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DIAGNOSTIC METHODS: ORIGINAL RESEARCH

Computerized photogrammetric assessment of postural alignment in visually impaired athletes

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A B S T R A C T

Objective: The aim of the study was to provide a computerized photogrammetric description of the postural alignment of visually impaired athletes.
Methods: Twenty-six athletes were evaluated. Athletes were asked to stand at easy with styrofoam balls placed on selected anatomical landmarks, and photographic images were acquired in four viewpoints. Postural Assessment Software (PAS/SAPO) was applied for image analysis. Body's angles and distances were calculated and transformed in absolute (nonnegative) values for analysis. Factor analysis was applied for data reduction.
Results: Absolute values of PAS/SAPO variables resulted in lower coefficient of variation (CV) than raw values (average of 57% versus 500%, respectively), which potentially enhances the comparative use of these measures. Head's forward positioning and rightward inclination were among the most prevalent postural deviation, being observed in more than 70% of the athletes. With respect to the magnitude of the deviation, large variability was observed in data derived from anterior/posterior compared with lateral viewpoint. For instance, head's rightward inclination (head horizontal alignment in the anterior view) achieved $2.9 \pm 2.5°$ (mean ± SD), with a CV of 86%, while head's forward positioning (C7 horizontal alignment in left viewpoint) reaches $42.7 \pm 6.6°$, with a CV of only 16%. Factor analysis did not result in significant data reduction, although anterior body's angles and distances were identified as important sources of data variability.
Conclusions: The PAS/SAPO values described here can be adopted as reference for future investigations of postural alignment in visually impaired athletes.

1. Background

Posture or postural alignment refers to the spatial orientation of the body's segments in relation to each other and of the body in relation to the environment (Shumway-Cook and Woollacott, 2000). An "ideal" standing human posture corresponds to the body's alignment in which minimal muscular effort is required to sustain upright stability (Houglum and Bertoti, 2012; Kendall et al., 2005). Notwithstanding this assumption about an "ideal" posture, large deviations in body's alignment among subjects are usually observed (Ferreira et al., 2011; Houglum and Bertoti, 2012; Krawczky et al., 2014). These postural deviations — the difference between the "ideal" and the actual body's alignment — are related to factors such as body dimension, age, gender, healthy status and muscle conditioning (Houglum and Bertoti, 2012; Kendall et al., 2005).

Significant deviations in body's alignment could contribute to joint degeneration and inadequate muscle tension. Maladaptive body's alignment was already associated with shoulder overuse impingements (Greenfield et al., 1995), hamstring strain (Hennessy and Watson, 1993) and knee and ankle injuries (Söderman et al., 2001). For these reasons, postural assessment has been considered an important tool for the evaluation of general health and musculoskeletal injury risk of sports practitioners (Singla and Veqar, 2014). However, most of the information regarding postural alignment in sports practitioners comes from able-bodied

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athletes, despite the increasing number of persons with disabilities currently practicing sports (Gold and Gold, 2007).

Since its origins as a rehabilitation tool, sports practice for persons with disabilities has evolved to a competition-oriented activity (McCann, 1996). The increasing number of persons with disabilities participating in sports events has been accompanied by a higher incidence and prevalence of musculoskeletal injuries in this population (Webborn and Emery, 2014). In the Paralympic Games of London 2012, for instance, injury rate was 13 injuries per 1000 athlete per day, and 15% of the athletes showed more than one injury in the period (Willick et al., 2013). Interestingly, from the top-seven sports with the highest injury rate, three of them (football 5-a-side, goalball and judo) are practiced by athletes with visual impairment (Willick et al., 2013).

Visual impairment refers to a partial or total loss of visual capacity (Resnikoff et al., 2004) that is usually associated with abnormal motor development and coordination (Houwen et al., 2008; Navarro et al., 2004). Importantly, the functional changes imposed by total or partial visual loss could induce maladaptive postural alignment (e.g., Patla, 1997). The limited evidence available demonstrated that postural deviations of the head, spine and lower limbs are not uncommon in persons with visual impairment (Catanzariti et al., 2001; Fjellvang and Solow, 1986; Grivas et al., 2006; Siegal and Murphy, 1970). Remarkable, musculoskeletal injuries prevalence is up to 80% in the population of persons with visual impairment that engage in high-level sports-related activities (Magno e Silva et al., 2013a; Magno e Silva et al., 2011).

Nowadays, proper investigations about the relationship between maladaptive postural alignment and sports-related injuries in the visually impaired athletes are precluded by the lack of reference data for this specific population. To add further information on this issue, in the present study we provide the results of a computerized photogrammetric postural assessment performed in visually impaired athletes. The data are described in term of body angles and distances' mean, standard deviation and 95% confidence interval. In addition, factor analysis was applied to unravel which body's angles and distances are the most relevant for postural assessment in this population. Technical coaches and their professional teams would benefit from these reference values for a more specific training prescription. Furthermore, the knowledge of the most relevant postural angles and distances would optimize systematic postural assessment in adapted sports contexts.

2. Material and methods

2.1. Participants

A convenience sample of twenty-six visually impaired athletes (7 females) was evaluated in this cross-sectional investigation. Inclusion criteria comprises (i) being classified as B1, B2 or B3 (from total blindness to low vision) according to the International Blind Sports Association (IBSA, 2016); (ii) had at least one year of sport practice; and (iii) had no musculoskeletal injury at the moment of postural assessment and (iv) aged 18 years or more. The procedures were approved by the local Ethical Committee (process number 17691113.1.0000.5235), being conformed to the amendments of the Declaration of Helsinki. The athletes provided written informed consent after all the documents were read aloud by the experimenters for those with total blindness.

Demographic and sport–related information, such as age, gender, classification, sports modality and years of sport practice were obtained through anamnesis. Body height and weight were measured with an analog scale with a mounted stadiometer (Welmy, BRA). The athletes aged (mean $\pm$ SD) 27 $\pm$ 6 years and had 169 $\pm$ 12 cm height and 80.1 $\pm$ 23.4 kg body weight. The sample of visual impaired athletes included 12 judoists, 9 goalball players, 3 football 5-a-side players and 2 athletics practitioners; together, they had 9 $\pm$ 6 years of sports practice. Fourteen athletes were classified as B1, 6 as B2 and 6 as B3. Causes of blindness varied from congenital glaucoma to toxoplasmosis and traumatic injury of eyes or visual nerve, among others.

2.2. Postural assessment

Postural assessment was made by means of computerized photogrammetry. The acquisition of the images followed the recommendations of the Postural Assessment Software (PAS/SAPO), which was developed for quantitative analysis of body's angles and distances (Ferreira et al., 2010). Briefly, photographic images were taken from anterior, posterior, lateral left and right viewpoints (Fig. 1). The digital camera (Alpha 100, Sony, BRA) used for image acquisition was placed on a tripod of 1 m heights at about 4 m away from the subjects. A plumb line marked with two styrofoam balls 1 m apart was positioned for vertical calibration and reference. Yellow styrofoam balls were placed in specific anatomical landmarks using double-faced adhesive tape (Fig. 1; see Table 1 in Do Rosário, 2014, and Fig. 1 in Ferreira et al., 2010).

For postural assessment, the athletes were instructed to wear comfortable clothes and to stand barefoot at easy in a wood platform, with the elbow flexed at about 90°. Different orientations in relation to the camera were assumed for image acquisition in the four viewpoints. To guarantee a similar standing posture among viewpoints, the feet position was marked in a paper sheet; sheet position was changed according to the viewpoint of interest.

After acquisition, the photographic images were transferred to a computer for analysis in the PAS/SAPO software version 0.68. Data processing consists in image calibration, proper identification of the anatomical landmarks, and computation of the corresponding body's angles and distances (Ferreira et al., 2010). Identification of the anatomical landmarks was performed manually by an experimented evaluator. To facilitate the identification of the center of ball-shaped landmarks, a cross-format screen cursor was used, and the evaluator was free to apply the zoom feature provided by the software. Body's angles and distances were calculated in degrees and centimeters, respectively.

2.3. Statistical analyzes

Kolmogorov-Smirnov analysis revealed that most of the PAS/SAPO data sets exhibit a Gaussian distribution (P-value >0.05 for 2/3 of the data) and then postural alignment's variables were described in terms of mean $\pm$ SD and 95% confidence interval (CI). The body's angles and distances estimated for each subject were transformed in absolute, nonnegative values for further analysis. This transformation was performed (i) to provide a simple measure of the *magnitude* of postural deviations, irrespective of its direction and (ii) to minimize the variability of the data. The last assumption was confirmed by computing the coefficient of variation (COV) of PAS/SAPO variables: the overall COV (considering all variables pooled together) averaged 500% and 57% for the raw and the transformed data, respectively. The distribution of negative and positive angles and distances (referring, for example, to left/right or forward/backward deviations) were considered separately.

Together with the description of body alignment of visually impaired athletes, a factor analysis was applied to identify the most relevant body's angles and distances able to explain the variability

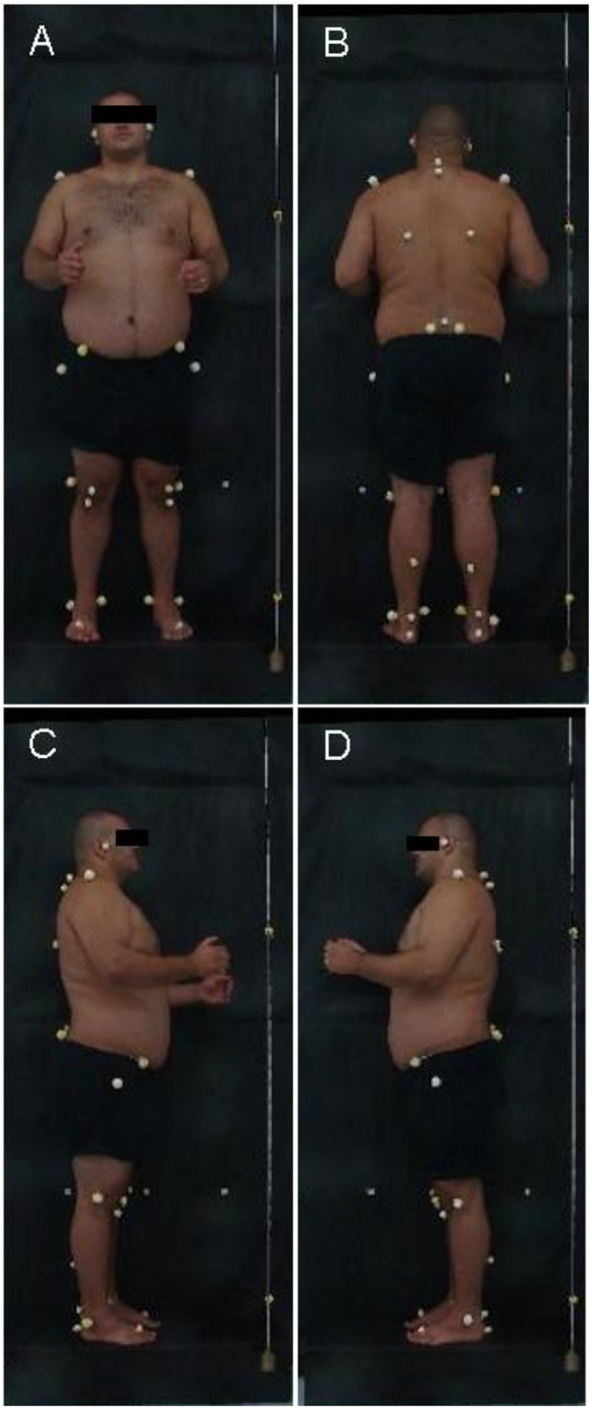

Fig. 1. Example of an acquired image for PAS/SAPO analysis. Photo from a representative athlete (no 27, judoists, B1, male, 184 cm height and 149 kg weight). The anterior (A), posterior (B) and lateral right (C) and left (D) viewpoint, as well as the plumb line marked with two styrofoam balls, are showed. Markers of different sizes were used for body's distances and angles estimation.

of PAS/SAPO's data distribution. Factor analysis was performed through principal component analysis (PCA) considering all variables and subjects. The *k* most relevant factors were chosen based on an eigenvalue >1, and the *k* most relevant variables were identified based on a factor loading (Pearson correlation coefficient, *r*) over ±0.5 (Hair et al., 2014). Statistical analysis was run in SPSS environment (IBM, USA).

3. Results

3.1. Postural alignment assessment

For all analyzes the data of the 26 athletes were pooled together, independently of the sport modality or classification. The 29 variables computed by PAS/SAPO based on the used landmarks and transformed in absolute values are present in Table 1, together with the corresponding mean, SD and 95% confidence interval. From Table 1 it could be observed that some variables showed a higher variability than others, with anterior and posterior view-derived variables exhibiting a large coefficient of variation (averaged 75%) than those obtained from lateral left/right view (average COV of 42%).

The direction of postural deviation was analyzed separately, and the number of occurrence of negative and positive deviations for each variable is presented in Table 2. Negative and positive deviations of each variable refer to a specific posture; for practical reason, only the meaning of the most prevalent deviation — those with higher number of occurrence — is described. Some PAS/SAPO variables showed frequent distribution of deviation to a specific side/direction: for example, head's forward positioning associated with rightward inclination were observed in 100% and 73% of the sample, respectively. The most discrepant distribution, with larger predominance to one side/direction, was observed for head, lower limbs' and most of the lateral viewpoint-derived variables.

3.2. Factor analysis

As measures in the lateral right side were quite similar to those assessed in the left side (Table 1; *P*-value of the *t*-test for dependent sample always higher than 0.073), subsequent factor analysis was performed only with right data set; the matrix size was then 26x21. PCA showed 8 relevant factors (eigenvalue >1) accounting for 83% of total variance. However, further considerations were limited to the first three factors accounting for 44.8% of total variance — the other factors either accounted for less than 10% of total variance or showed variables with factor loading lower than ±0.5. Based on these criteria, 11 variables from the 29 available were identified as relevant (Table 3). From the selected factor, the 1st one (accounting for 18.5% of the variance explained) consisted mainly of anterior alignment of the pelvis and lower limbs; the 2nd factor (14.0% of variance explained) grouped variables accounting for the anterior and lateral alignment of trunk-pelvis, together with the lateral alignment of the lower limbs; finally, the 3rd factor (12.3% of variance explained) was composed by measures of lower limbs alignment, mainly in the anterior view.

4. Discussion

The aim of the present study was to describe the body's angles and distances, derived from computerized photogrammetry, of a sample of visually impaired athletes. For this purposes, the following goals were accomplished: (i) descriptive statistics were provided for 29 PAS/SAPO variables, considering their absolute values, referring to the *magnitude* of the deviations; (ii) the distribution of the *direction* of the deviation for each variables was also provided, highlighting prevalent postural alignment patterns of visually impaired athletes; (iii) a factor analysis was performed, which did not result in significant data reduction, but indicated anterior viewpoint-derived body's angles and distances as important sources of postural variability among the athletes.

Absolute values of body's angles and distances were used in the present analysis to provide a simple indication of postural deviation *magnitude*, and to reduce the variability of PAS/SAPO data. For most

Table 1
Statistical description in terms of mean, standard deviation (SD) and 95% confidence interval (CI) of the PAS/SAPO's angles and distances (transformed in absolute values). The plane of view in which each variable was computed is also showed.

Angles and distances	Code	Mean	SD	95%CI	Viewpoint
Head horizontal alignment	HHA	2.9	2.5	1.9–4.0	anterior
Acromion horizontal alignment	AHA	1.9	1.2	1.5–2.4	
ASIS horizontal alignment	ASISHA	2.8	2.2	1.9–3.6	
Angle between acromion and ASIS	AAASIS	3.2	3.0	2.0–4.5	
Right limb frontal angle	RLFA	3.8	2.9	2.6–5.0	
Left limb frontal angle	LLFA	3.8	2.9	2.5–5.0	
Length differences between limbs	LDL	1.3	1.2	0.8–1.8	
Tibia tuberosity horizontal angle	TTHA	2.0	1.7	1.3–2.7	
Hip angle (right)	HpAR	27.0	12.6	21.7–32.1	
Hip angle (left)	HpAL	22.9	13.0	17.6–28.3	
Scapula horizontal asymmetry T3	SHAT3	18.4	14.9	12.3–24.5	posterior
Angle between right leg-foot dorsum	ARLF	12.4	7.0	9.5–15.3	
Angle between left leg-foot dorsum	ALLF	7.1	6.7	4.3–10.0	
Head-C7 horizontal alignment	HC7HAR	40.5	8.0	37.3–43.8	lateral right
Head vertical alignment	HVAR	25.5	8.4	22.1–29.0	
Chest vertical alignment	CVAR	8.0	3.0	6.8–9.3	
Hip angle	HAR	12.5	5.0	10.5–14.6	
Vertical alignment of the body	VABR	1.4	0.9	1.0–1.8	
Horizontal alignment of the hip	HAHR	14.7	6.2	12.1–17.3	
Angle of knee	AKR	5.9	4.8	3.9–7.8	
Angle of ankle	AAR	82.2	4.1	80.5–83.9	
Head-C7 horizontal alignment	HC7HAL	42.7	6.6	40.0–45.4	lateral left
Head vertical alignment	HVAL	28.5	9.3	24.7–32.3	
Chest vertical alignment	CVAL	7.5	4.2	5.8–9.3	
Hip angle	HAL	12.4	6.2	9.8–14.9	
Vertical alignment of the body	VABL	1.3	0.9	0.9–1.7	
Horizontal alignment of the hip	HAHL	15.2	5.6	12.9–17.5	
Angle of knee	AKL	5.3	3.9	3.6–6.9	
Angle of ankle	AAL	83.3	3.5	81.9–84.8	

ASIS, anterior-superior iliac spine.

Table 2
Distribution (number of occurrences) of negative and positive angles and distances for each PAS/SAPO's variables, separate by viewpoint. For each variable, the significance of the most prevalent postural deviation is described.

Code	Negative	Positive	Significance of the most prevalent deviation
Anterior			
HHA	27	73	Head inclined to right side
AHA	62	38	Shoulders inclined to left side
ASISHA	42	58	Pelvis inclined to the right side
AAASIS	35	65	Overall trunk inclination to right side
RLFA	69	31	Genu valgus
LLFA	58	42	
LDL	50	50	Similar length of right/left legs
TTHA	42	58	Left tuberosity in higher position than right tuberosity
HpAR	0	100	Only positive values computed. Lower limb Q-angle.
HpAL	0	100	
Posterior			
SHAT3	27	73	Right scapulae in higher position than left scapulae
ARLF	31	69	Ankle valgus
ALLF	50	50	Equal ankle varus/valgum distribution
Lateral (right/left)			
HC7HA (R/L)	0/0	100/100	Only positive values computed. Forward positioning of the head
HVA (R/L)	0/0	100/100	Forward positioning of the head
CVA (R/L)	100/92	0/8	Backward positioning of the chest
HA (R/L)	100/96	0/4	Extended positioning of the hip
VAB (R/L)	35/23	65/77	Forward positioning of the body
HAH (R/L)	96/96	4/4	Anteversion positioning of the hip
AK (R/L)	27/35	73/65	Genu flexum
AA (R/L)	0/0	100/100	Dorsoflexed positioning of the ankle

The acronyms are defined in Table 1, with exception of: R/L, right and left distribution of PAS/SAPO values.

of the PAS/SAPO variables assessed, the variability of raw data was usually large, with the coefficient of variation ranging from −793% to 7070%, and was reduced to 4-95% when absolute values were considered (average values were reported in Method section). This was not unexpected given that most of the variables exhibit very low-to-zero mean and large standard deviation (for example, see Ferreira et al., 2010; Ferreira et al., 2011; Krawczky et al., 2014). The expression of body's angles and distances in absolute terms was previously used to compare a sample of young sighted volleyball players with non-athletes (Grabara, 2015). Although not specifically stressed in the study, this procedure probably allowed a proper statistical contrast and the identification of differences in spine

Table 3
PAS/SAPO variables identified in the first three principal component analysis (PCA) factors (44.8% of variance explained), along with their correspondent factor loading (Pearson correlation coefficient, *r*). The percentage of variance explained for each factor is also showed.

PAS variables	1st factor (18.5%)	2nd factor (14.0%)	3rd factor (12.3%)	Viewpoint
ASISHA	0.75	0.51		anterior
AAASIS		0.79		
LLFA			0.71	
LDL	0.83			
TTHA	0.57			
HpAR			0.52	
HpAL			0.54	
CVAR		0.76		lateral right
HAR		0.53		
HAHR			0.54	
AKR	0.67			

The acronyms are defined in Table 1.

alignment between populations. Further investigations concerning postural alignment in visually impaired athlete should also apply statistical analyses based on the absolute values of photogrammetric variables, thus allowing the use of the statistical descriptors present in Table 1 of the present study.

Based on the most prevalent *directions* of postural deviations presented by our sample of visually impaired athletes (see Table 2), the global postural alignment adopted by this population could be summarized as follow: (i) overall rightward inclination of the body, leaded by head and trunk segments, with leftward deviation of the shoulder; (ii) forward positioning of the head, with backward inclination of the chest accompanied by a probably compensatory extension of the hips; (iii) a forwardly inclined pelvis, followed by a flexed knee and a valgus ankle aligned in dorsiflexion position. Our results were in accordance with previous investigations (Catanzariti et al., 2001; Fjellvang and Solow, 1986; Grivas et al., 2006). For example, Fjellvang and Solow (1986) showed that the blind persons usually adopt a forward-downward position of the head and neck, compared with visually healthy participants. Spine deviations were also observed in visually impaired persons, most frequently as cervical or thoracic scoliosis (Catanzariti et al., 2001; Grivas et al., 2006), even at an age of 11–13 years (Catanzariti et al., 2001). An early study assessing 45 visually impaired persons reported a variety of postural misalignment, including head drop and lateral tilt, left/right torso shift, moderate kyphosis, cervical and thoracic scoliosis, shoulder asymmetry, genu valgus and flat feet (Siegal and Murphy, 1970). Current knowledge attributes this maladaptive postural alignment to poor motor development and coordination of the blind persons (Houwen et al., 2008; Navarro et al., 2004). Given this variety of misalignment, we applied factor analysis to find whether a single postural alignment pattern could be extracted from the many PAS/SAPO variables available.

A principal component analysis was applied in the PAS/SAPO data to extract such postural alignment pattern, but the results were less than conclusive. Too many factors were identified as relevant, and too many variables were still present in the final model, precluding the proposal of a single pattern. For simplification purposes, only the most relevant factors were considered, and a general description could be made following its analysis: briefly, lateral and anterior alignment of the trunk and lower limbs account for 44.8% of total variance explained. The presence of several variables related to lower limb alignment (9 from 11 variables) must be highlighted, once 80%–87% of the musculoskeletal injuries reported in visually impaired athletes occur in the lower extremities (Magno e Silva et al., 2013a; Magno e Silva et al., 2013b).

Altogether, the data present in the study could be of the most value for those concerned with the higher incidence of musculoskeletal injury in the athletes with visual impairment (Magno e Silva et al., 2013a; Magno e Silva et al., 2013b; Magno e Silva et al., 2013c). Although some of these injuries are from traumatic origin, 20–80% of it are related to overuse (Magno e Silva et al., 2013a; Magno e Silva et al., 2013b) and possibly with maladaptive changes in body posture. Indeed, the relationship between maladaptive postural alignment and sports-related injuries occurrence is well demonstrated for the non-disable athletes (Greenfield et al., 1995; Hennessy and Watson, 1993; Söderman et al., 2001), making postural assessment a valuable tool in prescreening exams (Singla and Veqar, 2014). However, this line of investigation is missing from the literature scope regarding Paralympic sportspersons. It is strongly recommended that further investigation about postural alignment in visually impaired athletes also include measurement of musculoskeletal injuries, to advance our knowledge about its relationship.

Methodological constraints of the study are mainly related to the (i) sample size and (ii) heterogeneity of the sample. Firstly, the number of individuals enrolled could be considered small regarding the aim of the study — the provision of reference values for future investigation on visually impaired athletes. However, the provision of statistics estimates of body's angle and distances, in the form of 95% confidence interval — which corresponds to the level of uncertainty about the true value of a population's parameter —, helps to partially undermine this limitation and to strength the generalizability of our data; nevertheless, large cohort assessment is recommended in future investigations. Secondly, neither the gender of the visually impaired athletes, nor the athlete's classification was considered in the statistical description or factor analysis. Although not highly consistent, there are reports in the literature suggesting important differences in postural alignment depending on gender (Nguyen and Shultz, 2007; Dolphens et al., 2013; Araújo et al., 2014; but see Raine and Twomey, 1997). However, it is less clear whether and how the level of visual impairment (being it total, as in the case of B1 athletes, or partial, as in B2 and B3 athletes) impacts the person's body posture. Irrespective of these constraints, the results described in the present study could be useful to foster the development of postural alignment assessment and research in the Paralympic context. Future investigations are necessary to unravel differences in postural alignment in athletes with visual impairment, visually impaired non-athletes and sighted persons.

5. Conclusion

In summary, visually impaired athletes adopted an (i) overall rightward inclination of the body, a (ii) forward positioning of the head and (iii) a forwardly inclined pelvis, followed by a flexed knee and a valgus ankle aligned in dorsiflexion position. Interestingly, the alignment of the trunk and of lower limbs account for most of the total variance of PAS/SAPO data. These PAS/SAPO body's angles and distances measures described in the present study can be used as reference values for future investigations of postural alignment in visually impaired athletes. The descriptive measures of PAS/SAPO in terms of absolute values, which emphasize the *magnitude* of postural deviation, particularly of those variables describing anterior alignment of the major body joints, have potential applications in Paralympic sports medicine and rehabilitation research.

Conflicts of interest

None.

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