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Original Article

An Instrumented Workstation to Evaluate Weight-Bearing Distribution in the Sitting Posture

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ABSTRACT

Background: Sitting posture may be related to risk factors, including inadequate weight-bearing support, particularly when maintained for long periods. Considering that body weight is loaded in a closed support system composed of the seat, backrest, floor and working surface, the aims of the present study were to describe the development of an ergonomic sitting workstation to continuously record weight-bearing at the seat, chair, backrest, work surface, and floor and to test its measurement properties: reproducibility, criterion-related validity, and sensitivity.
Methods: Rigid bodies (1 to 30 kg) and participant weights were recorded to evaluate the workstation measurement properties.
Results: Rigid body tests showed variation values less than 0.050 kg on reproducibility test and errors below 5% of measured value on criterion validity tests. Participant tests showed no statistically significant differences between repeated measures ($p \geq 0.40$), errors were less than 2% of participant weights and sensitivity presented statistically significant changes ($p = 0.007$).
Conclusion: The sitting workstation proposed showed to be reliable, valid and sensitive for use in future ergonomic studies to evaluate the sitting posture.
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1. Introduction

The sitting posture is characterized by changes in body configuration and weight-bearing compared with the standing posture [1,2]. When seated, weight is distributed between support points over the floor, seat, backrest, work surface, and armrest, when available [2]. The sitting posture favors body stability during tasks that require concentration, visual demand, and fine motor control. Moreover, it involves less energy expenditure and load on the lower limbs [2].

However, the use of computers during both occupational and leisure time activities requires a longer time spent in the sitting posture [3]. In addition to the discomfort caused by immobility, the sitting posture also involves health risks that might result in increased intradiscal pressure [4], reduced venous return [5], reduced cervical movements, and changes in the configuration of the thoracolumbar spine [1,2].

The lack of ergonomic adjustments to sitting workstations may increase health risk through musculoskeletal overload [1]. Increased distance between trunk and the backrest is associated with high lumbar kyphosis, forward leaning pelvis, increased postural changes, and increased discomfort, resulting in a restless posture [6]. On the other hand, the use of the backrest appears to increase comfort and reduce paraspinal activation because of external support provided by it[7]. In relation to work surface, the addition of a wide arm support board for forearm support resulted in significant neck, shoulder, and upper extremity pain reduction [8].

Despite the importance of assessing the seated posture for preventive purposes, researchers do not measure weight-bearing while sitting, which results in limited evidence [8]. The analysis of the weight distributed on the chair surface and floor allows to estimate the center of gravity in relation to the ischial tuberosities and lumbar spine shape [9] and on the backrest allows to estimate real use the backrest and to indirectly estimate the trunk posture [6]. Simple and low-cost weight-bearing measurement systems, as well as more complex and high-precision systems, have been used to evaluate the pressure applied to the seat and backrest [6,10,11].

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The participants' body weights were evaluated in only one study [12]. However, this study was conducted with a simple setup consisting of a chair as a seat scale with supporting scales for the footrest, armrest, and backrest. In this setup, the percentage of the body weight supported by each scale was reported when participants remained in a relaxed sitting posture [12]. Carcone and Keir [10], Ellegast et al. [13], and Zemp et al. [11] also reported the use of systems to measure the pressure distribution among different chair configurations. Vergara and Page [6] reported a simple method to measure the use of the backrest by assessing the contact between the backrest and the participant's back. From this background, it is possible to assume that there is a lack of reports performing simultaneous and continuous weight-bearing assessments in all involved surfaces in the seated position. Considering that the sitting posture creates a closed system for body support, it seems relevant to assess the dynamics of weight-bearing among the points that support the weight. The closed support system could be applied to field studies to identify possible ergonomic interventions on biomechanical exposure, for example, to compare whether different heights of tables change arm weight-bearing on the table (as it is presented in sensitivity tests) and whether back school programs are efficient in improving the use of backrests, promoting more symmetrical weight distribution, avoiding a slumped posture, and allowing workers' feedback regarding their postural habits while using the chair and work surface.

Therefore, the first aim of the present study was to describe the development of an ergonomic sitting workstation that is instrumented with load cells to assess and continuously record weight-bearing at the seat, chair, backrest, work surface, and floor (footrest). The second aim was to test workstation measurement properties: the reproducibility (concerning the degree to which repeated measurements in stable conditions provide similar results), criterion validity (concerning the extent to which the workstation load cell scores relate to the gold standard), and sensitivity (concerning the ability of the workstation to detect changes over time).

Dependent variables evaluated are weight-bearing using the sitting workstation through different tests among rigid bodies and participants to evaluate measurement properties. The first trials of criterion validity and reproducibility were performed with rigid bodies and for each load cell separately. Then, the surfaces, which compose the sitting workstation, were tested among participants regarding criterion validity, reproducibility, and sensitivity.

2. Methods

The proposed sitting workstation consisted of three elements: a work surface similar to a table (referred here as the work surface), a chair (with a backrest and a seat), and a platform to support the feet (plantar support). All of these surfaces were instrumented with load cells, allowing weight-bearing measurement on each surface during the sitting posture.

2.1. Instruments

Load cells (model CD; Kratos, São Paulo, Brazil) with a single point for tension/flexion were adjusted to the flexion mode. They were insensitive to eccentric loads and presented a sensitivity of 2 mV/V and a capacity from 50 to 100 kg. The load cells were fixed under medium-density fiberboards (MDFs) placed on all surfaces of the prototype, serving as the seat of the chair, the backrest, the working area, and the plantar support, during sitting. Load cell data acquisition was performed by means of a portable system (DataLog; Biometrics Ltd, Gwent, UK) at a frequency of 20 Hz. The signals were connected by a wireless Bluetooth adapter to a computer, allowing real time data visualization.

The construction of the workstation was based on the physical principle of evaluating the normal force and inferring the weight force. When the points of the supported body are at rest, the normal force (measured by the load cell) had an equal mode and tension but an opposite direction in relation to the supported weight force [14]. The results provided by the cells correspond to the value of the mass over the cell. Therefore, throughout the text, the term "body weight" will be used instead of "body mass" to include the gravitational component of the concept.

Because of its configuration, the load cell is sensitive to the torque that is generated by the supported mass at its extremity (force identified by the black vertical arrow in Fig. 1). Each load cell was attached to two MDF plates (one MDF plate fixed to the workstation structure and the other one was free for weight-bearing). In Fig. 1, the bottom surface (MDF plate) is fixed to the workstation and the top MDF plate is free for weight-bearing, i.e., it is fixed only to the load cell. The MDF plates which receive the weight-bearing are close to each other; however, small sliding movements were allowed to avoid crossing effects. Only one of the extremities of the load cell was fixed to the bottom plate, and the other load cell extremity was fixed under the top plate. To ensure that only one of the load cell extremities maintained contact with

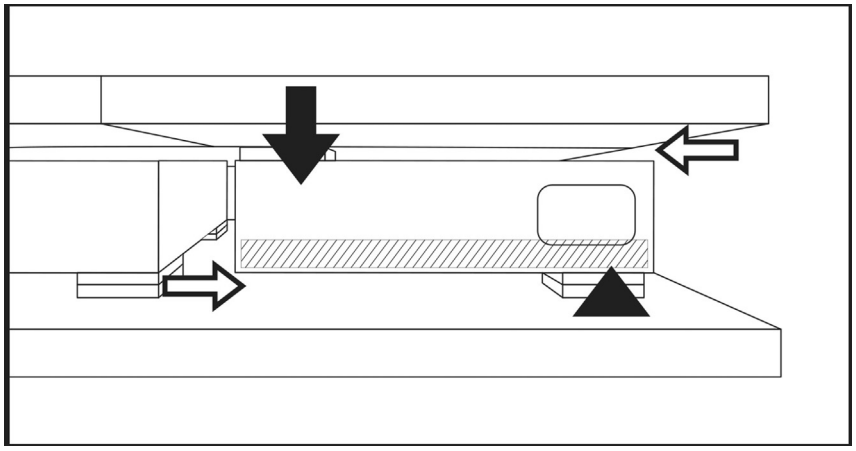

Fig. 1. Load cells attached to the MDF boards. White horizontal arrows showing the clearance needed to measure torque at the load cells. The other components in the figure represent the force system, with the black arrow representing the force on the load cell that is fixed at the right extremity as shown by the triangle. The rectangle represents the moment arm.

each MDF board, metal plates with a thickness of 6 mm were added between the load cells and the MDF boards. With insertion of these metal plates, the necessary clearances (white horizontal arrows in Fig. 1) that were needed to ensure the transmission of the force in flexion (Fig. 1) were preserved, thus avoiding measurement errors.

2.2. Development of the prototype workstation

The workstation consisted of 16 load cells that were distributed as follows: eight cells to measure the chair support, four cells for the work surface, and four cells for the plantar support. The load cells on the work surface and on the backrest had a maximum capacity of 50 kg, and the others had a maximum capacity of 100 kg. The workstation is shown in Fig. 2.

2.2.1. Surface for plantar support

The surface for measuring the weight-bearing of the feet and legs was composed of four plates, each containing a load cell at the center of the MDF boards (Fig. 2D). To avoid measuring the weight of the chair in the plantar support, the chair legs were positioned according to four holes made in the plates, as illustrated by the arrows in Fig. 2D, thus allowing the chair legs to rest on the inferior MDF plate and avoid contact with the load cells.

2.2.2. Work surface

The load cells on the work surface were fixed at the end of the plates to prevent tilting of the plate during the task (Fig. 2C, black arrows shown above the work surface). This option was considered after the pilot study results showed that the upper limb weight-bearing mainly occurred at the edges of the surface because of the support of the forearms.

The height was adjustable by screws in the supporting rods of the work surface (Fig. 2C, white arrows shown on the sides of the table). The perforations had a spacing of 3 cm between each other, allowing a fit of between 62 and 74 cm, excluding the height of the plantar support. The adjustment of the table height was defined in accordance with national and international ergonomic recommendations [15–17].

2.2.3. Chair

The chair was built with iron, with a 100° angle between the backrest and the seat and an angle of 3° between the seat and the horizontal reference line, which creates a slight backward inclination.

Similar to the height of the work surface, the chair dimensions were determined by considering the chair together with the plantar support to follow the ergonomic parameters of workstation dimensions. Holes for inserting screws on the rods of the chair were made to allow the height of the backrest and the height and length of the seat of the chair to be adjustable to the user population. Thus, a 12-cm adjustment range for the backrest height, a 4-cm range for the length of the seat, and a 13-cm range for the height of the seat were possible.

The backrest was composed of two MDF plates (40 × 15 cm), and the seat was composed of six plates (20 × 12 cm, Fig. 2B). Every load cell was centrally fixed between the superior and inferior plates of the backrest and seat.

The chair was designed as per the recommendations from the Brazilian furniture guides [15,16] and reports from the international literature based on anthropometric measures [1,17,18]. A comparison between the measurements of the developed chair and ergonomic recommendations that are available in the literature are shown in Table 1.

2.3. Procedures

2.3.1. Data acquisition settings

According to the operating principles of load cells, in which the electrical signal output is proportional to the deformation caused by the applied force (weight), a five-kilogram weight was used to adjust the sensitivity and excitation of the output. The weight was positioned over each load cell, and the sensitivity and excitation values were adjusted so that the value recorded by the data acquisition unit was exactly the same as the weight (5 kg). Through this adjustment, the sensitivity was set at 3 mV and the excitation ranged from 1450 to 1600 mV between the load cells. The data acquisition frequency was set at 20 Hz.

2.4. Workstation measurement property tests

2.4.1. Pilot test and the criterion-related validity for each part of the workstation—tests with rigid bodies

The criterion-related validity of the measurements was tested using different masses (weight plates) placed on the surfaces. The definition of the maximum load placed on each surface was based on a pilot test conducted with three women presenting with a normal body mass index and weight between 50 and 70 kg. In these pilot tests, every woman sat in the workstation chair and used a computer for 1 min. This pilot test was performed to estimate the mean weight that was to be supported by the load cells during the workplace recordings. Based on these tests, it was established that

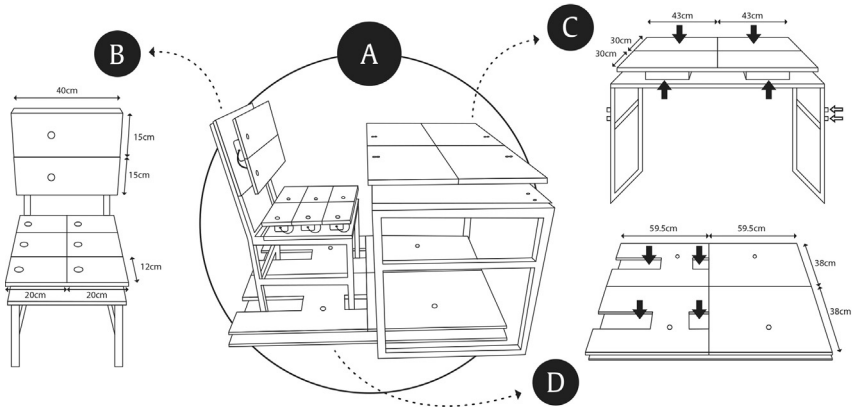

Fig. 2. A) Workstation adjusted for the sitting position and instrumented with load cells to evaluate weight-bearing on the chair, work surface, and plantar support. (B) Instrumented chair to evaluate weight-bearing on the seat and backrest. (C) Instrumented work surface to evaluate weight-bearing of the upper extremity on the work surface. (D) Instrumented platform to evaluate weight-bearing of the lower extremity on the platform.

Table 1
Furniture parameters suggested by the literature and those considered for the proposed chair.

Recommendations	Seat				Backrest			
	Height (distance from the floor to seat)	Width	Depth	Angle of inclination	Height (distance from the seat to backrest)	Width	Vertical extension of the backrest	Angle between the backrest and seat
Brazilian Association of Technical Standards [15]	42 to 50 cm	40 cm	38 to 44 cm	−2 to −7°	—	30.5 cm	24 cm	90 to 110°
Brazilian Ministry of Labor and Employment [16]	37 to 50 cm	40 cm	38 to 46 cm	—	—	30.5 cm	—	—
Carter and Banister [17]	38 to 57 cm	46 cm	33 to 47 cm	−8°	10 to 24 cm	30 to 48 cm	50 cm	90 to 120°
Proposed chair	43 to 56 cm	40 cm	36 to 40 cm	−3°	9 to 21 cm	40 cm	30 cm	100°

the ideal test masses ranged from 1 to 5 kg for each part of the working surface and the plantar support and between 5 and 30 kg for each part of the seat surface. Considering these results, each part of the seat and the working surface was evaluated individually.

Because of the perpendicular angle of the backrest relative to the floor, it was not possible to position weight plates above the backrest surface. In this sense, the validity test for this part of the workstation was carried out using a digital dynamometer (DDK, capacity 0—100 kgf; Kratos). The chair was positioned close to the wall to prevent the chair from moving during the test, and a manual compression force through dynamometer was applied perpendicularly to the vertical surface of the backrest. The intensity applied ranged from 0 to 10 kgf and was determined according to the results of the pilot study.

2.4.2. Reproducibility of the working surface and plantar support—tests with rigid bodies

Because larger MDF surfaces were fixed on each load cell at the working surface and the plantar support, the reproducibility of the measures was determined considering the displacement of the masses in different positions of the surface.

Reproducibility tests for the working surface and the plantar support were conducted through measurements that were repeated on the same day with the respective masses that were used in the validity test. To verify the reproducibility, the masses were positioned at the corners of the MDF plates. The plates were divided into quarters, and 1, 2, 3, and 5 kg masses were placed over the center of each quadrant, resulting in a total of 64 trials for the working surface and 64 for the plantar support (16 quadrants × 4 different masses on each quadrant).

2.4.3. Evaluation of the workstation criterion validity, reproducibility, and sensitivity—tests with participants

The study was approved by the Ethics Committee for Human Research of the UFSCar (Protocol CEP: CAAE 05658612.5.0000.5504).

2.4.3.1. Criterion validity and reproducibility. Ten healthy women aged from 25 to 35 years, with a weight of 68.84 ± 12.14 kg, took part in this evaluation.

The furniture was adjusted according to the participants' anthropometric measurements and the ergonomic recommendations [1,17—19]. Each participant had her weight recorded by a digital scale (Mallory, 100 g precision and 150 kg maximum capacity). The participants were instructed to sit comfortably with their arms on the table and to relax for 1 min before recording for familiarization, and the procedure was carried out by following the same ergonomic recommendations used for furniture adjustments: sitting upright with the buttocks as far back as possible using the backrest, having both feet resting on the floor, and resting both arms on the work surface (the posture adopted by the participants for this test is presented in Section 3, Fig. 3). Weight-bearing over the plantar support, working surface, backrest, and seat was recorded in three consecutive measurements for 5 s with 15 s of interval between them. A fourth measurement was carried out after the volunteer stood up and then sat down again at the workstation for more than 5 s. The weight-bearing registered by every load cell was then summed up and compared with the total body weight of each participant.

The backrest supported weight was determined by the following formula: $P = p * \sin 13°$, where P = body weight supported by the backrest (gravitational force); p = the value recorded by the load cells (normal force); and 13° = 103° of backrest inclination in relation to the floor. This adjustment was established considering that only the gravitational component of normal force measured by the load cells on the backrest represents the weight force.

2.4.3.2. Sensitivity. Nine healthy women aged from 25 to 32 years, with a weight of 63.98 ± 7.35 kg, took part in this evaluation.

The participants typed text using a word processor for 5 mins using a notebook on two different work surface heights using the sitting workstation. All sitting workstations were the same during both tests. Only the work surface was set at two different heights: (a) work surface adjusted according to the participants' anthropometric measurements and (b) work surface was 5 cm higher than the ergonomic recommendations. Because work surface was set higher than the elbow height for situation (b), we hypothesize the arm weight-bearing will be less than for the ergonomic condition (situation a). The order of the work surface heights was randomized.

2.5. Data analysis

The data were processed by means of a MatLab routine (version 7.0.1; MathWorks Inc., Natick, USA). A second-order low-pass Butterworth filter at a frequency of 2 Hz was used. The cutoff frequency was determined by residual analysis.

Data were descriptively analyzed by calculating the mean and standard deviation of the error. The error was calculated as the difference between the expected value (the known plate weights and the recorded body weight of each participant) and the values that were actually recorded and presented as percentages and were obtained as follows: error = (expected value − recorded value)/recorded value.

The reproducibility of the four tests performed with each volunteer was analyzed using the Friedman test because the data were not normally distributed.

For the typing test that was performed to assess the sensitivity, data were reduced by an amplitude probability distribution function, and the 50th percentile of the 3 central minutes of the recording was obtained for each load cell of the workstation. To remove the weight of the notebook from the work surface, a 30-s record was performed and the median of 10 s central data was subtracted from the measurement of the working surface. A paired *t* test was used for comparison between the weight-bearings of the upper arms on the work surface. No concurrent validity test was

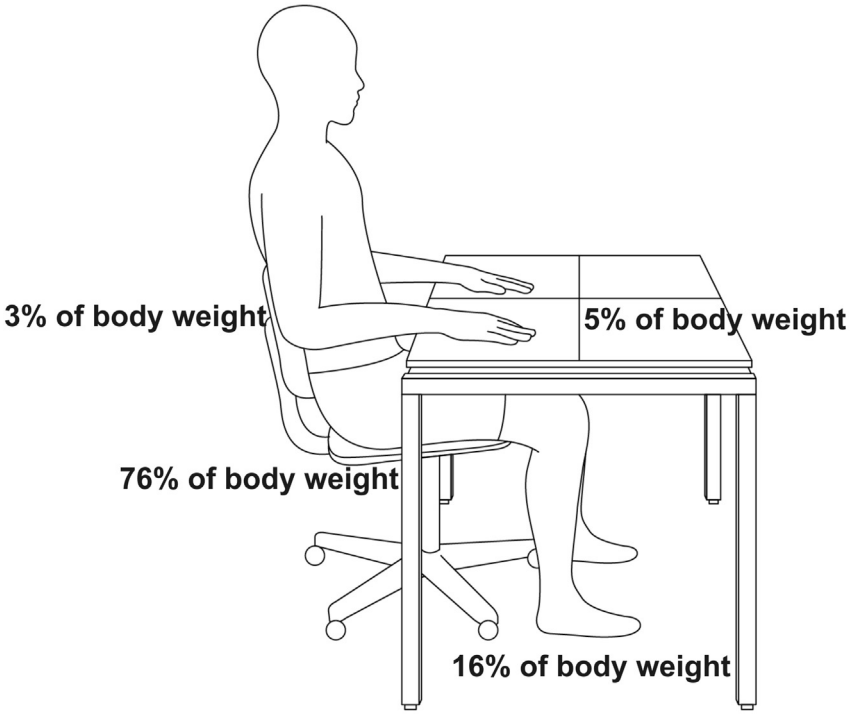

Fig. 3. Percentage of body weight distributed per workstation surface.

performed because no similar instrumented workstation is commercially available for this purpose.

The level of significance was set at 5%, and the analysis was performed using SPSS software (version 11.5).

3. Results

3.1. Criterion-related validity for each part of the workstation—rigid body tests

In general, the errors obtained in each load cell were below 5% of the measured value, as shown in Table 2. Comparatively, higher error values were recorded for the backrest, reaching up to 4.3% of the mass supported by the load cell.

3.2. Reproducibility tests for the segments of the working surface and plantar support—rigid body tests

When the different masses were placed over the quadrants, the average standard deviation identified showed values less than 0.050 kg. The average standard deviation, when the masses were placed over the quadrants of the plantar support, was 0.014 ± 0.008 kg (maximum 0.03 kg) and 0.011 ± 0.005 kg (maximum 0.045 kg) on the working surface.

Table 2
Mean and standard deviation of the error (in percentage) for the load cells on each surface per tested weights (in kg).

Surface	Percentage error Mean (SD)			
	Tested weights			
	1.0 kg	2.0 kg	3.0 kg	5.0 kg
Plantar support	0.6 (2.5)	0.2 (0.6)	0.1 (0.7)	0.5 (0.7)
Work surface	−1.8 (1.4)	−1.0 (0.9)	−0.2 (0.4)	−0.3 (1.5)
Backrest	−2.6 (1.7)	−3.1 (3.5)	−4.3 (3.5)	−2.2 (0.1)
	Tested weights			
	5.0 kg	10.0 kg	20.0 kg	30.0 kg
Chair seat	1.2 (1.0)	0.7 (0.7)	0.2 (0.7)	−0.1 (0.6)

SD, standard deviation.

3.3. Evaluation of workstation—tests with participants

3.3.1. Validity and reproducibility

On an average, the largest percentage of body weight was supported by the seat, representing approximately 76% of body weight, corresponding to 51.55 ± 11.17 kg in the first trial (Fig. 3).

The lowest percentage of body weight was supported by the backrest (3% = 2.03 ± 0.32 kg in the first trial), followed by the working surface (5% = 3.40 ± 1.48 kg) and plantar support (16% = 10.64 ± 3.46 kg, Table 3).

A small variation between the four consecutive measurements of the participants' body weights was identified. This occurred even for the last measurement, which was performed after the participant stood up and sat down again (Table 3). There were no statistically significant differences between these measurements, either for the values of total body weight ($p = 0.43$) or for the measured error difference between the measures of the sum of the load cell measurements and scales ($p = 0.40$).

The mean errors obtained by the sum of the values distributed over all surfaces of the workstation in relation to the participant's body weight, as assessed with a scale, showed maximum differences of 1.6%, 1.5%, 1.5%, and 1.4% for the first, second, third, and fourth measurements, respectively.

3.3.2. Sensitivity

There was a statistically significant difference ($p = 0.007$) between the mean of the weight-bearing of the upper arms while typing using the work surface ergonomically adjusted to each participant (2.56 ± 1.43 kg) and while using the work surface that was 5 cm higher (3.19 ± 1.38 kg). However, no significant difference was found for weight-bearing on the plantar support ($p = 0.241$) and the seat ($p = 0.464$).

Table 3
Mean (M) and standard deviation (SD) of the percentage of body weight supported by the backrest, seat, work surface, and plantar support. The total mass recorded for all surfaces (kg), the body mass measured by the scale (kg), and the percentage of error of the masses recorded on the surfaces and scale are also presented.

Repetitions	Percentage of total body weight (%) (M±SD)				Mass (kg) (M±SD)		
	Backrest	Seat	Work surface	Plantar support	Sum of the load cells from the workstation	Mass measured on a scale	% error
1	3.04 ± 0.36	76.08 ± 6.93	5.11 ± 2.09	15.77 ± 5.24	67.63 ± 12.44	67.59 ± 12.14	0.00 ± 1.35
2	3.15 ± 0.43	75.70 ± 6.60	5.03 ± 2.00	16.12 ± 5.15	67.62 ± 12.34		−0.00 ± 1.37
3	3.18 ± 0.44	75.29 ± 6.55	5.32 ± 2.04	16.21 ± 5.01	67.68 ± 12.30		−0.10 ± 1.36
4	3.00 ± 0.46	75.39 ± 5.55	5.30 ± 1.88	16.31 ± 4.36	67.58 ± 12.04		−0.01 ± 1.12

4. Discussion

The results obtained for the criterion-related validity tests showed errors less than 5% of the measured value, which were within the error range specified by the manufacturer of the load cells. This test indicated that the individual parts of the workstation presented high criterion validity.

While testing humans, the sum of all of the surfaces of the workstation also showed errors less than 2%. Similar to the evaluation of the criterion validity tests, tests with humans also indicated that the workstation, as a closed system, presented high validity.

Few studies have investigated weight-bearing distributed among different surfaces simultaneously, but none have reported continuous measurements for whole segments during the seated position. According to Chaffin et al. [20], when the backrest is used, less than 25% of the body weight would be supported by the feet, whereas approximately 50% or more would be supported by the seat, and the rest of the weight would be supported by the upper limbs. These values were extracted from a study by Schoberth (1962) that was cited by Chaffin et al. [20], in which changes in the center of mass were evaluated as a function of postural changes in the seated position. In the present study, less weight-bearing was recorded for the plantar support (approximately 16%) and even lower weight-bearing values were identified for the backrest (3%) and upper limbs (approximately 5%), whereas greater weight-bearing (approximately 75%) was identified for the seat. In a study by Swearingen et al. [12] in which platform scales were used to measure the weight at a time point, the weight-bearing findings were similar to those described in the present study for the footrest (18% of body weight) and backrest (4% of body weight). However, weight-bearing in the ischial region was inferior (65%) and superior to the values reported here for the upper limbs (12%). The differences might be explained by different variables such as the furniture configuration, adopted posture, and activities interfering with weight-bearing. Part of these variation sources were controlled in this study; however, future studies should address different furniture configurations and the performance of different activities.

The reproducibility tests showed that the quality of the measures were independent of the position of the masses over the quadrants on the work surface and platforms. In addition, tests with the participants also showed low variability on the repeated measures, indicating high reproducibility of the data recorded by the workstation.

In relation to the backrest, the weight supported by this surface was calculated considering the vertical component of the force, i.e., the gravitational force, which can add accuracy to the value of the achieved lumbar support. The fact that all surfaces that were evaluated were divided in quadrants also provides more precise localization of the weight loading of the users.

Previously, a study by Vergara and Page [6] reported electrode measurements for classifying backrest use as a lumbar and/or dorsal contact. Similarly, Ellegast et al. [13] reported pressure sensor measurements at the seat and backrest to classify the positions on the chair as front, central, and back. The purposed workstation provides quantitative measures of weight-bearing by quadrants, which also allows for the classification of the backrest contact and seat posture, as in the mentioned studies.

Compared with pressure sensor systems, in which the focus has been to only measure the weight-bearing on the seat surface, our workstation allows for recording of the weight-bearing on all surfaces for a long period of time in work environments through a portable and relatively easily operated system. The system also provides simultaneous visual feedback of the recordings because the signals are connected by a wireless Bluetooth adapter to a computer, allowing for real time data visualization.

Studies that evaluated weight-bearing of the upper limbs on the work surface are scarce. Among the studies that evaluated weight-bearing of the upper limbs, none assessed simultaneous weight-bearing of other body regions. Szeto et al. [21] used load cells under the keyboard to verify the force used during typing at different velocity levels. In another study, Hasegawa and Kumashiro [22] positioned load cells on chair armrests and compared the weight-bearing of the upper limbs at different armrest heights of 22, 24, and 26 cm above sea level while performing typing tasks. Similar to the present sensitivity results, Hasegawa and Kumashiro [22] also found statistically significant differences on the weight loading of the upper arms among the different armrest heights, which confirms the sensitivity of the present results to distinct furniture conditions.

Therefore, the workstation proposed here seems to be able to contribute to future ergonomic studies and interventions that may be conducted to reduce physiological and biomechanical overload by allowing for the evaluation of the weight distribution on the contact of the supported body areas during the sitting posture. This workstation allowed for the registration of body weight-bearing in a closed support system for long periods through a portable system and was relatively easy to operate; it provided visual feedback of the simultaneous recordings. As a matter of consequence, the gap in the current understanding of the dynamics of the whole body weight-bearing would be reduced.

4.1. Contributions

The present article described the construction of a closed system for body support on a sitting workstation, which will allow to record data of weight-bearing on all contact surfaces by means of simple, reliable, and valid method for long data recording. This sitting workstation could be used in field to assess ergonomic interventions, as reported by Vergara and Page [6] for backrest, Szeto et al. [21] for working surface, and Hasegawa and Kumashiro [22] for armrest measures, but for all surfaces at the same time.

The sensitivity test results revealed that the adjustment of the working surface height in accordance with ergonomic recommendations increases the weight-bearing of the upper arms on the

surface. The increase of 5 cm from the ergonomic recommendation was enough to reduce the upper arm support, reinforcing the importance of this surface height for reduction of muscle strain and upper arm discomfort [22].

4.2. Limitations

The tests were conducted on humans who presented with a normal body mass index during simulated situations for a short period of time. Future studies involving both genders, individuals presenting with a higher body mass index, and individuals performing different tasks should be conducted to verify the external validity and reproducibility of the workstation in different occupational settings and populations.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.shaw.2019.01.006.

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