School combo-desk comfort assessment: a method for weighting postural factors that affect the overall perceived comfort while performing different activities

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Abstract In recent years, a growing interest in ergonomics and comfort perception in secondary schools and universities can be detected, with the aim of going beyond the UNI-EN regulations and understanding how practically improve students' perceived comfort during lessons. The aim of this study was to analyse the discomfort perceived by students while sitting on combo-desk during lessons. A statistical sample of 20 healthy students performed a combination of three different tasks in two sessions - listening, reading on a tablet and writing - in a mixed sequence. Subjective perceptions were investigated through questionnaires, in which the expected comfort and the overall one were rated on a 10-point comfort scale and the perceived comfort on a 5-point Likert scale. Subject's postures were acquired non-invasively using cameras; Kinovea® software was used to detect postural angles directly on pictures; the acquired angles were used for the virtual-postural analysis, using a DHM (Digital Human Modelling) software; CaMAN® software was used to obtain an objective measure of the postural comfort. Once correlations between subjective and objective data were calculated, the results of the analysis were used to define the influence of each body part comfort on the overall perceived comfort and to quantify the weight of each factor influencing the overall perception. Finally, some guidelines to modify the combo-desk design, in order to increase the level of perceived comfort, were developed.

Keywords: Perceived (dis)comfort, School seat, Combo-desk, School activities.

1 Introduction

Ergonomics studies the interface between people and activities they perform, the products they use and the environments in which they work, travel or play; as stated by Mokdad and Al-Ansari [1], the use of ergonomic principles allows developing guidelines for improving and redesign old/new products. The interdisciplinary nature of ergonomics makes it markedly applicable to various fields that involve human performances. Education is one field where ergonomics can give a significant contribution, but the application of ergonomics to education receive only limited attention. Educational ergonomics is that branch of ergonomics/human factors concerned with the interaction of educational performance and educational design [2].
Much research on physical comfort and discomfort in the workplace were conducted; most papers discuss on relationships among environmental factors such as temperature, humidity, applied forces and so on that can affect perceived levels of comfort/discomfort [3]. Several papers follow the assumption that a relationship exists between self-reported discomfort and musculoskeletal injuries since these injuries affect perceived comfort [4,5]; however, theories relating comfort to products and product design characteristics are still rather underdeveloped.

In this work, the authors want to investigate the problems related to the adoption of a common combo-desk used by university students.
The classroom is a learning environment in which the furniture is an important physical element that is expected to facilitate learning by providing a comfortable and stress-free environment. Poor sitting posture in the classroom is one of the main negative effects of bad furniture design on students [6].
Since students spend a considerable part of the day at school, sitting on a chair [7,8], school furniture should match students' requirements. However, studying in fixed-type furniture may induce constrained postures [9,10]. Since people differ in size and postural preferences, workstations with adjustable seats are preferred as they have a significant positive effect on muscle tension and sitting posture, promoting health, comfort and concentration [11,12].
Commonly schools and universities prefer fixed-type chairs than adjustable chairs due to the higher price and maintenance costs of adjustable chairs [13]. Side-mounted desktop chairs are often used in university classrooms. However, their correct design is neglected, and Thariq's study [12] showed that side-mounted chairs in their learning environment do not meet postural and comfort requirements of university students. About that, Naddeo et al. [14–16] identified that a custom seat influenced positively the comfort perceived from students.
It is generally accepted that continuous static muscle activity results in discomfort [17]. Regarding the number of movements, Graf et al. [18] suggested that natural movements are desirable and necessary as long as they are within an acceptable range; another study [19] stressed the importance of variation between severable stable and healthy body postures. Several studies on seating, in general, describe a relation between seating time, discomfort and body movement. Telfer et al. [20] found that subjective discomfort and movement increases over time. Vergara and Page [21] stated that macro-movements are a good indicator of discomfort, Fujimaki and Noro [22] also found discomfort to increase over time but argued that macro-movements occur in order to decrease discomfort in a repeating pattern during prolonged sitting. Callaghan and McGill [23] suggested that humans redistribute their muscular loads according to their comfort level using posture adjustment. Finally, Fasulo et al. [24] suggested that the number of movements was a good indicator of perceived lower-body (dis)comfort, particularly, it was demonstrated that an increase in discomfort causes an increase in the number of movements.
Certain medical studies showed that each joint has its own natural Rest Posture (RP) [25,26], wherein the muscles are completely relaxed or at minimum strain level: when this occurs, the geometrical configuration corresponds to the natural position of the resting arms, legs, neck, etc. This position appears to minimize musculoskeletal disease and optimize comfort perception [3].
One area in which comfort studies can be applied is public offices and public furniture like those used in schools. Our study evaluates the level of comfort perceived by students while using university furniture (combo-desks). A study published in 2014 [25], involved a classroom of 126 Portuguese students and demonstrated that their university classrooms were not well-designed for the students.
In this paper, critical issues shown by the combo-desk are analysed using the quantitative method for comfort evaluation, the software CaMAN® was used [16,27] to make a quantitative evaluation of postural comfort, and the modifications of the combo-desk to increase the level of comfort perceived by the users are suggested.

2 Materials and methods

2.1 Purpose

The aim of this study was to investigate the discomfort perceived by participants during class-hours. The participants were observed during thirty minutes of lesson while sitting on a combo-desk. Each student performed a combination of three different tasks (listening, reading on a tablet and writing) and at the end of each task the perceived comfort, related to the upper limbs, was investigated by a questionnaire.

2.2 Participants

Twenty healthy volunteer MD students (8 females and 12 males), took part to the experiment. All participants signed the Informed Consent about the nature of the test, in accordance with ethical standards of the University of Salerno. Demographic data of participants are gathered in Table 1.

Table 1. Demographic data of the participants.

	Age (years)	Mass (Kg)	Height (m)
Mean	*25,6*	*67,9*	*1,7*
Std. Deviation	*2,1*	*11,7*	*0,1*
Minimum	*23*	*50*	*1,55*
Maximum	*31*	*86*	*1,9*

2.3 Testing Devices

The equipment used in this study for data acquisition and set-up was composed by: a common combo-desk, a photographic acquisition system and a comfort questionnaire.
The combo- desk was a side-mounted desktop chair (**Fig. 1.** Combo-desk.Fig. **1**). It was characterized by a rigid seat-pan, a rigid seat-back, a right armrest and a side desk.

Fig. 1. Combo-desk.

In the adopted configuration, the photographic acquisition system was equipped with five commercial cameras. This allowed to acquire photos from five points of view: front, behind, left side, right side, and above.
To acquire the subjective perceived comfort, a body comfort questionnaire was used in which students had to rate:
- the expected comfort before starting the experiment on a 10-point scale.
- the perceived comfort for each part of the upper body, left and right, (Fig. **2**), at the end of each task on a 5-point scale from 1 (Not comfortable) to 5 (Extremely comfortable);
- the overall perceived comfort, at the end of each task on a 10-point scale.

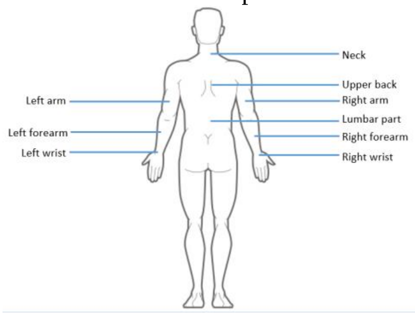

Fig. 2. Comfort questionnaire.

2.4 Simulation Software

CATIA® V5R16 was used for the virtual-modelling of the combo-desk. DELMIA® Digital Human Modelling (DHM) software was used for modelling a 'dummy' based on the real participants' anthropometric measurements [28–33] Kinovea® software rel. 0.8.7 was used for the angular detection of users' joints (while performing the required activities). Few small modifications were carried out to guarantee the accuracy of the manikin's postures, according to the photogrammetric acquisition previously verified in [34] and [35]. Comfort evaluations were performed using CaMAN® [5,16,27,36,37] – a MatLab application developed by Cappetti and Naddeo, which takes the angles describing operator posture as input, and gives an index of postural comfort (CI) with a value range of 0-10 as output.

2.5 Procedure

Testing was conducted in a class of the Faculty of Engineering at the University of Salerno. Participants were asked to sit on a combo-desk and to perform three main tasks: writing, listening and reading on a tablet. The overall duration of each test was 30 minutes, divided in two sessions of 15 minutes. In each session, each task was performed in 4 minutes, with a 1-minute pause between tasks to fill questionnaire. Photos, from all views, were taken simultaneously just before the end of each task, making sure to have the same participant's posture in all views. During the tasks, students were able to move freely.
Photos were processed by the software Kinovea® to gather postural angles of human joints.
Postural angles were then used into Delmia® to simulate each posture (Fig. **3**). In this step, some assumptions were made to ensure the correspondence between the angles evaluated by the two different software (Kinovea® and Delmia®). Delmia® was used to evaluate angles that were not available through the photographic acquisition, such as the arm medial rotation, the forearm pronation/supination and the hand flexion/extension, as well as the radio-ulnar deviation;
The upper limb angles were processed by CaMAN® to obtain comfort indexes of, shoulders, neck, hand and elbow.

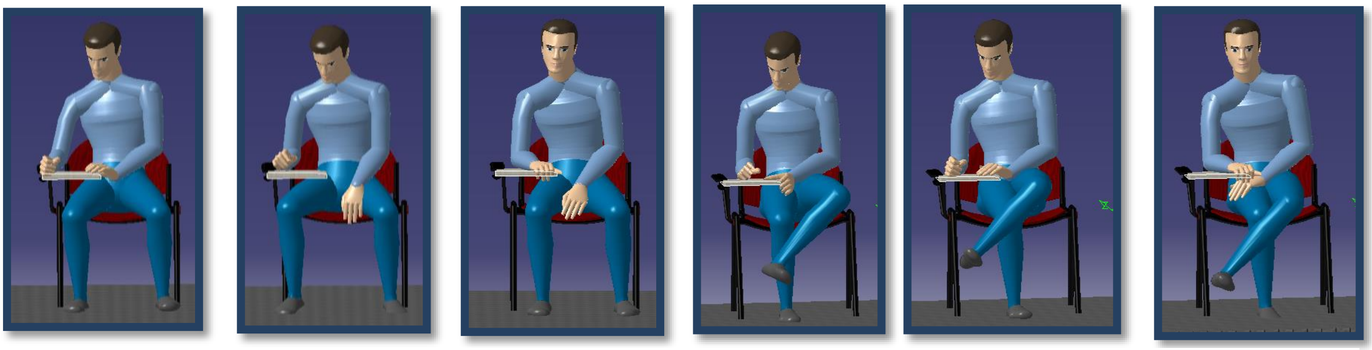

Fig. 3. (a) Writing 1; (b) Reading 1; (c) Listening 1; (d) Writing 2; (e) Reading 2; (f) Listening 2.

2.6 Data Analysis

Data were gathered to evaluate the impact of the objective/subjective comfort scores of each part of the body on the overall perceived comfort. The analyses were conducted for each task performed during the two sessions of the test. The statistical analysis software SPSS® rel.13 was used to perform these analyses. Spearman correlation coefficients were calculated to determine the strength of the relationships among the acquired variables.
Table 2 shows the most significant correlations between the subjective overall comfort and the subjective comfort scores for the body-parts during the reading and writing tasks. A strong correlation emerged between the overall comfort and the subjective comfort scores of the neck, upper back, lumbar part, right arm, right forearm and right wrist, perceived in the two sessions of reading and writing tasks. Meanwhile, the subjective comfort scores of the left arm, left forearm and left wrist were not correlated with the overall perceived comfort.

Table 2. Correlation between the overall comfort and the subjective comfort scores about reading and writing tasks.

Subjective Comfort	Neck	Upper back	Lumbar part	Right arm	Right forearm	Right wrist	Left arm	Left forearm	Left wrist
Writing1 (W1)	**	**	*	**	**	**			
Writing2 (W2)	**	**	*	**	**	*			
Reading1 (R1)	*	**	*	**	**	*			
Reading2 (R2)	*	*	*	**	*	*			

*** The correlation is significant at level 0.01 (2-queues)*
** The correlation is significant at level 0.05 (2-queues)*

In Table 3 are reported the significant correlations between the subjective overall perceived comfort and the subjective comfort perception for the body-parts, during the listening session. The table shows a strong correlation between the overall perceived comfort and the subjective comfort scores of the right arm, right forearm, right wrist and upper back. Even in this case, the subjective comfort scores of the upper left limb were not related to the overall perceived comfort. Unlike other tasks, there is a lack of correlation between the overall perceived comfort and the subjective comfort scores of the neck and the lumbar part.

Table 3. Correlation between the overall comfort and the subjective comfort scores about listening.

Subjective Comfort	Neck	Upper back	Lumbar part	Right arm	Right forearm	Right wrist	Left arm	Left forearm	Left wrist
Listening1 (L1)		*		**	*	*			
Listening2 (L2)		*		**	**	**			

*** The correlation is significant at level 0.01 (2-queues)*
** The correlation is significant at level 0.05 (2-queues)*

The correlation analysis, between the overall perceived comfort and the objective comfort scores of body-parts, showed no correlations. The reason is that the CaMAN® software calculates comfort scores assuming that the weight of the upper limbs is not supported, while in the analyzed tasks the sample rested the right elbow on combo-desk and the left one on leg, crossed arms on the stomach or on the legs. So, the objective comfort scores are not reliable for this comfort analysis.

2.7 New global comfort indexes

To understand the influence of perceived comfort of the different parts of the body on overall comfort, a new global comfort index for each task was created.
These new global comfort indexes were calculated as weighted averages, considering, for each of them, only the body parts where the correlations were found: neck, upper back, lumbar part, arm and forearm for the reading and writing tasks (see Table 2); upper back, arm and forearm for the listening task (see Table 3).
These indexes were calculated excluding the objective comfort scores.

The new global comfort indexes for the writing task (subscript W), performed two times, are defined by the following formulas (1) (2):

$$\text{Global Comfort Index (Writing 1)} = a_1*A_{W1}+a_2*N_{W1}+a_3*B_{W1}+a_4*L_{W1} \quad (1)$$

$$\text{Global Comfort Index (Writing 2)} = a_1*A_{W2}+a_2*N_{W2}+a_3*B_{W2}+a_4*L_{W2} \quad (2)$$

The new global comfort indexes for the reading task (subscript R), performed two times, are defined by the following formulas (3) (4):

$$\text{Global Comfort Index (Reading 1)} = b_1*A_{R1}+b_2*N_{R1}+b_3*B_{R1}+b_4*L_{R1} \quad (3)$$

$$\text{Global Comfort Index (Reading 2)} = b_1*A_{R2}+b_2*N_{R2}+b_3*B_{R2}+b_4*L_{R2} \quad (4)$$

The new global comfort indexes for the listening task (subscript L), performed two times, are defined by the following formulas (5) (6):

$$\text{Global Comfort Index (Listening 1)} = c_1*A_{L1}+c_3*B_{L1} \quad (5)$$

$$\text{Global Comfort Index (Listening 2)} = c_1*A_{L2}+c_3*B_{L2} \quad (6)$$

In which:

A is the subjective comfort score of the upper right limb, given as arithmetic mean of the subjective comfort index of arm, forearm and wrist;
N is the subjective comfort score of the neck;
B is the subjective comfort score of the upper back;
L is the subjective comfort score of the lumbar part.

The weights must be determined considering that:
- the sum of the weights must be equal to 1;
- the individual weights must be strictly included in the range [0,1];

2.8 Optimization Problems

To determine the weights of the new global comfort indexes, three optimization problems were settled.
The aim, in this phase, was to maximize the sum of:
- The correlation between the overall comfort perceived and the new global comfort index relative to the same task performed in the first session.
- The correlation between the overall comfort perceived and the new global comfort index relative to the same task performed in the second session.

O.F. max (correlation ($overall\_comfort_i$; $new\_global\_comfort\_index_i)_{1st\_session}$+ correlation ($overall\_comfort_i$; $new\_global\_comfort\_index_i)_{2nd\_session}$)
where i= reading, writing or listening tasks
Constraints:
$0<weight_i<1$ for i=1,2,3,4 (for reading and writing tasks); for i=1,3 (for listening tasks)
$\sum weight_i=1$ for i=1,2,3,4 (for reading and writing tasks); for i=1,3 (for listening tasks)

The weights of the three global comfort indexes were calculated using the Excel Solver (Table 4). The values of the objective function, and the correlations between the overall comfort perceived and the new global comfort index relative to the same task performed in the first and second session were reported in

Table *5* and
Table ***6***.

Table 4. Weights (Excel Solver).

WEIGHTS (EXCEL SOLVER)	LISTENING	READING	WRITING
	0.6715486	0.510145	0.46046757
		0.000000	0.09779941
	0.3284389	0.421435	0.12740034
		0.068420	0.31418044
Sum	1	1	1

Table 5. Correlations (Excel Solver).

CORRELATIONS (EXCEL SOLVER)	LISTENING	READING	WRITING
First session	0.73220626	0.822757	0.86209561
Second session	0.7706147	0.686990	0.73451648

Table 6. Objective Function (Excel Solver).

O.F. (EXCEL SOLVER)	LISTENING	READING	WRITING
	1.50282093	1.50974757	1.59661209

As a further check of the excellence of the results, a Macro was created in Excel to generate 10000 random weight values subject to the already-discussed constraints. If this research reveals a value of the objective function greater than the one found by the Excel Solver, it means that the weights associated to that O.F. are stored, in decreasing order, in a suitable table. Doing this macro for each task, the search never showed a value of O.F. higher than the one of the Excel Solver, which therefore has identified the optimum global point.
In addition, another Excel Macro was created to write, in decreasing order, all the results of its exploration for 10000 random values of the weights in a suitable table. The maximum value found by the Random Method is, however, closer to the one of the Excel Solver (Table 7, Table 8 and Table 9).

Table 7. Weights (Random Method).

WEIGHTS (RANDOM METHOD)	LISTENING	READING	WRITING
	0.67154423	0.513530623	0.461724661
		0	0.11
	0.32845577	0.41	0.11
		0.076469377	0.318275339
SUM	1	1	1

Table 8. Correlations (Random Method).

CORRELATIONS (RANDOM METHOD)	LISTENING	READING	WRITING
FIRST SESSION	0.732207534	0.822222405	0.8636268
SECOND SESSION	0.770613428	0.687399898	0.732818948

Table 9. Objective Function (Random Method).

O.F. (RANDOM METHOD)	LISTENING	READING	WRITING
	1.502820962	1.509622303	1.596445747

3 Results & discussions

The new global comfort indexes were used to evaluate the comfort perception and to compare the single tasks, in order to determinate in which tasks students perceived less comfort. In the Table 10 results obtained are shown:

Table 10. New global comfort for each task.

TASK	1° SESSION	2° SESSION
LISTENING	6,24909335	5,42
WRITING	5,359639179	4,556962546
READING	5,145628357	4,54339886

It is clear that in both sessions, the worst comfort index is related to reading, even though the value is very similar to writing. This result is mainly due to the position taken by students during these work activities that force the student-body to be located too far from the reading and writing surface.
In addition, there is a worsening of comfort indexes between the first and the second session, caused by student tiredness, that was accentuated during the test. This results is in accordance with the results of Vink et al. [38] in which the influence of effects over time on comfort and discomfort were studied
Instead, listening has the best value. This result was expected because: during the listening task the subjects were less constrained. They could place themselves in the most comfortable way to carry out the task. Definitely, analysis was reasonably satisfactory and consistent:

- In both sessions, listening is the better task and reading is the worst one
- Listening in the first session is the most comfortable activity
- Reading in the second session is the most uncomfortable activity

It is evident that, during learning activities, the student-body was always located too far from the working surface, and while taking notes or reading something, there were negative effects on his/her back, neck and arms. In order to solve this problem, it was necessary to make changes to the folding chair desk. The proposed changes consisted of a system that allows the student to set the distance between chair and writing surface and, in addition, to tit it during reading, for example. In this way, the physical characteristics of the users would be considered, so to set the system according to own needs. In this new configuration, we expect better results in terms of global comfort indexes.

4 Conclusions

In this work, the authors investigated the problems related to the adoption of a common combo-desk used by university students during a combination of three different tasks (writing, listening and reading).
The method used in this work was based on photo/video recording and photogrammetry, image processing using Kinovea® software, coupled with the use of DHM commercial software (CATIA® for modelling, DELMIA® for simulation) and comfort rating software developed by the authors for the evaluation of non-subjective comfort (CaMAN®) .
Via a correlation analysis, through the Spearman index, it was possible to understand the influence of subjective comfort (questionnaires) and non-subjective one (CaMAN®) of the different parts of the body on overall comfort. From the results obtained, a new global comfort index for each task was developed. Three optimization problems were set in Excel to estimate the best weights for each one.
In the work was showed a method for the definition of the comfort indexes. All the acquisition methods used are very cheap and easy to use. The precision of the acquisition method, as well as the fact that by not using complicated, expensive acquisition methods we were still able to reach a very good level of numerical/experimental are important results revealed by this paper. The method can be easily reproduced for other applications.
It is widely demonstrated that fixed-type furniture may induce constrained postures and these have a significant negative effect on comfort [9–12]: that was confirmed through the results of this work, based on a real application. During the tasks in which the subjects were obliged to utilize the desk (reading and writing) the subjective comfort was the lowest one. Instead, when they had to carry out the task in which they had not utilized the desk (listening) the subjective comfort was the highest one.

The comparison between global comfort indexes, firstly, was useful to understand the most uncomfortable task in both the sessions. The test procedure, additionally, allowed us to study the influence of effects over time on comfort. The second session showed that the comfort was reduced for all the tasks. Sitting still for extended periods of time can lead to physical discomfort.
Obtained results can be a useful support during the problem solving and directly suggest, to designers, easy solution to re-design the combo-desk. The proposed solution takes into account the characteristics of the tasks that the subjects have to carry out during the lessons and the subject's anthropometrics characteristics.

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