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Anthropometric Parameters for Sensor Placement in Wearable Technologies at the Trunk

A.Timmermans[1], R.Bootsman[2], T.Matheve[1], P.Markopoulos[2]
[1] Hasselt University, BIOMED-REVAL Research Institute, Belgium
[2] Eindhoven University of Technology, Department of Industrial Design, the Netherlands

Abstract

Background: Posture education is an essential part of the rehabilitation in musculoskeletal disorders of the spine. Sensor technologies may support patients in offering feedback on posture in rehabilitation settings or during everyday life activities (home, work, etc.). The aim of this study was to inform developers of wearable sensor technologies for the trunk on the correct position of the sensors.
Methods: In this cross sectional study, bony landmarks of the spinous processes from C7, T4, T12, L1, L5, and Spinae Iliacae Posterior Superior (SIPS) were palpated and marked in healthy persons. Intervertebral distances were measured by means of a flexible ruler. T-shirt size was determined by asking the patient to try on an available set of T-shirts and choose the best fitting size.
Results: Sixty healthy persons (age 40.57, ± 14.55) participated in the study. This study resulted in an overview of intervertebral distances in persons with different anthropometric characteristics. One-way ANOVA showed that there were significant differences between C7-T4 and T4-T12 for persons with different T-shirt sizes ($p=0.0144$ and $p=0.0042$), for persons with different trunk length ($p=0.0062$ and $p=<0.0001$), and for persons with different full body length ($p=0.0109$ and $p=0.0029$).
Conclusion: It can be concluded that intervertebral distances in the thoracic and lumbar spine are different for healthy individuals with different trunk length and different body lengths. For the thoracic spine, the intervertebral distances are also different in persons with different T-shirt sizes. For wearable smart textiles, a sensor position that is customized to the anthropometric measurements of the user is advocated.

Keyword(s): sensor, wearable, posture, spine

1. BACKGROUND

Seventy percent of all persons suffer at least once in a lifetime from low back pain (LBP). It is a very common and expensive condition and one of the main reasons for disability and work absence [1]. Common interventions that have proven to be beneficial for the treatment of LBP are posture education [2] and exercise therapy [3]. Sensor systems can provide meaningful feedback about posture [4], especially when they are integrated in wearable textiles [5]. A precise sensor placement in relation to the spine is necessary in order to provide correct feedback which means that relevant anthropometric measures need to be established. The aim of this study is: 1) to provide average values for intervertebral (i.e. interspinous) distances for persons with different anthropometric characteristics, and 2) to evaluate whether intervertebral distances vary between healthy individuals with different anthropometric characteristics.

2. METHODOLOGY

In this cross-sectional study, we included healthy individuals with a minimum age of 18, and a maximum age of 60 years old. Exclusion criteria were pregnancy or medical complaints. Bony landmarks of the spinous processes from C7, T4, T12, L1, L5, and Spinae Iliacae Posterior Superior (SIPS) (see figure 1) were palpated and marked subsequently by two assessors (the second assessor was blind to the assessment of the first assessor, a third assessor evaluated discrepancy). Distances between spinous processes were measured with a flexible ruler. Trunk length was measured between C7-SIPS. Also full body length (crane to floor distance) was registered. T-shirt size was determined by asking the patient to try on an available set of T-shirts and choose the best fitting size.
Statistical analysis was performed (SAS JMP Pro). The independent variables, trunk length and full body length, were converted from continuous data to nominal data with 4 equal intervals for each category (A, B, C and, D). Data were tested for normality and homoscedasticity. A One-Way ANOVA was used to compare the differences between Trunk length, t-shirt size and full body length for following dependent variables: the distances C7-T4 and T4-T12. Because the data for the distance L1 to L5 was not distributed normally a Kruskal Wallis test was used. Multiple comparison between different categories were done by means of a Tukey test for the distances C7-T4 and T4-T12, whereas for the distance L1-L5 a Wilcoxon method was used.

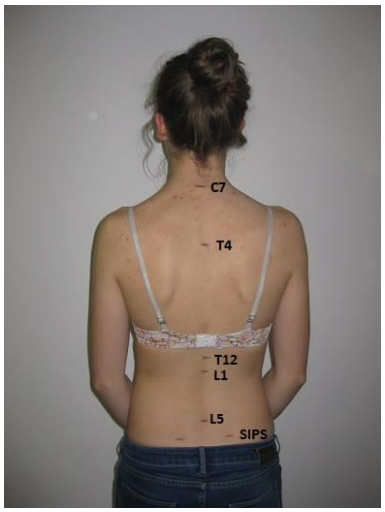
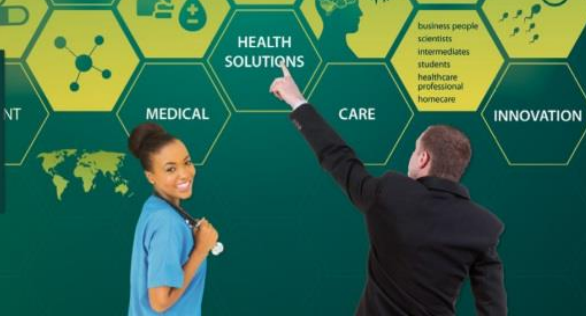


Figure 1: Bony landmarks on the spine

3. RESULTS

Sixty persons were included (18 male/42 female; age 40.57, ± 14.55). This study has inventorised the average interspinous distance at spinal level for persons with different anthropometric characteristics (Table 1). One-way ANOVA showed that there were significant differences between C7-T4 and T4-T12 for persons with different T-shirt sizes (p=0.0144/p=0.0042), for persons with different trunk length (p=0.0062/ p=<0.0001), and for persons with different full body length (p=0.0109/ p=0.0029).



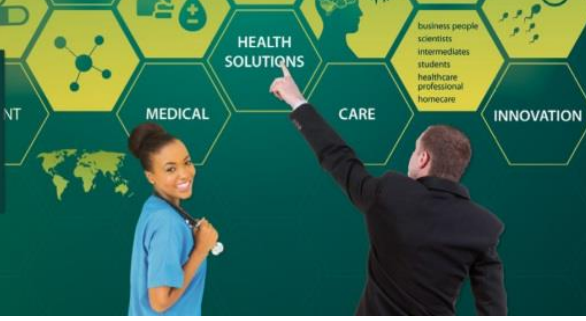
The Wilcoxon Kruskal Wallis showed significant differences for the intervertebral distance L1-L5 for persons with different trunk length (p=0.0041) and for persons with different full body length (p=0.0152) but not for persons with different T-shirt sizes (p=0.12). Subsequent multiple comparison analyses showed that there were significant differences in intervertebral distances in different categories for trunk length, full body length, and to a limited extent for T-shirt size.

Table 1: Average intervertebral distances for persons with different T-shirt size, trunk-, and body length (*p<0.05, **p<0.01, ***p<0.001)

T-shirt size		**C7-T4**	**T4-T12**	**L1-L5**
XS	Mean (SD)	11.15 (1.36)	22.74 (1.99)	7.57 (1.05)
S		11.56 (1.62)	22.99 (2.28)	7.77 (1.42)
M		13.05 (1.73)	23.13 (2.70)	8.27 (1.54)
L		12.99 (1.42)	25.27 (2.99)	8.39 (0.66)
XL		12.70 (1.22)	24.53 (2.44)	8.30 (0.70)
XXL		12.45 (2.40)	27.70 (1.80)	9.50 (1.73)
P-value (F-test or Wilcoxon/Kruskal-Wallis)		0.0144*	0.0042**	0.12
Trunk length		**C7-T4**	**T4-T12**	**L1-L5**
A (42.3 - 46.2 cm)	Mean (SD)	10.97 (1.80)	21.67 (1.75)	7.26 (1.41)
B (46.3 - 50.2 cm)		11.79 (1.60)	22.65 (1.85)	7.75 (1.06)
C (50.3 - 54.2 cm)		12.71 (1.55)	24.91 (2.33)	8.57 (1.24)
D (54.3 - 58.2 cm)		13.62 (1.01)	28.12 (1.67)	9.40 (1.29)
P-value (F-test or Wilcoxon/Kruskal-Wallis)		0.0062**	<0.0001***	0.0041**
Full body length		**C7-T4**	**T4-T12**	**L1-L5**
A (152.0 - 161.9 cm)	Mean (SD)	10.55 (0.86)	21.93 (1.61)	7.68 (1.27)
B (162.0 - 171.9 cm)		11.76 (2.06)	22.73 (2.42)	7.64 (1.31)
C (172.0 - 181.9 cm)		12.46 (1.48)	23.99 (2.56)	8.01 (1.13)
D (182.0 - 191.9 cm)		13.10 (1.37)	26.30 (2.46)	9.60 (1.26)
P-value (F-test or Wilcoxon/Kruskal-Wallis)		0.0109*	0.0029**	0.0152*

4. DISCUSSION

This study provided detailed information on the average intervertebral differences for healthy individuals with different body heights, trunk heights, and T-shirt sizes, which can inform the design of wearable sensing technologies for the upper body. Ernst et al [6] determined the position of certain thoracic and lumbar landmarks as a percentage of the total trunk length. However, no information is available on average distances for persons with different anthropometric characteristics. Another important result of the current study pertains to the significant differences that were found for all thoracic intervertebral measurements between different T-shirt sizes and categories of trunk length and full body length. With regard to the lumbar spine, significant differences between categories of trunk length and full body length could be found, but no differences exist for different clothing sizes. Clothing sizes may be more determined by body mass index (see the decrease in distance after size Medium, table 1), whereas intervertebral distances may be mainly determined by trunk length and full body length.



Depending on accuracy requirements of different applications, the size of the sensors that are used for wearable sensing, and depending on the specific area of interest in the spine (thoracic or lumbar spine), developers may choose for patient customized sensor locations for the monitoring of upper body posture and movement.

5. CONCLUSION

It can be concluded that intervertebral distances in the thoracic and lumbar spine are different for healthy individuals with different trunk length and different body lengths. For the thoracic spine, the intervertebral distances are also different in persons with different T-shirt sizes. For wearable textiles, a sensor position is that is customized to the anthropometric measurements of the user is advocated.

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