Occupational Safety and Hygiene II – Arezes et al. (eds)
© 2014 Taylor & Francis Group, London, *ISBN 978-1-138-00144-2*

Ergonomic and anthropometric evaluation of a footwear modification: A case study

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ABSTRACT: This study aims to evaluate the changes performed on a specific type of shoes, taking into account the ergonomic and anthropometric aspects involved in its use. Due to the need to evaluate the bone structure of the considered subject case study, a conventional X-ray was performed, which has demonstrated a shortening of the left leg of 29 mm and a probable adduct foot. Anthropometric evaluation of the subject confirmed the asymmetry in the left lower limb, located between the knee and the left foot in 27 mm. The corrective changes were implemented in the left boot. Asymmetries and associated pathologies were identified and the footwear chosen by the user was adapted according to the specificities identified. The anthropometric analysis showed that the adopted compensation on the left boot, and according to the observed data, contributed to a postural improvement. The proposed objectives were achieved.

1 INTRODUCTION

The intervention of ergonomics is basically centred in the improvement of the human living and working environments, as well as in the design of means to ensure a maximum of comfort, safety and efficacy (Carneiro, 2010). The contribution of anthropometry for ergonomics allows to clarify the inadequate sizing of the shoes and inadequate postures adopted by its users, which also allows to prevent the onset of injuries, usually musculoskeletal (Barroso & Costa, 2010).

According to Nurse *et al.* (2005) insoles for shoes and orthotics are typically considered mechanical interventions. Interventions in footwear are commonly used to alter gait patterns, improve comfort and treat a number of diseases of the lower limbs (Razeghi, 2000; Nurse, 2005). Use of orthopedic devices to enhance the function of the skeleton (Crabtree, 2009).

As indicated by Barroso e Costa (2010), the characteristics and limitations of physical disabilities are so variable that the help devices have, frequently, to be "custom made" for the user.

The development and adaptability of the footwear must meet the anthropometric aspects of the users, considering the ergonomic features related both to form and comfort.

Considering the previous, the current paper is the description of a case study related to a young man with a congenital deficiency in his left leg, where he has no posterior tibial tendon. He almost has no gastrocnemius muscles, which prevents him from performing the extension of the foot and the flexion of the leg (Seeley *et al.*, 2003). He has also underwent a surgery, in which the short peroneal tendon was transferred to the Achilles tendon and the extensor of the *hallux* to the posterior tibial, tenodesis of the *hallux* extensor with common extensor (Nascimento, 2010). Currently, he presents the appearance of an adduct foot. The left leg is 3 cm shorter, being the asymmetry practically totally located between the knee and the foot. The leg is slimmer from the knee to the foot. The left foot is smaller and has muscle atrophy.

The aim of this study was to evaluate the appropriate changes in a pair of shoes, taking into account the ergonomic aspects, particularly those relating to anthropometric issues of the subject considered in this case study.

2 METHODOLOGY

It was assumed to be essential, in addition to the medical report, to become aware of the real situation of the user, having for this purpose evaluated the bone structure through the prescription of conventional X-rays, as well as with an anthropometric evaluation, using the Protocol of Anthropometric Dimensions and Percentiles (UMinho) using a fix anthropometer and a laptop.

2.1 *Material*

In this study the following anthropometry equipment was used:

- Fix anthropometer (Figure 1), used to collect most of the anthropometric dimensions;
- Portable anthropometer (Figure 2) "*Harpenden*" anthropometer. *Holtain Limited*: *Crosswell*; *Crymych*;
- Dyfed. Used to collect some of the anthropometric dimensions;
- Protocol of Anthropometric Dimensions and Percentiles (UMinho).

2.2 *Procedure*

The anthropometric measurements (with the exception of the biacromial and bideltoid shoulder width) were gathered through a static fix anthropometer (Figure 1), in the standing position and in the sitting position on a chair with a 450 mm height and adjustable to a horizontal surface, the back in the upright position, the legs with a 90º angle and the feet well supported on the ground. During the measurement process, the user was barefoot, wearing shorts and a t-shirt.

The biacromial and bideltoid shoulder width, was measured with the portable static anthropometer (Figure 2). The dimensions used in this study were all the dimensions existing in the UMINHO table (Table 1), namely: standing height, height of the eyes in relation to the ground, shoulder height in relation to the ground, elbow height in relation to the ground, wrist height in relation to the ground, sitting height in relation to the seat, eye distance in relation to the seat, distance shoulder seat, distance elbow seat, thigh thickness, thigh maximum length, distance thigh-popliteal, knee height in relation to the ground, popliteal height in relation to the ground, shoulder width (bideltoid), shoulder width (biacromial) hips width, chest (bust) thickness, abdominal thickness, distance elbow-wrist, functional vertical reach (standing), functional vertical reach (sitting), functional anterior reach, lumbar height in relation to the seat and weight. Taking into consideration all positions and ranges, having as reference the guidelines of the main static anthropometric dimensions (Figure 3). At the end an adjustment was made, removing the seat height (450 mm) in the measurements in which it was associated to. As the user showed asymmetries between the left and the right side, all the performed measurements take these asymmetries into consideration and were duly registered.

All the measurements were performed by the same measurer and registered in mm by a second person. The measurements were performed in the *Ergonomy Laboratory* of the *Department of Production and Systems from the School of Engineering of University of Minho*.

The data collection method used for the gathering and treatment of the data was in accordance with the protocol elaborated by the laboratory. The anthropometric data presented in the protocol constitute the first databank of anthropometric data of the Portuguese adult working population, with relevance to *design* ergonomic implementation (Barroso *et al.*, 2005).

The corresponding percentiles for the registered measurements of the user were calculated. This calculation was performed for each dimension. In the cases where asymmetries were observed, the percentiles related to right and left side were calculated as well.

The weight factor was evaluated by calculating the *Body Mass Index* (BMI).

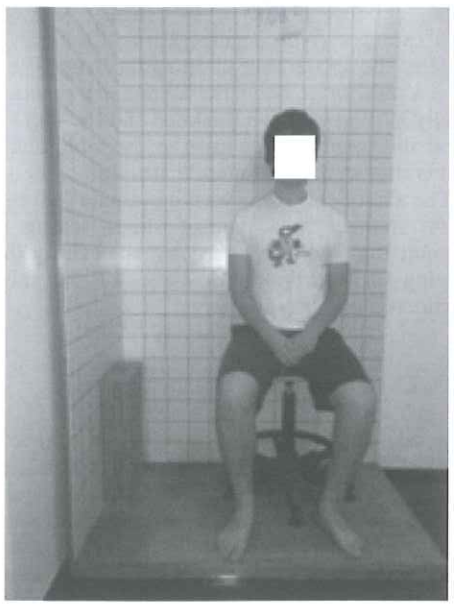

Figure 1. Fix anthropometer with subject.

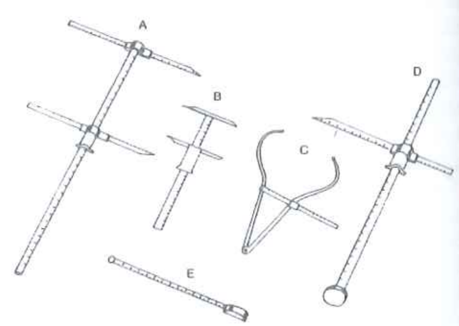

Figure 2. Portable anthropometer.

Table 1. Anthropometric data UMINHO—data from the Portuguese population.

Tabela UMINHO – dados antropométricos população portuguesa adulta								
Dimensão antropométrica	População masculina				População feminina			
	5	50	95	dp	5	50	95	dp
1. Altura de pé	1565	1690	1815	76	1456	1565	1674	66
2. Altura dos olhos (rel. ao solo)	1463	1585	1707	74	1355	1465	1575	67
3. Altura do ombro (rel. ao solo)	1277	1395	1513	72	1181	1290	1399	66
4. Altura do cotovelo (rel. ao solo)	966	1050	1134	51	889	965	1041	46
5. Altura do punho (rel. ao solo)	664	735	806	43	619	685	751	40
6. Altura sentado (rel. ao assento)	818	920	1022	62	799	865	931	40
7. Distincia olhos-assento	716	810	904	57	696	760	824	39
8. Distincia ombro-assento	576	630	684	33	496	590	684	57
9. Distincia cotovelo-assento	206	255	304	30	191	250	309	36
10. Espessura da coxa	134	180	226	28	124	165	206	25
11. Comprimento máximo da coxa	518	590	662	44	517	570	623	32
12. Distincia coxa-poplíteo	419	485	551	40	421	470	519	30
13. Altura do joelho (rel. ao solo)	459	525	591	40	434	480	526	28
14. Altura do poplíteo (rel. ao solo)	347	400	453	32	327	365	403	23
15. Largura dos ombros (bideltóide)	426	475	524	30	379	445	511	40
16. Largura dos ombros (biacromial)	299	335	371	22	251	300	349	30
17. Largura das ancas	341	380	419	24	342	400	458	35
18. Espessura do peito (busto)	221	265	309	27	226	275	324	30
19. Espessura abdominal	204	260	316	34	201	260	319	36
20. Distincia cotovelo-punho	320	350	380	18	292	320	348	17
21. Alcance funcional vertical (de pé)	1875	2030	2185	94	1719	1860	2001	86
22. Alcance funcional vertical (sentado)	1117	1250	1383	81	1071	1165	1259	57
23. Alcance funcional anterior	628	730	832	62	621	675	729	33
24. Altura lombar (rel. ao assento)	166	215	264	30	174	220	266	28
25. Peso (Kg)	57	75	93	11	49	65	81	10

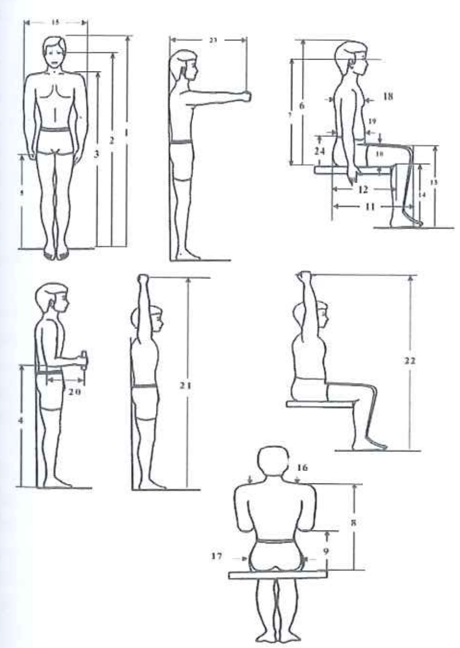

Figure 3. Main static anthropometric dimensions.

2.3 *Changes performed on the footwear*

Due to the asymmetry between the two lower limbs, the necessary changes to the footwear were undertaken. After performing the corrective changes on the boots, the soles and insoles were measured at different points.

The right foot, without alterations, presents a 36 mm heel and a 13 mm half sole. The left foot, subject to the alterations, has a 45 mm heel and a 23 mm half heel, having an increase of approximately 10 mm. The insole has a thickness of 10 mm on the foot sole zone, on the heel zone 15 mm and on the inner part, to correct the adduct foot it has 5 more mm, with a total of 20 mm.

All in all, there is an increase of 20 mm on the foot sole zone and approximately 30 mm on the heel zone.

These changes were confirmed and approved by the user, who tried them out and was pleased with the changes and the level of aesthetics of the boots, mentioning that: "*one can note very little of the alterations on the soles, and on the inside the foot is comfortably settled*".

3 RESULTS DISCUSSION AND ANALYSIS

3.1 *X-ray analysis*

The obtained radiography in extra-long chassis noted a large radius and right concavity back-lumbar scoliosis (Figure 4), centered at L1-L2 (Sarmento, 2012). Scoliosis is an abnormal lateral curvature of the spine, often accompanied by abnormal secondary curvatures (Seeley et al., 2003).

Figure 4. Spine in extra-long chassis (90 cm).

The X-ray (Figure 5) reveals a shortening of the left leg of about 29 mm compared with the right one (Sarmento, 2012).

Figure 5. Lower limbs in extra-long chassis (120 cm).

The radiograph of the feet extremities (Figure 6) seem to note a certain degree of hypoplasia of the third and forth metatarsal to the left and possible adduct foot (Sarmento, 2012).

3.2 *Anthropometric analysis prior to footwear alteration*

The user has the height percentile of 97% compared with the Portuguese population (Table 2). The remaining percentiles are around 90%, lying within the normal range for a 16 years old young man.

The physiatry service found that he had showed 30 mm less length on the left leg. The relearning of the gait was immediately started with new instructions about the proper posture and feet positioning so that the signals reached the nervous system and the new changes were assimilated (Figueiredo, 2006). The left leg shows 27 mm less length between foot and leg in relation to the right one.

Figure 6. Foot, front view.

Table 2. Anthropometric dimensions and corresponding percentiles.

Anthropometric dimensions (mm)	Left	Right	Mean	SD	Z left	Z right	P left (%)	P right (%)
Stature	1835		1690	76	1,91		97	
Eyes height	1700		1585	74	1,55		94	
Shoulder height	1500	1505	1395	65	1,62	1,69	95	95,5
Wrist height	790		735	43	1,28		90	
Elbow height	1097	1100	1050	51	0,92	0,98	82	84
Distance elbow-wrist	390		350	18	2,22		98,5	
Previous functional range	810		730	62	1,29		90	
Vertical functional range (standing)	2165		2030	94	1,44		92,5	
Seated height	970		920	37	1,35		91	
Eyes height (in relation to the seat)	835		810	34	0,74		77	
Lumbar height (in relation to the seat)	240		215	20	1,25		89	
Maximum thigh thickness	175	185	175	17	0,00	0,59	50	72
Knee height	560	587	525	30	1,17	2,07	88	98
Popliteal height	402	428	400	26	0,08	1,08	53	86
Length thigh-popliteal	500		485	32	0,47		68	
Maximum thigh length	640		590	33	1,52		93,5	
Chest thickness	254		265	23	−0,48		32	
Abdominal thickness	255		265	32	−0,31		38	
Vertical functional range (sitting)	1268		1250	55	0,33		63	
Shoulder-seat height	630		630	33	0,00		50	
Elbow-seat height	270		255	30	0,50		69	
Shoulder width (biacromial)	372		335	22	1,68		95	
Shoulder width (bideltoide)	500		475	30	0,83		80	
Rump width	410		380	24	1,25		89	
Weight (kg)	90,4							

Table 3. Anthropometric data after alteration of the boots.

Anthropometric dimensions (mm)	Left	Right	Mean	SD	Z left	Z right	P left (%)	P right (%)
Shoulder height	1500	1505	1395	65	1,62	1,69	95	95,5
Elbow height	1097	1100	1050	51	0,92	0,98	82	84
Maximum thigh thickness	175	185	175	17	0,00	0,59	50	72
Knee height	582	587	525	30	1,90	2,07	97	98
Popliteal height	433	428	400	26	1,27	1,08	90	86

The entire left lower limb presents atrophy at a muscular level. While walking, since the right leg carries more load, it is over strengthened, presenting 50% on the left thigh and 72% on the right.

At the shoulder level there is barely no asymmetry. Due to the spine scoliosis it readjusts at each situation, correcting the decompensations, which may exist on the lower limbs through the spinal curvatures.

With a BMI of 26.8, is above the ideal weight, once it exceeds the BMI of 25. This overweight harms his gait and shows another negative factor, which is the fact that his gait does not appear symmetrical.

3.3 *Anthropometric analysis after footwear alteration*

During the anthropometric evaluation it became quite evident that the present asymmetry between left and right leg was located between the foot and the knee. Therefore, a new assessment was done, using only the data in which the asymmetries between left and right side were observed, in order to verify if the alterations showed any improvements of the posture.

The measurements were done in the same way as the previous ones, with the difference that the user was wearing the altered boots. Since the right boot had a height of 35 mm, this difference was deducted from both sides, having then achieved the results showed on Table 3.

As far as the differences of the shoulder and elbow height are concerned, no improvements were observed, since the same differences are shown. This is due to the fact that the spine readapts to new situations. The thigh difference remains the same as well, and due to the same reason of atrophy of the left side, the leg is thinner.

Regarding the knee and popliteal height, these present a difference of 5 mm only, due to the atrophy on the left leg. Globally, the compensation done on the left boot, and according to the observed data, a posture improvement was confirmed.

Figure 7. Finalized boots in front profile → changed boot.

Figure 8. Finalized boots in back profile → changed boot.

4 CONCLUSIONS

The pathologies and asymmetries were identified and confirmed. Through the X-ray an asymmetry of approximately 29 mm between the lower limbs and the adduct foot was identified. The anthropometric evaluation confirmed this deviation. The changes were designed and implemented based on these data.

The corrective changes were only implemented in the left boot, with an increase of 20 mm in the insole (20 mm in the heel zone, 10 mm in the foot sole) and 10 mm in the sole. The total increase was of 20 mm in the foot sole zone and of approximately 30 mm in the heel zone. The corrective changes on the boots proved a pronounced improvement at an anthropometric level, correcting the posture with the elevation of the left foot of approximately 30 mm.

The spine tends to restore the natural position, so that the scoliosis detected by X-ray does not progress and may even vanish.

The anthropometric analysis showed that the adopted compensation on the left boot, and according to the observed data, contributed to relevant postural improvement.

In general, it can be concluded that the main defined aims were achieved. The changes were performed on the boots chosen by the user who was also part of the case study. The asymmetries and associated pathologies were identified, the footwear was corrected according to the identified specificities and without changing its original appearance and, consequently, maintaining the acceptance of the user.

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