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Design and Analysis of an Ergonomic-Automated Adjustable Drafting Table

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ABSTRACT

Most of the students in engineering departments, especially architecture department, spend a lot of time while working on the drafting tables. As a result, they suffer from discomfort, back and neck pain because of the fixed dimension of the tables, which make it incompatible with their body dimensions. The present study is aimed to design an ergonomic-automated adjustable drafting table based on the anthropometric data of a randomly sample of 60 engineering students; 30 males and 30 females from engineering's college in Applied Science Private University, Jordan. The recommended drafting table's dimensions were the following: adjustable table height is 67 ± 8 cm, adjustable table width is 152 ± 15 cm, table depth is 84 cm and adjustable desktop angle is 0 - 45 ºand. Then an automated drafting table with three flexible joints was designed, constructed and operated based on mechanical design of power screws and electrical design circuits. A survey was conducted to test and validate the proposed drafting table by using a six-question questionnaire on a sample of 40 engineering students. Hypothesis testing, one sample T- test was used to analyze the data by using Minitab 16 statistical software. As a result, students prefer the proposed design which has adjustable height, width and desk top inclination with automated mechanism more than the current fixed one. So the musculoskeletal disorder in the affected parts of the body will be decreased.

Key words: anthropometry, automation, Ergonomics, drafting table design.

1. INTRODUCTION

Ergonomics focuses on the study of human fit. It is applied to office furniture design to fit the people at work, school, or home, to be more comfortable, less stressful, and achieve higher productivity [1]. Anthropometric data is the collection of human' body dimensions those are useful in ergonomic design of the workplace [2]. From the ergonomic approach, the design should be adapted to accommodate the dimensions of the studied population. Literature surveys shows that many researches have been conducted regarding designing furniture for colleges or schools based on the variation of the anthropometric measures of the countries. Due to such variation, there is a need of having good database of anthropometric measurements that can be used in design. According to that, the development of an anthropometric database for Jordanian males was initiated. The study collected twenty-five body dimensions from a sample of 70 Jordanian males. The results showed significant differences in anthropometric data between Jordanians and three other nationalities, so their data could be used in designing equipment and workstations [3].

In engineering collage, Architecture students use drafting tables intensively for their main academic activities. Since 86% of their subjects need drafting tables in both lectures and drafting subjects, a study of the designs was carried out and analyzed and should be implemented [4]. NORDIC musculoskeletal questionnaire was one of the methods used to evaluate the current design of drafting tables in Kano State University. The results showed that the current design caused severe pains in lower and upper back and neck. A prototype with recommended dimensions of an ergonomic chair and ergonomic drafting table was designed by using locally sourced materials based on the anthropometric dimension of a sample of 100 students, 97 males and 3 females [5]. Another study showed that there was a mismatch between classroom furniture dimensions and the dimensions of students based on a sample of 400 engineering students in the age group 18-24. The height of desk was far from the sum of sitting elbow height and popliteal height, which imposed students to adopt unhealthy postures. The furniture was designed by local manufactures. The study developed an anthropometric database of students, which could be used in design with adjustability range or in more than one size design [6]. In addition to the previous studies, the anthropometric data, NORDIC questionnaire and RULA were used to design an ergonomically designed drafting table and chair with recommended dimensions based on a sample of 21 females and 21 males of engineering students of LPU-Laguna. The results indicated that most of the students sever pain was at lower back while performing drawing activity [7]. Reference. [8] showed that chairs and tables were designed with greatly

difference of Nigerian students' dimensions by taking various body dimensions of a sample of 720 students in three selected tertiary institutions in Abeokuta, Nigeria. Another work also stated that the anthropometric data of the Nigerian students in three higher institutions in Abeokuta were not considered in designing of tables and chairs. Various body dimensions of 720 students were measured and 5th, 50th and 95th percentiles were calculated by using a SPSS statistical package and used in designing the dimensions in chairs and tables [9]. In designing products, Anthropometry has three major principles. First principle is "design for extreme individual" which can be either Design for the maximum population as commonly the 95th percentile male or design for the minimum population value as commonly referred as 5th percentile female [10]. The second principle is "designing for an Adjustable Range" which put consideration of both 5^{th} %ile female and 95^{th} %ile male in order to accommodate 90% of the population [11]. Many researchers suggested adjustability principle because if its importance in designing school furniture, in order to accommodate the variation in anthropometric measures of different genders, cultures and ages [12]. A design of adjustable classrooms furniture based on anthropometric measurements regarding engineering students in India was carried. The implementation of these data would help to create comfortability, safety, reduce musculoskeletal disorders, and improve performance of students. Whenever the use of adjustability is impractical especially for government's colleges, last principle is "designing for the average" is mostly being used [13]. One of the applications of the anthropometry was to design a pseudo-anthropomorphic robotic arm with four degrees of freedom. It had an anthropomorphic jointed arm configuration that provided a work envelope similar to the work envelope of a human arm [14]. Another application based on the variations and differences on individual human faces was the development of face detection system by using various techniques. this process eliminated the need for passwords, fingerprint data, and even keys. It had also developed research and implementation based on mobile phone system [15]. The purpose of this study is to develop an ergonomic- automated drafting table suitable for engineers working while they are using drafting tables. For this purpose, the dimensions of the current fixed drafting table that has a flexible inclination with mechanical fixture are being identified first. As a result, the drafting tables that are often used are not as comfortable as it should be. In order to solve this problem, the anthropometric data has been collected and analyzed and used to determine the optimal measurements of the drafting table to reduce the likelihood of musculoskeletal disorder. Ergonomic principles, mechanical principles and electrical principles were used in designing, constructing and operating of the proposed drafting table. A questionnaire was conducted and analyzed to evaluate the proposed design of automated drafting table compared to the current design.

2. MATERIAL AND METHODS

2.1 Evaluation of the Current Drafting Tables

The Architecture Engineering Department in Applied Science Private University contains drawing tables with fixed dimensions and the students suffer from this problem. The drafting table's height is 81 cm, width is 120 cm, depth 80 cm and the inclination angle of the desktop is flexible inclination with mechanical fixture as shown in Figure 1.

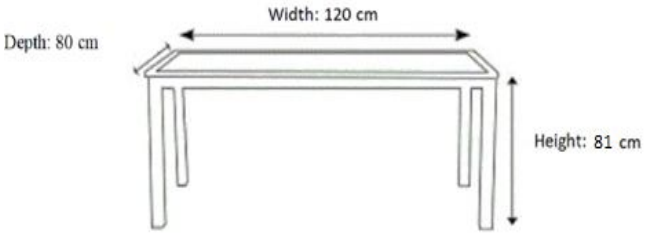

Figure 1: Current Drafting Table's Dimensions

For the purpose of this study, 30 male students and 30 female students were randomly selected making 60 engineering students of Applied Science Private University, Jordan. Three instruments were used which are, standard anthropometer, measuring tape and protractor.

2.2 Ergonomic Design

2.2.1 Measured Anthropometric Data

To design an ergonomic-automated drafting table, nine anthropometric measurements were taken in this case as shown in Figure 2. All measurements were measured in centimeter (cm) with the exception of the angle was in degrees.

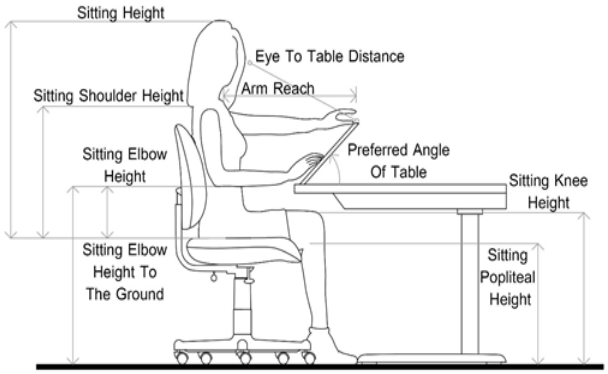

Figure 2: Anthropometric Dimensions Measured

2.2.2 Anthropometric data analysis

The collected anthropometric data were statistically analyzed by using Minitab 16, as Statistical Package and Microsoft Excel 2016 as shown in Table 1 and Table 2. Mainly the minimum, maximum, mean, standard deviation (SD), 5th percentile (%ile) and 95th %ile were used to design the drafting table.

Table 1: Descriptive Statistics of the Measured Anthropometric Measurements for Female Students

Parameter	Min	Max	5th %ile	95th %ile	Mean	SD
Sitting height	73	83	72.4	82.8	77.6	3.1
Sitting Shoulder height	46	57	46.1	55.5	50.8	2.8
Sitting Elbow height	14	24	13.8	22.8	18.3	2.7
Sitting Knee height	50	61	50.4	60.7	55.6	3.1
Sitting Popliteal height	43	50	42.6	49.2	45.8	2
Arm reach	68	76	68.2	77.2	72.7	2.8
Twice of the arm reach	136	152	137	154.6	145.5	5.5
Angle of the sheet	0	60	0	45	22.3	16
Sitting elbow height to the ground	59	72	59	69.8	64.2	3.4

Table 2: Descriptive Statistics of all Measured Anthropometric Measurements for Male Students

Parameter	Min	Max	5th %ile	95th %ile	Mean	SD
Sitting height	76	92	78	91.2	84.6	3.97
Sitting Shoulder height	47	64	50.4	64	57.2	4.14
Sitting Elbow height	15	22	16	22.8	19.3	2.1
Sitting Knee height	51	64	52.4	64.1	58.3	3.5
Sitting Popliteal height	43	56	43.9	53	48.4	2.8
Arm reach	66	86	70.3	84	76.8	3.9
Twice of the arm reach	132	172	140.6	167	153.7	7.9
Angle of the sheet	0	40	0	41.5	17.8	14.3
Sitting elbow height to the ground	58	76	61.6	75	67.8	3.9

2.2.3 Results of the Anthropometric Data

Table 3 shows the recommended drafting tables dimensions for both male and female based on 5th percentile and 95th percentile to determine the minimum and maximum design parameters. An old rule of thumb is to design large enough for a large man and small enough for a small woman [16].

Table 3: Comparison Between Current Drafting Tables' Dimensions and the Recommended Drafting Tables' Dimensions for Both Male and Female

Feature	Current drafting table dimension	Anthropometric measure	Recommended dimension	Determinant
drafting table height	80 cm	Sitting elbow height to the ground	59-75 cm	5%ile of female to 95%ile of male
Drafting table depth	80 cm	Arm reach	84 cm	95%ile of male
Drafting table width	120 cm	Twice of the arm reach	137 -167 cm	5%ile of female to 95%ile of male
Desk top angle to horizontal	flexible inclination with mechanical fixture	Angle of the sheet	0 - 45 degree	Maximum range of all students

2.3 Mechanical Design of Power Screws

The front view of power screw is shown in Figure 3.

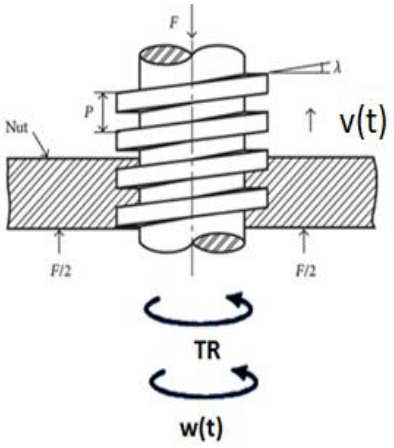

Figure 3: Front View of Screw Gear

Power screws are used to convert the rotation of the screw to linear motion where the following equations can be applied:

$$v(t) = p \times \omega(t) \quad (1)$$

$$\omega(t) = RPM \times \frac{\pi}{30} \quad (2)$$

Where:

$v(t)$: the nominal linear velocity in meter per second.

$\omega(t)$: the angular velocity in radian per second.

p : the screw pitch in meter per rotation.

RPM: Revolution per Minute of power screws

The torque of the motor required to raise or lower the load of the joint is calculated by using the following equation and demonstrated in Figure 3 above:

$$TR = \frac{Fdm}{2}\left(\frac{p + \pi Fdm}{\pi dm - fp}\right) \quad (3)$$

Where:

TR : the torque required to raise the load.

F : the axial compressive force.

dm : the mean diameter.

f : the coefficient of friction.

The efficiency of motors is calculated by the following equation:

$$e = \frac{Fp}{2\pi TR} \quad (4)$$

2.4 Description of Electromechanical System

The electromechanical system consists of three electric drivers: the first is for the joint with adjustable height, the second is for the joint with adjustable depth, and the third for the inclination adjustability angle of the desktop. The hardware components for each flexible joint are shown in Figure 4.

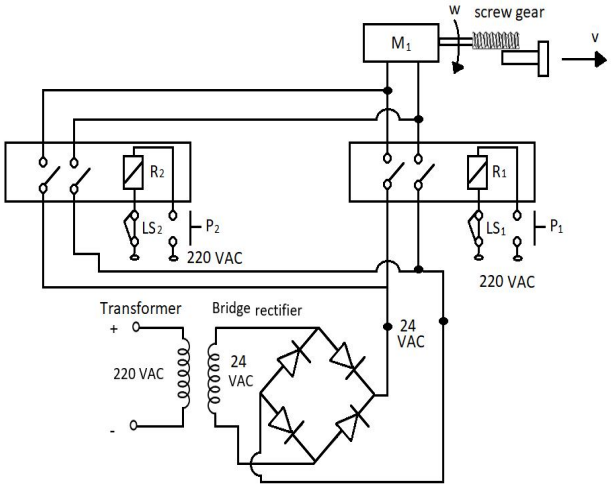

Figure 4: The Electromechanical Circuit for Controlling Each Flexible Joint

All hardware components are located in control box, except the motors and their screw gears. It can be seen from Figure 4, that the electromechanical system has bridge rectifier, which converts the 220 VAC of power supply into 24 VAC, then into 24 VDC to power electrical motor M1. The operation of relay R1 represents the operation of motor M1 in forward direction. The operation of relay R2 represents the operation of motor M1 in backward direction. P1 is the push button to operate the motor in forward direction, and P2 is the push button to operate the motor in backward direction. LS1 is the limit switch to stop the motion in forward direction when the motion reaches the upper limit, and LS2 is the limit switch to stop the motion in backward direction when the motion reaches the lower limit. The students are allowed to get their preferred adjustable values by pressing of push buttons.

2.5 Integrated Design

The mechanical design of the drafting table is drawn by using AutoCAD showing the range of adjustability for each dimension as shown in the Figure 5, Figure 6 and Figure 7.

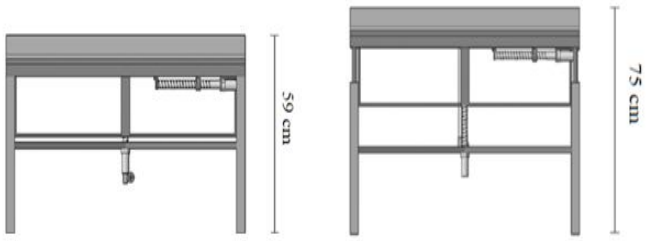

Figure 5: Range of Adjustability of the Ergonomic-Automated Adjustable Drafting Table's Height

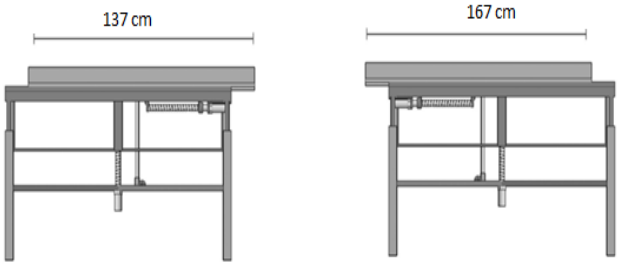

Figure 6: Range of Adjustability of the Ergonomic-Automated Adjustable Drafting Table's width

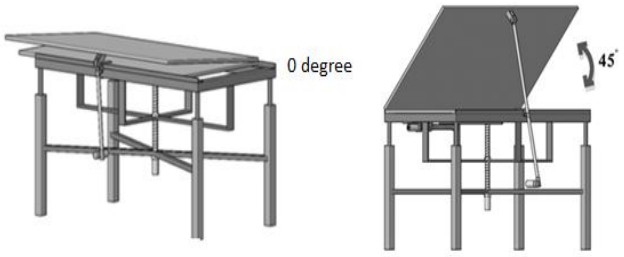

Figure 7: Range of Adjustability of the Ergonomic-Automated Adjustable Drafting Table's Desktop Angle

2.6 Manufactured Design

The manufacturing of the automated ergonomic drafting table has been done in Applied Science Private University's workshops as shown Figure 8:

Figure 8: The Manufactured Ergonomic-Automated Adjustable Drafting Table

2.7 Automated Drafting Table Testing and Validation

In order to perform the required testing and evaluation of the developed drafting tables, the students were interviewed to observe whether their needs have been adequately met or not.

2.7.1 Survey Questionnaire

Six questions were prepared in a questionnaire and distributed during the testing and validating survey, which were as follows:

1. Do you agree that the adjustable height of proposed drafting table is more appropriate than height of the traditional drafting table?
2. Do you agree that the adjustable inclination of proposed drafting table is more appropriate than the traditional drafting table?
3. Do you agree that the adjustable width of proposed drafting table is more appropriate than the traditional drafting table?
4. Do you agree that the depth of proposed drafting table is more convenient to draw than the traditional drafting table?
5. Do you agree that the legroom of proposed drafting table is more appropriate than the traditional drafting table?
6. Do you agree that proposed drafting table is more comfortable than the traditional drafting table?

The 5-point Likert scale was used to assess the ergonomic-automated adjustable drafting table compared to the traditional fixed one. The scoring of the questionnaire is "5 for Completely agree", "4 for agree", "3 for Neutral", "2 for Disagree" and "1 for Completely disagree"

Questionnaires were distributed to 40 participants of engineering college. All six questions were analyzed with Minitab 16 statistical software after collecting student's feedback.

2.7.2 Test of Hypothesis and Statistical Treatment of Data

This study tests the hypothesis that the students prefer the proposed ergonomic-automated adjustable drafting table. To test the research hypothesis, a one-sample t-test is used. The null hypothesis, which assumes that the students prefer the proposed ergonomic-automated adjustable drafting table with a mean more than 3. The second hypothesis will be an alternative hypothesis, which assumes that students prefer the current fixed drafting table with a mean less than 3. The study used α of 5% significance level.

3. RESULTS AND DISCUSSION

The Results of the six-question questionnaire were analyzed with Minitab 16 statistical software and tabulated in Table 4.

Table 4: Results of Questions as used for Testing and Validation of the Proposed Drafting Table.

Question No.	Mean	P value
1	3.725	0.999
2	4.15	1
3	4	1
4	4.275	1
5	3.1	.67
6	4,175	1

The P-value helps you determine the significance of the results. P-value is a number between 0 and 1 and interpreted in the following way:

A small p-value (typically ≤ 0.05) indicates strong evidence against the null hypothesis, so you reject the null hypothesis.

A large p-value (> 0.05) indicates weak evidence against the null hypothesis, so you fail to reject the null hypothesis.

As can be seen from results, P value in all questions is more than 0.05, so the students found that:

1. The automated adjustable height (59 -75 cm) of proposed drafting table is more appropriate than the fixed drafting table height (81 cm).
2. The automated adjustable inclination (0 - 45º) of proposed drafting table is more appropriate than the traditional drafting table, which has flexible inclination with mechanical fixture.
3. The automated adjustable width (137 -167 cm) of proposed drafting table is more appropriate than the traditional drafting table width (120 cm).
4. The depth of the proposed drafting table (84 cm) is more convenient to draw than the traditional drafting table (80 cm).
5. The legroom of proposed drafting table is more appropriate than the traditional drafting table.
6. The proposed drafting table is more comfortable than the traditional drafting table.

The results reflect that most of the students prefer the new ergonomic-automated adjustable drafting table's height, desktop inclination, width, depth, legroom and comfortability compared to the current fixed one.

4. CONCLUSION

From this research study, it is noticed that a considerable mismatch occurs between the measurement of the student body dimensions at Applied Science Private University, Jordan and the traditional drafting tables used. A mismatch can be defined as incompatibility between the dimensions of the student's body and the dimensions of traditional drafting table.

The anthropometric data of 60 engineering students have been determined for the design of the drafting table. The measured anthropometric data are: sitting elbow height to the ground, arm reach, twice of the arm reach and desktop inclination angle.

In this research study, an innovative and ergonomically suitable drafting table is proposed. The proposed drafting table which would accommodate 90% of the target population has many ergonomic features including adjustability based on students' anthropometric measures by automated mechanism with three flexible joints. The ergonomic design the modified drafting table is proposed. The table height is 67 ± 8 cm, table width is 152 ± 15 cm, table depth is 84 cm and adjustable desktop angle is 0° - 45°.

The overall design structure of the drafting table and its testing and validation is also highlighted within the scope of this research. From the survey, it is noticed that most of the students strongly recommend the newly designed drafting table. Achieving this, will help to create safety, comfort, adaptability, suitability, free Musculoskeletal Disorders (MSDs), and ultimately satisfaction to users.

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