ORIGINAL ARTICLE

Redesign and Fabrication of a Folding Ergonomic Laptop Desk for College Students

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Abstract

Background: Awkward posture during work is one of the most critical risk factors for musculoskeletal disorders. A laptop desk fitting with users' body dimensions plays a crucial role in maintaining proper posture and reducing musculoskeletal disorders. This study aimed to redesign and fabricate a folding ergonomic laptop desk for college students.

Methods: In this experimental applied study, two hundred and seven college students were considered participants to design an ergonomic laptop desk and fifty students for posture evaluation. Six anthropometric dimensions were measured: height, the height of elbows in the sitting position, elbow-elbow breadth, the length and height of both knees in the cross-legged sitting posture, and the length of the elbow-fingers. Then, two best-selling laptop desks were selected and the RULA method assessed laptop users' posture. Finally, using students' anthropometric dimensions (n=207), a new laptop desk was designed and built in 2017.

Results: The height of our designed laptop desk is adjustable (range of 20-28 cm), with a variable inclination of the desk (0- 34 degrees). It is possible to shorten or lengthen desk legs (48-72 cm), and a special plate of the mouse (19×46 cm) supports both elbows on the sides of the desk. RULA method showed action level 3, which required early change in desks 1 and 2.

Conclusion: Applying user›s and expert opinions, measuring users› body dimensions, and applying those dimensions in design and construction can play a significant role in improving and correcting the laptop›s desks so that it could result in suitable posture in students.

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Introduction

Nowadays, with increasing development in all scientific and research fields, it is not possible to carry out many tasks without the aid of a computer. Furthermore, advancements in technology and micro-processes, battery technology, and improvement in storage capacity have resulted in the creation of portable computers, which are also referred to as laptops.[1,2] Given the nature of the laptop in terms of its portability, lightweight, and processing capabilities similar to desktop computers, it has become popular among people, especially students in recent years.[3] A study conducted on 154 students in the United States indicated that 88% of people preferred laptops to desktop computers to perform their tasks.[4] Students frequently prefer to sit on the floor rather than behind a desk or office chair habitually because it would be more convenient to use the laptop in various positions. Such people maintain an inappropriate physical posture while using a laptoplying on the floor and placing the laptop on their legs or other objects. The study carried out by Rafiei et al. on 300 students in Tehran confirms the mentioned statement.[5] Thus, awkward postures cause discomfort in stressed organs and lead to chronic disorders in long time exposure.[6,7] Bubric reported that over 53% of participants experienced musculoskeletal

discomfort while using a laptop computer.[8] In addition, previous studies on musculoskeletal disorders (MSDs) in students who used laptops indicated the greatest discomfort in the students' neck, shoulders, and wrists.[5, 6] Also, results showed a high prevalence of neck pain (69.19%) due to laptop use among students.[9] Working with a laptop without using a desk can increase neck discomfort (25-50%) and back pain (15-30%).[10] So, there was a positive correlation between differential patterns of laptop use and musculoskeletal discomfort.[9]

A study by Moffet et al. demonstrated that a workstation is one of the factors affecting physical variables of the body, so people who used laptops on their legs reported more musculoskeletal pain than those who sat behind a desk.[11] Therefore, incompatibility of the bodily dimensions of students with laptop desks in the position of cross-legged sitting will aggravate musculoskeletal disorders in the limbs involved while working with their laptops.

The product must be appropriately designed to be suitable for all people, considering its adjustability and sizes. In order to optimize such decisions, we require anthropometric characteristics of the user population to create an effective match between the product and the user.[12]

Inappropriateness between technology and users has negatively impacted work efficiency and resulted in a high rate of musculoskeletal disorders in workplaces.[13] The tools and facilities could be designed and applied safely for the whole life considering anthropometry science.[14, 15] Therefore, it is essential to pay attention to user features in order to design ergonomically friendly products and decrease musculoskeletal disorders.[16]

An awkward posture is one of the most important MSDs risk factors in workstations.[17] RULA features in assessing posture, force, and repetitive movements identify MSDs risk factors in the upper extremities during work.[18]

The main issue in obtaining a proper design is that human beings are significantly different from one another in terms of various biological aspects such as their physical dimensions, mentality, and intelligence.[19, 20] Mostly, designers and engineers must ensure comfort, safety, efficiency, and health of users during products design It should be better to consider capabilities and limitations of the human physical and mental abilities in the design and production of such equipment.[21] Therefore, this study aims to redesign and fabricate a folding ergonomic laptop desk for college students. So, the innovation of the present study is to discover the problems of existing laptop desks from the perspective of students and professionals and use their opinion in the construction of an adjustable and folding laptop desk which would be usable by both hands based on anthropometric dimensions of students.

Methods

Samples

The university ethics committee has authenticated this experimental applied study under the code of IR.QUMS.REC.1395.186. This study was carried out on students living in Qazvin University of Medical Sciences dormitories in 2017. After informing the students, those who showed their willingness to cooperate entered the study by obtaining verbal consent. Based on the previous studies,[19] the sample size was estimated at 185 participants, considering the 95% confidence interval and standard deviation of 0.347 mm. The subjects were selected by simple classification-randomization among students. Regarding the students' interest in participating in the study, 207 people were analyzed.

$$N = \frac{(Z^2 \times \delta^2)}{d^2} = \frac{(1.96^2 \times 0.347^2)}{0.05^2} = 185$$

Also, Based on the previous studies[5], the sample size to evaluate students' posture while using laptop desks was estimated to be 48 participants, taking into account the 90% confidence interval and prevalence of 77%. In order to obtain more accurate data, two more participants were added to the estimated samples. So, the final sample was about 50 participants. The sample data was collected in dormitory by simple random sampling.

$$N = \frac{\left(Z_{1-\frac{\alpha}{2}}\right)^2 \times P(1-P)}{d^2} =$$

$$\frac{(1.64)^2 \times 0.77(0.23)}{0.1^2} = 47.63 \sim 48$$

Measurement of Anthropometric Dimensions in Students (n=207)

In this study, six anthropometric dimensions of the students were measured including height, elbow height while sitting, the width of elbows, length of both knees in a cross-legged sitting posture, the height of both knees in a cross-legged sitting posture, and the elbow-fingertip length (Figure 1).[12, 22-24] Anthropometric dimensions were measured using tape or static anthropometer device (Two vertical rectangular plates with a horizontal floor that the length and width of each plate was 135 cm and 200 cm, respectively with accurately measured 1 millimeter, and an adjustable chair), digital calipers, Marcal 18 EWR, with a movable jaw (with measuring range 0-500 mm and 0-1000 mm with resolution 0.01 mm), a goniometer with an accuracy of one degree, and a special scale for weight. At the time of measurement, the individuals had minimal clothing and were assessed in a sitting position with their heads resting on the anthropometer plate.

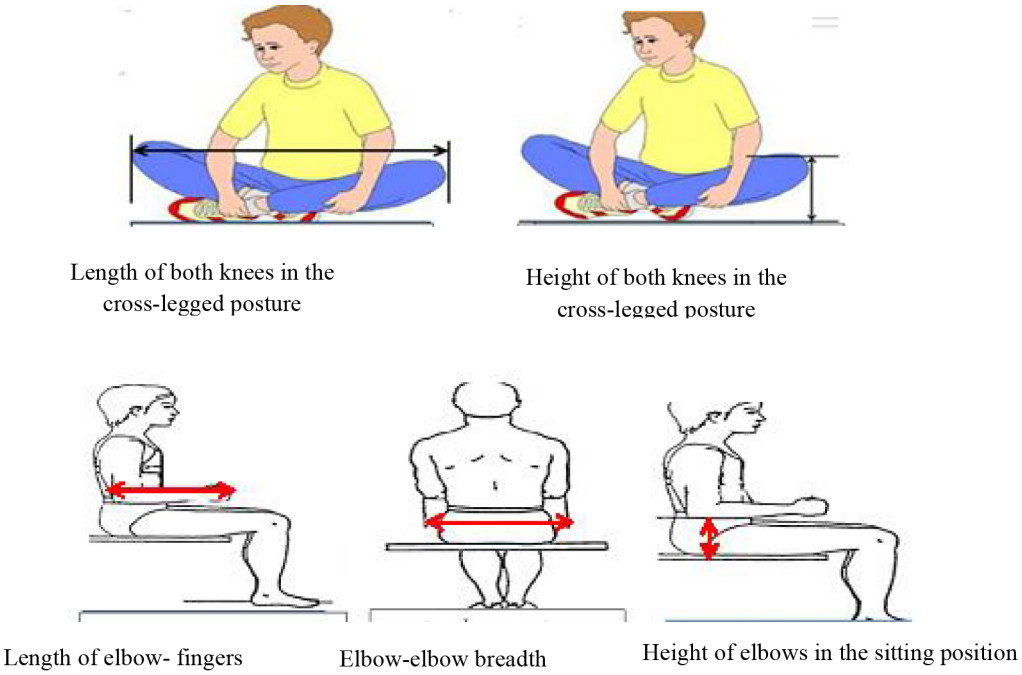

Figure 1: Measured anthropometric dimensions

Determining the Dimensions of Current Laptop Desks and Examination of Their Problems

The dimensions of the current best-selling desks on the market (Figure 2) were measured, which include the total length and width of the surface on the desk, the longitudinal distance of the desk legs from each other, adjustable desk height from the level on the desk and adjustable desk height from the level under the table. Appropriate percentiles were considered to compare students' anthropometric dimensions with the current desks' dimensions (Table 1).

In the next stage, the ergonomic issues of laptop desks used in cross-legged sitting positions were identified by the researcher, a group of ergonomics and occupational health experts, and industrial designers. Then, the ergonomic suggestions from students were gathered fora better design of existing laptop desks. Furthermore, ergonomic issues and students' suggestions were discussed in a symposium with a group of well-known experts, and the initial design was drawn.

Posture Analysis While Utilizing Current and Designed Laptop Desks (n=50)

According to Tirgar's study, students usually spend more than one hour working on computer workstations.[25] Therefore, all laptop desks were used at least one hour before analyzing participants' postures by RULA: Rapid Upper Limb Assessment method. RULA method assesses the posture of the different regions of the body, especially in the upper extremities, force or load, and muscle activity (static posture or repetitive movements).[18]

Figure 2: The current best-selling desks on the market

Generally, it is common to classify and assess all the body parts in two groups by the RULA method. These groups include group A (upper limbs including shoulders, elbows, wrists, and hands) and group B (neck, trunk, and legs).[26] Each group was analyzed and scored separately based on the table method. Following that, repetition and force scores were considered to calculate the final RULA score (Figure 3).[27]

The priority level of corrective action of the RULA method is demonstrated in Table 2.

Design and Fabrication

Experts' and students' corrective suggestions were applied to design a new desk in the VISIO Microsoft Office environment. First, the initial sketch was drawn according to an appropriate percentile of anthropometric dimensions in Table 1. Then, the prototype of the laptop desk was made using double-layer cartons and wood.

Following that, based on the expert group's decision and troubleshooting, the wooden laptop desk was constructed.

Table 1: Properties percentile for each anthropometric dimension in designing the laptop desk

Dimension of the body	Properties percentile	Desk parameter
Length of both knees in the cross-legged posture	5-95	Longitudinal distance of the desk legs from each other
Height of both knees in the cross-legged posture	5-95	Adjustable desk height from the level under the table
Height of the elbows in the sitting position	5-95	Adjustable desk height from the level on the desk
Elbow-elbow breadth	95	The total length of the desk
Length of the elbow- fingers	95	Width of mouse handles

Table 2: Interpretation of the final score in the rapid upper limb assessment method

The final score	The priority level of corrective action	Interpretation
1-2	1	Acceptable posture
3-4	2	Further investigations, changes may be needed
5-6	3	Further investigations, change soon
7	4	Investigate and implement change

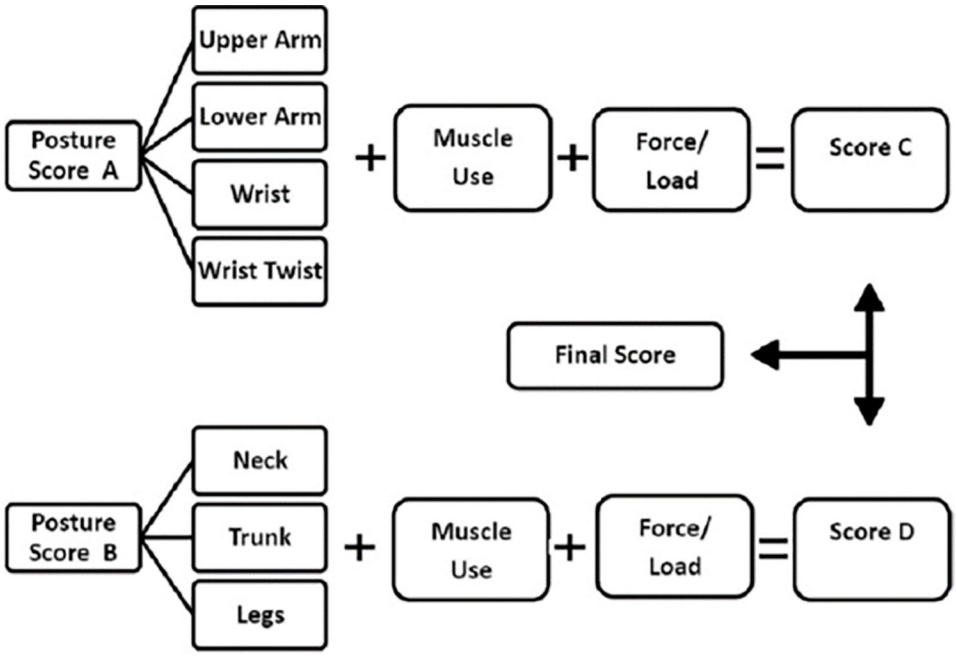

Figure 3: Scoring by the RULA method

Result

Demographic Characteristics

The results showed that the mean and standard deviation of the age for the students who participated in anthropometric dimensions measurement (n=207) and those who used laptops to evaluate posture (n=50) as 20.82±1.56 and 21.72±2.38 years, respectively. Other demographic characteristics of the subjects have been presented in Table 3.

Current Laptop Desks Problems

Our study showed that there were major problems in the first current laptop desk, including lack of a paper holder, lack of adjustability of desk legs, no special mouse plate, Lack of ability to adjust the inclination of the laptop and mouse plate separately, having sharp edges on the desk, and no elbow support for the rest when typing or working with the mouse.

In addition to the problems mentioned above, there were other problems in the second current laptop desk such as fixed special mouse plate, lack of special mouse plate for left-handed operators, adjustable laptop plate in just two inclinations of 0 and 27 degrees and of its failure to attract operators who like having desks with adjustable height.

Anthropometric Dimensions of Fabricated Laptop Desk

The anthropometric dimensions regarding the length of both knees in the posture of cross-legged sitting have the 5th percentile of 48.85 cm and the 95th percentile of 70.26 cm. Other characteristics regarding the anthropometric dimensions have been presented in Table 4.

According to Figure 4, the total surface length of the constructed table was measured to be 90 cm. In addition, this table features 9 inclinations with

Table 3: Demographic characteristics of the participants (n=207) and current laptop desks users (n=50)

Variable		Participants (n=207)		Laptop users (n=50)	
		Number	Mean±SD or Percent	Number	Mean±SD or Percent
Age (year)		207	20.82±1.56	50	21.72±2.38
Height (cm)		207	168.14±9.01	50	168.92±8.37
Weight (Kg)		207	62.78±11.45	50	63.58±11.16
Sex	Male	82	39.6	17	34
	Female	125	60.4	33	66
Field of Study	Operation room	20	9.7	4	8
	Occupational health	44	21.3	11	22
	Environmental Health	17	8.2	4	8
	Public health	15	7.2	1	2
	Nursing	20	9.7	5	10
	Medicine	4	1.9	2	4
	Dentistry	5	2.4	2	4
	Laboratory sciences	17	8.2	2	4
	Medical emergencies	21	10.1	1	2
	Midwifery	12	5.8	5	10
	Healthcare management	20	9.7	11	22
	Anesthesia	12	5.8	2	4

Table 4: Anthropometric dimensions in the students (Cm)

Anthropometry Dimension	Mean±SD	Minimum	Maximum	5ile	50ile	95ile
Length of both knees in the cross-legged posture	58.17±6.44	41.35	81	48.85	58.20	70.26
Height of both knees in the cross-legged posture	23.72±2.50	15	33	20	23.50	28
Height of elbows in the sitting position	24.50±2.84	17	36	19.20	24.50	29
Elbow-elbow breadth	41.59±4.80	25.53	56.15	35.17	40.92	51.09
Length of the elbow-fingers	44.37±3.23	34.20	52.36	39.30	44.15	49.76

ile: Percentile

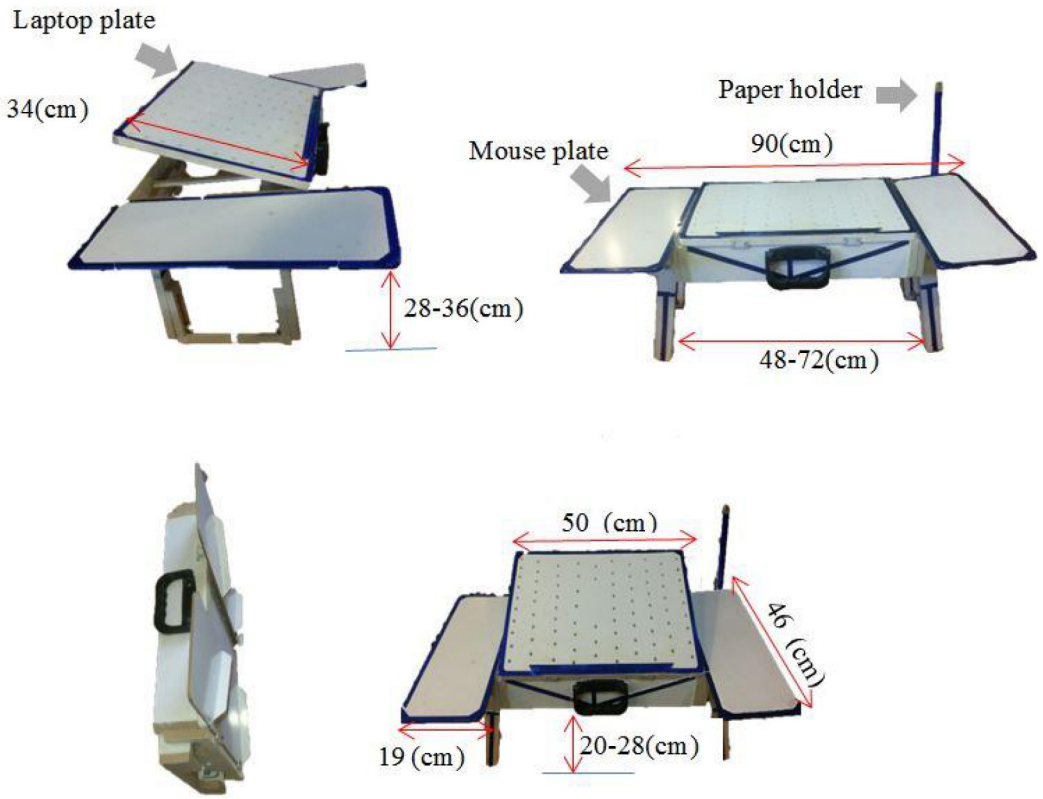

Figure 4: Laptop desk designed and built (from a different perspective)

intervals of 4.25 degrees. The other dimensions of the constructed table have been presented in Table 5 and Figure 4.

Comparison of Fit between Students' Anthropometric Dimensions with Current and Fabricated Laptop Desks

The results of matching the anthropometric dimensions of students with the dimensions of the desks showed that the length of both knees in the cross-legged posture with the longitudinal distance of the desk legs from each other in desks 1, 2, and fabricated ones were 32.4%, 61.8%, and 95.7% fit, respectively.

However, two types of the most common laptop desks on the market had anthropometric proportions of about 32% in only three anthropometric dimensions, and our fabricated laptop desk had a proportion of more than 70% in four anthropometric dimensions (Figure 5).

The Corrective Action Priority Level of Various Laptop Desks

The level of corrective action 2 showed that further investigation and changes may be needed in desks 1, 2 and fabricated desks with a rate of 82%, 92%, and 74%, respectively, which means that the fabricated desk has a more suitable posture for users (Figure 6).

Discussion

Using laptops has resulted in musculoskeletal disorders in users, especially among students. On the other hand, designing a new product or rectifying the design of a product is mostly based on a clear understanding of users' needs and the demands of operators. Furthermore, one of the ways to improve the design and increase user health and satisfaction is to identify, collect, and solve the problems of existing desks used by users. Therefore, the present study has tried to identify the problems of best-selling laptop desks used in the cross-legged sitting posture through students' and experts' opinions. In

Table 5: Dimensions of laptop desk designed and built and current laptop desks (Desk 1 and 2)

Dimensions of the laptop desk		Size (Cm or Degree)		
		Made desk	Desk 1	Desk 2
The total length of the surface on the desk		90	61	63
The total width of the surface on the desk		46	34	35
Longitudinal distance of the desk legs from each other	Min	48	54.5	60
	Max	72	54.5	60
Adjustable desk height from the level on the desk	Min	28	20	26
	Max	36	31	26
Adjustable desk height from the level under the table	Min	20	18	18
	Max	28	29	18
Adjustable laptop plate inclination	Min	0	2.6	0
	Max	34	7.8	27
Adjustable mouse plate inclination (Left and right)	Min	0	2.6	0
	Max	0	7.8	0
Laptop plate dimensions	Length	50	-	46
	Width	34	-	35
Mouse plate dimensions (Left and right)	Length	19	-	17
	Width	46	-	35

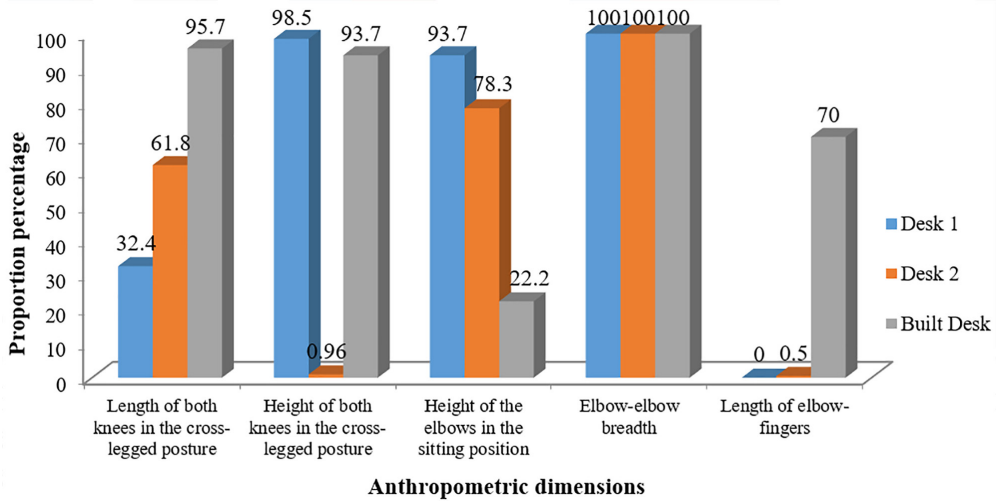

Figure 5: Percentage of fit of anthropometric dimensions of students with the dimensions of laptop desks

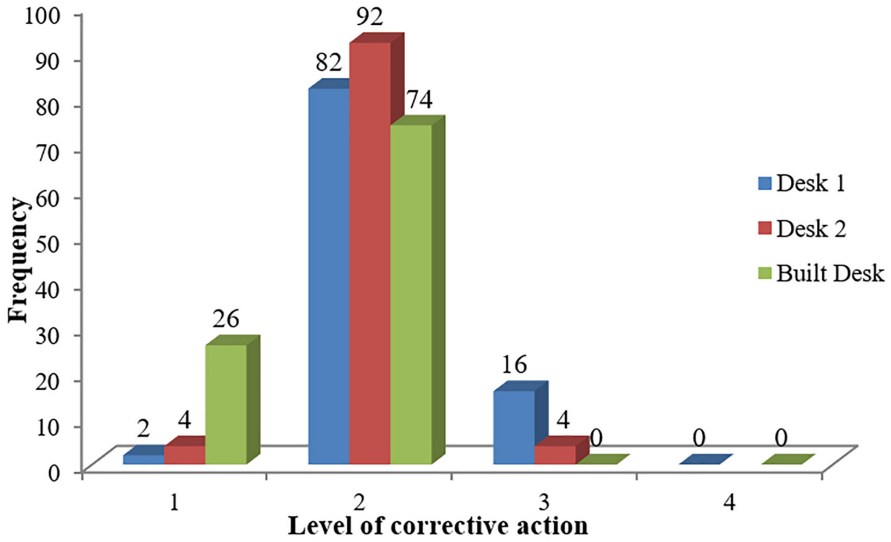

Figure 6: Frequency of RULA method corrective action level on laptop desks

addition, anthropometric dimensions of students have been used to optimize a laptop desk ergonomically to improve students' posture in cross-legged sitting.

In this study, the problems of purchasing two desks such as lack of adjustability in desk legs , no special mouse plate, lack of paper holder, lack of adjustability in the inclination of the laptop and mouse plates separately, the sharp edges of the desk surface, not-being foldable and not-being portable showed that it would be necessary to consider and solve the problems above in new laptop desk design. Our study is similar to the Purnomo study, which designed a student laptop desk to identify the problem, find ideas and recommendations, implement, and evaluate recommended solutions.[10] The results of students' posture evaluation when using desks 1 and 2 showed that the problems in the desks mentioned above, lead to awkward posture in the neck, trunk, arm, and wrist. So, further investigation and change may be needed (action level 2), or a change soon (action level 3) is required. This result is in good agreement with the Gautam findings[28] and Kaur's, which is supported by RULA scores ranging from 3–6 (action level 2, 3), indicating risk at the workstation.[29]

Users, professors, and experts' opinions concerning our new fabricated desk led to a more acceptable level of corrective action (action level 3=change soon 0%) compared with existing desks. So, the risk of developing musculoskeletal disorders and fatigue would be decreased with eliminating previously mentioned problems in existing desks, and operators' posture would be improved while using the new laptop desk.

Few studies have been carried out on the design and fabrication of laptop desks in the cross-legged sitting position based on the anthropometric dimensions of students in Iran or other parts of the world. Therefore, it was hardly ever possible to compare the results of the present study with other similar studies.

In the present study, the anthropometric dimensions of male and female students according to the 5th and 95th percentiles were used to design different parts of the laptop desk in the cross-legged sitting posture, which is very close to the anthropometric data of Mououdi et al. So, it indicates the accuracy of measuring dimensions among students in this study.[24]

Studying the proportionality of students' anthropometric dimensions with the dimensions of desks showed that the longitudinal distance of the desk legs from each other in desks 1 and 2 fit about one-third to two-thirds, respectively. It means these desks could not be easily used on average by almost half of the users in the cross-legged posture. On the other hand, participants could easily operate our new fabricated desk due to the adjustability of the desk legs from each other. Moreover, in desk number 2, the space under the desk for the knees is suitable for almost 1% of people due to the fixed height of the desk. In contrast to the existing desks, the fabricated one would be more applicable to most users, as it is possible to adjust the knee space, which is in line with the range of accommodation distance between the desk bases in the study conducted by Mououdi[24] et al.

In the dimension of the height of both knees in the cross-legged sitting posture, desk 2 had the least adaptation to the anthropometric dimensions. In contrast, our fabricated desk has a lot of matching, consistent with the study of Mououdi[24] et al. Musculoskeletal pain, including neck and upper back pain, can be reported during laptop use when working at the unsuitable -height table.[30]

There was no good fit between the height of the upper surface of the fabricated desk and the height of the users' elbows such that fit proportionality was measured to be one-five. Moreover, it should be noted that this proportion in the new laptop desk was less

than other existing desks. The reason behind this finding is that the distance between the upper and lower surface of the fabricated desk was thicker, about 8 cm, in order to fold legs and special mouse plates from the two sides of the desk in such a manner that it could be handled as a portable desk.

The lowest proportion percentage was measured between the minimum length of students' elbow-fingertip with the width of best-selling existing desks numbers 1 and 2. However, this proportionality was remarkably increased in the newly built desk.

The built of a laptop desk is considered superior to laptop desks available on the market as opinions of students and professionals were taken into account. The fact that it has features such as being adjustable (in terms of the desk height, the distance between the desk legs, and the special laptop plate) enabled working with the mouse with both hands, having elbow support, being equipped with a paper holder during typing, reducing neck disorders, and easy and convenient movement in a bag. A study carried out by the first author and colleagues evaluated student satisfaction rate with the best-selling laptop desks indicated that laptop desks that are close in design and capabilities to this constructed desk are more satisfactory.[31]

Conclusion

As far as the design and construction elements allow, the present laptop desk is made based on the 5th and 95th percentile anthropometric dimensions (length, width, and height) so that the final product provides more strength and durability. It seems that using our fabricate desk might be effective in reducing MSDs and their long-time complaints among students. Thus, it would be recommended to consider a broad age group with different working postures in future studies to provide more comprehensive results that could be generalized to wider society. Furthermore, the existing shortcomings can be modified by considering the ergonomic suggestions of designers and users, so the laptop desk would be improved ergonomically. As a result, students' postures would be maintained in a suitable position.

Advantages and Limitations of This Study

One of the advantages of the present study was to use the opinions of students and ergonomics experts to eliminate the shortcomings of existing laptop desks and use their suggestions to improve the design of the built laptop desk. In addition, using students' anthropometric features in designing desk dimensions, adjustable and folding parts of the table, and making them usable for left-handed and right-handed users are other advantages of the present study. On the other hand, the limitation of the study included using few available laptop desks and the lack of research among all people (with different ages) who use laptop desks.

Conflicts of interest: None declared.

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