Vertebral Metrics
Application of a Non-invasive System to Analyse Vertebrae Position using Two Seating Platforms

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Abstract: The study of the biomechanical changes in the spinal column is particularly important in modern society since they are considered the main responsible for back pain. *Vertebral Metrics* is an instrument that aims the global evaluation of the spinal column. Noninvasively and semi-automatically, this image processing based system allows the identification of *X*, *Y* and *Z* position of each spinal process on standing position. The analysis of vertebraes position using two different seating platforms through the application of *Vertebral Metrics* is the aim of this work. Along the paper the main stages concerning to the study will be described. Nine volunteers were recruited and an ergonomic chair and a bench were used to perform the study. Results show that differences in vertebrae position are not relevant when sitting in the ergonomic sit or in the lab. Also, spinal curvatures as well as lateral deviations of the spine were properly represented from data collected with *Vertebral Metrics*. The study proved that *Vertebral Metrics* has a huge potential to perform the analysis of the spinal curvatures.

1 INTRODUCTION

Spinal column is an essential component of human body promoting support and protection functions. Also, trunk and limbs movements are provided by the spine (Seeley et al., 2003).

Back pain has long been a relevant problem in modern society. The number of people affected by this symptom increases every year (Manek and MacGregor, 2005). Previous studies pointed out that 50% to 80% of the individuals experience at least one episode of back pain during their lifetime (Rubin, 2007). From those 80% to 90% are caused by mechanical spinal disorders (Najm et al., 2003; Quaresma et al., 2010). Congenital malformations, sedentary lifestyle, posture and incorrect physical exercise have a great contribution for the mechanical disorders (Jordão et al., 2011).

An important tool to identify the spinal problem and delineate the appropriate methodologies is the study of the spinal curvatures. Radiological techniques are the most widely used methods for assessing the spinal column however they use ionizing radiation. Thus, these techniques must be carefully applied (Harlick et al., 2007; Pinel-Giroux et al., 2006).

Ionizing radiation free devices are needed to evaluate, in a global way, the spinal column. Although many non-invasive devices have been developed to assess the spinal column most of them does not allow the three-dimensional evaluation of the spine. In addition, those who allow a *3D* analysis are extremely expensive as the methods that use infrared cameras (Hinman, 2004).

Vertebral Metrics – National patent PT/103990, European patent PCT/IB2009/005018 and American patent US20110004125 - is a non-invasive system designed to identify the spatial position of the spinal apophysis from the first cervical to the first sacral vertebrae in the standing position. Using a fluorescent marker to identify the skin projection above the spinal processes, recognition is achieved with software capable of distinguish the marks (Gabriel et al., 2015a; Gabriel et al., 2015b). Due to its versatility the equipment can have several applications from screening and prevention to monitoring the intervention methodologies for each clinical case.

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The aim of this paper is to present a study concerning to the application of *Vertebral Metrics* in the sitting position. Sedentary lifestyle is a significant concern of modern society and seating position is one of the most adopted positions. In addition, the majority of the occupational activities are carried out in that position.

According to studies performed by Chen et al. (Chen et al., 2006), a significant change in spinal curvature is found in a sitting position, causing a forward displacement of the lumbar spine, increased thoracic kyphosis and a decrease in pelvic angle. It contributes to a posterior pelvic tilt. They concluded that the pressure on the intervertebral discs is larger in this position than in the standing position, which is explained by the pelvis rotation. This causes a change in the biomechanics of the spinal column, leading to a pressure increasing in the lumbar intervertebral discs. The sitting posture is highly stressful because it requires large static work of the muscles involved.

During the study nine volunteers were recruited and vertebrae's configuration was analysed in the sitting position using two seating platforms - an ergonomic seat and a lab seat. The ergonomic seat is prescribed by physicians as a good posture promoter in sitting position. Lab seats are widely used however as they do not have a lumbar support they stimulate bad postures. The main goal of the study is to quantify postural differences between the two sitting platforms.

2 MATERIALS AND METHODS

2.1 Vertebral Metrics

For a better understanding of the object of this study the considered axis system will be defined as follows: the transversal distance is *X* coordinate, the antero-posterior distance is *Y* coordinate and the height is the *Z* coordinate (Figure 1).

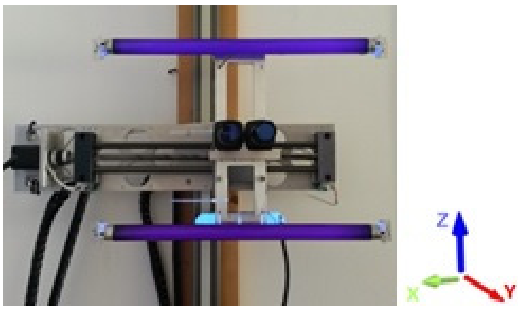

Figure 1: Mechanical apparatus of Vertebral Metrics and axis system.

Vertebral Metrics system consists of a vertical positioner – *Z positioner* - and a horizontal positioner – *X positioner* – with a bracket coupled. A stereo vision system and two ultraviolet lights are fixed on the bracket in specific positions. A resolution better than *1 mm* in each direction is provided by the stereo vision system. Therefore two monochromatic video cameras are fixed side by side in the horizontal support. The cameras (model UI-3480ML from IDS™) are *47 mm* from each other. They have 2560x1920 pixels resolution and a lens with *12 mm* of focal distance (Optica Goyo from IDS™). Hardware is controlled by software that was specially developed for that purpose. Communication functions as well as the user interface were defined in Visual Studio™ (Gabriel, 2015b).

A fluorescent marker is used to identify the spinal processes above the skin. When excited by ultraviolet light this dye emits a well-known wavelength – *635* – whereas the ultraviolet light emits at 400 *nm*. Image processing algorithms were implemented in Matlab™ to recognize the fluorescent marker and determine the spatial coordinates of each point. To simplify the definition of the image processing algorithms an optical filter *(BP635 from MedOpt*™) was coupled to each camera. The optical filters selectively transmit light in a particular range of wavelengths - from *600 nm* to *700 nm* - while blocking the remainder. Therefore the fluorescent marks stand out in the pictures acquired by the cameras which allowed the definition of less demanding image processing algorithms (Gabriel, 2015b).

In the beginning of each scan, the mechanical structure must be positioned under the point that identifies the first sacral vertebrae. This step is performed by a physician using the user interface. When the previous condition is accomplished the physician should press the *Start Button* to initialize data collection. Thereby an automatic cyclical process is carried out by software. During that process a pair of images is acquired simultaneously by the cameras and then the mechanical structure moves upwards. After *50 mm* the equipment stops and another pair of images is acquired by the cameras. Sequential images are recorded in a folder to be posteriorly analysed by image processing algorithms. The algorithms will identify the fluorescent marks and determine its tridimensional coordinates. It is noteworthy that data acquisition is completed in such a short period of time – between *30* and 40 seconds - because image processing is performed after a complete full scan of the spine (Gabriel et al., 2015b).

Data collection with *Vertebral Metrics* becomes available a table with the *3D* coordinates of each spinal process as well as a *3D* representation of these points. By definition, first sacral vertebrae is always considered the reference – its coordinates are *(0,0,0)* – and the other vertebraes coordinates represent relative positions comparing with the reference.

2.2 Application Protocol

The application of *Vertebral Metrics* to analyse vertebrae position using two seating platforms is the main goal of this work. Thus an ergonomic sit and a lab sit were used consecutively to perform the study (Figure 2). Nine volunteers – eight male and one female - aged between 18 and 27 years old and with no associated pathology were recruited. Letters from *A* to *I* were used to identify the volunteers. Procedures, purposes and risks associated with the study were explained and informed consent was obtained from each volunteer before participation. Tests were performed in the Instrumentation for Medicine Laboratory under a project lead by FCT/UNL.

Figure 2: Seating platforms: a) ergonomic sit; b) lab sit.

Before data collection, the spinal processes were identified by the physician. In each individual twenty spinal processes were identified – from the sixth cervical vertebrae to the first sacral vertebrae – and five consecutive scans were performed using the ergonomic sit followed by five consecutive scans using the lab sit. The first five cervical vertebraes were not identified because their skin projection was covered by hair. The fluorescent marker spreads when applied above hair. Thus, the marks are not identified by the image processing algorithms as they are optimized to recognize circular shapes only. This problem will be addressed in the future with a better method to place the markers. Figure 3 shows volunteer C during the data acquisition process with both seating platforms.

It is noteworthy that he number of subjects (nine volunteers) as well as the number of consecutive scans (five for each subject in each sitting platform) was set based on what was considered correct given the data acquisition time and the reasonable number of measurements.

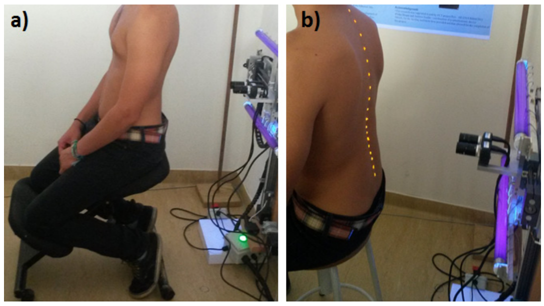

Figure 3: Data collection: a) ergonomic sit; b) lab sit.

3 RESULTS

Collected data was carefully analysed in order to evaluate vertebrae position differences between the two seating platforms used along the study.

As five scans were performed to each platform, the first approach included the determination of means and standard deviations. Spinal processes are represented by 3 coordinates – *X*, *Y* and *Z* – and we performed five scans with each seating platform so mean value and standard deviation were calculated for each coordinate of each vertebrae. Several standard deviation values obtained are bigger than system resolution – *1 mm* in each spatial direction. As the sound of the repositioning movement of the mechanical apparatus was identified by the volunteers, postural adjustments performed during this periods are the main responsible for the unexpected values. Furthermore, the standard deviation increases in the upward region which is explained by the larger spinal mobility in the thoracic and cervical area. Besides the previous constraints the *3D* coordinates obtained in each independent scan of the spine are not affected by the movement artefacts. Postural adjustments are insignificant during the *30* seconds required for a complete scan. In these circumstances, a comparison of vertebrae coordinates mean values does not make any sense. An alternative approach involved the analysis of the first scan for both situations. First scan was chosen because volunteers were extremely focused in stay perfectly still in the begging of each test. Nevertheless any other scan could have been analysed. Spinal process position observed from the coronal and sagittal planes are shown in Figure 4 and Figure 5, respectively.

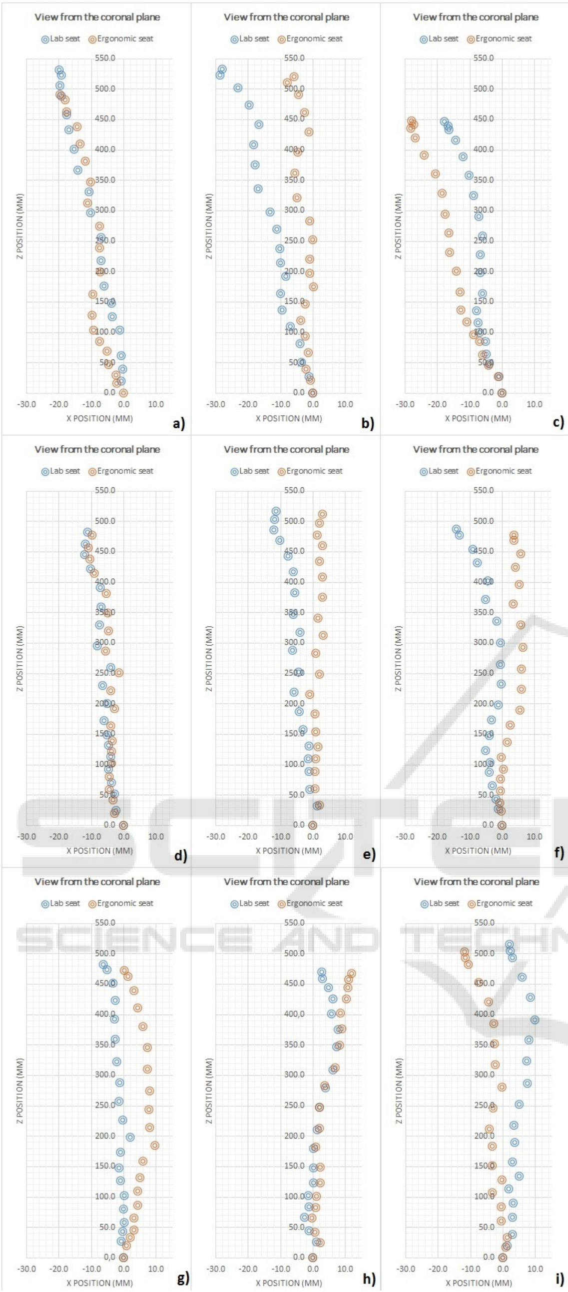

Figure 4: Vertebrae position observed from the coronal plane: a) volunteer *A*; b) volunteer *B*; c) volunteer *C*; d) volunteer *D*; e) volunteer *E*; f) volunteer *F*; g) volunteer *G*; h) volunteer *H*; i) volunteer *I*.

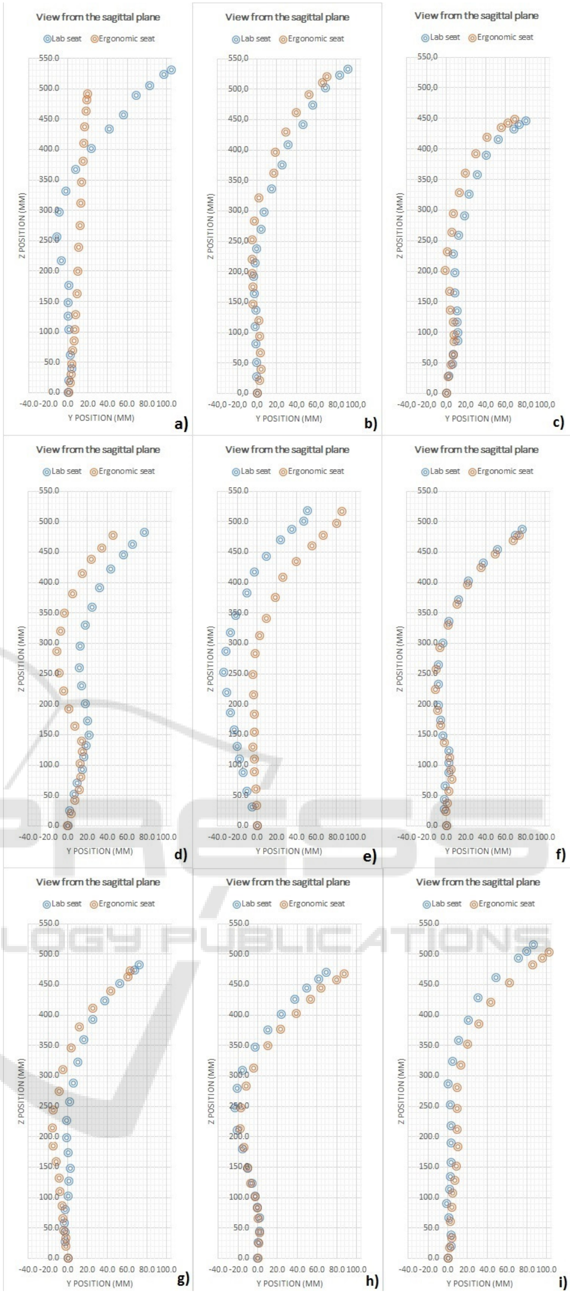

Figure 5: Vertebrae position observed from the sagittal plane: a) volunteer *A*; b) volunteer *B*; c) volunteer *C*; d) volunteer *D*; e) volunteer *E*; f) volunteer *F*; g) volunteer *G*; h) volunteer *H*; i) volunteer *I*.

Spinal curvatures information is not comprehensive by observing vertebrae position from the coronal plane – *x0z*. Nevertheless this view is useful to analyse lateral deviations of the spine. Although Figure 4 *b, c, d, e, f* and *g* present an identical shape regarding to lateral deviations between both seating platforms, there is no link on which platform contributes to a bigger deviation. Lateral deviation differences as well as the absence of a standard may be explained by movement artefacts. Changing the seat implies up and sit down which leads to postural changes.

Figure 5 allows the analysis of spinal curvatures by observing vertebrae position form the sagittal plane – *y0z*. Similar to what was found in the analysis of lateral deviations there is no standard on the results. Once again movement artefacts have contributed to the unexpected results. However spinal curvatures have an identical shape in both cases.

At last another type of analysis was performed. To the *X* and *Y* coordinates separately, distances between vertebrae position in lab seat and the ergonomic seat were calculated. In Figure 6 a scheme of the referred distance in *X* direction just to one vertebrae is presented in order to understand which distance - ΔX - we are determining. The same method was used to calculate distances in *Y* direction.

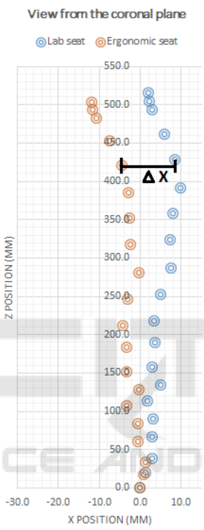

Figure 6: Scheme of the calculated distance in *X* direction.

Mean and standard deviation were determined for the *X* and *Y* coordinate each vertebrae considering the five acquisitions performed with both seats in each volunteer. Moreover mean and standard deviation were determined for each vertebrae considering all the acquisition performed in all volunteers. Table 1 presents the results obtained for the second condition. In both cases mean values are smaller than the deviation so it is not possible to conclude the adjustment carried out by each seating platform.

By observing the aforementioned table it is found that $|\Delta X|$ increases along the spinal column, namely from S1 until C6 vertebraes. As ΔX represents the difference between the lab seat and ergonomic seat ($X_{Lab\ sit} - X_{ergonomic\ sit}$), negative values indicate that, in general, the lateral deviation of the spine is greater to the ergonomic chair. The same correlation is identified to the standard deviation. High values of this parameters are explained by interpersonal differences. Regarding to the *Y* coordinate, there is no standard in ΔY and it was found an increase in the standard deviation. Again this is explained by interpersonal differences.

Table 1: Mean and standard deviation of distance between *X* vertebrae position in the lab sit and the ergonomic sit and distance between *Y* vertebrae position in the lab sit and the ergonomic sit for all acquisitions in all volunteers.

	$\overline{\Delta X}$ *(mm)*	$\sigma_{\overline{\Delta X}}$ *(mm)*	$\overline{\Delta Y}$ *(mm)*	$\sigma_{\overline{\Delta Y}}$ *(mm)*
S1	0.00	0.00	0.00	0.00
L5	-0.35	0.79	-1.44	2.84
L4	-0.48	1.45	-2.07	3.81
L3	-0.54	2.47	-3.07	5.62
L2	-0.82	3.17	-3.12	6.93
L1	-1.09	3.88	-1.78	8.31
T12	-1.48	4.61	-0.96	9.44
T11	-1.83	5.37	-0.03	9.73
T10	-1.82	5.89	0.40	11.18
T9	-2.25	6.65	2.37	12.62
T8	-2.49	7.30	3.22	13.20
T7	-2.75	7.77	4.20	14.73
T6	-3.06	8.05	5.41	15.80
T5	-3.10	8.16	5.49	17.29
T4	-3.40	9.12	3.57	15.93
T3	-3.40	9.80	6.76	20.45
T2	-4.38	10.46	-0.64	22.17
T1	-4.91	11.06	6.85	21.95
C7	-5.81	11.64	5.73	22.30
C6	-6.28	12.10	6.73	23.33

4 CONCLUSIONS

Vertebral Metrics is a non-invasive equipment developed by our research group. It was primarily designed to identify the spatial position of the spinal processes from the first cervical to the first sacral vertebrae in the standing position.

Present another application of the equipment - the analysis of vertebrae position using two seating platforms - is the object of this study. Nine volunteers were recruited and five acquisitions with the ergonomic sit followed by five acquisitions using the lab sit were performed. Collected data was carefully analysed and results show that there are no significant differences in vertebrae position when sitting on the ergonomic sit or in the lab sit. Also a standard was not found regarding to the use of the two platforms. Postural adjustments when the seat was changed contributed to the lack of uniformity.

A complete scan of the spine takes about *30* seconds while the automatic repositioning of the mechanical structure to return to the initial position takes *15* seconds approximately. Thus the time required to perform five consecutive acquisitions is about *4* minutes which is too long for any person stand perfectly still. Although *Vertebral Metrics* not touch the volunteer's backs, motion artefacts were identified between scans. Postural adjustments performed during the repositioning of the mechanical structure are the cause of the artefacts.

Overall, remarkable differences were not found in vertebrae position regarding to the use of an ergonomic seating or a lab seating. Also results does not allow to conclude the adjustment performed by each seat. However, spinal curvatures as well as lateral deviations are properly viewed from data collected with *Vertebral Metrics*.

The study proved that *Vertebral Metrics* has a strong potential to become a powerful tool to evaluate the spinal column curvatures in standing or sitting position. This unique and already patented device will avoid unnecessary invasive methodologies as well as qualified staff for screening and prevention of spinal disorders because it will allow repeated scans without causing damage to the individuals. *Vertebral Metrics* will also became available the definition of the most appropriate intervention methodologies to each particular clinical case.

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