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Computerized Measurements of Hand Deviation

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Abstract— Deteriorated hand movement of diabetic patients can be linked to a non-properly functioning nervous system. Therefore, in this paper, a setup is proposed to measure and analyze such deterioration in the form of skew (vertical deviation) - resulting from hand motion - as well as its duration. A personal computer equipped with a touchpad is used to enable the user to draw a pre-specified horizontal line on the computer screen. The skew of the hand from the prescribed track, and the time of motion while drawing this line are digitally measured based on the X and Y coordination of the position of the index finger on the pad and the duration of the movement made. At the same time, the system clock values were continuously recorded for each point of the movement made. In this paper, kinematics of hand movements for diabetics compared to normal subjects is investigated in details. The results reveal that the mean values of skew are found at 2.7 mm; i.e., standard deviation (SD) of 2.2 mm for diabetic subjects compared to 0.92 mm (SD of 0.43 mm) for controls (healthy subjects). With a mean value of 6.03 s (SD of 3.02 s) for diabetic subjects, compared to 4.38 s (SD of 1.75 s) for controls, the time of motion is also found to be affected by the state of health (diabetic or non-diabetic). The results also indicate significant correlation between a skew value higher than 1.8 mm and diabetes which can be used as an indicator for diagnosing the disease. Finally, the obtained results show that the proposed setup and the followed procedure can be successfully utilized for diabetes diagnosis.

Keywords— Diabetic neuropathy; Kinematics; Skew; Movement time; Diabetes.

1. INTRODUCTION

About 463 million people are affected by diabetes worldwide in 2019 according to the International Diabetes Federation (IDF), and it is predicted to increase by 51% (i.e.700 million) in 2045 [1]. Diabetes is a disease that results when the level of blood glucose, often known as blood sugar, is too high. Over time, it can cause serious health problems varying from pain and loss of feeling of feet and hands to complications in major organ activities. Diabetics are more likely to have heart disease, stroke, paralysis, foot ulcers, and peripheral nerve disorders. Peripheral neuropathy is a form of nerve damage usually affecting the feet and legs and often impacting the arms and hands which eventually negatively impact the daily activities of people [2, 3].

Since diabetes affects the nervous system whose role is partially to transfer orders from the brain to the hand, then spatial hand movement and its time domain analysis are good measures of the the nervous system's state of and hence health state. The study of hand movement, therefore, requires a setup which consideres both space and time parameters working together concurrently, and can differentiate between diabetics and normal controls. At the same time, a setup has to be as simple as possible to use - so that a person can operate it and conduct a test on his own without requiring assistance from anybody - and it should not be expensive - so that a laptop computer or (very soon a mobile phone) may suffice for its adaptation at home or in hospitals.

Unfortunately, resources in this area are insufficient, and literature – that focuses on

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hand deviation and movement time as proposed in this study - is unavailable. Moreover, devices utilized are difficult to use by individuals without interference from medical staff, which in turn limits the source of information and gives less data for medical staff to base their medical decisions to prevent hand dysfunction [4].

Based on these facts, the purpose of our study is to present a simple setup to measure hand dysfunctions among people with diabetes and compare them to normal subjects for diagnosing purposes. Jagota et al. studied movement disorder [5] as well as Delrobaei et al. who also studied hand functions in people with type 1 and type 2 diabetes and found that they had a negative impact on occupational performance [6]. Jackson found that movement disorders are useful in diagnosing disability [7], while Polla et al. used transducers to acquire body movement by tightening them to the part needed [8]. Muheilan captured and analyzed the vertical deviation of the hand movement from a prescribed horizontal track using a personal computer, programmed for this purpose using Visual Basic, in an attempt to find any relationship that may exist between the deviation of the hand with age [9]. Later on, Muheilan managed to compute the latency and angle of deviation of the hand and produced a comparative study for normal control and subjects suffering from mental illness [10]. Cerveri et al. described methods and experimental studies concerned with real-time quantitative reconstruction of finger movements using a multi-camera system, which was costly and slightly uncomfortable [11]. Casellini et al. used Sudoscan and hence Sudomotor dysfunction as an early detectable abnormality in diabetic small fiber neuropathy [12]. The aim of their study was to evaluate the efficacy of Sudoscan in detecting diabetic neuropathy in comparison with other standardized tests, in patients with diabetes. Sudoscan measures electrochemical skin conductance of hands and feet. Grujic et al. recorded hand movements by a 3D optical motion-tracking system and used a set of six infrared cameras which could trace the positions of active infrared-emitting markers with very high precision [13]. Goyal et al. indicated that diabetes mellitus is linked with a number of hand-influencing musculoskeletal (MSK) symptoms which can dramatically affect the quality of life of a patient. Although much attention is paid to chronic microvascular complications of diabetes, in clinical practice, the complications of MSK are often ignored [14].

Based on those findings and the modified setup used in [15], which consisted of a compuer and a mouse (used as an interface to transform hand motion into a trace on the computer screen), the authors of this study postulate that hand movement deviation and motion time and other parameters can be used as a diagnostic technique of diabetes. Therefore, to get such understanding, this study will consider the following parameters: skew or deviation of the hand while drawing a horizontal line of 15 cm long, movement time while drawing this line, the interrelationships between skew and movement time, taking into account subjects gender (A), age (B), weight (C), the subject being smoker or not (D), eyes sight (E) and the state of health i.e. diabetes (F). The measurements were made while hand was moving on a horizontal datum, this is necessary to eliminate three-dimensional motion complexity which is outside the scope of this study.

2. SUBJECTS, SETUP AND METHODS

The study population consisted of two grpups: the first group was comprised of 50 patients with insulin-dependent diabetes, males and females, aged 21 to 89 years. They were inpatients at Prince Ali Bin Al Hussein Hospital or Al-Karak Hospital who have been admitted in by the medical staff at the department of medicine of Mut'ah University or the royal medical services staff. The second group consisted of 209 normal males and females referred to henceforth as controls with non-diabetic history aged 18 to 60 years. Groups' members who consented to participate in the study were selected such as they did not have any obvious previous hand pathology, that is to say, subjects who had hand diseases were excluded.

The setup and the programs used were as given in [15], but with a slight modification to the type of interface used, which is now the touchpad of a laptop instead of the mouse interfaced to the personal computer that was used before. The idea behind using the touchpad is to eliminate holding of the light pen or the mouse which is very uncomfortable for both diabetic patients and elderly subjects. The setup movement time was calculated by the addition of the times between every two pixels crossed where a similar idea was adapted in [16] in which the mouse movement was utilized as a detector to monitor hand movement, and the whole system was comprised of three modules: hand detection, hand tracking, and gesture recognition. In our system, hand detection specifically is based entirely on computer vision and touchpad tracking mechanism through which the subject was comfortably seated in front of a laptop, taking into consideration whether he or she is left or right handed;then given some time to get used to the experiment by trying it beforehand. A laptop was programmed using Visual Basic [17] to show a 15 cm long straight line on its screen. The 15 cm line was chosen to allow the hand to move comfortably without requiring a full arm movement and the touchpad width is around 15 cm.

Fig. 1. shows the setup used for this study where the 15 cm long line starts from the left side of the screen which serves as reference line to the user who was asked to move the index finger and hence his/her hand on the touchpad. Finger movement is reflected on the screen as if the subject is drawing on the screen itself in the same plain as the reference lines.

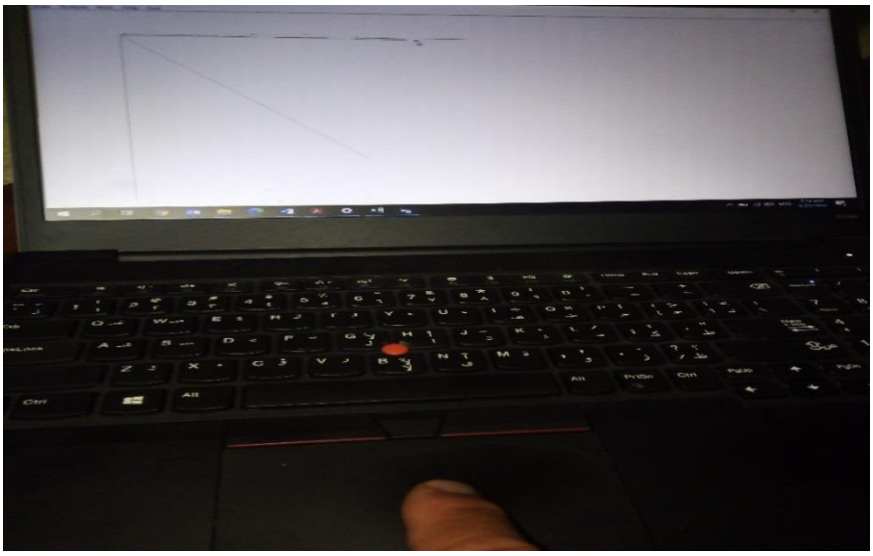

Fig. 1. A healthy subject conducting the test.

The trace is produced by the user in a non-perfect straight line, and is made up of many discrete points each has a pair of X and Y coordinates and is saved in the computer memory as an array. The time of each point drawn is also recorded and the total time of motion elapsed while drawing is measured and referred to as the movement time. The line drawn by the user starts at a discrete point of certain altitude, this is the altitude of the reference line. It is important that the subject keeps the finger touching the pad while moving as any separation between the finger and the pad is considered as discontinuity and treated as a separate test. As the hand moves, it reproduces the line, but not straight and perfect as shown in Fig. 2.

Fig. 2. Trace made by the hand of a diabetic subject (the dotted line represents hand movement while performing the test and the straight line represents the reference line).

While the hand moves, it unintentionally makes deviations to either above or below the reference line. Therefore, the movement of the hand even though was meant to produce a straight line could not do so, it was actually producing a non-straight line. If we assume that the altitude of the first point of the reference line is given as Y_r, the difference between any point made by the hand and the altitude of the reference line is termed skew, or vertical deviation.

For the first point drawn by hand with respect to the first point of the reference line, the skew or deviation can be represented by:

$$D_1 = Y_1 - Y_r \tag{1}$$

where D_1 is the vertical deviation in [mm] of point 1, Y_1 is altitude of discrete point1 made by the hand and Y_r is the altitude of the reference line (Y_r is constant for all points of the reference line). The total skew (vertical deviation) of the hand D_v which is calculated away from the reference line is the sum of these deviations and is given as:

$$D_v = \sum_{i=1}^{n} \left| Y_i - Y_r \right| \tag{2}$$

where i=1 is the initial point and n is the last point drawn.

It should be mentioned that while the hand is performing a horizontal movement, the deviation above the line was considered positive, while deviation below the line was considered negative. This means that summing the deviations' leads to adding positive and negative values and this would make them cancel each other. To eliminate such situation, the absolute values of deviations are considered to give the true values of hand skew because any movement away from the reference line whether upward or downward is an erratic hand movement regardless of its sign.

To calculate the movement time of the hand, the authors of [18] used a human hand movement measuring system composed of a computer and a data glove. The data glove used fifteen 9-axis magnetic sensor units to measure joint angles of a hand by sticking one sensor unit in the middle of each phalanx of a finger. Each sensor unit consists of an acceleration sensor, a gyro sensor, and a magnetic sensor. The computer is responsible for receiving, processing, and displaying the measured data transmitted from the data glove, and it communicates with the data glove through RS232. But our method is far easier and a lot more practical than that because while drawing the line, the systems real-time clock was read at the onset of the hand movement and for every point in sequence up to the last point, which was termed "movement time", and was kept in a certain array reserved for this purpose. To calculate the hand movement duration, the time difference between the last point and the initial point was calculated.

After the subject drew the horizontal line, the vertical deviation and the movement time were calculated as given by equations above. Results were statistically analyzed using Minitab 19. Finally, means, standard deviations (SD) and other functions were considered for comparison purposes and correlation was used as appropriate at certain stages.

3. RESULTS AND DISCUSSION

The vertical deviations are calculated for each subject and hence, for the whole population, while drawing the horizontal line as presented in Fig. 3 which includes both the diabetics and controls. It can be seen that the vertical deviation is largely affected by the state of health, with a mean value of 0.92 mm (SD of 0.43 mm) for controls compared to 2.7 mm (SD of 2.2 mm) for diabetics with a ratio of 2.93.

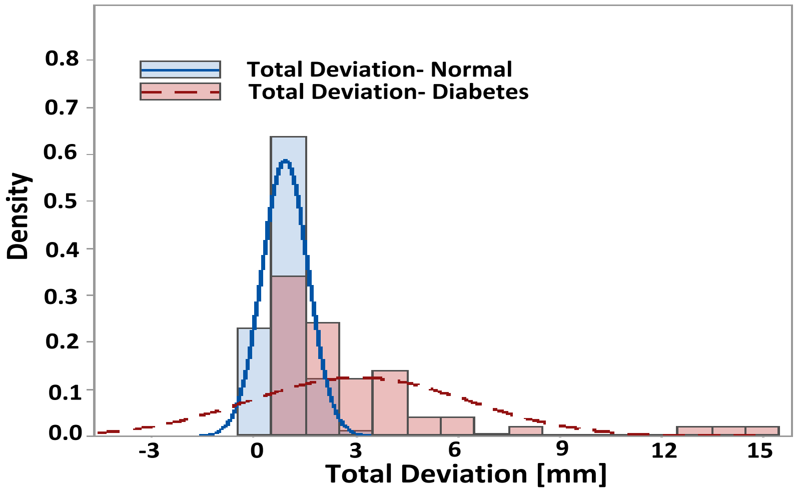

Fig. 3. Histograms of hand vertical deviations for diabetic and control subjects.

The time of motion elapsed while drawing the reference line by each subject, and hence for the whole population, diabetics and controls, is presented in Fig. 4. It can be seen that it was slightly affected by the state of health, with a mean value of 4.38 s (SD of 1.75 s) for controls compared to 6.03 s (SD of 3.02 s) for diabetics.

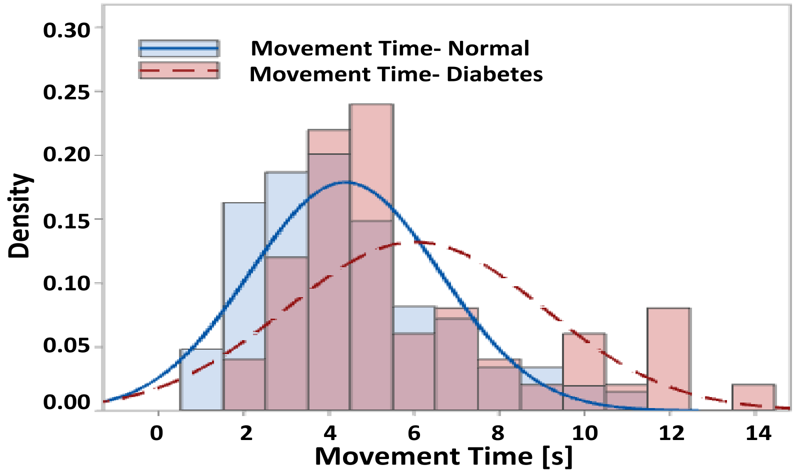

Fig. 4. Histograms of hand movement time for diabetic and control subjects.

The effects of multiple parameters on the hand vertical deviation of the whole population, such as gender, age, weight, smoking and state of health (diabetics or normal), are presented in Fig. 5. It was found that the state of health had the highest effects on deviation (i.e. statistically a very significant factor) as it crosses the reference line whose value is 1.97 that represents the α=0.05 (hypothesis testing value). The rest of parameters have a minor effect on deviations since none of them crosses this 1.97 line.

The regression equation for the hand deviation for all subject is given as:

$$Total\ \ Deviation\ [mm] = 0.531 - 0.056A + 0.00421B + 0.00377C + 0.223D - 0.106E + 1.535F \qquad (3)$$

Fig. 5. which is the Pareto plot of hand vertical deviations for diabetic and control subjects, was achieved by inserting the data into the Minitab software package. Eq. (3) is the regression equation for the hand deviation for all of the subjects taking into account all parameters, and this is a normal regression equation which describes the data in an equation form known in mathematics as polynomial regression.

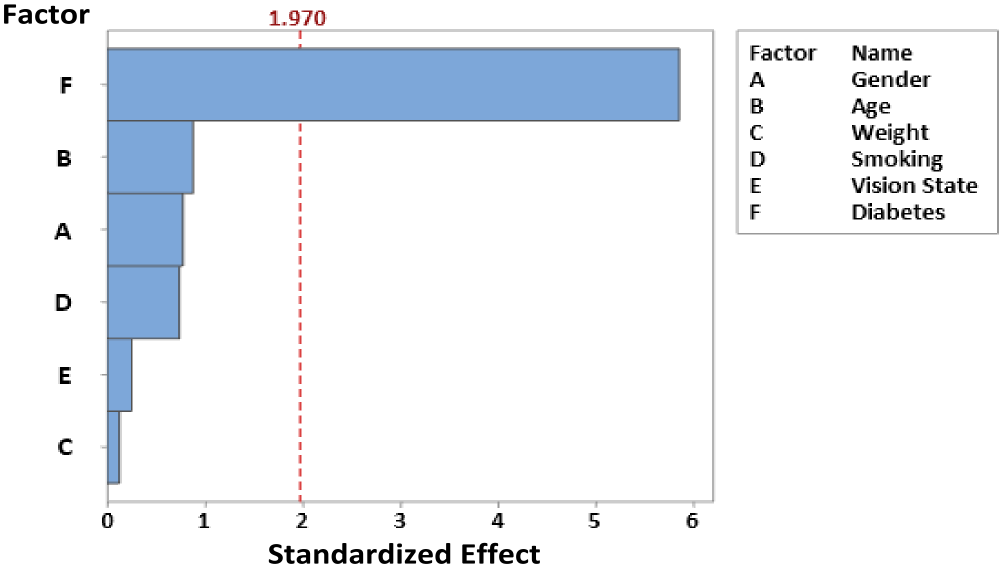

Fig. 5. Pareto plot of hand vertical deviations for diabetic and control subjects.

It is clear, from the regression equation and Fig. 5 as well as Fig. 6, that state of health is the dominant parameter that affects deviation with a low value of mean deviation for normal subjects and a high value for diabetics while other parameters have minor effects. Inclinations of the different segments in this figure can be explained such that gender has minimum influence on deviation as the movement is of short length and no real effort is needed in hand motion, so male and female subjects behave similarly, hence mean values were very close to each other. Age has more effect on deviation with elderly subjects showing more skew while moving the hand and hence poor results. Weight was also considered and since movement is of a short length and no real effort is needed in hand motion, hence mean values are slightly weight dependent, but overweighed people had higher deviation since they are less likely to be comfortable while moving their extremities. Smoking had a bad effect too on the subject's deviation, since smokers have less oxygen contents in their body and as motion normally requires more oxygenated blood; therefore, smokers have these higher deviations.

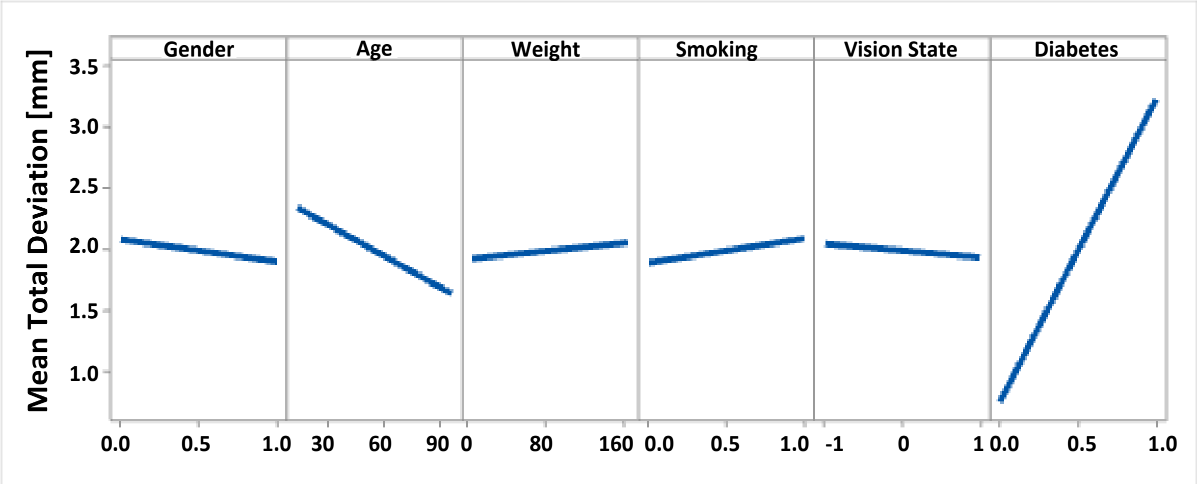

Fig. 6. Graphical representation of the parameters of regression equation of total deviation.

The effects of the above-mentioned parameters on the hand movement time for the whole population are presented in Fig. 7. It was found that state of health had not markedly affect the result as compared to other parameters, as it came third among other parameters.

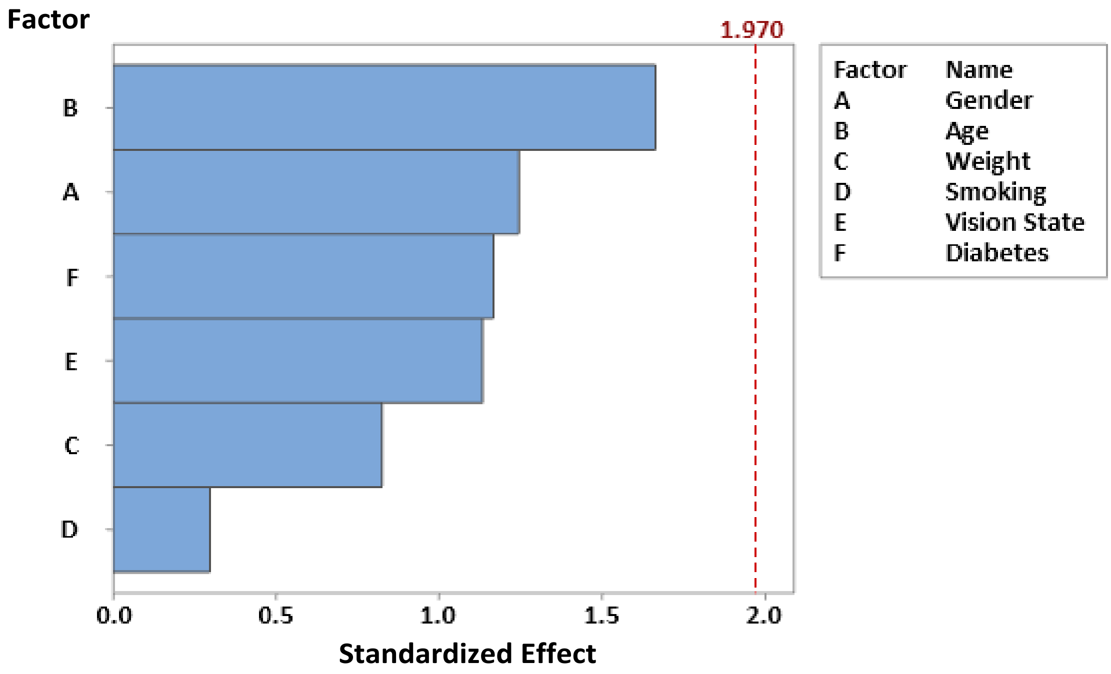

Fig. 7. Pareto plot of hand movement time for diabetic and control subjects.

In the Pareto plot of Fig. 7, none of the parameters crosses the reference line that is at 1.97. Therefore, none of them is statistically significant. The regression equation for the movement time for all subjects is given as:

$$\text{Movement Time [s]} = 2.813 + 0.459A + 0.0199B + 0.011C - 0.134D - 0.365E + 0.830F \qquad (4)$$

Therefore, diabetes is neither an absolute nor dominant parameter that affects movement time. The trends shown in Fig. 8 indicates that movement time was slightly increased with gender, age, weight, and diabetes while smoking had a negligible effect.

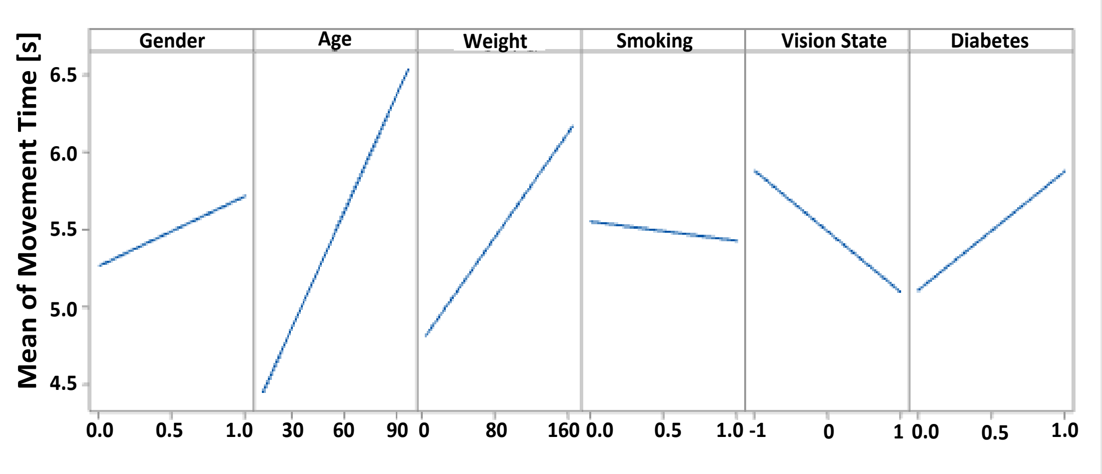

Fig. 8. Graphical representation of the factors of the regression equation of movement time.

Since vertical deviations were largely affected by the state of health, it was further investigated and concentration will be made henceforth on the two groups separately, diabetic and controls. The comparative means for vertical deviation of the females and males, diabetics to controls are presented in Fig. 9.

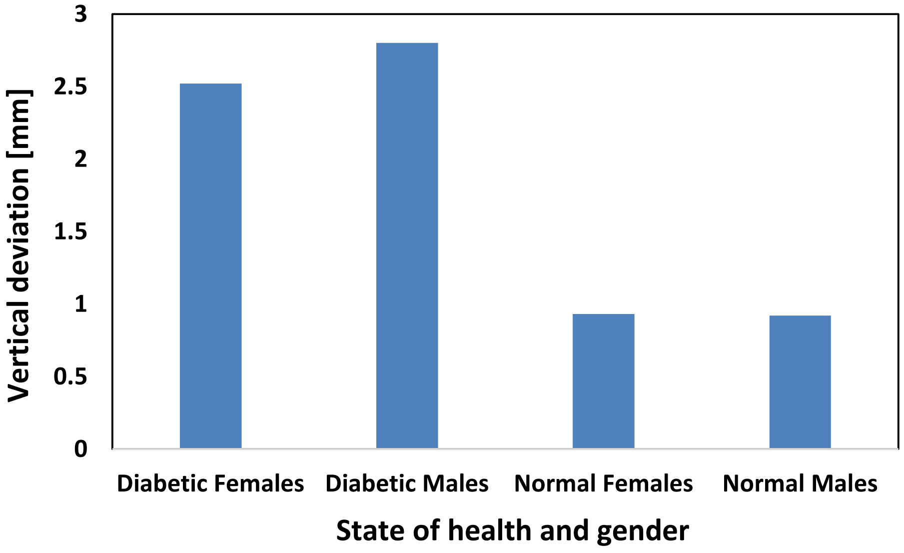

Fig. 9. Mean values of vertical deviation as a function of state of health and gender.

This detailed figure shows that diabetic females have a mean value of vertical deviation equal to 2.56 mm compared to 0.93 mm of normal females, and that diabetic males have a mean value of 2.82 mm compared to 0.92 mm for normal males. So, the ratio of the means for either gender is approximately 3 to 1, which agrees with the results achieved earlier as was shown in Fig. 3 for the whole population. An independent verification group was included in the form of the results of young aged subjects who were considered as base line measurements. The comparative means for movement time of the females and males, diabetics to controls are presented in Fig. 10.

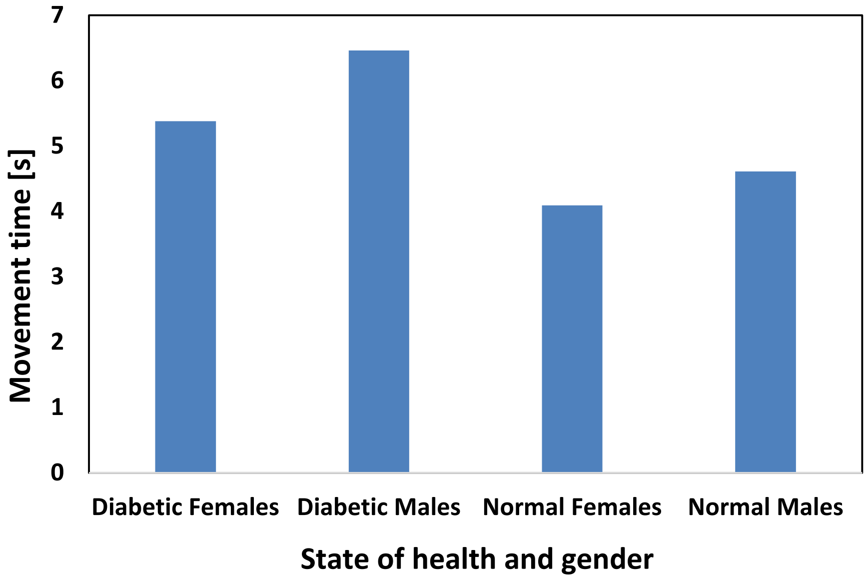

Fig. 10. Mean values of movement time as a function of state of health and gender.

This detailed figure shows that diabetic females have mean value of time of motion equal to 5.63 s compared to 4.09 s for normal females, and that diabetic males have a mean value of 6.46 s compared to 4.61 s for normal males. This confirms the result found earlier for the whole population but these results were not as sensitive as those of dependence of vertical deviation on the state of health. The reason behind which lies the less dependence of time of motion on health, is that hand movement time is based on personal attitude and willingness to move, rather than solely the state of health.

The correlation values calculated for vertical deviation and movement time for males and females with respect to state of health is shown in Fig. 11. The low value of nearly zero for normal males indicates that no real consistency between deviation and movement time, while that of approximately 0.1 for normal females indicates that minor (direct) proportionality exists between deviation and movement time. On the contrary, negative value of correlation as for diabetic females and males designates inverse proportionality between deviation and movement time, i.e. as a diabetic moves the hand poorly which results in large deviation he or she does that quickly. Thus, that movement time is decreased while deviation was increased. This means that no clear relation exists between them, i.e. none of them gave a value close to 1, this can be explained by the fact that deviation was due to poor health so a person cannot actually improve it. Movement time was related to willingness of subject to move the hand so some diabetics moves hand fast while others slower.

By close inspection of Figs. 3, 5, 6 and 9, it can be concluded that hand deviation is larger with the presence of diabetes which is a sign of poor performance. This was also ascertained by the high value of the slope of diabetes as shown in Fig. 6. which represents graphically the parameters of regression equation for hand deviation.

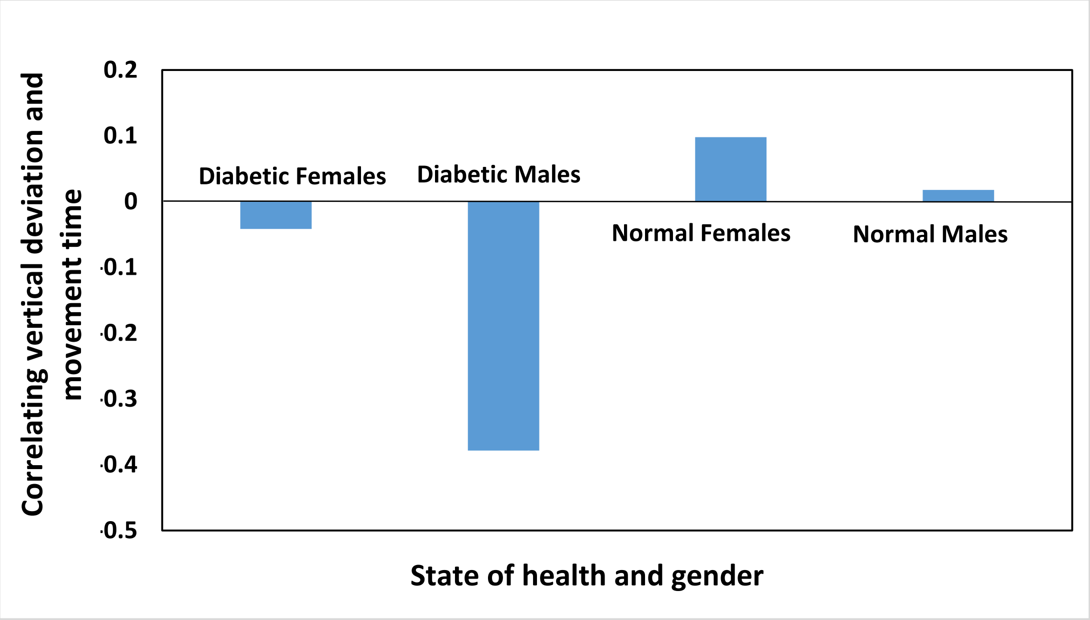

Fig. 11. Correlating vertical deviation and movement time as functions of state of health and gender.

Likewise, by inspection of the results of hand movement time as described by Figs. 4, 7, 8 and 10, it can be concluded that these movement times were larger with the presence of diabetes which were again signs of poor performance and lack of interest and concentration by the subject undertaking the test. Table 1 summarizes the correlation of age with diviation, and age with movement time.

Table 1. Correlation of age with diviation , and age with movement time.

State of health and gender	Age [years]	Correlating age with deviation	Correlating age with time of movement
Normal Females			
	18-29 (75 subjects)	0.13	0.16
	31-54 (16 subjects)	0.07	0.047
Normal Males			
	18-29 (93 subjects)	0.04	0.05
	30-60 (25 subjects)	0.26	0.011
Diabetic Females			
	21-22 (2 subjects)	1	1
	50-62 (9 subjects)	0.56	0.236
	64-89 (15 subjects)	0.26	0.164
Diabetic Males			
	23-34 (2 subjects)	1	1
	40-57 (9 subjects)	0.08	0.76
	60-97 (13 subjects)	0.03	0.188

In general, the results above agrees with those found by others such as Pandey et al. who found that the prevalence of hand deviation increases with diabetes [19]. It also ascertained the work done on hand parameters by Mota et al. who found that hand disorders in diabetic patients was 40.5% compared to 19% for controls (i.e. a ratio of approximately 2:1)

[20]. Other studies such as [21, 22], found that diabetes limited joint mobility indicates increased risk for microvascular disease. Seibold also found that sclerosis is a possibility with children having insulin-dependent diabetes mellitus [23]. Similar effects of diabetes and deterioration of limbs behavior were noticed in [24, 25].

4. CONCLUSIONS

The goal of this study was to establish a quantitative criterion for the evaluation of hand deviation and time of movement as a function of state of health, gender, age, weight, and smoking. The system used had many advantages over other systems performing tests for hand movement in the sense that it was fully computerized, no other interfaces were needed, easy to use and not overpriced. The mean values of the vertical deviation were equal to 2.7 mm for all diabetic participants. Contrasted with 0.92 mm for controls, the deviation is worsened by diabetes. Movement time was also influenced by the state of health to a lesser degree. Mean values of movement time were found at 6.03 s for diabetic subjects, compared to 4.38 s for controls. It was also found that diabetic females have a mean value of vertical deviation of 2.56 mm compared to 0.93 mm of normal females, and that diabetic males have a mean value of 2.82 mm compared to 0.92 mm for normal males. Thus, the ratio of the means for each gender is approximately 3:1. Mean values of hand movement times were found at 5.63 s for diabetic females compared with 4.09 s for normal females, while they were at 6.46 s for diabetic males compared with 4.61 s for control males. Therefore; it can be said that the setup was successful for analyzing hand movement in terms of measurements of deviation and duration. In Future, the test can be performed using a mobile phone (work on this matter is underway by authors).

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