore, it was decided to use the Mann-Whitney U test to study the differences between the various sample groups examined. The statistical significance level was set considering a value of $p < 0.05$. All data were analyzed using the MedCalc 12.2.1.0 calculation software (MedCalcSoftware).

The statistical comparison was performed between the following groups: symmetrical sports athletes versus asymmetrical sports athletes; asymmetrical sports athletes versus sedentary subjects; symmetrical sports athletes versus sedentary subjects; symmetrical and asymmetrical sports athletes versus sedentary subjects.

3. Results

The 157 subjects were recruited (100 males and 57 females) among sedentary subjects, professional athletes playing asymmetrical sports (sports with greater musculoskeletal involvement of one limb or one body side) and symmetrical ones (sports with a homogeneous musculoskeletal involvement of both body sides). Subjects sample was divided in the following groups: 69 subjects playing different symmetrical professional sports like soccer, rugby, CrossFit, athletics, swimming and American football, aged between 20 and 34 years; 23 subjects playing asymmetrical sports like volleyball, shooting and fencing; 65 healthy sedentary subjects.

For the three groups examined, the following variables in relation to three plans of motion (frontal, sagittal and transverse) have been assessed [19,20]:

- antero-posterior flexion: horizontal distance between DM, midpoint of the segment connecting DR-DL (right and left lumbar dimples), and the vertical passing through VP (vertebra prominent or C7 spinous apophysis; "-" indicates retroflexion);
- lateral flexion: on frontal plan, horizontal distance between DM and the vertical passing through VP;
- pelvic inclination: vertical height difference between DL and DR on frontal plan;
- pelvic rotation: DL-DR line rotation compared to the line passing posteriorly to the heels;
- cervical flèche: on sagittal plan, horizontal distance between VP and tangent to spine curvature in KA (kyphotic apex) parallel to VP-DM axis (6–8 cm according to Stagnara);
- lumbar flèche: on sagittal plan, horizontal distance between LA and tangent to spine curvature in KA (kyphotic apex) parallel to VP-DM axis (4–6 cm according to Stagnara);
- kyphosis angle (deg), measured as the angle between tangents of the spine curve calculated at the points of cervicothoracic (ICT) and thoracolumbar (ITL) inflexions;
- lordosis angle (deg), measured as the angle between tangents of the spine curve calculated at the points of ITL and lumbosacral junction (ILS) inflexion;
- sagittal pelvic alignment (deg), calculated as the arithmetic mean between the two angles formed by the perpendicular to the surface in DR and DL to the vertical axis (pelvic torsion average). Since DR and DL represent the posterior superior iliac spines at the surface of the skin, this data gives us an indication of the alignment in the sagittal plane of the pelvic bone. It is not a radiographic parameter;
- surface rotation: vertebral bodies rotation (calculated as the angle between the surface normal referred to the symmetry line and the normal to frontal plane starting out from the same point). "L" or "-" indicate surface motion to the left and thus right vertebral rotation, vice versa for "R", "rms" = quadratic mean, "max" = maximum value;
- trunk torsion: surface rotation of VP compared to surface rotation at DM ("-" indicates a right vertebral rotation di VP compared to the one at DM);
- lateral deviation: on frontal plan, horizontal lateral deviation of vertebral bodies centres compared to the VP-DM line ("rms" = quadratic mean, "max" = maximum value, "R" indicates a right convexity, "L" left convexity).

Subsequently, a descriptive assessment of the various parameters has been performed, taking in account, for each group, the median and even reporting maximum and minimum values. Results are shown in Tables 1–4.

Table 1. Postural comparison between Symmetrical and Asymmetrical sports.

Parameters	Symmetrical Sports Mediana (val.max/val.min)	Asymmetrical Sports Mediana (val.max/val.min)	*p*-Value
Antero-posterior Flexion VPDM (°)	2.375 (8.42/−5.03)	2.53 (8.9/−1.77)	0.324
Antero-posterior Flexion VPDM (mm)	19.765 (69.5/−36.82)	20.69 (76.60/−14.54)	0.298
Lateral Flexion VPDM (°)	−0.355 (3.09/−5.35)	−0.6350 (2.26/−4.05)	0.316
Lateral Flexion VPDM (mm)	−3 (25.05/−39.09)	−3 (25.05/−39.09)	0.32
Pelvic tilt DLDR (°)	0 (35.71/−38.29)	0 (15.95/−7.77)	0.421
Pelvic tilt DLDR (mm)	0 (36/−45)	0 (18/−9)	0.499
Hemi-pelvic torsion (°)	0.915 (9.97/−30.17)	0.8050 (6.54/−4.64)	0.97
Pelvis rotation (°)	1.315 (18.19/−12.62)	2.135 (7.39/−5.43)	0.076
Cervical flèche (mm)	71.49 (106.56/0)	65.875 (105.6/26.4)	0.041
Lumbar flèche (mm)	41.48 (70.8/17.26)	38.63 (62.64/9.19)	0.047
Kyphotic Angle VPITL (°)	46.095 (70.47/7.94)	44.845 (59.90/17.34)	0.363
Lordotic angle ITLDM (°)	35.165 (57.2/10.94)	37.785 (55.2/14.83)	0.512
Pelvic Antero-retro version (°)	17.285 (37.967/−3.99)	21.465 (36.7/−5.25)	0.016
Surface Rotation Rms (°)	3.2 (11.05/1.09)	3.525 (8.73/1.28)	0.271
Max Surface Rotation (°)	−2.98 (13.92/−16.18)	−2.97 (16.06/−12.41)	0.646
Trunk Torsion (°)	1.19 (26.46/−11.33)	0.545 (25.1/−11)	0.194
Lateral deviation VPDM Rms (mm)	4.045 (18.68/0.99)	4.765 (14.09/0.93)	0.277
Lateral deviation VPDM Max (mm)	5.945 (28.84/−26.61)	6.38 (26.97/−12.82)	0.504
Lateral deviation VPDM Max (mm) (+max)	6.17 (28.84/0)	7.06 (26.97/0)	0.43
Lateral deviation VPDM Max (mm) (−max)	−3.47 (0/−26.61)	−2.71 (0/−12.82)	0.466
Lateral deviation VPDM (mm)	10.43 (28.84/2.85)	10.43 (28.84/2.85)	0.863

Table 2. Postural comparison between Sedentary and Asymmetrical sports.

Parameters	Sedentary Mediana (val.max/val.min.)	Asymmetrical Sports Mediana (val.max/val.min.)	*p*-Value
Antero-posterior Flexion VPDM (°)	3 (−4.99/10.26)	2.5300 (−1.77/8.90)	0.863
Antero-posterior Flexion VPDM (mm)	22.51 (−38.25/92.39)	20.6900 (−14.54/76.60)	0.7
Lateral Flexion VPDM (°)	−0.52 (−3.17/4.44)	−0.635 (−4.05/2.26)	0.429
Lateral Flexion VPDM (mm)	−4.5 (−24/37.5)	−5.4050 (−34.50/18.00)	0.389
Pelvic tilt DLDR (°)	0 (−15.07/25.11)	0.0000 (−7.77/15.95)	0.835
Pelvic tilt DLDR (mm)	0 (−21/22.5)	0.00 (−45.0/36.0)	0.873
Hemi-pelvic torsion (°)	0.02 (−7.95/7.43)	0.8050 (−4.64/6.54)	0.097
Pelvis rotation (°)	1.08 (−7.96/19.80)	2.1350 (−5.43/7.39)	0.046
Cervical flèche (mm)	62.24 (0/140.65)	65.875 (26.40/105.06)	0.472
Lumbar flèche (mm)	37.17 (8.03/80.44)	38.6300 (9.19/62.64)	0.881
Kyphotic Angle VPITL (°)	47.26 (13.11/67.35)	44.8450 (17.34/59.90)	0.647
Lordotic angle ITLDM (°)	39.30 (3.46/60.27)	37.7850 (14.83/55.20)	0.113

Table 2. *Cont.*

Parameters	Sedentary	Asymmetrical Sports	*p*-Value
	Mediana (val.max/val.min.)	**Mediana (val.max/val.min.)**	
Pelvic Antero-retro version (°)	22.59 (−4.00/47.75)	21.4650 (−5.25/36.70)	0.162
Surface Rotation Rms (°)	3.79 (1.12/12.67)	3.5250 (1.28/8.73)	0.331
Max Surface Rotation (°)	5.08 (−24.27/16.03)	−2.97 (−12.41/16.06)	0.115
Trunk Torsion (°)	3.01(−13.55/21.51)	0.545 (−11.00/25.10)	0.024
Lateral deviation VPDM Rms (mm)	4.72 (1.43/22.79)	4.7650 (0.93/14.09)	0.740
Lateral deviation VPDM Max (mm)	5.91 (−22.50/39.76)	6.3800 (−12.82/26.97)	0.334
Lateral deviation VPDM Max (mm) (+max)	6.24 (0.00/39.76)	7.0600 (0.00/26.97)	0.261
Lateral deviation VPDM Max (mm) (−max)	−2.96 (−22.50/00)	−2.7100 (−12.82/0.00)	0.786
Lateral deviation VPDM (mm)	10.40 (4.13/39.85)	10.0050 (2.09/31.24)	0.721

Table 3. Postural comparison between Sedentary and Symmetrical sports.

Parameters	Sedentary	Asymmetrical Sports	*p*-Value
	Mediana (val.max/val.min.)	**Mediana (val.max/val.min.)**	
Antero-posterior Flexion VPDM (°)	3 (−4.99/10.26)	2.375 (8.42/−5.03)	0.107
Antero-posterior Flexion VPDM (mm)	22.51 (−38.25/92.39)	19.765 (69.5/−36.82)	0.280
Lateral Flexion VPDM (°)	−0.52 (−3.17/4.44)	−0.355 (3.09/−5.35)	0.690
Lateral Flexion VPDM (mm)	−4.5 (−24/37.5)	−3 (25.05/−39.09)	0.743
Pelvic tilt DLDR (°)	0 (−15.07/25.11)	0 (35.71/−38.29)	0.123
Pelvic tilt DLDR (mm)	0 (−21/22.5)	0 (36/−45)	0.163
Hemi-pelvic torsion (°)	0.02 (−7.95/7.43)	0.915 (9.97/−30.17)	0.031
Pelvis rotation (°)	1.08 (−7.96/19.80)	1.315 (18.19/−12.62)	0.939
Cervical flèche (mm)	62.24 (0/140.65)	71.49 (106.56/0)	0.390
Lumbar flèche (mm)	37.17 (8.03/80.44)	41.48 (70.8/17.26)	<0.001
Kyphotic Angle VPITL (°)	47.26 (13.11/67.35)	46.095 (70.47/7.94)	0.856
Lordotic angle ITLDM (°)	39.30 (3.46/60.27)	35.165 (57.2/10.94)	<0.001
Pelvic Antero-retro version (°)	22.59 (−4.00/47.75)	17.285 (37.967/−3.99)	0.001
Surface Rotation Rms (°)	3.79 (1.12/12.67)	3.2 (11.05/1.09)	0.851
Max Surface Rotation (°)	5.08 (−24.27/16.03)	−2.98 (13.92/−16.18)	0.555
Trunk Torsion (°)	3.01 (−13.55/21.51)	1.19 (26.46/−11.33)	0.751
Lateral deviation VPDM Rms (mm)	4.72 (1.43/22.79)	4.045 (18.68/0.99)	0.604
Lateral deviation VPDM Max (mm)	5.91(−22.50/39.76)	5.945 (28.84/−26.61)	0.874
Lateral deviation VPDM Max (mm) (+max)	6.24 (0.00/39.76)	6.17 (28.84/0)	0.924
Lateral deviation VPDM Max (mm) (−max)	−2.96 (−22.50/0.00)	−3.47 (0/−26.61)	0.877
Lateral deviation VPDM (mm)	10.40 (4.13/39.85)	10.43 (28.84/2.85)	0.693

Table 4. Postural comparison between Sedentary and sports.

Parameters	Sedentary	Sport	p-Value
	Mediana (val. max/val. min.)	Mediana (val. max/val. min.)	
Antero-posterior Flexion VPDM (°)	3 (−4.99/10.26)	2.3600 (8.90/−5.03)	0.117
Antero-posterior Flexion VPDM (mm)	22.51 (−38.25/92.39)	19.6000 (76.60/−36.82)	0.356
Lateral Flexion VPDM (°)	−0.52 (−3.17/4.44)	−0.3900 (3.09/−5.35)	0.919
Lateral Flexion VPDM (mm)	−4.5 (−24/37.5)	−3.0000 (25.05/−39.09)	0.995
Pelvic tilt DLDR (°)	0 (−15.07/25.11)	0.0000 (35.71/−38.29)	0.116
Pelvic tilt DLDR (mm)	0 (−21/22.5)	0.0000 (36.00/−45.00)	0.166
Hemi-pelvic torsion (°)	0.02 (−7.95/7.43)	0.8700 (9.97/−30.17)	0.016
Pelvis rotation (°)	1.08 (−7.96/19.80)	1.5400 (18.19/−12.62)	0.547
Cervical flèche (mm)	62.24 (0/140.65)	69.5800 (108.12/0.00)	0.003
Lumbar flèche (mm)	37.17 (8.03/80.44)	40.7900 (70.80/9.19)	0.027
Kyphotic Angle VPITL (°)	47.26 (13.11/67.35)	45.9900 (70.47/7.94)	0.694
Lordotic angle ITLDM (°)	39.30 (3.46/60.27)	35.5900 (57.20/10.94)	0.001
Pelvic Antero-retro version (°)	22.59 (−4.00/47.75)	18.5700 (37.96/−5.25)	<0.001
Surface Rotation Rms (°)	3.79 (1.12/12.67)	3.1900 (11.05/1.09)	0.651
Max Surface Rotation (°)	5.08 (−24.27/16.03)	−2.8800 (16.06/−16.18)	0.001
Trunk Torsion (°)	3.01 (−13.55/21.51)	1.8700 (26.46/−11.33)	0.045
Lateral deviation VPDM Rms (mm)	4.72 (1.43/22.79)	4.2300 (18.68/0.93)	0.753
Lateral deviation VPDM Max (mm)	5.91 (−22.50/39.76)	5.8900 (28.84/−26.61)	0.585
Lateral deviation VPDM Max (mm) (+max)	6.24 (0.00/39.76)	6.3700 (28.84/0.00)	0.426
Lateral deviation VPDM Max (mm) (−max)	−2.96 (−22.50/00)	−3.3800 (0.00/−26.61)	0.674
Lateral deviation VPDM (mm)	10.40 (4.13/39.85)	10.3000 (31.24/2.09)	0.679

From the comparison between subjects playing symmetrical and asymmetrical sports, arises a statistically significant difference on cervical (p = 0.041) and lumbar (p = 0.047) flèche of Stagnara, with higher values for symmetrical athletes' group. Pelvic anteroretroverison also showed a statistically significant difference (p = 0.016), with a higher value for the asymmetric group.

By evaluating asymmetric athletes versus sedentary subjects, statistically significant variations have been observed on pelvic rotation (p = 0.046), represented by higher median values for sportive subjects. Furthermore, also trunk torsion analysis presents a statistically significance (p = 0.024), with increased median values in sedentary group.

Symmetrical sports athletes and sedentary subject's comparison showed more statistically significant differences. Hemipelvis torsion (°) (p = 0.031) and lumbar flèche ($p \leq 0.001$) of Stagnara (mm) are higher in symmetrical athletes' group. Differently, on sagittal plan, lordotic angle and sagittal pelvic alignment, resulted higher on sedentary group ($p \leq 0.001$ and p = 0.001 respectively).

The evaluation of sedentary versus athletes' groups (asymmetric and symmetric) highlighted numerous statistically significant differences. Hemipelvis torsion (°), cervical and lumbar flèche resulted to be higher among athletes (respectively p = 0.016, p = 0.003 and p = 0.027).

Differently, lordotic angle (°) (p = 0.001), sagittal pelvic alignment (°) ($p \leq 0.001$), Max surface rotation (°) (p = 0.001) and trunk torsion (°) (p = 0.045) are increased only in sedentary group. All different results are summarized on Tables 1–4.

4. Discussion

Employment of rasterstereographic-system Formetric-4D postural evaluation technique represents a valuable tool for studying and for imaging acquisition of the entire spine. This device presents a good degree of validity in comparison to exams using X-rays [21]. Moreover, it presents an excellent intra/inter-operator reliability and a good validity for inter- and intraday measurements [18]. Validity of rasterstereography compared to X-rays assessments have been confirmed by Mohokum et al. [22], identifying the first technique as a method which simplifies spine analysis without radiation use and which allows to detect different spine deformities like thoracic kyphosis or the most common scoliosis.

Rasterstereography, indeed, appears to be related to Raimondi method for the evaluation of vertebral rotation in young patients with idiopathic scoliosis, with the advantage of being easily repeatable for screening and follow-up, without any risk of exposure to ionizing radiations [16]. Compared to traditional radiography, rasterstereography presents the disadvantage to be influenced by subcutaneous tissue thickness, which can consequently alter the evaluation of the parameters related to spine internal morphology [22].

In literature, different studies focused their attention on an eventual correlation between sport typology and postural adaptations. It has long been known that there are various factors which can influence paravertebral musculature, and among them an important role is attributed to the typology of sport activity performed [23]. For example, a symmetrical sport as soccer considerably affects iliopsoas muscle tone on both body sides, in comparison to tennis (asymmetrical sport) in which iliopsoas muscle hypertrophy occurs mainly on one side. This also applies to gluteal musculature, which shows unilateral hypertrophy in tennis players, while muscle tone appears to be balanced in soccer players and sedentary subjects [24].

Furthermore, sports activity can even significantly affect sagittal curvatures of the spine, increasing dorsal kyphosis [25,26]. A study performed in 2017 at Cairo University analyses how sagittal curves in volleyball players, mainly males, are characterized by an increasing trend of the normal dorsal kyphosis. However, sport typology can also have an impact on the development of degenerative vertebral pathology, as occurs in throwing sports (discus throwers) and sports that involve high jump. During these activities, the spine is subjected to a stress, such as to result in degenerative alterations, especially in those sport typologies involving a repeated flexion-extension movement of the spine [27].

Through the use of rasterstereography it has been noticed how an asymmetrical sport, like tennis, could influence different parameters of posture, like rotation of vertebral surface, trunk length (distance between prominent vertebra and the median point between the two lumbar dimples) and lateral right or left deviations, depending on training sessions number, but also on the level of sport experience of each athlete [24].

Moreover, through the implementation of rasterstereography, it has been demonstrated how sport (symmetrical and asymmetrical) could influence posture of children aged between 8 and 12 years. It has been observed how weekly training hours increase reduces thoracic kyphosis on sagittal plan and lateral deviation on frontal plan with a consequent improvement of erect posture [28].

Another study performed in 2015 at Napoli University focused on investigating the incidence of eventual postural anomalies in 14 water-polo female players. Nevertheless, this study did not demonstrate any correlation between the typology of performed sport and postural adaptations, even if authors support the idea that eventual postural adaptations could affect spine development during growth.

Regarding the comparison between sedentary subjects and asymmetrical sport players, statistically valid postural variations on transverse plan have been observed.

As previously analyzed, pelvic rotation presents a difference between the two examined groups ($p \leq 0.05$), with higher values observed in athletes. This is partially confirmed by a study in which rasterstereographic-system Formetric-4D implementation highlighted how subjects playing asymmetrical sports (archers) show an higher pelvic rotation value [29], while it partially agrees with the study of where rotational pelvic value was greater only in female athletes' group [30]. Pelvis has a laterally symmetrical structure and since it affects postural control, efforts are needed to contrast unilateral disbalance and asymmetry, to keep center of gravity. Misalignment refers to a postural anomaly or an imbalance of spine curvature assumed by sedentary subjects but especially by athletes as a consequence of continuous and reiterated unilateral positions during performed activities (volleyball spike, hits in fencing, shooting position of shooting players). All these movements elicit a hyper tone of one side of the body compared to the other, thus determining a deformity caused by mechanical forces.

The muscles involved are all those participating to movements of the hip on transverse plan: sartorius, external and internal obturator, superior and inferior gemelli, quadratus femoris, piriformis, biceps femoris (partially also gluteus maximus, posterior bundles of gluteus medius, adductor brevis and longus and pectineus muscles) for external rotation; tensor fasciae latae, anterior fibers of gluteus medius and minimus and inferior bundle of adductor magnus muscle for internal rotation.

Since representing an integral part of lumbar spine, intervene in these postures even all those muscles taking part of the "core stability" complex: rectus abdominis, external and internal oblique muscles, transversus abdominis, serratus anterior, multifidus spinae, quadratus lumborum, diaphragm, intercostal, iliopsoas and pelvic floor muscles.

The unilaterality of performed movements produces a functional deformity. Since this pelvic deformity gives rise to changes on spine alignment, the movement of the spine itself is strongly associated to postural changes. This asymmetry of the pelvis could determine alterations on the entire body, leading to development of compensatory mechanisms, which, over time, could cause articular pain.

Another statistically valid variant has been observed on trunk torsion ($p \leq 0.02$). It has been noted a higher angle of torsion in sedentary subjects rather than in athletes. Given the activities performed by the first ones (university students and employees), the difference between them can be explained as an adaptation due to the assumed posture, which is not always correct, at writing and sitting at pc workstation.

In sedentary subjects' group, in comparison both to the entire athletes' group (symmetric and asymmetric) and to symmetric athletes, there is a preponderance of higher lordotic angle and higher lateral deviation (rms) of the trunk in sedentary subjects. Even previous studies demonstrated a higher value of lordotic angle in control groups, differently from athletes, presenting a lower one. This was also associated to lumbar pain development, especially when lordotic angle was increased in a manner to entail an excessive imbalance in the alignment between lumbar and sacral region [29].

Lordotic angle increase in sedentary subjects, and indirectly also sagittal pelvic alignment increase, could be affected by iliopsoas muscle shortening, by a low abdominal and paravertebral muscles tone, and by hamstring muscles shortening, in view of the fact that this group did not perform any kind of training (stretching, muscle strengthening exercises, physical activities) [31]. Always remaining on sagittal plan, higher cervical and lumbar flèche values can be explained by a muscular imbalance due to sports activity.

Athletes subjects' sample, after frequent trainings, could have developed a stronger muscle mass only in certain muscle groups at the expense of cervical and lumbar musculature. This is partially justified by the higher rise of cervical and lumbar flèche values in the sample of subjects practicing symmetrical sports, such as athletics, soccer, or physical activities mainly stimulating inferior limbs.

Furthermore, it has been observed that the lateral deviation relative to the frontal plan, presented higher values in sedentary subjects. This is in accordance with scientific literature, which states that trunk lateral deviation value is higher in sedentary subjects rather than in athletes, which present a higher stability of the trunk on axial plan, probably related to a homogeneous strain of spinal muscles given by sport activity [28,29,32].

Differently from what expected, higher surface rotation values have been found in sedentary subjects rather than athletes (symmetric and asymmetric). This disagrees with the study of Gallotta et al. (2015) [32], where athletes presented higher vertebral rotation values. It is possible to explain that result as a possible influence owed to sample typology. Indeed, if in the study of Gallotta et al. [32], the sample examined included exclusively subjects playing asymmetrical sports, our study considers subjects practicing both symmetrical and asymmetrical sports, thus influencing the final result. In comparing subjects performing symmetrical sports and subjects performing asymmetrical ones, there are adaptations developing mainly on sagittal plan; particularly, it can be noticed how symmetrical athletes present higher values of both sagittal pelvic alignment and lumbar flèche of Stagnara, that is that parameter indicating plumbline distance from lumbar lordosis apex, allowing to evaluate the forward projection of the curve. From this it is clear that athletes present a particular development, in terms of muscle tone and hypertrophy, of erectors spinae, among which some lumbar muscles, particularly quadratus lumborum, iliopsoas, rectus femoris of quadriceps, adductor longus and brevis, pectineus and tensor fasciae latae. These muscles belong to a system of structures which tend to increase sagittal pelvic alignment and thus lumbar lordosis curvature with a consequent hypotonicity of rectus abdominis muscle, internal and external obliques, piriformis, gluteus maximum, adductor magnus muscle and hamstrings muscles, namely biceps femoris, semitendinosus and semimembranosus; these latter muscles, instead, make part of a group of myofascial structures which tend to facilitate pelvic retroversion. All of this would justify the reason why in athletes practicing symmetrical sports there occurs an increase of lumbar lordosis, consequent to a poor involvement of posterior chain muscles, as happens for some sporting gestures commonly performed during training phase or in competition, such as the running and frontal contact phase. Furthermore, in athletes practicing symmetrical sports, an increased pelvis anteversion is always ascribed to sportive gesture, since it is enough to consider guard position of fencing or serve and spike of volleyball: these postures, assumed for prolonged times, could lead to these postural adjustments.

5. Conclusions

Implementation of objective evaluation methods of posture, such as video rasterstereography, assumes an ever-increasing value in the field of both of the clinical and the re-educative and rehabilitative practice, since it represents an evaluation method free of ionizing radiations, rapid, scientifically recognized and easily repeatable. Based on our results, it is desirable to carry out further studies that support the use of rasterstereography in addition to postural evaluation in the evaluation of competitive athletes.

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