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Abstract: The aim of this work is to define a new method that helps researchers to analyze perceptions of (dis)comfort in dynamic conditions. Recent studies pay considerable attention to body movements, mobility, and stability to measure comfort or discomfort when seated. Most of these discuss the relations between subjective comfort/discomfort and objective measurements (e.g. body pressure distribution, body movement and EMG) for short- and medium-term sitting. The present analysis took place in a classroom of the Industrial Engineering Department at the University of Salerno. The participants included 25 students (12 females and 13 males), who were observed during classroom hours. The students were invited to sit at a combo-desk and were free to perform different combinations of movements while writing and listening. These activities required that they adapt their body movements, as the combo-desk was fixed to the floor. A pressure pad was used to detect pressure at interface and center of pressure's changes, allowing for the bodies' motion data to be recorded. Our aim was to identify the correct threshold to be used for movement detection and to investigate correlations between the number of movements and the perceived (dis)comfort. The study also identifies those body parts that have the greatest effect on (dis)comfort perception.

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Ms. Ref. No.: JERG-D-17-00750 Title: A study of classroom seat (dis)comfort: relationships between body movements, center of pressure on the seat, and lower limbs' sensations Applied Ergonomics

Dear Alessandro,

We have now received review reports on the above paper. My decision based on these reports is that the paper is accepted for publication in Applied Ergonomics but we would like you to revise the paper along the lines suggested by the reviewers, since we believe that this would make the paper even stronger with advantages for you and for the journal.

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I look forward to receiving your revised manuscript.

Reviewers' comments:

Reviewer #1: Even if this work is interesting in terms of achieved results I suggest some improvements: 1) to describe in more detail the methodological approach and the experimental results;

The methodological approach is already described in Method (in particular in "set-up" and "Procedure" paragraph and is similar to the one cited in the reference Naddeo et al., 2018 that has been added in the paper. Nevertheless, some sentences have been added. In the "Results" paragraph some figures describing the statistical distribution of data have been added in order to clarify some sentences.

2) to improve the figures (some of them are not so relevant and, on the other hand, figures related to experimental work lack);

The figures have been changed.

3) the references should mainly be taken from already published papers (preferably in English);

The references have been updated. Not published papers have been deleted.

4) the English language should be revised

The paper has been checked by a professional mother tongue English editor. Some typos and minor errors have been adjusted.

Reviewer #2:

It is a interesting experimental setup with acceptable conclusions (more movements result in more discomfort) but I have a few remarks. -

In Table 3 there is a value of 3.333 that needs more explanation in the text.

An explanation has been given

-looking at de values of the SD in regarding to the Mean value and the Max and Min, I assume this statistical distribution is not Gaussian. This means, the mean value and the SD might not give a good representation of the distribution. So it might be better to show 1 or more maybe even all graphical distributions to show the readers how it looks like.

The distributions have been shown in fig.9. They looks both like Gaussian and Weibull distributions. Some new comments have been added in the text and the Spearman-Rho analysis has been made in order to check the results. Some sentences have been added to explain that.

-the correlations in the tables are very low. The highest value is about 0,4 which means 0,16 or 16% of the variance can be predicted by one of the variables and 84% is not explained. it might be caused by a lot of other variables which are not inside the scope of this investigation. I think you should say something about this fact in the discussion as a limitation.

This aspect has been highlighted in discussion paragraph, as limitation. Also in results paragraph the term "significant correlation" has been deleted.

-The 2 first sentences of the Discussion express opposite statements. I suppose the first sentence includes an error.

There was a not well formulated sentence. The thought has been reformulated.

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Yours sincerely,

Sarah Sharples, PhD Special Content Editor Applied Ergonomics

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HIGHLIGHTS

- 1) Body movements, pressure at interface and perceived comfort while seated have been investigated
- 2) It has been demonstrated that 25 mm is the best threshold for detecting movements through the variation of the centre of pressure
- 3) School chairs in combo desk have been evaluated in terms of perceived comfort in constrained setup
- 4) The relation between perceived (dis)comfort and movements is different in cases of constrained posture (combo desks) and free posture (adjustable chair)
- 5) Number of movements increases in time (the more the duration of the test is long, the more the number of movements is high).

A study of classroom seat (dis)comfort: relationships between body movements, center of pressure on the seat, and lower limbs' sensations

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ABSTRACT

The aim of this work is to define a new method that helps researchers to analyze perceptions of (dis)comfort in dynamic conditions. Recent studies pay considerable attention to body movements, mobility, and stability to measure comfort or discomfort when seated. Most of these discuss the relations between subjective comfort/discomfort and objective measurements (e.g. body pressure distribution, body movement and EMG) for short- and medium-term sitting. The present analysis took place in a classroom of the Industrial Engineering Department at the University of Salerno. The participants included 25 students (12 females and 13 males), who were observed during classroom hours. The students were invited to sit at a combo-desk and were free to perform different combinations of movements while writing and listening. These activities required that they adapt their body movements, as the combo-desk was fixed to the floor. A pressure pad was used to detect pressure at interface and center of pressure's changes, allowing for the bodies' motion data to be recorded. The aim was to identify the correct threshold to be used for movement detection and to investigate correlations between the number of movements and the perceived (dis)comfort. The study also identifies those body parts that have the greatest effect on (dis)comfort perception.

Keywords: comfort, discomfort, center of pressure, pressure map, body movements, classroom seat, school furniture

Authors' biography

Luisa Fasulo, MD. She was born in 1989. On September 2014 she graduated from the University of Salerno in Industrial Engineering, with a Thesis whose title is: The Ergonomic Valuation of Classroom Combo Desks: The Case of University of Salerno. After obtaining her B.D., she started the M.D. studies and, during this period, she worked on a project regarding the Comfort of one Students in the Classroom, the comfort in the aircraft and the factors affecting comfort in cabins. She worked on her thesis during the Traineeship at TU-Delft and in 2017 she had her M.D. in Industrial Engineering. Now she is employed in an automotive-industry supplier, as junior engineer.

Alessandro Naddeo, PhD, Prof., He was born in 1975 and since 2002 is Assistant Professor in Design and Engineering Methods at the Industrial Department of University of Salerno. Since 2018 he is Associate Professor in the same University. His fields of interest go from Industrial Design, through Axiomatic Design, Fuzzy Logic, Virtual Prototyping and Virtual Reality, Ergonomics and Comfort Analyses, to Biomechanics and Biomedical Engineering. He has a wide international experience as Visiting Professor and Visiting researcher in USA (Fiat R&D/GM research center) in The Netherlands (TU-Delft and TNO), in Germany (ESI-Group), in Turkey (Dumlupinar University) in Romania (Polytechnic University of Bucharest, Transilvania University of Brasov). He has more than 80 publications in national and international journals and conferences.

Nicola Cappetti, MD, Prof.. He was born in 1964. He had his degree cum laude in Mechanical Engineering at University of Salerno (Italy); he is Associate Professor in the Scientific-Disciplinary-Sector of Design and Methods of Industrial Engineering at Engineering Faculty of University of Salerno; field of interest: Industrial Design, Axiomatic Design, Fuzzy Logic, Virtual Prototyping and Virtual Reality; scientific achievements: more than 60 publications in national and international journals; reviewer in international conferences and for International journals. He has developed 4 patents regarding medical devices for spine surgery.

A study of classroom seat (dis)comfort: relationships between body movements, center of pressure on the seat, and lower limbs' sensations

Luisa Fasulo, Alessandro Naddeo, Nicola Cappetti

Abstract

The aim of this work is to define a new method that helps researchers to analyze perceptions of (dis)comfort in dynamic conditions. Recent studies pay considerable attention to body movements, mobility, and stability to measure comfort or discomfort when seated. Most of these discuss the relations between subjective comfort/discomfort and objective measurements (e.g. body pressure distribution, body movement and EMG) for short- and medium-term sitting. The present analysis took place in a classroom of the Industrial Engineering Department at the University of Salerno. The participants included 25 students (12 females and 13 males), who were observed during classroom hours. The students were invited to sit at a combo-desk and were free to perform different combinations of movements while writing and listening. These activities required that they adapt their body movements, as the combo-desk was fixed to the floor. A pressure pad was used to detect pressure at interface and center of pressure's changes, allowing for the bodies' motion data to be recorded. The aim was to identify the correct threshold to be used for movement detection and to investigate correlations between the number of movements and the perceived (dis)comfort. The study also identifies those body parts that have the greatest effect on (dis)comfort perception.

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Introduction

Products are designed according to specific functions that benefit users. However, their successful function is dependent on people being able to use them correctly. In the past, the principles of user-centred design were defined as methods for creating products, environments and systems that are fit for human use (Pheasant and Haslegrave, 2006). Ergonomics, meanwhile, studies the interfaces between people, the activities they perform, the products they use, and the environments in which they work, travel or play. As stated in Mokdad and Al-Ansari (2009), ergonomics principles allow to develop guidelines for improving and redesigning both old and new products.

A wide range of research on physical comfort and discomfort in the workplace has been carried out. Most papers discuss the relationships between environmental factors that can affect perceived levels of comfort/discomfort, such as temperature, humidity, applied forces, and others (Galinsky et al., 2000).

Several papers follow the assumption that a relationship exists between self-reported discomfort and musculoskeletal injuries, with these injuries affecting perceived comfort (Hamberg-van Reenen et al., 2008; A. Naddeo et al., 2009). Theories relating comfort to products and product design characteristics, however, are rather underdeveloped.

The last 15 years have seen only five "comprehensive models" that considered every aspect of human perception: the Helander model [5], the Moes model [6], the Vink-Hallbeck model [7], the Naddeo-Cappetti model [8] and the Vink model [9].

In the Naddeo-Cappetti model (see fig. 1), the internal body and perceived effects play a fundamental role in comfort/discomfort perception and evaluation.

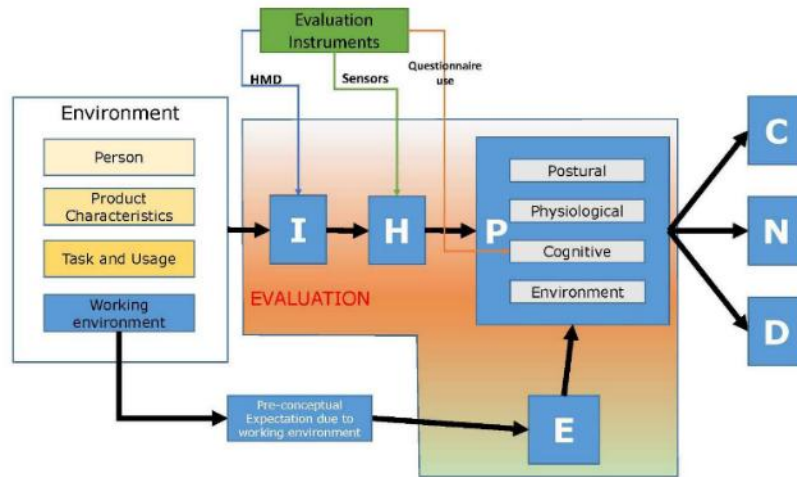


Figure. 1 Naddeo-Cappetti model of comfort/discomfort perception

The purpose of this work was to define a method to evaluate (dis)comfort perceptions based on body movement by observing the behavior of university students during lectures. The classroom is a learning environment in which the furniture is an important physical element. The furniture's function is to facilitate learning and provide a comfortable, stress-free environment. Poor classroom sitting posture is one of the main negative effects of bad furniture design on students (Dianat et al., 2013).

Students spend a considerable portion of their day at school, and most of that time is spent doing schoolwork in the sitting position (Castellucci et al., 2010; Macedo et al., 2013). Fixed-type furniture is commonly used, and, while this should meet the students' requirements, it may induce constrained postures (Gouvali and Boudolos, 2006; Parcels et al., 1999). Given that people differ in size and postural preferences, workstations with adjustable seats are preferred, as these have a significant positive effect on muscle tension and sitting posture. As well as promoting health and comfort (Koskelo et al., 2007; Thariq et al., 2010), they may also be related to better academic grades (Koskelo et al., 2007).

In the past, schools and universities often chose fixed-type chairs and tables due to the higher price and maintenance costs of adjustable alternatives (Straker et al., 2006). Side-mounted desktop chairs are often used in university classrooms. However, their correct design has been neglected. A study by Thariq et al. (2010) shows that side-mounted chairs do not meet the postural and comfort requirements of university students. Further to this, Naddeo et al. (2015) identified a custom seat that had a positive influence on students' perceived comfort.

To investigate student's perceived (dis)comfort, a pressure pad was used to measure the pressure at the interface between the chair and the buttocks. Previous studies have developed the ideal pressure distribution for a car seat, whereby minimal pressure is applied to the intervertebral discs (Zenk, 2008). Furthermore, it is generally accepted that continuous static muscle activity results in discomfort (e.g. Falla et al., 2007). Regarding the number of movements, Graf et al. (1995) suggest that natural movements are desirable and necessary as long as they are within an acceptable range. Leuder (2003) stresses the importance of variation between several stable and healthy body postures. General seating studies describe the relation between seating time, discomfort, and body movement. Telfer et al. (2009) found that subjective discomfort and movement increases over time, with the amount of movement greater in chairs rated most uncomfortable. Vergara and Page (2002) proposed that macro-movements are a good indicator of discomfort. Fujimaki and Noro (2005) also found that discomfort increases over time, although they argued that macro-movements occur in a repeating pattern during prolonged sitting as a means to decrease discomfort. Similarly, Graf et al. (1995) found that work tasks which resulted in more muscular-

1 skeletal disorders allowed for less frequent and less distinctive postural change. Finally, Callaghan and
2 McGill (2001) suggested that humans redistribute their muscular loads using posture adjustments
3 according to their comfort level.

4 The aim of this study is to understand if it is possible to use the analysis of pressure map data to describe
5 the movements of a seated student, and to examine how these movements (number, description and
6 frequency) can be used as indicators of perceived (dis)comfort. To this end, the output of the pressure pad
7 was recorded to monitor the center of pressure and to evaluate the number of movements. This
8 methodology was implemented to analyze (dis)comfort perceived by students during classroom hours.
9 Results were validated via a consolidated methodology based on a manual count of the number of
10 movements.
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13 Method

14 Interactions can be recorded by many sensors (Vink, 2005). Most studies investigated the effects of
15 pressure variables, such as mean and peak pressure (Hostens et al., 2001; Moes, 2007), contact area (Paul
16 et al., 2012; Kyung and Nussbaum 2008; Vos et al. 2006) and pressure distribution (Mergl 2006; Zenk 2008).
17 Mergl (2006) and Zenk (2008; 2012), for example, defined the ideal pressure distribution for a car driver.
18 Even though pressure distribution seems to be the best objective measure for discomfort (De Looze et al.
19 2003), it is influenced by other variables such as posture (Tessendorf et al., 2009; Oyama et al., 2003;
20 Zhiping and Jian, 2011; Naddeo et al., 2015-2), movement (Wang et al., 2011; Ciaccia and Sznelwar, 2012),
21 expectations (Naddeo et al., 2015-1) and first sight (Vink, 2014). Helander and Zhang (1997) and de Looze
22 et al. (2003) stated that discomfort is more related to physical factors, while comfort is more related to
23 luxury and feelings of refreshment.
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28 In this study, data from a pressure mat mounted on the seat-pan of the combo-desk was used to detect
29 and classify movements. Specifically, we used the amplitude of the center of pressure's shift to analyze
30 changes in (dis)comfort perception for seated students during a one-hour lesson.
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33 Subjects

34 Twenty-five students (12 females, 13 males), all volunteers, participated in the experiment. None had a
35 history of musculoskeletal diseases. The main characteristics of the subjects are summarized in Table 1. All
36 subjects were informed of the nature of the tests, and written consent was obtained. The subjects'
37 selection method and the experimental setup and tests were approved by the university's ethical
38 committee.
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	Age	Mass	Height	Body Mass Index
	(years)	Kg	m	Index
Mean	21,4	66,7	1,7	22,3
Std.Deviation	0,5	12,7	0,1	2,3
Minimum	21	48	1,6	18,6
Maxmum	22	95	1,9	27,8

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54 **Table 1.** Descriptive statistics of selected variables for the participant population.

55 Set-up

56 Subjects were selected from the third-year Industrial Engineering course. This choice allowed to obtain data
57 for the same kind of students from the same time and day of the week (Wednesday from 8:30 to 13:30)
58 (Sammonds et al. 2017). Tests were performed in the same classroom at the Engineering Faculty.
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1 The following equipment was used for data acquisition and set-up: a simple wooden seat (rigid seat-pan,
2 rigid seatback, no armrest, no knee support) fixed to the floor; a pressure data acquisition system;
3 a photo/video-graphic acquisition system; and a (dis)comfort questionnaire. In this way, it was possible to
4 evaluate the distribution of pressure and to investigate the corresponding (dis)comfort, without
5 considering the effect of soft parts such as cushions or padding. Figure 2 shows the combo-desk that was
6 the subject of analysis. The evaluated workstation was a classroom combo-desk (desk + chair). This desk is
7 class C1, fire resistant, and made of chipboard covered in melamine.
8

9 The Medilogic® pressure measurement system was used to record the pressure distribution (Figs 3 and 4).
10 The pressure pad was placed only on the seat and not on the backrest. The sensors' matrix has 480 sensors
11 over a 500 x 500 mm² area, and pressures were recorded using the mat. The students' behavior was
12 observed and recorded using a video camera (Fig. 5).
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36 **Figure 2.** The combo-desk and the pressure acquisition system



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58 **Figure 3.** Experimental setup: Front-View



Figure 4. Experimental setup: Top-View



Figure 5. Setup and video equipment

The (dis)comfort questionnaire is divided into several sections. The lower limbs are divided into eight regions, as shown in the Figure 6 (areas numbered from 13 to 20, so-called P13 to P20). Subjects were asked to rate their perceived (dis)comfort on a 5-point Likert scale.

Students were also asked to give a score from 1 to 10 for overall comfort, and to indicate the area of greatest discomfort between the right and left side of the lower limbs.

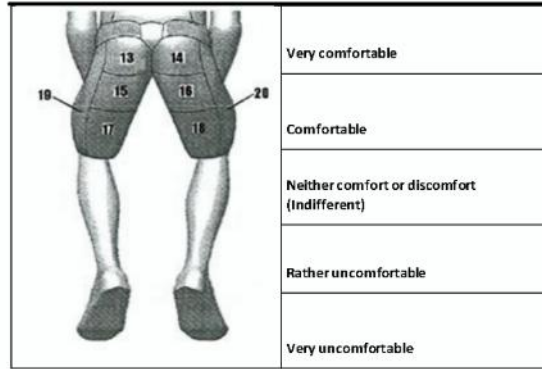


Figure 6. Body regions (dis)comfort questionnaire.

Procedure

The one-hour test was split into three sessions of twenty minutes. Pressure readings were taken for each of these twenty-minute sessions, after which the subjects were asked to complete the (dis)comfort questionnaire. During the test, the students were free to move their bodies while performing two main tasks: writing and listening. The pressure values were acquired with a frequency of 1Hz, and the 3,600 values were processed, using a software written in Python3.5, to calculate the center of pressure in the plane of the seat (x-y coordinates) and its variation over time.

The combo-desk model and the video recording indicated that we should focus our attention on left-to-right and right-to-left movements (sideways movements), as forward-backward movements were limited or hindered by the combo-desk layout. To define the methodology for counting the number of movements, only the x coordinates (sideways movements) were considered, which was useful for describing the movements performed by the lower limbs. The following rule was used to define a movement:

“If the difference (Dx) of $x_t - x_{t-1}$ is more than a given threshold, this constitutes a movement.”

In which x_t is the value of the x coordinate at time t, and t is from 0 to 3,600 (seconds). The acquisition frequency was 20 Hz, while the processed data frequency was 0.2 Hz, with an averaged value taken every 5 seconds. Another purpose of this work is to understand which threshold is optimal for counting the number of movements. To this end, a threshold sensitivity analysis was performed in a range between 5 and 30 mm, with 5mm increments, giving the following five “Levels”: Level5, Level10, Level20, Level25 and Level30.

The first part of the study was also focused on investigating the correlation between the threshold value (and the consequent number of movements) and the (dis)comfort perception.

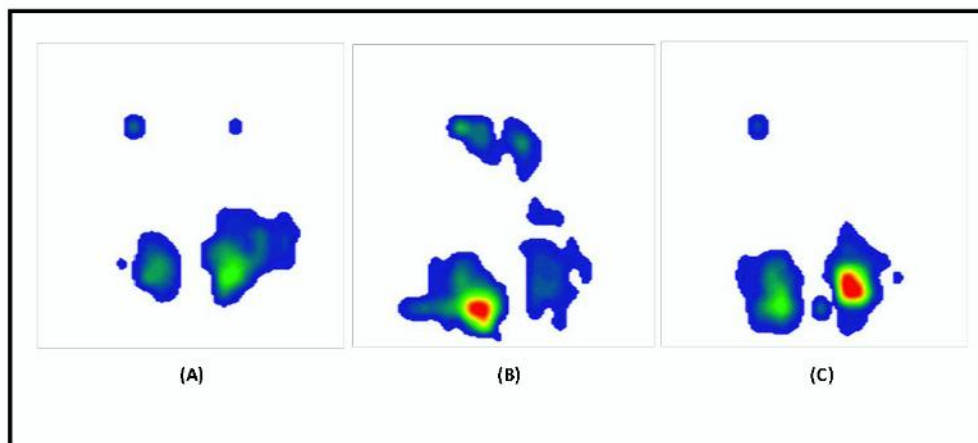


Figure 7. An example of analysis periods: a) first 20 minutes; b) second 20 minutes; c) third 20 minutes.

Answers to the questionnaires were rated using the values shown in the Table 2.

Figure. 8 presents an example of the number of movements (Level 5) made by a student during an analysis period.

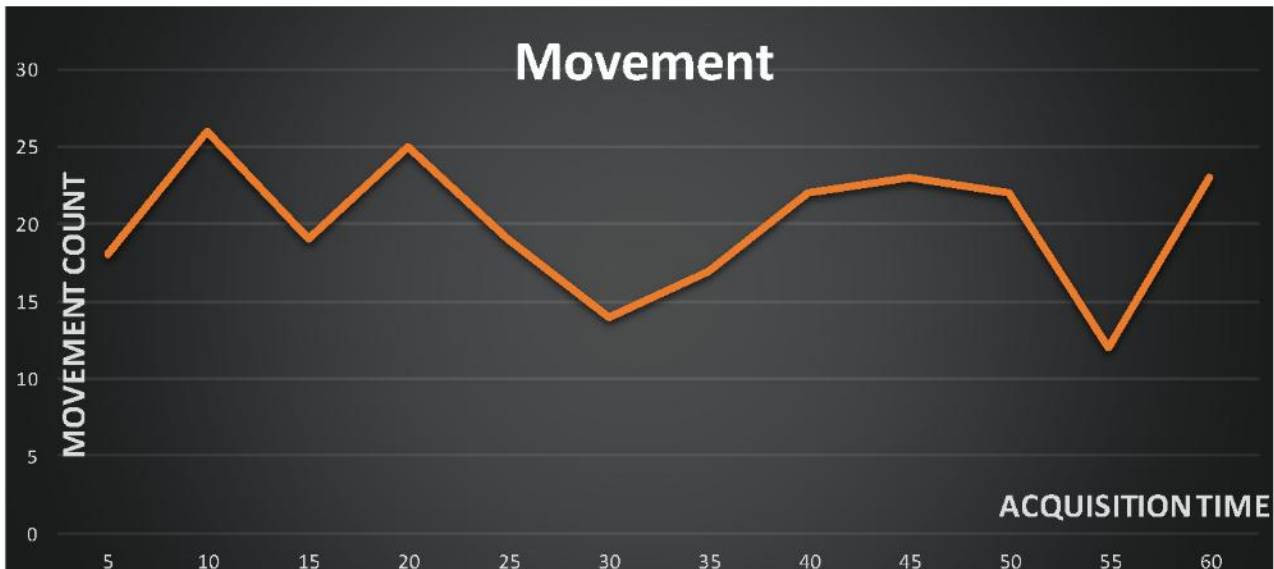


Figure 8. Movement count for the 5 mm threshold (level5) over one hour of analysis (the x-axis shows time in minutes)

Very comfortable	2
Comfortable	1
Neither comfort or discomfort (Indifferent)	0
Rather uncomfortable	-1
Very uncomfortable	-2

Table 2. Indexes of Comfort (IC) associated with each item of the questionnaire.

The questionnaire was developed to discover correlations, if any, between overall comfort, the total number of movements detected, the number of right and left movements, (dis)comfort perception in different lower limb regions, and the relative suffering of the buttocks (right or left). Correlations between the number of movements and characteristics such as weight or height were also investigated.

Validation

This methodology for detecting body movements was validated by comparing the X-movement of the center of pressure with another methodology based on the number of movements recorded by the video camera. Three different people with no health or vision problems analyzed all the videos recorded during the study. The Wilcoxon Rank test was used to compare the methodologies. The number of lower-body movements was compared with the total number of movements counted using different threshold levels.

They each counted the number of movements, returning a reliability rate of more than 95%. This work allows the new method of counting movements using center of pressure analysis to be validated by

1 comparing it to others in the literature (Naddeo et al., 2013; Bouwens et al., 2018; Hiemstra-van Mastrigt et
2 al., 2015).
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5 Results

6 The first interesting result concerns a comparison of movement counts made by the different
7 methodologies. Level20 and the Level25 gave similar results, and these results are quite similar to the
8 number of movements count ($p=0.310$ and $p=0.192$, respectively). The other Levels, however, are
9 significantly different ($p<0,01$). This result indicates that the two methods are similar, and that Level25 (and
10 the related threshold) is a good indicator for the movements' count.
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13 Table 3 shows the average, maximum, minimum, and standard deviation of the total movements detected
14 via the center of pressure analysis. (Note: In the first five lines, the number (n) of total movements for each
15 Level are represented, while the other rows give the number of movements (right and left) for different
16 Levels). At level 30 (a movement is detected only when the D_x is more than 30 mm) very few movements
17 have been detected in one hour test.
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21 Threshold	22 Mean (n)	23 Maximum	24 Minimum	25 Std.Deviation
26 Level5	83,1	158	8	34,1
27 Level 10	37,6	100	2	21,1
28 Level20	10,2	43	0	9,4
29 Level25	5,8	31	0	6,7
30 Level30	3.333	19	0	4,3
31 Rg Level5	41,9	80	5	18,1
32 Lf Level5	50,0	78	3	16,7
33 Rg Level10	17,9	49	0	10,6
34 Lf Level10	19,3	51	2	11,0
35 Rg Level20	4,8	20	0	5,0
36 Lf Level20	5,3	23	0	4,9
37 Rg Level25	2,9	16	0	3,5
38 Lf Level25	2,9	15	0	3,4
39 Rg Level30	1,7	10	0	2,3
40 Lf Level30	1,7	10	0	2,1

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47 **Table 3.** The average, maximum, minimum, and standard deviation of the movements (Rg and Lf are right
48 and left movements for each level, respectively).
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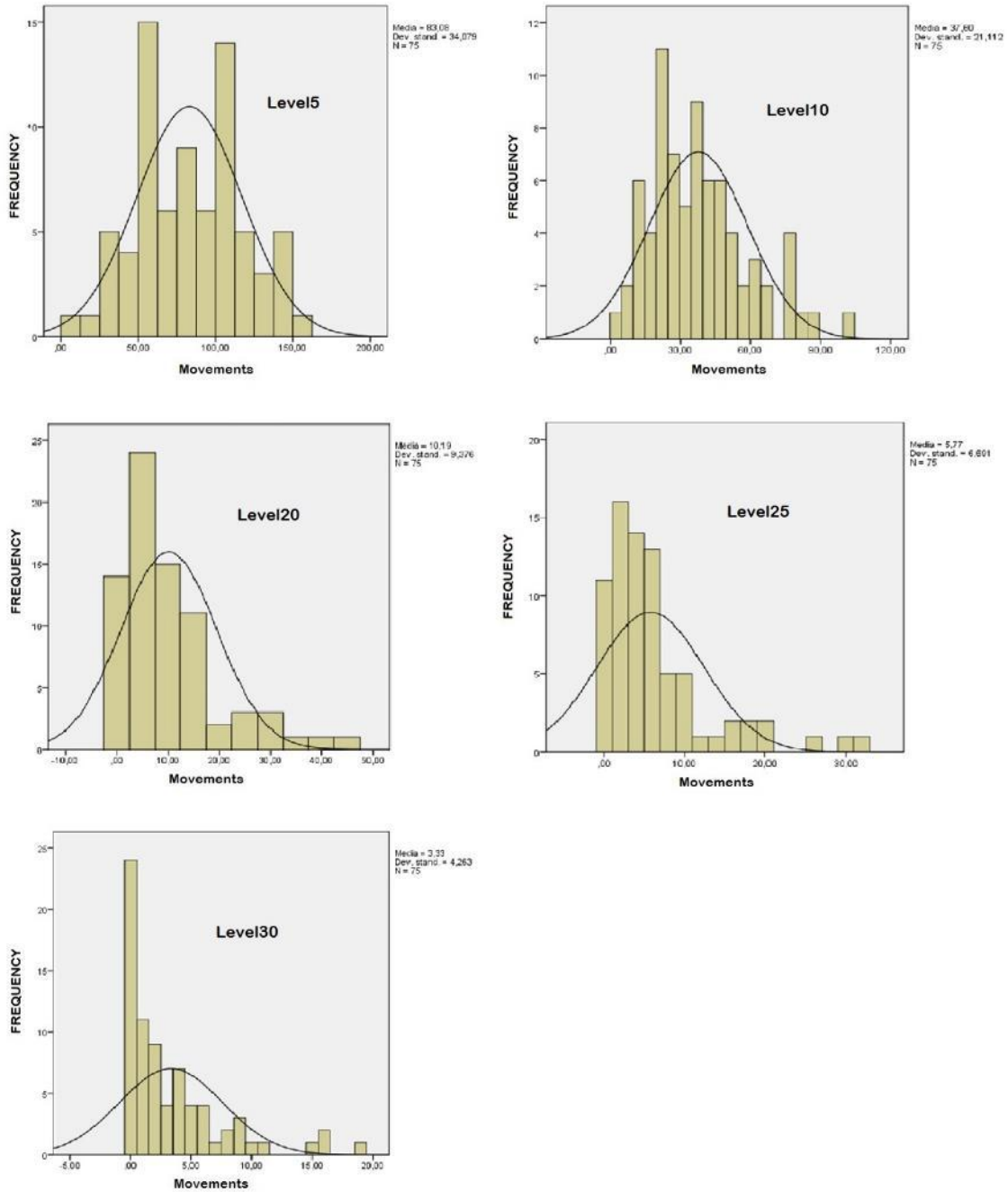


Figure 9. Statistical distributions of movements at different detection threshold.

The statistical distributions show a Gaussian shape for Level 5 and Level 10 and a Weibull shape for Level 20, Level 25 and Level 30. A multivariate analysis was performed to verify the correlations among the variables. R 3.2.2 statistical analysis software was used to perform the analysis. Pearson correlation and Spearman coefficients were calculated to check and evaluate the correlations between the variables.

Both the Pearson index and the Spearman-Rho multivariate analysis revealed the same “weak to medium” correlations between the variables. Regarding the anthropometric data, a negative correlation was detected between the student’s weight and the average of the number of movements performed (i.e. the number of movements decreases as the subjects’ weight increases). This result also gives an indication of the comfort perceived by subjects during the analysis. As described below, an increase in the number of movements correlates with an increase in comfort. The minimum weight thus gives an indirect indication of the extent of the perceived comfort increase.

Table 4 shows the results of the sensitivity analysis for each Level through the Pearson indexes. Level25, which has a movement detection threshold of 25 mm, shows the highest correlations with all analyzed parameters, and is therefore a good indicator of movement-related comfort. Only the body part P14 shows a higher correlation for Level20. This correlation indicates that perceived comfort increases in line with the number of movements. Also Spearman-Rho analysis shows the better correlation result (0,352 at 0.05 level of significance) of overall comfort with movements detected through the “Level25” threshold.

	Level5	Level10	Level20	Level25	Level30
Overall comfort	0,134	0,212*	0,335*	0,342*	0,327*
P13	-0,014	0,081	0,210*	0,229*	0,174
P14	0,172	0,250*	0,307*	0,281*	0,200*
P15	-0,013	0,110	0,316*	0,369*	0,358*
P16	0,084	0,203*	0,364*	0,406*	0,349*
P17	0,072	0,151	0,274*	0,305*	0,257*
P18	0,080	0,155	0,277*	0,320*	0,268*
P19	0,019	0,077	0,190	0,243*	0,216*
P20	-0,001	0,076	0,207*	0,235*	0,219*

* 0.05 level of significance

Table 4. Analysis results (P13-P20 are the body parts for which subjects gave a subjective evaluation of perceived (dis)comfort).

Pain for the left- and right-side body parts was also investigated via the questionnaire. Taking Level25 as the most representative level for (dis)comfort correlation, data analyses show that when subjects move to the left part of the seat (i.e. his/her center of pressure shifts left), left-side discomfort increases and right-side discomfort decreases.

Level25 is a good movement detection indicator for movements to the left, while Level30 is the best for movements to the right. Both of these are good indicators of comfort (in terms of Pearson correlation), with results similar to those for pain: the number of movements towards the right part of the seat (i.e. his/her center of pressure shifts right) causes an increase in perceived left-side discomfort and a decrease in perceived right-side discomfort.

This difference can be explained by the position of the subjects in the classroom. All of the subjects were sitting on the right side of the classroom. To see the blackboard, they had to turn their body slightly to the left. This caused an increased load on the right side of the lower body, leading the center of mass to become unbalanced. Each movement therefore allowed subjects to improve their perceived comfort (or lower their perceived discomfort) for the right side of the body that was consistently more loaded than the left.

This fact was evident in the video recordings. It is also indicated by the mean percentage of time in which the center of pressure is on the right and left side of the seat (about 58% and 42%, respectively).

No correlations were found between the direction of movements, individual body parts and overall comfort. We may therefore state that overall comfort is influenced more by movements than by each individual body part comfort.

	Left	Right
M.Dx 5mm	-0.203*	0.179
M.Sx 5mm	0.131	-0.109
M.Dx 10mm	0.150	-0.192
M.Sx 10mm	0.016	-0.013
M.Dx 20mm	0.083	-0.120
M.Sx 20mm	-0.144	0.168
M.Dx 25mm	0.057	-0.094
M.Sx 25mm	0.245*	-0.225*
M.Dx 30mm	0.201*	-0.251*
M.Sx 30mm	-0.114	0.131

* 0.05 level of significance

Table 5. Correlation between “Right and left movements” and “Right- and left-side discomfort perception”.

Discussion

This paper shows that performing a high number of movements in a constrained space is due to the increase of discomfort; after a movement or a change of position, the decrease of discomfort is perceived; the decrease of postural discomfort concurs to a more overall comfortable state. This result is in line with those found in the literature. Cascioli et al. (2011), Netten et al. (2013), Mansfield (2017), Vink (2017), and Sammonds et al. (2017) all state that an increase in discomfort causes an increase in the number of movements. The availability of the space required to perform these movements thus increases perceived comfort (after the movements themselves).

Heavier subjects are also shown to experience greater discomfort, as stated in Zenk (2008, 2012).

Our analyses produced evidence that may appear contradictory. Whatever the direction of the movement (right or left), perceived discomfort decreases in the left side of the body and increases in the right side. However, this result was anticipated due to the experimental setup. Given the relative position between the chair and the blackboard, the subjects' bodies were always rotated and unbalanced toward the left, overloading the left buttocks. Any movement therefore tended to improve left-side comfort by “distributing” the discomfort perception towards the right side. This result is confirmed by the lack of correlation between overall comfort and the number of movements to the left.

One limitation of this study is the lack of correlation of individual body parts (dis)comfort with left and right movements; however, this was not the purpose of this study. Due to the not-Gaussian distribution of some data, also a Spearman-Rho analysis was performed and the results were the same of the Pearson one. In general, the Pearson index analyses reveal only weak and medium correlations among variables and this is another limitation of the study. Probably it is due to the high numbers of variables that have to be taken into account in a one-hour test (environmental factors, psycho-physiological factors, noises coming from other students and so on) and cannot be easily controlled.

Another limitation is the lack of attention to upper-body posture and its influence on the pressure maps. We did not know the configurations of the body parts – for instance, when and if one or both arms were

hanging down or leaning on the desk. This could be an interesting topic for further research. The proposed methodology that bases the movement count on centre of pressure analysis could open up new fields of investigation in the study of whole body movement. The evolution of the centre of pressure, as well as the methods used to understand and predict overall comfort by studying the interaction between the buttocks and the seat-pan, are potentially interesting topics of future research.

Conclusion

Several studies have reported a strong correlation between the number of movements performed and perceived (dis)comfort. This paper seeks to demonstrate this concept by converting the pressures measured at the interface between the seat and the subject into specific movements. The results revealed a correlation between these movements and the (dis)comfort perceived by students. The first applicable result is undoubtedly the identification of Level25 as a good indicator for detecting and counting movement and assessing lower-body comfort. Both Level30 and Level25 gave a realistic indication of the perceived (dis)comfort caused by the direction of the movements (right or left). In Vergara et al. (2002), Graf et al. (1995) and Lauder et al. (2003) discomfort is shown to increase when subjects change position. In all of these cases, the participants' movements were natural and not obligatory. In our study, however, the movements were obligatory as subjects had to write or listen within a limited space, with no possibility to change the combo-desk layout. We thus observed the opposite result: a decrease in discomfort when the subject changed position. This decrease was more evident when the center of pressure moved in either the right or left direction.

Finally, we found that the number of movements gave us an indication of perceived lower-body (dis)comfort, while the direction of the movements allowed us to evaluate general (dis)comfort perception. Figure 10 shows the macro-movements trend (Level25) that gave the highest correlation.

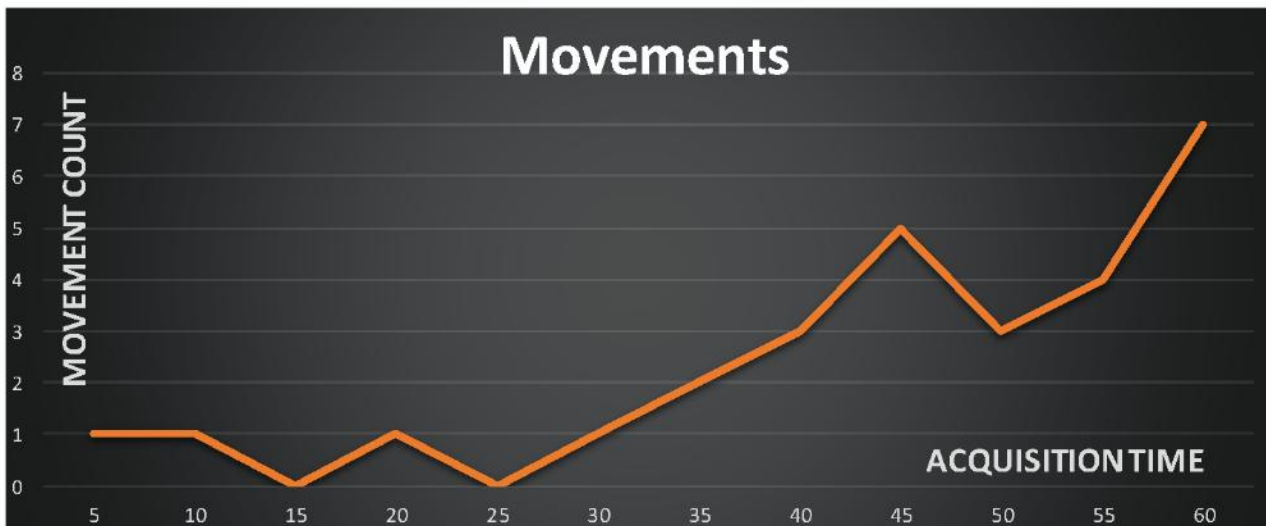


Figure 10. Example of movements (Level25) by a student over one hour of analysis (the x-axis represents time; the y-axis represents the number of macro-movements; the acquisition time is in minutes).

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Figure 1
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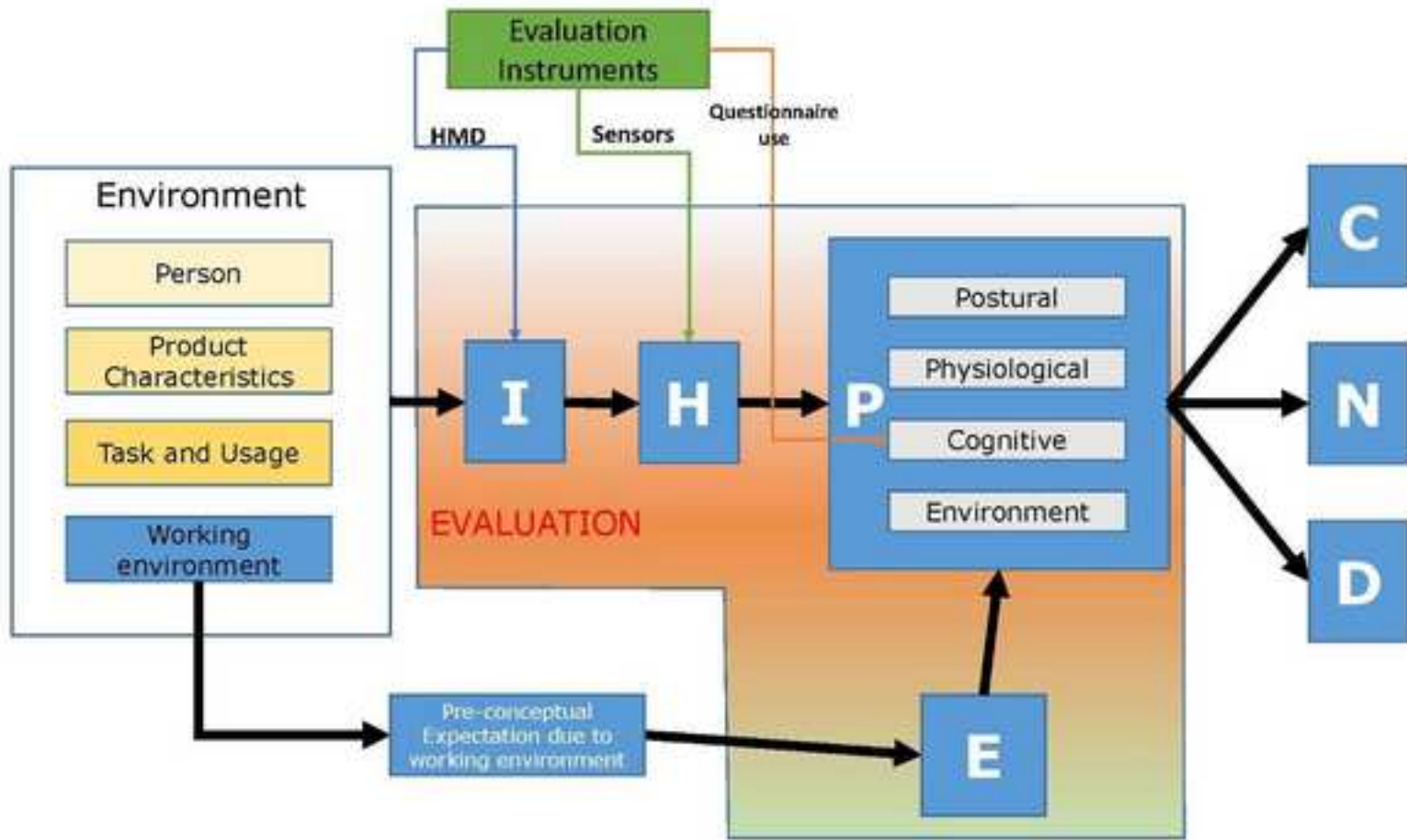


Figure 2
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Figure 3
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Figure 4
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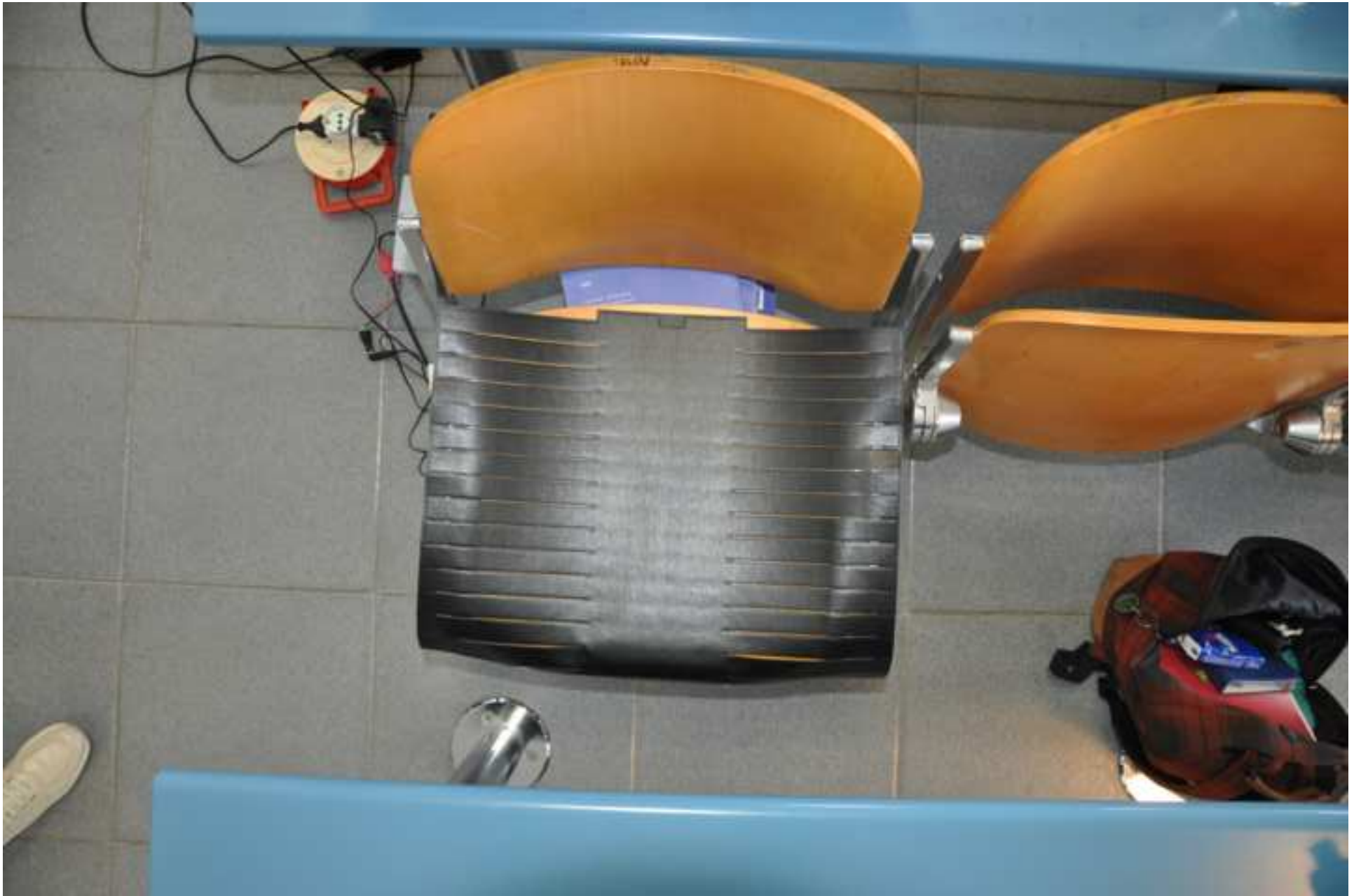


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Figure 6
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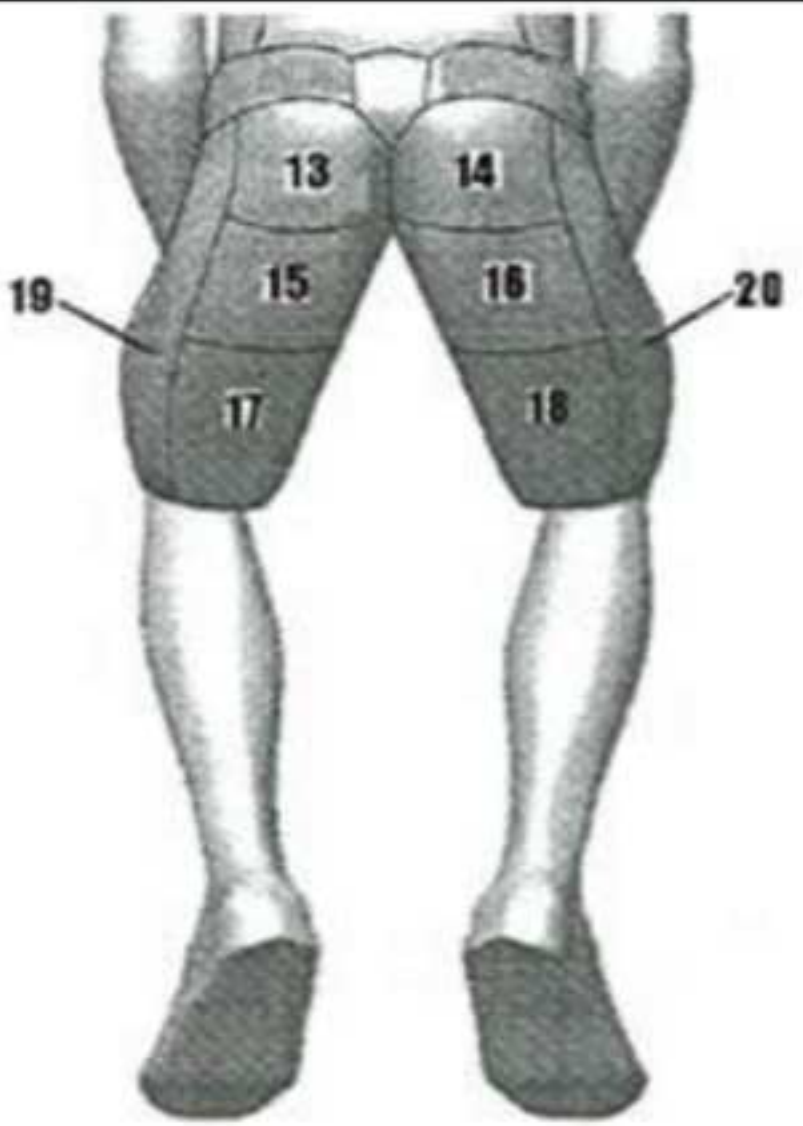
 <p>The diagram shows a human lower body from the waist down to the feet. The buttocks and thighs are divided into eight numbered regions: 13 and 14 on the buttocks; 15 and 16 on the upper thighs; 17 and 18 on the lower thighs; and 19 and 20 on the outer sides of the thighs. The legs and feet are also visible.</p>	Very comfortable
	Comfortable
	Neither comfort or discomfort (Indifferent)
	Rather uncomfortable
	Very uncomfortable

Figure 7
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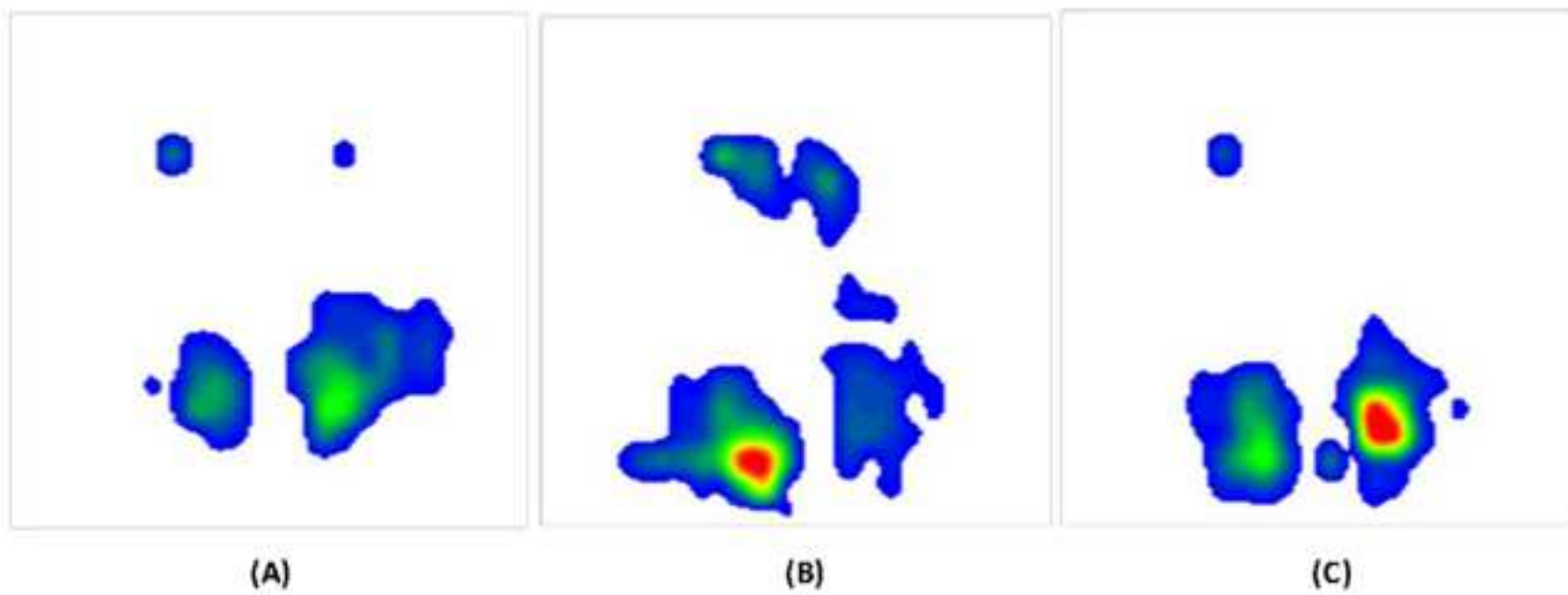


Figure 8
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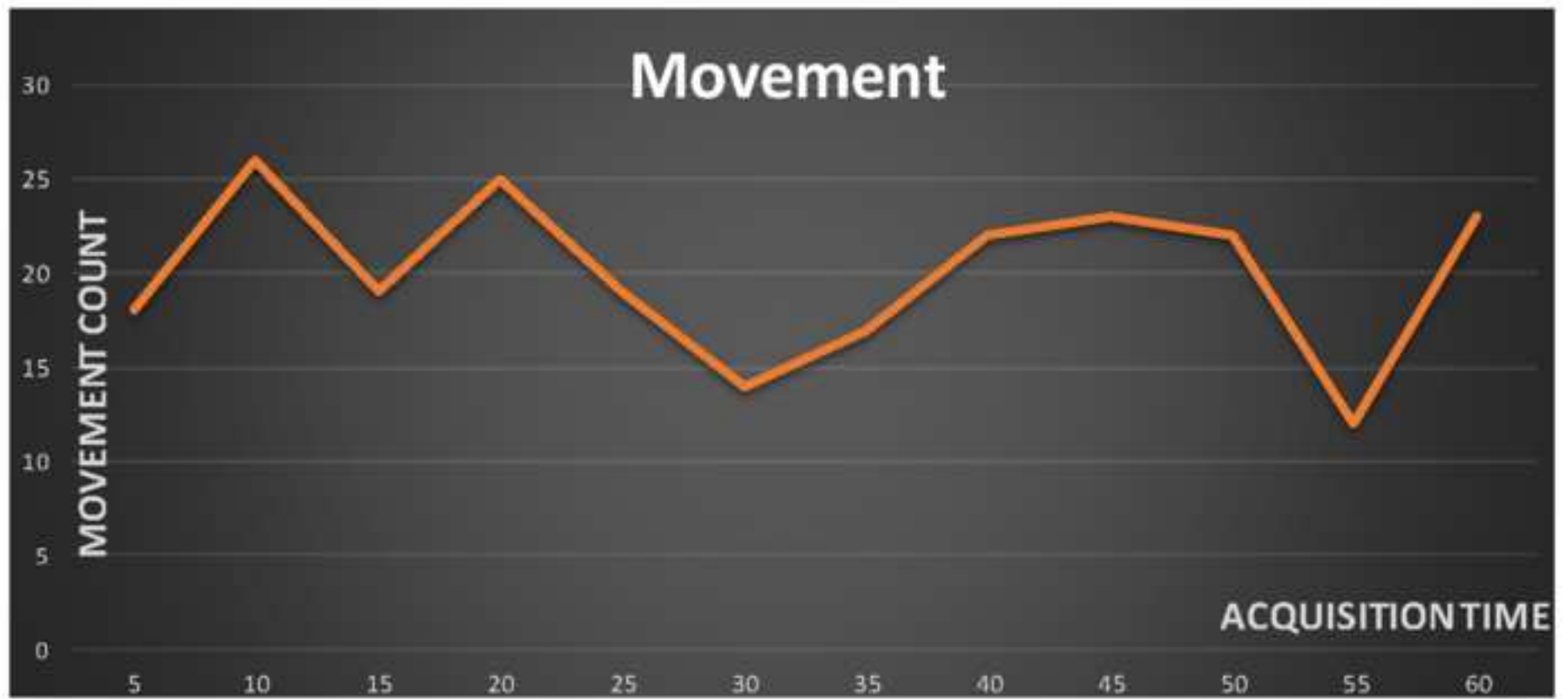


Figure 9

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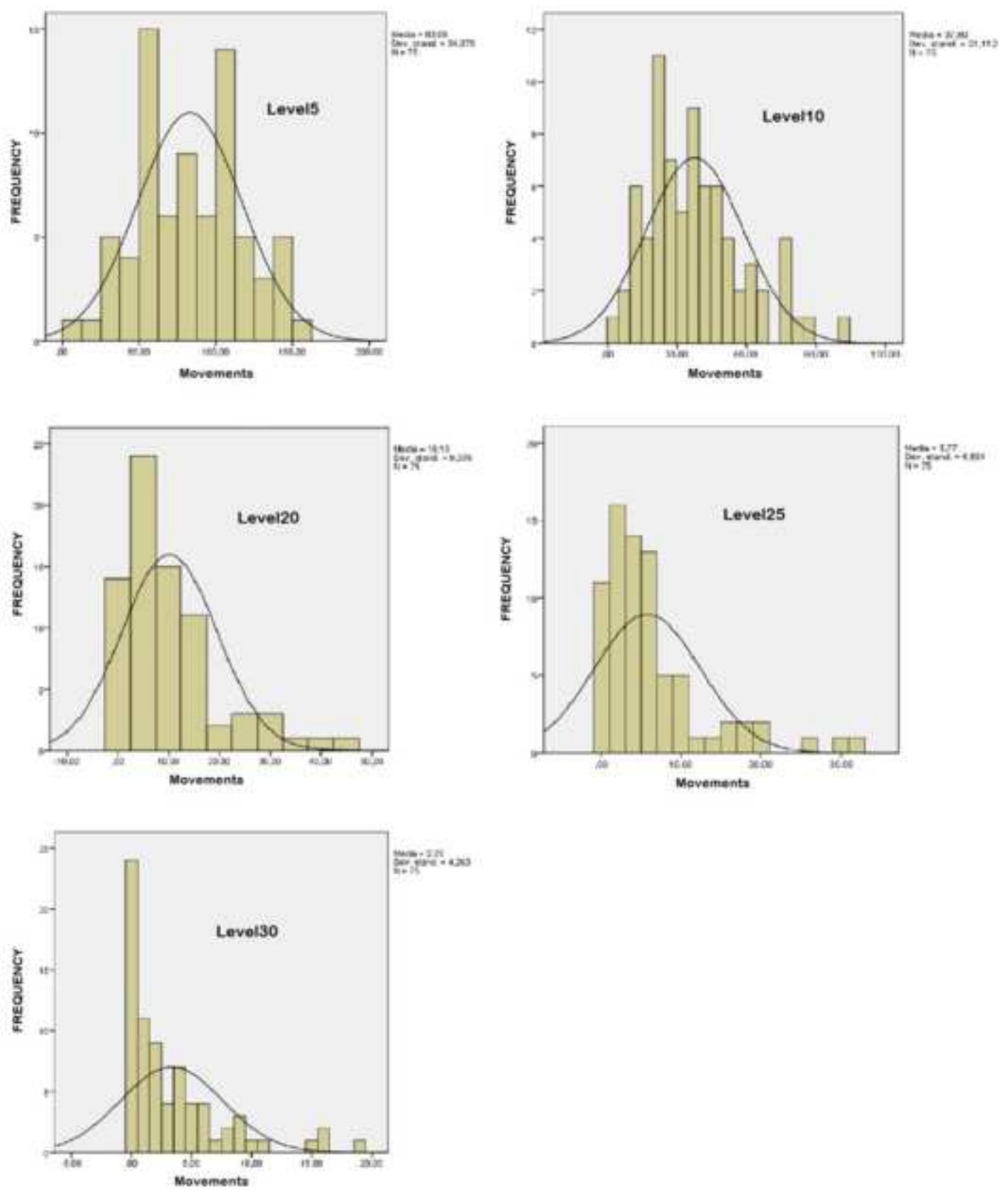


Figure 10

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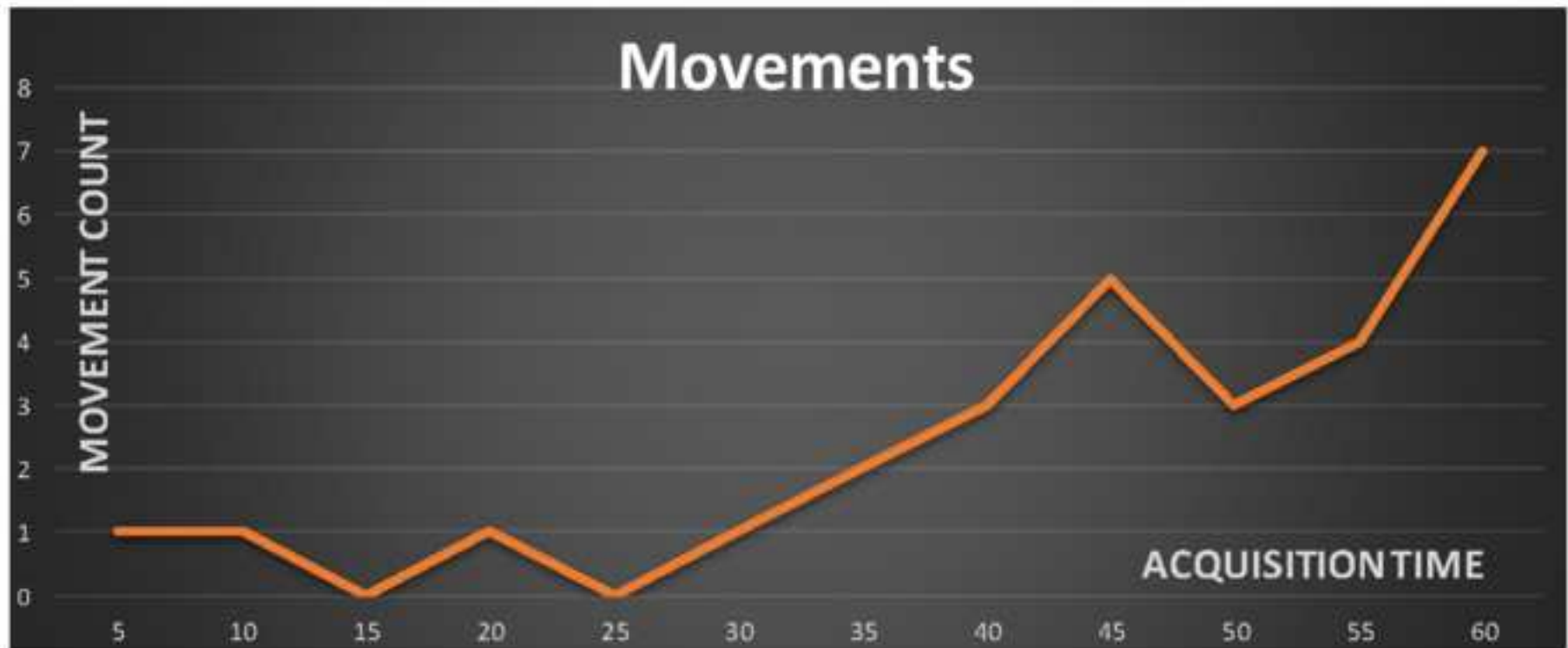


Table 1

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	Age	Mass	Height	Body Mass Index
	(years)	Kg	m	Index
Mean	21,4	66,7	1,7	22,3
Std.Deviation	0,5	12,7	0,1	2,3
Minimum	21	48	1,6	18,6
Maxmum	22	95	1,9	27,8

Table 2

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Very comfortable	2
Comfortable	1
Neither comfort or discomfort (Indifferent)	0
Rather uncomfortable	-1
Very uncomfortable	-2

Table 3

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Treshold	Mean (n)	Maximum	Minimum	Std.Deviation
Level5	83,1	158	8	34,1
Level 10	37,6	100	2	21,1
Level20	10,2	43	0	9,4
Level25	5,8	31	0	6,7
Level30	3.333	19	0	4,3
Rg Level5	41,9	80	5	18,1
Lf Level5	50,0	78	3	16,7
Rg Level10	17,9	49	0	10,6
Lf Level10	19,3	51	2	11,0
Rg Level20	4,8	20	0	5,0
Lf Level20	5,3	23	0	4,9
Rg Level25	2,9	16	0	3,5
Lf Level25	2,9	15	0	3,4
Rg Level30	1,7	10	0	2,3
Lf Level30	1,7	10	0	2,1

Table 4

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	Level5	Level10	Level20	Level25	Level30
Overall comfort	0,134	0,212*	0,335*	0,342*	0,327*
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Table 5

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	Left	Right
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M.Dx 10mm	0.150	-0.192
M.Sx 10mm	0.016	-0.013
M.Dx 20mm	0.083	-0.120
M.Sx 20mm	-0.144	0.168
M.Dx 25mm	0.057	-0.094
M.Sx 25mm	0.245*	-0.225*
M.Dx 30mm	0.201*	-0.251*
M.Sx 30mm	-0.114	0.131

Tables in MSWord

[Click here to download Supplementary Interactive Plot Data \(CSV\): Tabelle.docx](#)