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Ergonomic Design of a Computer Keyboard Layout for the *Jawi* Script

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ABSTRACT

Due to unavailability of a computer keyboard layout for the *Jawi* script, users of this script make use of the Arabic keyboard layout for typing texts in this particular script. Obviously, the layout of the Arabic script keyboard is not designed for the ancient writing of the *Jawi* script. Keeping this in view, a research was conducted to design a new keyboard layout suitable for the users of the *Jawi* script from an ergonomics point of view, and the outcome of the research is presented in this study. In order to design the *Jawi* script keyboard layout, the relative finger strengths of both male and female subjects were determined experimentally. The relative frequency of the characters and two special characters (full-stop and comma) that appeared in the script were determined by counting their presence in a large number of texts in the script that represent the workload of the fingers. The keys were rearranged in such a way that the workload of each finger was approximately matched with its relative strength. The newly proposed arrangement of the keys was not much different compared to the Arabic script keyboard layout, and hence it is convenient for users to switch between the layouts.

Keywords: Human computer interaction, keyboard layout, ergonomics, product design, the *Jawi* script

INTRODUCTION

Computer is used in various applications and tasks. In the Human-Computer-Interaction (HCI) system, keyboard is an important input device and primary mode for text entry (Shneiderman, 1992). The layout of the keyboard is therefore a crucial variable in determining the speed, accuracy, ease of learning, and efficiency of the interaction between the user and the computer (Hurlburt and Ottenbacher, 1992). Keyboard proficiency is developed in schools since it helps prepare students for the working world, where such skills are used to enhance productivity (Struck, 1999). Although QWERTY keyboard is widely used, many new keyboard layouts have been ergonomically designed to improve the efficiency of specific end users. However, the layouts have been designed merely on the basis of keys arrangements, rather than the shapes or geometries of the keyboard. Among the many keyboard layouts available, the most common design is the DVORAK layout. August Dvorak proposed it in 1932 (Preece *et al*., 1994). The layout is arranged on the basis of the frequency of the usage of letters and the frequency of the letter patterns together with the sequences in the English script. All vowels and the most frequently used consonants are on the home row (Preece *et al*., 1994). The DVORAK keyboard was evaluated by the US Navy in 1944. It was found that

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ج jim	ث tha	ت ta	ب ba	ا alif
ذ dzal	د dal	خ kha	چ cha	ح ha
ص shad	ش shin	س sin	ز zai	ر ra
غ ghain	ع ain	ظ dzo	ط tho	ض dhad
ك kaf	ق qaf	ڤ pa	ف fa	ڠ nga
و wau	ن nun	م mim	ل lam	ݢ ga
ي ya	ء hamzah	لا lam alif	ه ha	ۏ va
				ڽ nya

Fig. 1: Characters used in the Jawi *script*

typists had improved their relative level of typing efficiency using this keyboard (Tanebaum, 1996). Other keyboard layouts, such as ABCDE, were also designed but studies showed no advantage of this particular style over QWERTY (Shneiderman, 1992).

Although English is the most widely used language internationally, there are still many users who prefer using their own languages. According to Kaplan and Wissink (2003), Microsoft has provided many other keyboard layouts, which were specially designed for different languages/scripts that are either in the Roman scripts (Danish, French, German, Italian, Portuguese, Finnish, etc.), or non-roman scripts (Arabic, Greek, Russian, Tamil, Thai, Chinese, Japanese, and Korean, etc.). In addition, a computer keyboard layout for the Malay language has been proposed by the authors (Khan *et al*., 2006). However, an ergonomic keyboard layout has not been designed for the *Jawi* script, even though this language is used widely in the Southeast Asian countries like Malaysia, Indonesia, Brunei, Singapore, and Thailand. Since the total population of these countries is approximately 340 millions, a reasonably large number of people use the *Jawi* script in writing and typing. Consequently, a keyboard layout should be designed for the *Jawi* script for its users' benefits from the ergonomics point of view. Moreover, it is important to mention here that the *Jawi* script is similar to the Arabic script and it uses 36 characters (see *Fig. 1*).

This paper presents a design for a keyboard layout, specifically for the *Jawi* script in order to improve typing efficiency and enhance the work performance and productivity of its users. The keyboard layout was designed by taking into consideration the human factors and linguistic aspects. The relative strength of the fingers was determined for ergonomical reasons. This gave an estimate of the load that each finger could bear without fatigue. In addition, the relative frequency of each character and two special characters (full-stop and comma), that frequently appear in the *Jawi* script, were obtained by counting their occurrences in a large number of texts printed in the *Jawi* script to represent the workload of the fingers. Subsequently, the keys of the keyboard were rearranged according to the relative strength of each finger and its corresponding workload so that the finger with higher relative strength is utilized to operate key of the alphabet having higher relative frequency. In the following section, the detailed methodology as well as results and discussion are presented. The paper is concluded with the important findings and suggestions for future work.

METHODOLOGY

This section describes the methodology used to find the relative finger strength, the relative frequency of each character and each special character that frequently appear in the *Jawi* script. In addition, the keyboard layout design approach and the method for evaluating alternative keyboard layouts are also discussed.

Procedure for Finding Relative Finger Strength

The procedure adopted in the present study has also been used by other researchers (Khan *et al.*, 2006) for the design of other types of keyboard layout. End users normally make use of only eight fingers for striking the alphabet keys, excluding the thumbs. Matias *et al*. (1996) suggested that a keyboard could be mapped into two halves, and each half could be used by the fingers of each hand for higher typing efficiency. It is advisable to use both hands for typing texts with the keyboard and one hand for spatial inputs to the machine and control panels (Kabbash *et al.,* 1993). Thus, experiments were carried out to determine the relative finger strength of each of the eight fingers for both males and females. Details of the participating subjects and experimental procedure are given below:

Subjects

Initially, 10 male and 10 female subjects were selected to participate in an experiment which was specifically designed to determine their relative finger strengths. In order to verify whether the number of subjects were sufficient for a given level of accuracy and confidence level, the following formula (Barnes, 1980) was used.

$$N' = \left(\frac{2 \times \sqrt{N(\Sigma x^2) - (\Sigma x)^2}}{A \times \Sigma x} \right) \qquad (1)$$

where, N' = *number of subjects required,*
N = *number of subjects used,*
A = *accuracy level,*
x = *relative finger strength of an individual finger for all subjects,*

In the above formula, A was set at ±10% and the confidence level at 95%. The value N' of was calculated for each finger of both right and left hands. It was found that for the male subjects, the values of N' were less than 10 for all the fingers except for the ring fingers of both right and left hands. On the other hand, the values of N' for all the fingers of the female subjects did not exceed the number of subjects taken (N' <10), so the number of the female subjects were adequate. On the contrary, more male subjects were required. Consequently, five more male subjects were employed in the experimental study and the new values of N' were calculated using equation (1) on the basis of 15 male subjects.

This time, the values of N' for the right hand index, middle, ring and little fingers were 6.7, 5.9, 10.6 and 8.7, respectively. Similarly, the left hand index, middle, ring and little fingers had values of 4.2, 8.0, 8.6 and 10.0, respectively. It is evident from these values that N' for all the fingers were less than 15, which ensured the fact that 15 male subjects were adequate. Finally, 15 male and 10 female subjects participated in the finger strength experiment. All the subjects were final year mechanical engineering students aged between 22 to 24 years old. Nine of the male subjects were ethnically Chinese but Malaysian nationals, while 6 others were Malaysians by birth. Similarly, four female subjects were ethnically Chinese but Malaysian nationals, while 6 were Malaysians by birth. The mean age, weight, and height of the male subjects were 22.60 years (S.D. $\pm$ 0.74), 59.87 Kg (S.D. $\pm$ 2.07), and 176.80 cm (S.D. $\pm$ 3.05), respectively. Similarly, the mean age, weight, and height of the female subjects were 22.50 years (S.D. $\pm$ 0.71), 51.40 Kg (S.D. $\pm$ 1.96), and 165.90 cm (S.D. $\pm$ 2.60), respectively. The subjects were healthy and none of them had any past record of either physical or mental abnormality.

Experimental Task and Procedure

The experiment used a specially designed load lifting apparatus which was fabricated and mounted on a wooden laboratory table. A schematic view of the experimental set up is shown in *Fig. 2*. The subjects were required to lift a load of 0.5 kg or 5 N (0.5 kg x 10 ms^{-2}) using each finger of both the hands excluding the thumbs. The reasons for choosing 0.5 kg load are that a small load of 0.5 kg enables the subjects to perform the load lifting task with their fingers comfortably without an undue amount of fatigue and to make it more closely simulate the typing task where one exerts almost the same amount of force in striking the keys (Radwin and Ruffalo, 1999). The load was attached to one end of a cotton string, while the other end was attached to the finger of the subjects. The string was put on a frictionless pulley in such a way that the load hung freely. Two knots were made on the string to act as stops to ensure that the load was lifted to the same height by each finger. The distance between the knots was arbitrarily chosen as 10 cm. The subjects performed the lifting task with their fingers in a sitting posture in an air-conditioned room. The lifting task was considered to determine the relative finger strength of the subjects since several studies have indicated that individuals with greater muscular strength (used in the present study) usually have greater muscular endurance in terms of relative striking ability of different fingers (Burke, 1952; Berger, 1960; Eckert and June, 1971). They started the lifting task with the index finger of one hand at a steady speed, and, when they felt fatigued, they switched to the corresponding finger of the other hand. This was done to provide a rest period to the fatigued hand. The same procedure was used for the middle, ring, and little fingers. The number of lifts performed by each finger was counted and recorded by the experimenter using a tally counter. The total number of lifts made by all fingers of a subject was computed by adding the number of lifts made by each finger. The relative finger strength of each of the participants' fingers for a subject was determined by dividing the number of lifts made by that finger by the total number of lifts, and it was expressed as a percentage.

Statistical Hypotheses and Their Test for Significance

After obtaining the relative finger strength for both the male and female subjects, the data were analyzed to test the following null and alternative hypotheses:

H_0: there is no significant difference between male and female relative finger strength.
H_1: there is significant difference between male and female relative finger strength.

Hypotheses testing were done to find out whether the same or different versions of keyboard are required for both males and females. Minitab software was used to perform a 2-sample T-test in order to reject or fail to reject the null hypothesis. In addition, box-plots were also obtained from the software to exhibit the mean and range of relative finger strength of each finger of the right and left hands for the male and female subjects. The first sample consisted of the relative finger strength of each finger of the male subjects, and the second sample comprised of those of the female subjects. The criterion of either rejecting or failing to reject the null hypothesis was the *p*-value. The smaller the *p*-value, the smaller the probability a mistake will be by rejecting the null hypothesis. A cut-off value which is often used is 0.05. The null hypothesis is rejected when the *p*-value is less than 0.05; otherwise, it is accepted (Ryan and Joiner, 1994).

Determination of Relative Frequency

The frequency of each character and each special character was found by counting their presence in a large number of the *Jawi* script articles which were taken from websites having printed articles in the *Jawi* script. Then, their relative frequencies were calculated using the following formula:

$$F_n = \left(\frac{f_1 + f_2 + f_3 + \dots + f_n}{T_1 + T_2 + T_3 + \dots + T_n}\right) \times 100$$

or

$$F_n = \left(\sum_{n=1}^{m} f_n \bigg/ \sum_{n=1}^{m} T_n\right) \times 100 \qquad (2)$$

where, F_n = relative frequency of a particular alphabet or a special character,
f_n = frequency of a particular alphabet or a special character in the article n,
T_n = total number of the characters in article n,
n = number of articles, ($n = 1, 2, 3 \dots, m$),
m = total number of articles analyzed.

In order to get a stable value of the relative frequency, a line graph was plotted to observe the variation in the cumulative number of the characters in the articles analyzed until it stabilized. This final stable value actually represented the true value of the relative frequency.

Keyboard Layout Design Approach

Since keyboard layout is important in enhancing speed and accuracy, it is important to use a keyboard that meets an individual's needs (Poole, 1995). As mentioned earlier, eight fingers of both hands are normally used for striking various keys. *Fig. 3* illustrates how each finger is used to strike different keys. It can be seen from this figure that the left little finger is used to strike the keys for "Q", "A", and "Z", while the left ring finger is for "W", "S", and "X", the left middle finger for "E", "D", "C", the left index finger is for "R", "F", "V", "T", "G", and "B", the right index finger for "Y", "H", "N", "U", "J", and "M", the right middle finger for "I", "K", and ",", the right ring finger for "O", "L", and "."; the right little finger for "P" and the other three (empty) yellow coloured keys.

The first step in designing a keyboard layout for the *Jawi* script was to evaluate the existing Arabic script keyboard layout to determine whether the work load of the fingers matched with their relative strength. *Fig. 4* shows the keyboard layout for the Arabic script considered in this study. Based on the evaluation, a rough idea for the possible *Jawi* script keyboard layout was visualized. Then, the keys were rearranged so as to match as much as possible the relative fingers' strengths

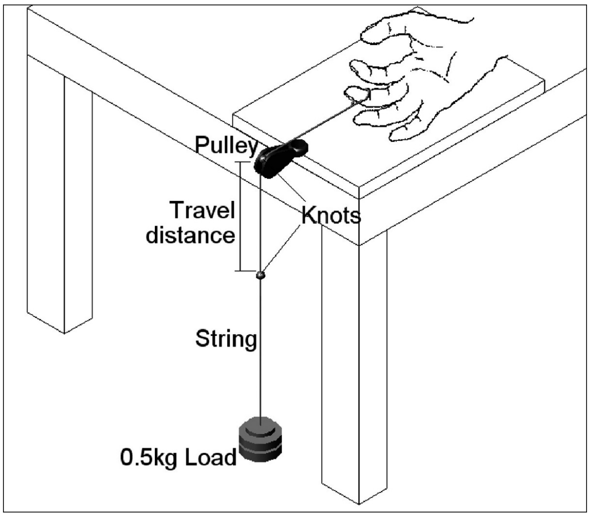

Fig. 2: Schematic view of the experimental setup

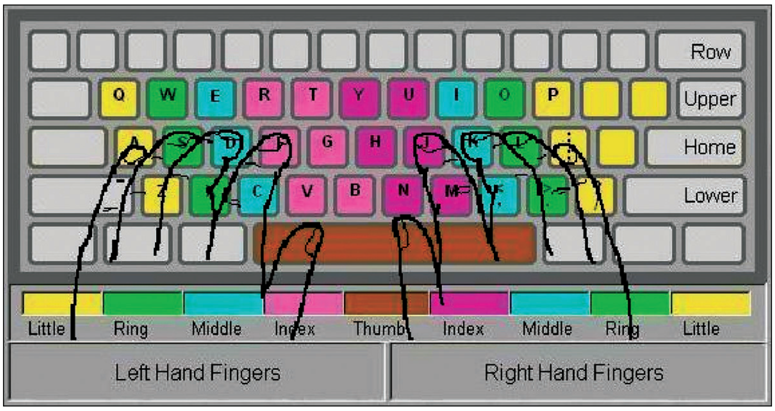

Fig. 3: QWERTY keyboard with typing fingers position

with the relative frequencies (workload) of the characters. In addition, some other features like the total workloads of the right and left hands were also taken into consideration. The keys were arranged in such a way that the right hand fingers would bear a relatively higher workload since most users are right handed. As shown in *Fig. 3*, the three rows of keys in a keyboard layout are the upper, home, and lower rows. The fingers rest on the home row and travel a particular distance between the rows to strike the keys while using a keyboard in the normal posture. Greater finger travel between keys may also result in increased fatigue (Kincaid, 1999). Thus, to avoid unwanted travel, the keys for higher frequency characters were arranged in the home row. The rest of the keys were placed either on the upper row or on the lower row with minimum possible change of key positions from the Arabic keyboard. Since the *Jawi* script has 36 characters and the standard QWERTY keyboard has only 33 keys in all the rows, there are therefore not enough keys on the QWERTY keyboard to accommodate all the *Jawi* characters. The extra *Jawi* characters were

Fig. 4: Keyboard layout of the Arabic script

combined with other characters that were represented by the keys on the right hand side of the lower row in such a way that they could be invoked by pressing these keys together with the “Shift” key in the same way as the characters like “<”, “>”, “?”, etc. are typed on the QWERTY keyboard.

Following this approach, various alternative keyboard layouts were designed arbitrarily. In order to select the design which best fulfils the requirements of the *Jawi* script with minimum change in keys positions from the Arabic keyboard, alternative keyboard layouts were evaluated using the same procedure given in the next section.

Evaluation of the Alternative Keyboard Layouts

Five arbitrarily chosen alternatives and an existing Arabic script keyboard layout were considered for evaluation in this study. The evaluation was done on the basis of 12 design criteria. Criteria 1 to 8 were based on the strength of 8 fingers, criteria 9 and 10 were related to the total workload of the right and left hands, while criterion 11 was based on the finger workloads for operating the home row keys, and the last design criterion was based on the number of changes in the key positions of the Arabic keyboard. A pair-wise comparison between these design criteria was made and a weighting score of either 1 or 0 was assigned to each criterion. A weighting score of 1 was assigned if the design criterion was relatively more important and 0 if it was relatively less important. After comparing all possible pairs of the design criteria, the total weighting score of each design criterion was found by simply counting the number of 1s assigned to that particular design criterion. The total weighting score was subsequently converted into a percentage weighting score by dividing the total weighting score of each design criterion by the grand total and then multiplying it by 100.

Next, the concept of competitive benchmarking was used where numerical values of five different alternatives and an existing Arabic keyboard layout were compared with the desired values. It should be noted that the numerical values obtained on the basis of criteria 1 to 11 represented the workload. On the other hand, the numerical values for the last design criterion represented the number of keys positions which are different from the Arabic script keyboard layout. Obviously, all 11 criteria should be as high as possible since the use of the home row keys is preferred. While quantifying criterion 12 is difficult, it should logically be as low as possible since most users are expected to be familiar with the Arabic script keyboard layout.

Finally, a decision matrix was developed and analyzed to select the best keyboard layout. The decision matrix method was effective for comparing alternative designs that were not refined enough for a direct comparison with engineering specifications (Ullman, 1997). This method provides a means for scoring alternative designs relative to the others in its ability to meet the design criteria.

The decision matrix was developed by subjectively assigning either a positive or a negative score to each keyboard layout on the basis of comparison between the numerical value and the corresponding desired value that were obtained in the competitive benchmarking. The following four-level scale was used to assign scores to each keyboard layout in the decision table for criteria 1 to 10:

+2 for very close agreement with the desired value
+1 for close agreement with the desired value
-1 for large deviation from the desired value
-2 for very large deviation from the desired value

Similarly, the following four-level scale was used to assign scores to each keyboard layout in the decision table for criteria 11:

+2 if the numerical value is very high
+1 if the numerical value is high
-1 if the numerical value is low
-2 if the numerical value is very low

Finally, the following four-level scale was used to assign scores to each keyboard layout in the decision table for criteria 12:

+2 if the numerical value is very low
+1 if the numerical value is low
-1 if the numerical value is high
-2 if the numerical value is very high

Next, the total scores were found by adding the scores of each keyboard layout. Then, the overall weighted total score for each keyboard layout was computed by taking the algebraic sum of the product of the percentage weighting score of each criterion and the score assigned for that particular criterion. Finally, the keyboard layout design with the highest weighted total score was selected as the best alternative.

RESULTS AND DISCUSSION

In the following section, the results pertaining to the finger's strength, relative frequency of characters and final design of the keyboard layout are presented.

Relative Finger Strength

Following the methodology discussed in sub-section 2.1, the results for the finger strength were obtained. Tables 1 and 2 present the relative finger strength of individual fingers for all the 15 male and 10 female subjects, respectively. In addition, these tables also show the total relative finger strength of the left and right hand fingers and the average relative finger strength of individual fingers. Table 1 depicts that the relative finger strength of the males varies from 5.2% to 21.6%. Meanwhile, the index finger of the right hand has the maximum average relative strength (17.0%) and the little finger of the left hand has the minimum (6.5%). Table 2 reveals that the relative finger strength of the female subjects varies from 5.1% to 22.7%. The middle finger of the right hand has the maximum average relative strength (17.3%) and the little finger of the left hand has the minimum (5.9%). Table 3 illustrates that the relative finger strengths obtained in the present study are close to those reported by Barnes (1980).

TABLE 1
Relative finger strength for the male subjects

Subject, *N*	Relative finger strength, % (L-Left; R-Right)									
	Index		Middle		Ring		Little		Total	
	L	R	L	R	L	R	L	R	L	R
1	15.9	16.4	14.9	15.8	11.4	10.5	7.0	8.1	49.2	50.8
2	13.7	20.6	13.9	11.8	8.6	15.2	5.8	10.4	42.0	58.0
3	11.9	18.7	11.8	17.4	10.4	14.7	6.1	9.0	40.2	59.8
4	14.3	15.5	13.6	15.0	13.8	12.6	6.7	8.5	48.4	51.6
5	12.6	16.0	12.7	17.2	10.3	16.2	6.4	8.6	42.0	58.0
6	13.4	15.5	11.1	16.0	10.3	16.7	8.0	9.0	42.8	57.2
7	11.9	18.5	12.1	17.5	10.1	15.0	6.4	8.5	40.5	59.5
8	13.0	15.5	17.1	15.1	13.8	9.4	7.1	9.0	51.0	49.0
9	13.2	13.3	16.0	14.2	11.3	14.1	8.6	9.3	49.1	50.9
10	14.0	17.0	11.0	19.1	8.0	14.2	7.9	8.8	40.9	59.1
11	13.9	14.8	16.9	14.9	10.5	17.7	4.9	6.4	46.2	53.8
12	10.7	21.6	12.7	19.5	11.4	11.6	6.1	6.4	40.9	59.1
13	15.7	15.9	11.6	17.8	9.3	17.0	5.3	7.4	41.9	58.1
14	12.3	16.5	14.5	18.5	11.7	13.9	5.2	7.4	43.7	56.3
15	14.5	19.2	13.7	17.6	9.7	13.2	6.2	5.9	44.1	55.9
Average	13.4	17.0	13.6	16.5	10.7	14.1	6.5	8.2	44.2	55.8
S.D. (±)	1.41	2.27	1.99	2.07	1.63	2.38	1.06	1.25	3.64	3.64

TABLE 2
Relative finger strength for the female subjects

Subject, *N*	Relative finger strength, % (L-Left; R-Right)									
	Index		Middle		Ring		Little		Total	
	L	R	L	R	L	R	L	R	L	R
1	14.4	17.7	15.2	15.7	11.7	13.6	6.3	5.4	47.6	52.4
2	13.4	16.8	13.2	17.2	10.2	16.0	5.8	7.4	42.6	57.4
3	13.7	19.2	13.5	16.8	8.2	13.7	5.8	9.1	41.2	58.8
4	12.7	16.0	16.1	16.5	11.7	12.9	6.6	7.5	47.1	52.9
5	14.4	16.7	15.7	17.7	9.6	13.5	5.3	7.1	45.0	55.0
6	14.3	18.0	13.8	16.2	10.5	13.1	5.9	8.2	44.5	55.5
7	15.1	15.6	16.1	16.8	11.3	11.8	5.5	7.8	48.0	52.0
8	17.3	15.9	15.1	15.3	10.0	13.4	5.6	7.4	48.0	52.0
9	11.4	18.1	9.4	22.7	6.5	17.6	5.1	9.2	32.4	67.6
10	13.7	16.7	13.4	18.0	9.8	13.0	6.9	8.5	43.8	56.2
Average	14.0	17.1	14.1	17.3	9.9	13.9	5.9	7.8	43.9	56.1
S.D. (±)	1.55	1.15	2.02	2.07	1.61	1.68	0.57	1.10	4.72	4.72

TABLE 3
Comparison of relative finger strength

	Relative finger strength, %							
	Left hand				Right hand			
	Index	Middle	Ring	Little	Index	Middle	Ring	Little
Present study	13.4	13.6	10.7	6.5	17.0	16.5	14.1	8.2
Barnes (1980)	14.2	12.8	8.8	8.1	18.5	15.3	13.4	8.9

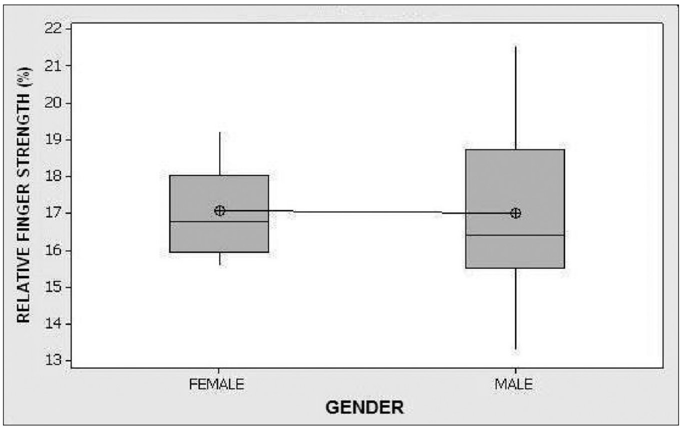

Fig. 5: Box-plot of the right hand index finger relative strength for males and females

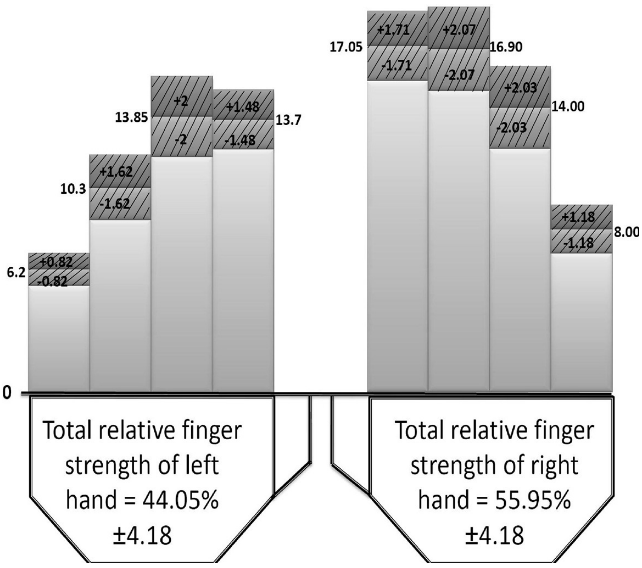

Fig. 6: Average relative finger strength of the left and right hand fingers with error values shown by hatched bars

TABLE 4
Number of male subjects required, N'

Subject, N	Right hand								Left hand							
	Index		Middle		Ring		Little		Index		Middle		Ring		Little	
	x	x^2	x	x^2	x	x^2	x	x^2	x	x^2	x	x^2	x	x^2	x	x^2
1	16.4	268.96	15.8	249.64	10.5	110.25	8.1	65.61	15.9	252.81	14.9	222.01	11.4	129.96	7.0	49.00
2	20.6	424.36	11.8	139.24	15.2	231.04	10.4	108.16	13.7	187.69	13.9	193.21	8.6	73.96	5.8	33.64
3	18.7	349.69	17.4	302.76	14.7	216.09	9.0	81.00	11.9	141.61	11.8	139.24	10.4	108.16	6.1	37.21
4	15.5	240.25	15.0	225.00	12.6	158.76	8.5	72.25	14.3	204.49	13.6	184.96	13.8	190.44	6.7	44.89
5	16.0	256.00	17.2	295.84	16.2	262.44	8.6	73.96	12.6	158.76	12.7	161.29	10.3	106.09	6.4	40.96
6	15.5	240.25	16.0	256.00	16.7	278.89	9.0	81.00	13.4	179.56	11.1	123.21	10.3	106.09	8.0	64.00
7	18.5	342.25	17.5	306.25	15.0	225.00	8.5	72.25	11.9	141.61	12.1	146.41	10.1	102.01	6.4	40.96
8	15.5	240.25	15.1	228.01	9.4	88.36	9.0	81.00	13.0	169.00	17.1	292.41	13.8	190.44	7.1	50.41
9	13.3	176.89	14.2	201.64	14.1	198.81	9.3	86.49	13.2	174.24	16.0	256.00	11.3	127.69	8.6	73.96
10	17.0	289.00	19.1	364.81	14.2	201.64	8.8	77.44	14.0	196.00	11.0	121.00	8.0	64.00	7.9	62.41
11	14.8	219.04	14.9	222.01	17.7	313.29	6.4	40.96	13.9	193.21	16.9	285.61	10.5	110.25	4.9	24.01
12	21.6	466.56	19.5	380.25	11.6	134.56	6.4	40.96	10.7	114.49	12.7	161.29	11.4	129.96	6.1	37.21
13	15.9	252.81	17.8	316.84	17.0	289.00	7.4	54.76	15.7	246.49	11.6	134.56	9.3	86.49	5.3	28.09
14	16.5	272.25	18.5	342.25	13.9	193.21	7.4	54.76	12.3	151.29	14.5	210.25	11.7	136.89	5.2	27.04
15	19.2	368.64	17.6	309.76	13.2	174.24	5.9	34.81	14.5	210.25	13.7	187.69	9.7	94.09	6.2	38.44
Total	255.0	4407.20	247.4	4140.30	212.0	3075.58	122.7	1025.41	201.0	2721.50	203.6	2819.14	160.6	1756.52	97.7	652.23
N'	**6.7**		**5.9**		**10.6**		**8.7**		**4.2**		**8.0**		**8.6**		**10.0**	

TABLE 5
Number of the female subjects required, N'

Subject, N	Right hand								Left hand							
	Index		Middle		Ring		Little		Index		Middle		Ring		Little	
	x	x^2	x	x^2	x	x^2	x	x^2	x	x^2	x	x^2	x	x^2	x	x^2
1	17.7	313.29	15.7	246.49	13.6	184.96	5.4	29.16	14.4	207.36	15.2	231.04	11.7	136.89	6.3	39.69
2	16.8	282.24	17.2	295.84	16.0	256.00	7.4	54.76	13.4	179.56	13.2	174.24	10.2	104.04	5.8	33.64
3	19.2	368.64	16.8	282.24	13.7	187.69	9.1	82.81	13.7	187.69	13.5	182.25	8.2	67.24	5.8	33.64
4	15.9	252.81	16.5	272.25	12.9	166.41	7.5	56.25	12.7	161.29	16.1	259.21	11.6	134.56	6.6	43.56
5	16.8	282.24	17.7	313.29	13.5	182.25	7.1	50.41	14.4	207.36	15.7	246.49	9.7	94.09	5.3	28.09
6	18.0	324.00	16.2	262.44	13.1	171.61	8.2	67.24	14.3	204.49	13.8	190.44	10.5	110.25	5.9	34.81
7	15.6	243.36	16.8	282.24	11.8	139.24	7.8	60.84	15.1	228.01	16.1	259.21	11.3	127.69	5.5	30.25
8	15.9	252.81	15.3	234.09	13.4	179.56	7.4	54.76	17.3	299.29	15.1	228.01	10.0	100.00	5.6	31.36
9	18.1	327.61	22.6	510.76	17.6	309.76	9.2	84.64	11.4	129.96	9.4	88.36	6.5	42.25	5.1	26.01
10	16.7	278.89	18.0	324.00	13.0	169.00	8.5	72.25	13.7	187.69	13.4	179.56	9.8	96.04	6.9	47.61
Total	170.7	2925.73	172.9	3028.17	138.6	1946.48	77.6	613.12	140.4	1992.70	141.5	2038.81	99.5	1013.05	58.8	348.66
N'	**1.6**		**5.2**		**5.3**		**7.3**		**4.4**		**7.3**		**9.3**		**3.4**	

TABLE 6
p-values obtained from the 2-sample T-test

Finger	*p*-value	
	Right hand	Left hand
Index	0.920	0.308
Middle	0.358	0.490
Ring	0.740	0.266
Little	0.386	0.067

The required number of the male and female subjects' was determined according to the procedure described in sub-section 2.1.1. Tables 4 and 5 show the values of the relative finger strength, x of each finger for the 15 male and 10 female subjects, N' respectively. They also show the squared values of x (x^2), sum of x (Σx) and x^2(Σx^2), and the value of N' for each finger. It can be seen from these tables that the value of N' for each finger is less than 15 for the males and less than 10 for the females. Thus, 15 male and 10 female subjects were adequate for the present study.

As stated earlier, a 2-sample T-test was used to test the statistical significance of the null hypothesis, H_0, and the alternative hypothesis, H_1. The *p*-values for each finger were found to be much higher than 0.05 (Table 6) and therefore, the null hypothesis was accepted. This indicated that there was no significant statistical difference between the male and female relative finger strength. *Fig. 5* shows a typical box-plot for the relative strength of the right hand index fingers of the male and female subjects. The box-plot shows that the range of the relative finger strength of the male is wider than that of the female, but the mean relative finger strength of both male and female is almost the same.

Meanwhile, the average relative strength of each finger of left and right hands is summarized in *Fig. 6* which shows the total relative finger strength of both hands. It should be noted that the relative finger strength is the mean of the average relative finger strength of both the males and females derived from Table 1 and Table 2, respectively. The right index finger has the maximum relative strength (17.05%), while that of the left has the minimum (6.20%).

Relative Frequencies of Alphabets and Special Characters

As outlined in sub-section 2.3, the relative frequency of each character and two special characters was determined. *Figs. 7* and *8* illustrate how the relative frequencies of *alif* ("ا") and full-stop, "." respectively vary with the cumulative number of the characters in the articles. In the beginning, the relative frequency of the alphabet *alif* ("ا") varies considerably but it stabilizes after almost 110x10^3 characters. Thus, the relative frequency of alphabet *alif* ("ا") is 14.90%, as illustrated in *Fig. 7*. Similarly, *Fig. 8* shows that the relative frequency of the special character full-stop, "." is 1.40%.

The relative frequency of other characters and two special characters were determined in a similar manner. Table 7 shows the relative frequency of each character and two special characters considered in the present study. The relative frequency of the alphabet *alif* ("ا") is the highest (14.90%), and that of *dzo* ("ظ") and *ghain* ("غ") are the lowest (0.01%). In addition, the relative frequency of the special character comma "،" is 0.10% and that of the full-stop "." is 1.40%.

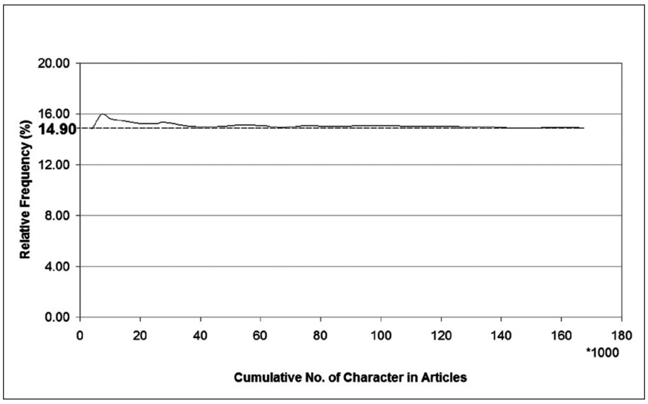

Fig. 7: Graph of the relative frequency for alphabet alif, "ا"

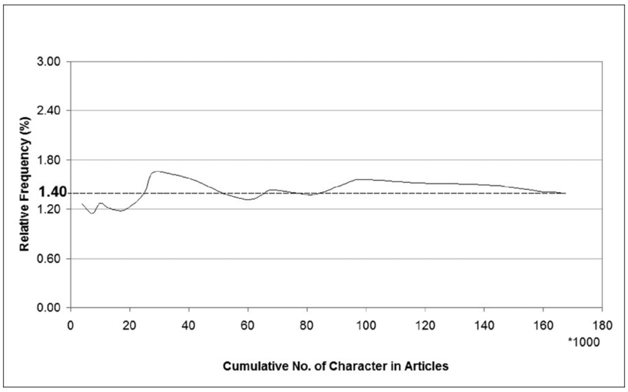

Fig. 8: Graph of the relative frequency for the special character full-stop, "."

Alternative Keyboard Layout Designs

As mentioned in sub-section 2.4, the keyboard layout of the Arabic script was first evaluated in terms of finger strength and the corresponding total workload to find its suitability for the *Jawi* script. *Fig. 9* shows the keyboard layout of the Arabic script with the relative frequencies (indicated on the keys) and the total workload of each finger and hand. The total workload of each finger was obtained by adding the relative frequency of the corresponding keys. The total workload of the right index finger is 22.35%, whereas its relative strength is only 17.05%. Thus, this finger is not strong enough to strike the keys and they should be changed. Similarly, other fingers have the total workloads that do not match the corresponding relative finger strength. Thus, it can be concluded that the Arabic script keyboard layout is not suitable for the *Jawi* script. Consequently, other alternative keyboard layouts were considered and evaluated so as to find the best possible layout. *Fig. 10* shows an alternative keyboard layout with the relative frequency of characters, special characters and the total workload of each finger. This layout shows that the finger workloads are relatively close to the corresponding relative finger strengths. It should be noted that the changes in the key position are indicated by putting a dot sign on the lower right corner of the keys.

TABLE 7
Relative frequency of each character and two special characters

Alphabet	ا	ب	ت	ث
Relative frequency (%)	14.90	3.78	5.67	0.07
Alphabet	ج	ح	چ	خ
Relative frequency (%)	2.35	0.47	0.43	0.15
Alphabet	د	ذ	ر	ز
Relative frequency (%)	5.21	0.04	5.46	0.12
Alphabet	س	ش	ص	ض
Relative frequency (%)	5.42	0.23	0.15	0.03
Alphabet	ط	ظ	ع	غ
Relative frequency (%)	0.06	0.01	0.58	0.01
Alphabet	ک	ف	ڤ	ق
Relative frequency (%)	3.01	0.34	3.51	1.27
Alphabet	ى	گ	ل	م
Relative frequency (%)	0.04	1.44	5.20	5.67
Alphabet	ن	و	ژ	ه
Relative frequency (%)	9.55	8.53	0.03	3.00
Alphabet	ال	ء	ي	ڤ
Relative frequency (%)	1.19	0.31	9.58	0.69
Alphabet	،	.		
Relative frequency (%)	0.10	1.40		

Evaluation of the Alternative Keyboard Layouts

As described in the sub-section 2.5, five arbitrarily chosen alternatives and an existing Arabic keyboard layout were evaluated on the basis of 12 design criteria. Table 8 shows the design criteria and the results of the pair-wise comparison between them. It also shows the total weighting score and the percentage weighting score of each design criterion. The percentage weighting scores were found vary from 4% to 12%. Next, the concept of competitive benchmarking was applied as discussed in sub-section 2.5. The results which show the numerical values obtained for each design criterion for each keyboard layout and the targeted values are presented in Table 9.

The final step in the evaluation process was to develop a decision matrix in order to select the best keyboard layout. The procedure for developing the decision matrix was described in sub-section 2.5. The results which indicate the design criteria, percentage weighting score of each criterion, scores assigned to each keyboard layout, as well as total positive and total negative scores, overall total score, and overall weighted total score for each of the keyboard layouts are presented in Table 10. Clearly, the Arabic keyboard layout is not an ideal choice for the *Jawi* script since its overall weighted total score is very low (+10), whereas the alternative keyboard layout 5 is the best choice

TABLE 8
Pair-wise comparison

Criterion number	Design criteria	Weighting score (1 or 0)																					Total weighting score	Percentage weighting score (%)
1	Relative right hand index finger workload	1	1	0	1	1	0	0	0	1	0	1											6	9
2	Relative right hand middle finger workload	0	-	1	0	0	1	0	0	0	1	0	1										4	6
3	Relative right hand ring finger workload		0	0	-	0	0	1	0	0	0	1	1	1									4	6
4	Relative right hand little finger workload			1	1	1	-	1	0	1	1	0	1	0	1								8	12
5	Relative left hand index finger workload				0	1	1	0	-	1	1	0	1	0	0	1							6	9
6	Relative left hand middle finger workload					0	0	0	1	0	-	1	0	1	0	0	1						4	6
7	Relative left hand ring finger workload						1	1	1	0	0	0	-	0	1	0	0	1					5	8
8	Relative left hand little finger workload							1	1	1	0	1	1	1	-	1	0	0	1				8	12
9	Relative right hand workload								1	1	1	1	0	0	0	0	-	1	1	0			6	9
10	Relative left hand workload									0	0	0	0	1	1	1	1	0	-	1	0		5	8
11	Relative home row workload										1	1	0	1	1	1	1	1	0	0	-	0	7	11
12	Number of changes in the keys positions compared to the Arabic keyboard											0	0	0	0	0	0	0	0	1	1	1	3	4
Grand total																							66	100

TABLE 9
Competitive benchmarking for six alternative and three existing keyboard layouts

Criterion number	Design criteria	Alternative keyboard layout					Existing Arabic script keyboard layout	Desired value
		1	2	3	4	5		
1	Right hand index finger workload (%)	22.64	22.41	22.39	19.95	17.63	22.35	17.05
2	Right hand middle finger workload (%)	14.34	15	15.44	15.57	15.57	21.18	16.90
3	Right hand ring finger workload (%)	16.17	12.71	12.6	15.81	15.81	7.34	14.00
4	Right hand little finger workload (%)	8.16	7.12	7.9	7.46	7.54	11.65	8.00
5	Left hand index finger workload (%)	11.4	17.44	16.98	13.83	16.07	17.24	13.70
6	Left hand middle finger workload (%)	16.68	13.75	14.08	12.65	12.65	11.09	13.85
7	Left hand ring finger workload (%)	6.84	11.24	6.84	8.66	8.57	5.88	10.30
8	Left hand little finger workload (%)	3.77	0.33	3.77	6.07	6.16	3.27	6.20
9	Right hand workload (%)	61.31	57.24	58.33	58.79	56.55	62.52	55.95
10	Left hand workload (%)	38.69	42.76	41.67	41.21	43.45	37.48	44.05
11	Workload for striking home row keys (%)	41.19	59.44	49.18	60.69	69.1	60.1	*AHAP**
12	Number of changes in the keys positions compared to the Arabic keyboard (#)	30	25	29	34	34	0	*ALAP**

(*AHAP*- As High As Possible; ALAP*- As Low As Possible*)

TABLE 10
Evaluation matrix to select the best alternative keyboard layout

Criterion number	Design criteria	Percentage weighting score (%)	Alternative keyboard layout					Existing Arabic script keyboard layout
			1	2	3	4	5	
1	Right hand index finger workload	*9*	-2	-2	+1	+2	-2	-2
2	Right hand middle finger workload	*6*	+2	+2	+2	+2	-2	-2
3	Right hand ring finger workload	*6*	+1	+1	+2	+2	-1	-1
4	Right hand little finger workload	*12*	+1	+2	+2	+2	-1	-1
5	Left hand index finger workload	9	+1	+1	+2	+1	+1	+1
6	Left hand middle finger workload	*6*	+2	+2	+2	+2	+1	+1
7	Left hand ring finger workload	*8*	+2	+1	+2	+2	-1	-1
8	Left hand little finger workload	*12*	-2	+1	+2	+2	+1	+1
9	Right hand workload	*9*	+2	+1	+1	+2	+1	+1
10	Left hand workload	*8*	+2	+1	+1	+2	+1	+1
11	Workload for striking home row keys	*11*	+2	+1	+2	+2	+2	+2
12	Number of changes in the keys positions compared to the Arabic keyboard	*4*	-1	-2	-2	-2	-	-
Total of positive score			12	15	13	19	21	7
Total of negative score			-5	-3	-4	-2	-2	-7
Overall total score			7	12	9	17	19	0
Overall weighted total score		*100*	63	77	85	158	175	10

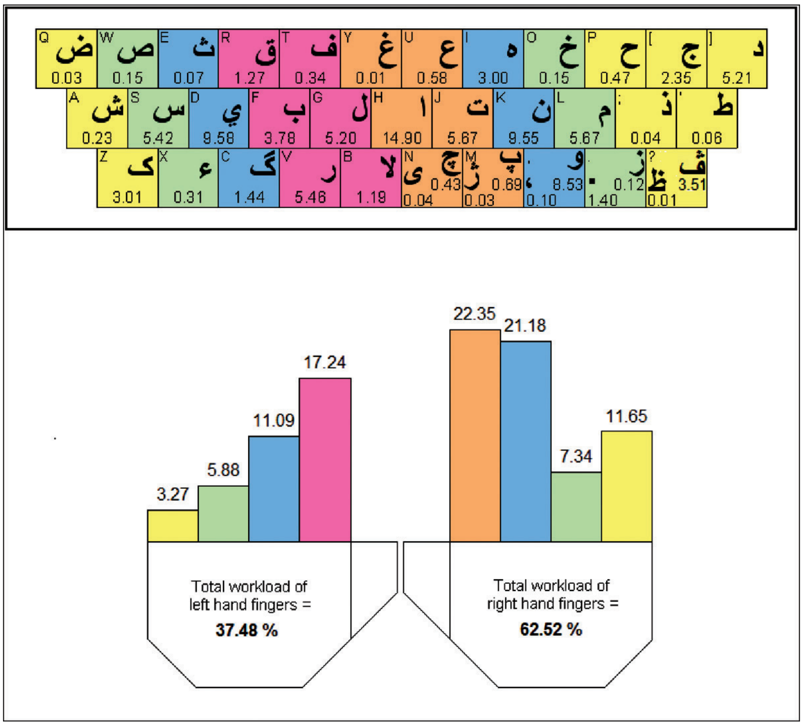

Fig. 9: Keyboard layout of the Arabic script with the relative frequencies and finger workloads

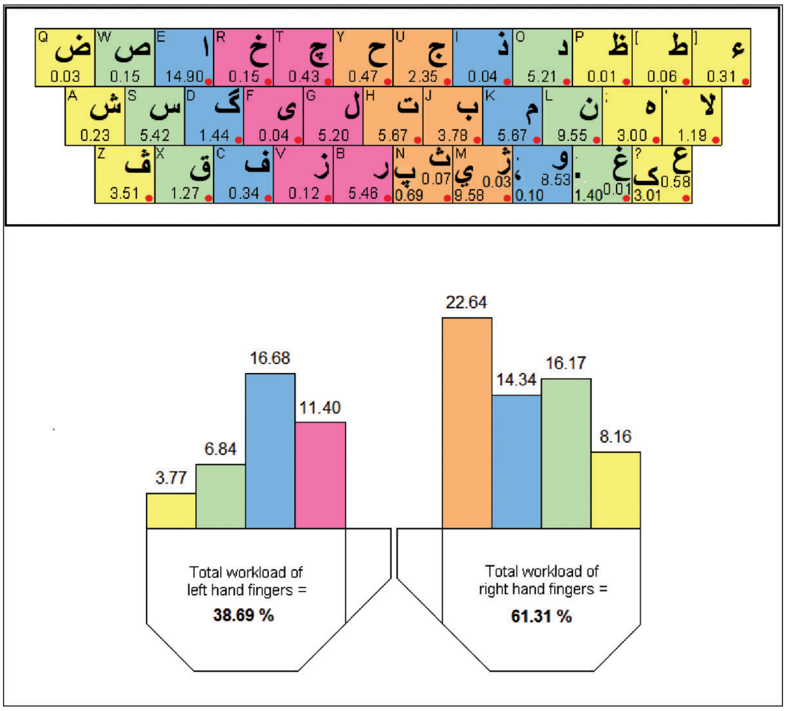

Fig. 10: Alternative keyboard layout

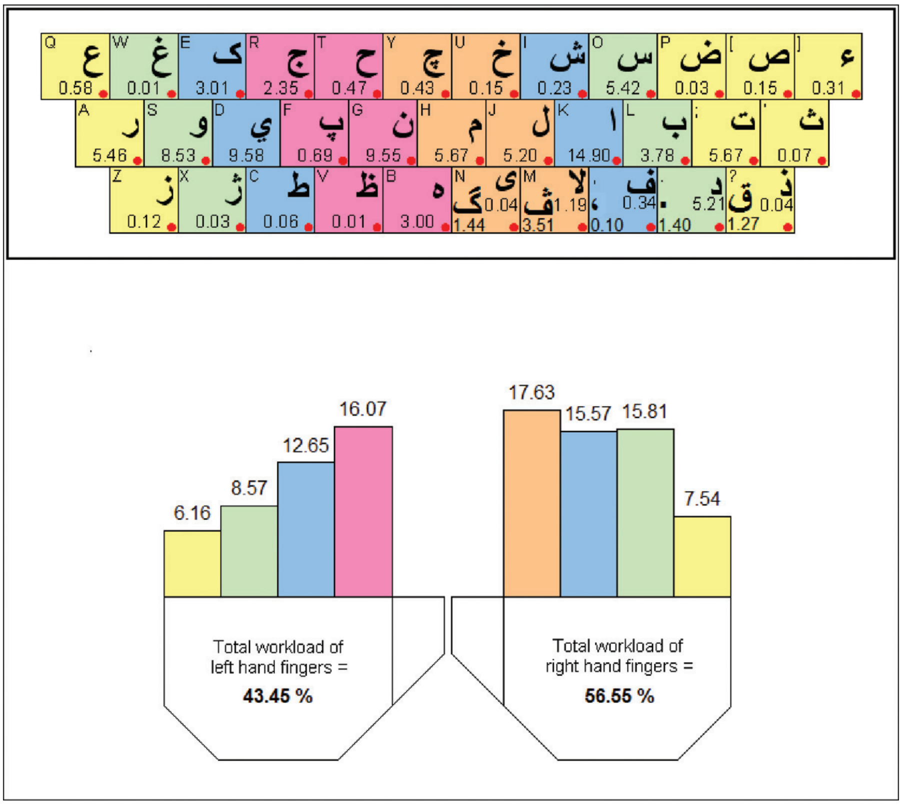

Fig. 11: Proposed keyboard layout for the Jawi *script*

with the maximum overall weighted total score of +175. *Fig. 11* shows the layout of this particular keyboard with the relative frequency of the characters as well as the total workload of each finger and hand. This figure shows that the relative finger strength matches well with the corresponding total workload. The keys with the dot sign at the lower right corner of the keys indicate the change in the key position.

CONCLUSIONS

This paper presented a systematic approach for designing of a computer keyboard layout for the *Jawi* script from an ergonomics point of view. The relative finger strength of the male and female subjects was experimentally designed through a simple load lifting task performed by their fingers. Meanwhile, a 2-sample T-test method was used to investigate whether different versions of the keyboard were required for the two genders. The results indicated that there was no significant difference between the relative finger strength of the males and females, so both genders could efficiently use the same keyboard. In addition, the relative frequencies of the characters, including two special characters (comma and full-stop) that frequently appeared in this script, were found by counting their presence in a sufficiently large number of the printed articles from various sources. The relative frequency represented the finger workload for striking the keys. Five alternative and an existing Arabic keyboard layouts were evaluated on the basis of 12 design criteria using the concept of competitive benchmarking and a decision matrix. The Arabic keyboard layout was found to be unsuitable for the *Jawi* script since the arrangement of the keys does not match the finger workloads and relative strengths. Consequently, an alternative keyboard layout is proposed. Although the proposed keyboard layout does not provide 100% matching between the finger workloads and relative strengths, it is the best layout obtained from the evaluation of different alternatives. One limitation of this research is that the relative finger strength has been determined by simply counting the number of lifts performed by the fingers which may not be as accurate as desired. Therefore, the relative finger strength should be measured with sophisticated and accurate instruments like an electromyogram (EMG). Nevertheless, the approach outlined in this paper could be used to design keyboard layouts for other languages as well.

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