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Ergonomic Evaluation of the Angle of Abduction in Laptops Environment

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Abstract
Laptops in 21st century are an integral part of every professional in vivid fields. Off late there has been emergence of several ergonomic injuries such as repetitive strain injuries (RSIs) due to extensive usage of laptops, which can be closely linked with applied force and postures. This study investigated the effect of various angles of keyboard on the applied force and motor action plus response time while performing five distinct tasks. On the basis of literature two different laptops were selected for performing different tasks. For each case the three levels of platform angle were considered as 0°, 5°, and 10°. Male subjects were selected to perform five distinct tasks for each platform angle for both laptops. The force applied (in milli-volts) and the motor action plus response time (milli-seconds) were recorded using an oscilloscope. The data collected were analyzed through ANOVA using MINITAB software. The abduction angle with the least mean response time and applied force were considered as the best from ergonomics viewpoint. The ANOVA results showed that the angle of abduction for both laptops (small and large) do have significant effect on applied force but not on motor action plus response time. The analysis of results indicate that 10° angle of abduction in case of small laptops should be applied to minimize musculoskeletal disorder and repetitive strain injuries.
Research relevance: This work suggests that those responsible for the function and operation of laptops would have to redesign the system to reduce injuries, as far as musculoskeletal disorder, repetitive strain injuries and other related problems are concerned. The present work can be quite useful for the system designers of tomorrow.
Keywords: ANOVA, Laptops, Force applied, Motor action time, Response time, Abduction angle.

I. Introduction

Laptops are nowadays commonly used in a variety of settings, such as at work, in education, and for personal multimedia. When it comes to laptops, the number of them in use has risen in India over the last few years. Almost one-half of American adults own a laptop computer. In contrast to desktop computers, which are typically utilized in a seated position, the portable nature of laptop computers allows for a variety of postures during usage. Given the popularity of the laptops, many researchers have analyzed its usability, including comparing the performance of operating tasks, different sized laptops, different age groups, and the design considerations for laptops. With the convenience of laptops increasing frequency and duration of use, the design characteristics of the laptops give rise to concerns regarding their impact upon body mechanics and the musculoskeletal system. The nature of laptop use may facilitate the potential for the development of the musculoskeletal symptoms. With more and more people owning laptops and spending greater amounts of time emailing, surfing the net and e-reading, physiotherapists have seen a significant increase in hand held device related injuries.

The posture often assumed while using a laptop is unnatural and can result in number of overuse and posture-related aches and pains. The spine in not designed to be held in awkward postures for long periods of time, in such small area. It is important to be aware of the risks associated with using the laptop to take healthy steps and safety measures to avoid potential injury. Many ergonomically designed products are also used or recommended to treat or prevent such disorders, and to treat pressure-related chronic pain. One of the most prevalent types of work-related injuries is musculoskeletal disorder. Work-related musculoskeletal disorders (WMSD) result in persistent pain, loss of functional capacity and work disability, but their initial diagnosis is difficult because they are mainly based on complaints of pain and other symptoms. Cognitive ergonomics is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system.

Anthropometry is an important field used in ergonomics. Ergonomists use anthropometric factors such as angle of abduction to optimize human interaction with equipment and workplace. Anthropometry can be referred to as the measurement of the human individual. An early tool of physical anthropology, it has been used for identification, for the purpose of understanding human physical variations, in palaeoanthropology and in various attempts to correlate physical with racial and psychological traits. Today anthropometry plays an important role in industrial design, clothing design, and architecture where statistical data about the distribution of body dimensions in the population are used to optimize products. Changes in lifestyles, nutrition, and ethnic composition of populations lead to changes in the distribution of body dimensions (e.g. the obesity epidemic), and require regular updating of anthropometric data collections. Today, anthropometry is performed by several measuring instruments like 3-D scanners, baropodographic devices and neuro imaging.

Text entry is a fairly complex process, involving visual, tactile, motion, memory, learning, and other cognitive functions. Moreover, they belong to different levels of cognitive processing. The process of text entry is subject to the biomechanical constraints of the hand. Whether perceptual and cognitive concepts are suitable will dominantly affect the user's final performance, such as the response time and accuracy rate (Khan 2014a; Khan 2014b; Khan; 2014c; Khan 2014d; Khan and Asghar 2011; Khan and Asghar 2010). Therefore, if a new input method is to be designed, ergonomically designed operation and cognitive compatibility must be emphasized. According to Fitts' law concerning motion execution (Fitts, 1954), the keyboard layout should be arranged so that a finger travels the minimum distance necessary, allowing text entry efficiency to be improved. Realizing that the procedural memory has a subtle effect on users, many researchers have employed the transfer effect of learning to conduct relevant designs or studies (Carey, 2001; Jacob and Brad, 2008; Liang and Chang, 2009). Further, according to the findings regarding the stimulus-response compatibility effect (SRC effect), different hand postures will affect encoding patterns, which will vary with the relationship between visual stimulus and finger reaction (Ehrenstein et al., 1989; Lyons et al., 2004; Lyons et al., 2006). Input accuracy is critical to usability of laptops because people frequently use them for a variety of purposes such as personal information organizers, communicators, business appliances, and entertainment devices. High input accuracy enables users to finish their tasks quickly with few errors. Thumb length might affect users` reach ability of the keys whereas users with large thumbs might find it cumbersome keying in messages via the tiny keys (Balakrishnan and Yeow, 2008). Work-related Musculo-Skeletal Disorders (WMSDs) result in considerable costs to industry annually (Khan 2012). Various studies shows that risks of WMSDs are associated with certain jobs and certain work related factors compared with other population groups not exposed to risk factors. It is necessary to study repetitive exertions combined with tapping force for wrist abduction angle. So, the present study was designed to look at the effects of repetitive force exertion for abducted wrist postures.

II. Problem formulation

On the basis of the literature reviewed, it can be observed that majority of the people using laptop feel discomfort irrespective of its size. In the past studies, ergonomists studied different postures while using laptop that are suitable as well as comfortable to fit the body and the mind of the user. In this study, it was observed that the angle of abduction and different tasks performed while using the small and large laptops are the important parameters that affect the human performance in terms of response time and the applied force. In this work two sets of studies were undertaken on both (small and large size) the laptops. Based upon surveys, three angles of abductions 0^0, 5^0 and 10^0 were considered for developing an ergonomic database. The studies have been formulated as follows:

In terms of null hypothesis, the problem could be formulated as:

a. The angle given to the laptop base does not have a significant effect on laptop users' performance in terms of response time.
b. The angle given to the laptop base does not have a significant effect on laptop users' performance in terms of force applied.
c. The two laptop sizes do not have a significant effect on laptop users' performance in terms of response time.
d. The two laptop sizes do not have a significant effect on laptop users' performance in terms of force applied.

III. Methodology

The experimental hypothesis stated in section 2 was tested through a set of experimental investigations. For conducting the investigations, an experimental setup (figure 1) was designed which is summarized as follows:

Experimental investigations were conducted in an isolated environment. The light intensity level was kept in the range of 85 lux. The setup comprised of the following sub system:

a. Large Laptop (LL) (HP Pavilion g series, 15.6")
b. Small Laptop (LL) (Acer Aspire One ZE7 10.1")
c. Mica plate with piezo-electric sensor attached
d. Oscilloscope
e. Wooden angle wedges

One of the important requirements for conducting the experimental investigation was the selection of subjects participating in the study. The present experimental investigation was carried out with a group of 10 subjects of the same finger, wrist and elbow lengths and the same age group. All the subjects had prior experience with using a laptop. The wooden wedges were used to give the angle to the laptop base and thus variable wrist abduction angles (figures 2 and 3). Performance of each subject was recorded on the basis of response variables i.e. force applied and motor action response time through oscilloscope. Mica plate attached with piezoelectric sensor was used to station the laptops for measuring the human performance (figure 4) at different angle of abductions provided through angle wooden wedges.

Figure 1: Experimental setup

Figure 2: Wooden wedges for 5^0 wrist abduction

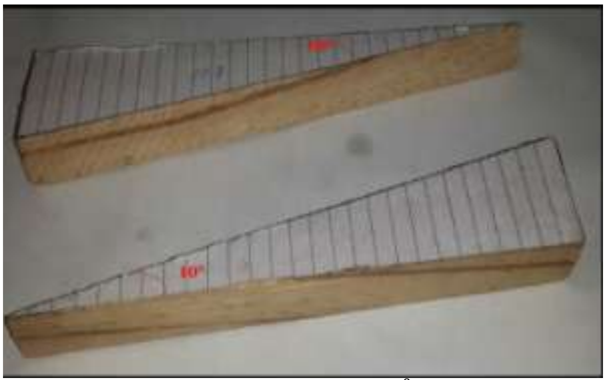

Figure 3: Wooden wedges for 10^0 wrist abduction

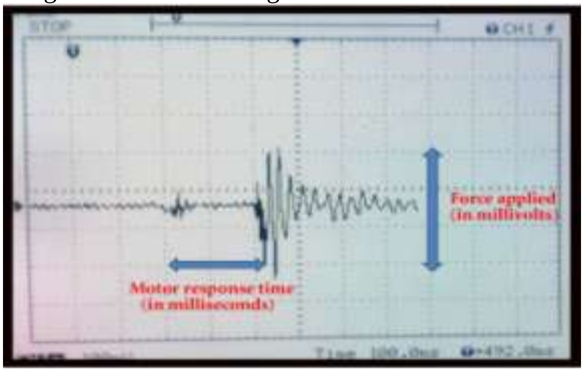

Figure 4: Oscilloscope readings showing force applied on Y-axis and response time on X-axis

To evaluate the laptop users' performance in context with the wrist abduction angle for both small and large laptops, a set of experimental investigations were carried out as follows:

a. The angle of the base of the laptop was varied by changing the inclination of mica plate with the help of wooden wedges.
b. The laptop was placed above the sensor point connected to the mica plate.
c. The subjects were asked to keep their fingers at the initial reference point i.e. 'ctrl' key.
d. A pre-recorded voice signal 'start' was given to the subject to perform each task by moving the forefinger from the reference point. The five target keys for the respective five tasks were 'P', 'Q', 'Z', '?' and 'G' respectively.
e. After completion of each task i.e. key press, the force applied and motor action response time was recorded through the oscilloscope.
f. The performance of each subject was recorded separately at angle of abductions 0^0, 5^0 and 10^0 at five distant tasks for both small and large laptops.
g. Each of the subjects was imparted instructions so as to get complete familiarity with the tasks and postures for using both small and large laptops.

The collected data through the experimental observations were analyzed by analysis of variance (ANOVA) using the MINITAB software and is presented in the next section.

IV. Experimentation and Results

Tables 1 through 6 presents the average force applied in milli-volts and average motor action response time in milli-seconds for large laptop (LL) and small laptop (SL) at three wrist abduction angles namely 0^0, 5^0 and 10^0 respectively.

4.1 Large laptop

Table 1 -Experimental observations for 0^o angle of abduction for five different tasks

Subject	Force applied (mean) (in milli-volts)	Motor action response time (mean) (in milli-seconds)
1	240	382
2	312	408
3	536	352
4	444	380
5	476	432
6	536	444
7	304	400
8	420	444
9	336	448
10	328	444
Mean	393.2	413.4

Table 2 -Experimental observations for 5^o angle of abduction for five different tasks

Subject	Force applied (mean) (in milli-volts)	Motor action response time (mean) (in milli-seconds)
1	184	368
2	304	388
3	584	328
4	444	418
5	552	460
6	600	432
7	368	380
8	296	464
9	320	452
10	472	476
Mean	412.4	416.6

Table 3 -Experimental observations for 10^o angle of abduction for five different tasks

Subject	Force applied (mean) (in milli-volts)	Motor action response time (mean) (in milli-seconds)
1	272	404
2	584	404
3	624	356
4	360	388
5	496	440
6	424	520
7	256	364
8	472	436
9	296	450
10	504	312
Mean	428.8	407.4

4.2 Small laptop

Table 4 -Experimental observations for 0^o angle of abduction for five different tasks

Subject	Force applied (mean) (in milli-volts)	Motor action response time (mean) (in milli-seconds)
1	164	360
2	176	368
3	196	280
4	280	368
5	280	408
6	100	408
7	92	316
8	220	468
9	148	328
10	156	440
Mean	181.2	374.4

Table 5 -Experimental observations for 5^o angle of abduction for five different tasks

Subject	Force applied (mean) (in milli-volts)	Motor action response time (mean) (in milli-seconds)
1	116	360
2	212	368
3	352	336
4	140	356
5	328	436
6	160	316
7	120	324
8	100	412
9	276	380
10	234	400
Mean	203.8	368.8

Table 6 -Experimental observations for 10^o angle of abduction for five different tasks

Subject	Force applied (mean) (in milli-volts)	Motor action response time (mean) (in milli-seconds)
1	112	320
2	236	300
3	308	280
4	164	432

5	200	456
6	156	540
7	116	348
8	120	372
9	152	384
10	236	388
Mean	180.0	382.0

Figures 5 through 8 presents bar graphs for mean response time and mean applied force for two experimental considerations interms of large and small laptops.

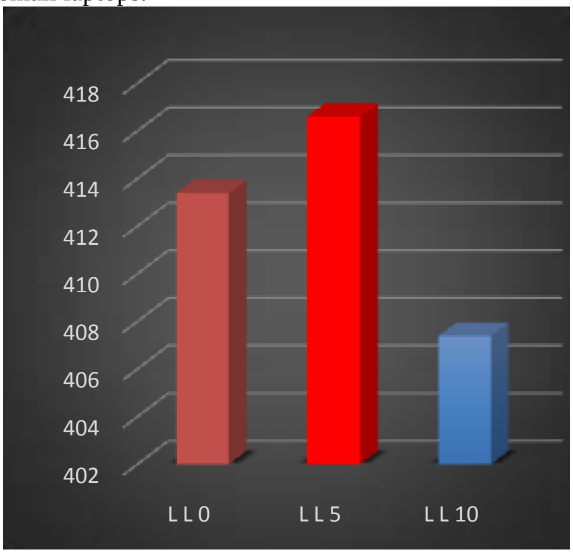

Figure 5: Bar graph showing mean response time on Y-axis for large laptop (LL) at angles of abductions 0^0, 5^0 and 10^0 respectively

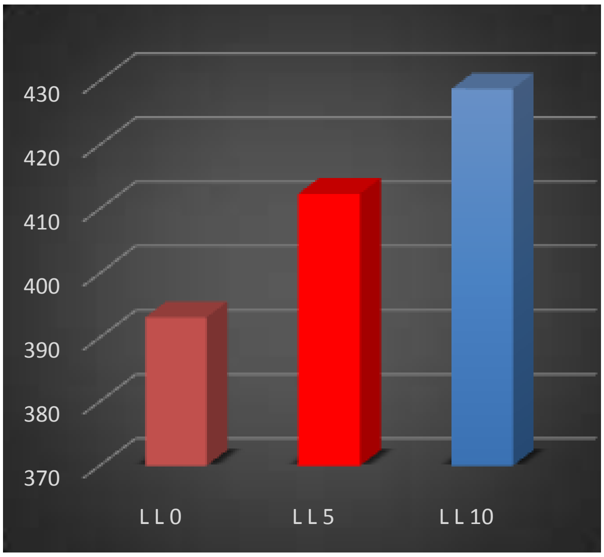

Figure 6: Bar graph showing mean applied force on Y-axis for large laptop (LL) at angles of abductions 0^0, 5^0 and 10^0 respectively

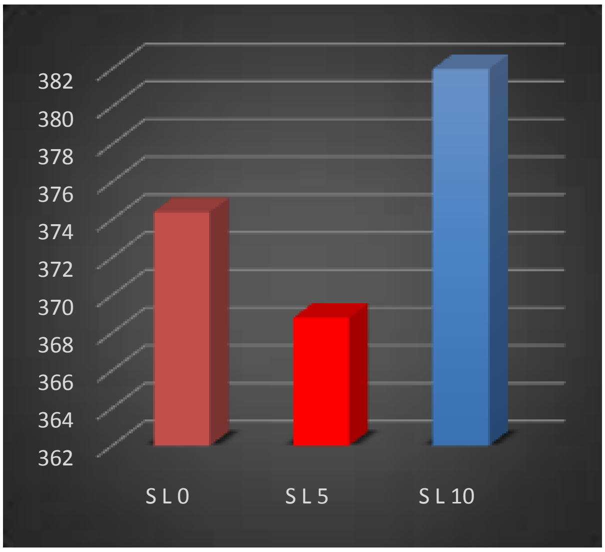

Figure 7: Bar graph showing mean response time on Y-axis for small laptop (SL) at angles of abductions 0^0, 5^0 and 10^0 respectively

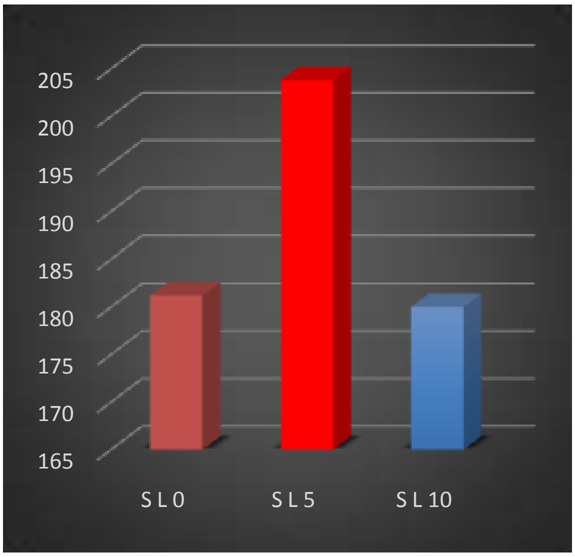

Figure 8: Bar graph showing mean applied force on Y-axis for small laptop (SL) at angles of abductions 0^0, 5^0 and 10^0 respectively

Analysis of variance (ANOVA) was carried out to know the significant effect of wrist abduction angle for both the small and large laptops over force applied and reaction time. For analysis, the force applied and response time were the response variables and six different conditions as given in table 7 were considered. The conditions were for the three abduction angles namely 0^0, 5^0 and 10^0. Further ANOVA was applied for checking the significance of the abduction angle with respect to the size of the laptops used (table 7). Over here also, the force applied and response time were the response variables.

Table 7 –Showing six conditions with three abduction angles and two conditions with two types of laptops with their degrees of freedom

		N
Conditions	L L 0 L L 5 L L 10 S L 0 S L 5 S L 10	30 30 30 30 30 30
Laptops	L L S L	60 60

Table 8: ANOVA table for force applied at six different conditions

	Sum of Squares	Degree of freedom	Mean Square	F	Sig.
Between Groups	756773	5	151355	14.24	.000
Within Groups	574127	54	10632		
Total	1330899	59			

Significance level at 0.05

Table 8 shows the ANOVA result through MINITAB software at six different conditions with force applied as response variable. Through analysis, the following conclusions are drawn:

(i) Null hypothesis has been rejected because the aggregate does not have the same force applied at the six different conditions considered (L L 0^0, L L 5^0, L L 10^0, S L 0^0, S L 5^0, S L 10^0).

(ii) Null hypothesis has been rejected because F_{ov}= 14.24 isgreater than [$F_{0.05}$ (5, 54)] ; cv = 2.393 obtained from using the values of degree of freedom (5, 54) [where ov = observed value and cv = critical value].

(iii) Null hypothesis has been rejected because P-value for F-value = 14.24 is found to be less than the set significance level i.e. a = 0.05.

(iv) The above results indicate that the null hypothesis was rejected and it was found that the different wrist abduction angles for both small and large laptops have a significant effect on the human performance interms of the force applied.

Table 9: ANOVA table for response time at six different conditions

Source	Sum of Squares	Degree of freedom	Mean Square	F	Sig.
Factor	22296	5	4459	1.49	0.207
Error	161241	54	2986		
Total	183537	59			

Significance level at 0.05

Table 9 presents the ANOVA result through MINITAB software at six different conditions with response time as output variable. Through analysis, the following conclusions are drawn:

(i) The aggregate does not have the same response time at the six different conditions considered (L L 0^0, L L 5^0, L L 10^0, S L 0^0, S L 5^0, S L 10^0).

(ii) Null hypothesis has been accepted because F_{ov}= 1.49 is lesser than [$F_{0.05}$ (5, 54)] cv = 2.393 obtained from using the values of degree of freedom (5, 54) [where ov = observed value and cv = critical value].

(iii) Null hypothesis has been accepted because P-value for F-value = 1.49 is found to be greater than the set significance level i.e. α = 0.05.

The above results indicate that the null hypothesis was accepted and it was found that the different wrist abduction angles for both small and large laptops do not have significant effect on the human performance interms of response time.

Table 10: ANOVA table for response time at three abduction angles with respect to type of laptops

Source	Sum of Squares	Degree of freedom	Mean Square	F	Sig.
Factor	20981	1	20981	7.49	0.008
Error	162555	58	2803		
Total	183537	59			

Significance level at 0.05

Table 10 shows the ANOVA results for various conditions interms of response time. Through analysis, the following conclusions are drawn:

(i) Null hypothesis has been rejected because the aggregate does not have the same response time at the six different conditions considered (L L 0^0, L L 5^0, L L 10^0, S L 0^0, S L 5^0, S L 10^0).

(ii) Null hypothesis has been rejected because F_{ov}= 7.49 is greater than [$F_{0.05}$ (1, 58)] cv = 4.009 obtained from using the values of degree of freedom (1, 58) [where ov = observed value and cv = critical value].

(iii) Null hypothesis has been rejected because P-value for F-value = 7.49 is found to be less than the set significance level i.e. α = 0.05.

The above results indicate that the null hypothesis was rejected and it was found that the different wrist abduction angles for both small and large laptops do have a significant effect on human performance interms of the response time.

Table 11 : ANOVA table for force applied at three abduction angles with respect to type of laptops

Source	Sum of Squares	Degree of freedom	Mean Square	F	Sig.
Factor	746827	1	746827	74.16	0.000
Error	584072	58	10070		
Total	1330899	59			

Significance level at 0.05

Table 11 presents the ANOVA results for various conditions interms of force applied. Through analysis, the following conclusions are drawn:

(i) Null hypothesis has been rejected because the aggregate does not have the same response time at the six different conditions considered (L L 0^0, L L 5^0, L L 10^0, S L 0^0, S L 5^0, S L 10^0).

(ii) Null hypothesis has been rejected because F_{ov}= 74.16 is greater than [$F_{0.05}$ (1, 58)] cv = 4.009 obtained from using the values of degree of freedom (1, 58) [where ov =

(iii) Null hypothesis has been rejected because P-value for F-value = 74.16 is found to be less than the set significance level i.e. $\alpha = 0.05$.

The above results indicate that the null hypothesis was rejected and it was found that the different wrist abduction angles for both small and large laptops do have a significant effect on human performance interms of the force applied.

V. Conclusion

Through the set of experimental investigations, an attempt has been made to develop a better understanding of human performance with respect to anthropometric factors and postures while interacting with a laptop. The first study explored the effect of wrist abduction angle having a significant effect on two performance parameters i.e. response time and force applied for both small and large laptops. The second study investigated the effect of two different laptops generally used while performing various tasks. In both the studies, performance of the laptop user was in terms of response time and force applied.
On the basis of results obtained the following concluding remarks are drawn:

(i) The angle of wrist abduction while using laptops has a significant effect over the force applied.

(ii) The results obtained for the large laptop was significantly different from small laptop for different abduction angles in terms of performance parameters, response time and force applied.

(iii) For large laptop, force applied was found to be least for 0^0 angle of abduction while response time was found to be minimum at 10^0 wrist abduction angle.

(iv) For small laptop, force applied was found to be least for 10^0 angle of abduction while response time was found to be minimum at 5^0 wrist abduction angle.

(v) Comparision of results indicate that the minimum applied force at keys was observed for small laptop with the angle of abduction 10^0 and minimum response time was observed for small laptop at 5^0 angle of abduction.

On the basis of experimental investigation, it is explored that the users should use small laptop at 10^0 abduction angle for ergonomically better performance and to minimize musculoskeletal disorder and repetitive strain injuries. Small laptop should be preferred over large laptops for better efficiency in use as investigated interms of response time. The results of this work may be directly applied to the practical field. Further studies may be considered using parameters like more wrist abductions, elbow abductions, and arm abductions and other anthropometric and environmental considerations.

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