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Computerized Assessments of Hand Skew for Diabetes Diagnosis

Mustafa M. Muheilan[1*], Muheilan M. Muheilan[2]

[1] Electrical Engineering Department, College of Engineering, Mu'tah University, Karak, Jordan
E-mail: muheilan@mutah.edu.jo
[2] Urology Department, Tallaght University Hospital, Tallaght, Dublin, Ireland

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Abstract— Hand movement deteriorations are mostly associated with certain diseases and poor functioning of the nervous system. Also, extremities dysfunction has an antagonistic impact on daily activities of subjects. In this paper, a practical tool is proposed to diagnose the presence of diabetes by measuring such dysfunction in the form of hand skew as related to blood glucose level (BGL) for certified diabetics compared to normal subjects, all as a function of gender and age. To accomplish this task, a personal computer equipped with touch pad is programmed to enable the subjects (diabetic and healthy people) to draw - with their index finger - two pre-specified reference lines, one is vertical and the other is horizontal. Practically, the finger motion will not produce the lines as intended, but rather a jerky line is produced which is assumed to deteriorate with illness or other factors. Hand movement is digitally measured based on the X and Y coordination of the index finger's position on the pad. Analysis of the data captured from hand movement concentrated on the deviations or skew of the hand from the prescribed tracks (lines). The results show that the mean values of vertical and horizontal deviations for the diabetics are larger than those for normal subjects. Moreover, female subjects have better tracking results than male subjects while older aged subjects show more deviations than younger ones. The results also reveal that high values of BGL worsened diabetic hand movement especially for males, since correlation of vertical deviations with BGL of diabetic females is at 0.17 compared to 0.369 for diabetic males, and these were at 0.23 and 0.27 when horizontal deviations are considered. Finally, the obtained results demonstrate the efficiency of proposed tool to successfully diagnose the presence of diabetes and its effect on vertical and horizontal hand movements. They also show the main advantages of the proposed tool, compared to similar ones; namely, that it is fully computerized, easy to use and non-invasive.

Keywords— Diabetes; Blood glucose level; Hand skew; Horizontal deviation; Vertical deviation.

1. INTRODUCTION

Diabetes is due to an increase in blood glucose level (BGL) beyond maximum permissible limit and usually ends in serious health problems such as loss of sensation of hands and feet [1]. Therefore, fluctuations in BGL need to be tightly controlled to reduce the risk of developing complications in people with type 1 diabetes. Many people - as given by International Diabetes Federation (IDF) - are affected by diabetes and lots of them are vulnerable to have diseases like peripheral neuropathy that deteriorates the hands and feet mobility, and hence influence their daily activities [2]. Diabetic peripheral neuropathy (DPN) affects more than 50% of diabetic patients [3]. It may lead to lower rates of perceived health and increased mortality rates [4]. In this framework, hand deviation is assumed to be a good measure of the neuropathy's severity. In order to differentiate between hand movements' behaviour of diabetics and normal controls, a setup is prepared to measure this parameter. A laptop computer with a touch pad is used to suffice for the completion of the needed measurements. On the contrary, the setups used by others were difficult to use by an individual people without assistance from medical staff [5]. No literature was found to focus on horizontal or vertical hand deviations as proposed in this study, which in turn limits the

* Corresponding author
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source of information available for comparison and gives less data for medical staff to base their medical decisions upon for picking up the check and diagnosing of hand complications [6]. Consequently, this study intends to present a suitable tactic and setup for diagnosing hand pursuing dysfunctions.

Disorders of the hand were studied by Rahimi et al. [7] who found that hand functions in people with diabetes had negative impact on working performance. Disability may be diagnosed by movement disorders according to Jackson [8]. Transducers were used by Polla et al. to acquire extremities movement by fixing them to the part needed [9]. Another hands-on tool was used by Muheilan for capturing and analysing horizontal hand deviation using a personal computer, programmed for this purpose using visual basic, and found that deviation is greater with deteriorated state of mental health [10] and produced a comparative study for normal control and subjects suffering from mental illness [11]. Tamara offered a system which analysed finger movements using a multi-camera system that was slightly uncomfortable to use [12].

Casellini et al. used Sudoscan - a technique for measuring electrochemical skin conductance of extremities to evaluate diabetic neuropathy- and hence Sudomotor dysfunction as an early detectable abnormality in diabetic neuropathy [13]. Hand movement record by a 3D optical motion-tracking system, which used multiple infrared cameras to trace the positions of active infrared-emitting markers was adopted by Grujic [12]. It was noticed that diabetes mellitus is associated with a number of musculoskeletal symptoms as specified by Goyal et al. [6]. Measurements of finger joint angle using stretchable carbon nanotube strain sensor was conducted by Park et al. who used strain sensors capable of monitoring complex human motion which was highly desirable for the monitoring healthcare. In this study, a highly stretchable strain sensor was fabricated via inkjet printing of single-walled carbon nanotube thin films on a stretchable polydimethylsiloxane substrate [14]. Tactile weakness in people suspected of suffering from neuropathy was studied by Kennedy et al. in which a technique named the Bumps was used to measure the sensitivity of the finger pads. The Bumps test sets the tactile detection threshold by ensuring the subject rub the finger pad over a smooth surface to identify single and coin-shaped bumps of varying heights [15]. Zhan et al. used computer and a data glove for measuring human hand movement [16]. The data glove uses fifteen magnetic sensor units to measure joint angles of a hand by sticking one sensor unit on the middle of each phalanx of a finger. These units are connected to the computer that communicates with the data glove through an interface. Kuo et al. investigated the performance of handwriting of patients with carpal tunnel syndrome and healthy subjects to study the sensory-related deficits in sensorimotor control of the hand and were monitored using a 3D device [17].

Concerning the facts above, this study postulates that horizontal and vertical hand deviations from their corresponding tracks can be used as a diagnostic technique for identifying diabetes with special attention being given to the effects of other parameters on deviations such as: gender, age and BGL. Therefore, a modified setup to that utilized by Muheilan et al. [11] is used in this research. Muheilan et al. used a fully computerized system for hand movement capture using a light pen in which the subject moves his hand holding the light pen for a certain distance. A line was drawn from first point to last point; this was called the width of the movement. The hight or the vertical deflection was also calculated by subtracting the smallest point from the highest point and the arctan (angle) is found by dividing hight by width, so that angles produced by every subject were compared. The smaller the produced angle meant that less deviation is made and , hence, better hand movement. This was conducted by normal and mentally ill subjects for both males and females. Latency was measured by taking the time between the apearence of a reference line and the onset of hand movement.

2. SETUP AND METHODS

Normal females and males were selected to be of young age within a very narrow range of 18 to 22 years old, in an effort to produce a standard reference of hand movement (base line for future work or a datum point). They are compared with diabetic subjects and later on with other age groups; therefore, a group consisting of 50 female controls as well as 50 males with non-diabetic history and with no previous hand diseases was nominated for the tests. Also, for comparison purposes, 24 females aged 50 to 89 years old as well as 24 males aged 23 to 97 years old participated in the study who were all inpatients of insulin-dependent diabetes.

Data was collected via a system consisting of a laptop equipped with a touch pad. No other peripherals were utilized such as the light pen or the mouse which were used by other studies such as Muheilan [10]. The touch pad usage removed the restriction caused by the mouse and the light pen to hand movement, which was then thought to have affected the results of the tests. Amendments were made to the software operating this setup to make it more appropriate for the new parameters presented hereafter.

Deviation measurements were based on the tracing mechanism which was achieved while the subject was restfully seated in front of the laptop screen. The software - used to acquire the signal - was prepared by the authors using visual basic [18].

Two tests were performed by every subject: the vertical test and the horizontal test. The vertical test is to track a vertical reference line while the horizontal test is to track a horizontal reference line.

In the first test, a 15 cm long straight vertical line is drawn on the screen, starting from the top side downward as shown in Fig. 1. In the second test, a 15 cm long straight horizontal line is drawn starting from the left side of the screen to the right. Each of these two lines perform as reference lines to the user who was asked to move the index finger and hence the hand on the touch pad to redraw each of these line as accurately as possible. The finger movement on the touch pad is reflected on the screen as if it is drawing on the screen itself in the same plain as the reference lines. It is important to keep the finger touching the pad while moving as any separation between the figure and the pad is considered as discontinuity. The trace produced by the finger is not a pure straight line as intended, but rather sporadic line, because of the state of health or age. Both are forms of inability to control hand movement perfectly. In both tests' measurements, finger trace must be made while hand is resting on a horizontal datum. This is necessary to eliminate three-dimensional motion complexity. Each trace made by the hand movement is captured as a collection of discrete points with a pair of X and Y coordinates which are saved in the computer memory as an array for analysis.

Considering the first test, the user draws the vertical line which starts at a discrete point of certain height which is the height of the first point; i.e., top of the reference line. As the hand moves downward to reproduce the vertical reference line, but not as perfect as the reference line shown in Fig. 1.

Fig. 1. Vertical trace made by the hand of a diabetic subject (the straight line represents the reference line and dotted line represents the trace made by the hand during the test).

The vertical downward hand movement involuntarily makes skew to both sides along the reference line. Although it was predestined to produce a straight line, it could not do that, in fact it created bends. The X coordinate of the vertical reference line is assigned a value of Xr, this value is the same for all points of the line as the line is drawn vertically downward. The difference between the coordinate of each point made by the hand Xi while tracing the line and the coordinate of this reference line is labeled skew or horizontal deviation. Based on that, skew for all points drawn by hand is given by:

$$S_h = \sum_{i=1}^{n}(X_i - X_r) \quad (1)$$

where S_h is the total skew (horizontal deviation in mm).

In this sense, deviations to the right of the line will cancel deviations to the left of the line as the sum of deviations is calculated. This will lead to false value since we are adding positive and negative values as these are on opposite sides as shown above. To eliminate such false results, the absolute values of deviations are considered and therefore,

$$S_h = \sum_{i=1}^{n} MOD(Xi - Xr) \quad (2)$$

The MOD function (modulus) preserves the errors from both sides of the line, rather than cancelling their values based on their signs.

The second test performed by the subject is the horizontal hand movement through which a horizontal reference line of 15 cm appears on the screen as shown in Fig. 2. The subject is asked to move his finger on the touch pad to reproduce that line. Line drawn by the user begins at a distinct point of certain height; this is the height of the reference line as the hand moves. It reproduces the line but not as perfect as shown in Fig. 2.

Fig. 2. Horizontal trace made by the hand of a diabetic subject (the straight line represents the reference line and dotted line represents the trace made by the hand during the test).

It is clear again that the hand makes deviations to both sides above or below the reference line in an unintentional behavior. Assuming the height of first point of reference line is Yr, the difference between any point made by the hand and this height is termed skew or vertical deviation.

The Y coordinate of the horizontal reference line is assigned a value of Yr which is constant for the rest of the line. The difference between the coordinate of each point made by the hand Yi while tracing the line and the coordinate of this reference line is labeled skew or vertical deviation. Based on that, skew for all points drawn by hand is given by:

$$S_v = \sum_{i=1}^{m}(Y_i - Yr) \quad (3)$$

where S_v is the total skew (vertical deviation in mm).

The absolute values of deviations are considered as in previous case and thus:

$$S_v = \sum_{i=1}^{m} MOD(Yi - Yr) \quad (4)$$

Results were statistically analyzed using MS Excel 2019. Means, standard deviations and correlations were considered for evaluation purposes at different stages where appropriate.

3. RESULTS AND DISCUSSIONS

3.1. Vertical Hand Movement

The results of vertical hand movement are exhibited in Figs. 3 – 5. The minimum and maximum vertical deviations for normal females were at 0.053 mm and 2.5 mm, respectively with a mean value of 0.87 mm, and a standard deviation of 0.5 mm. Age had no effect on results and correlation coefficient between age and deviation was equal to -0.01 since this was a very narrow age range which was meant to set a standard base line value (datum point) of deviation for healthy female's hand movement as shown in Fig. 3.

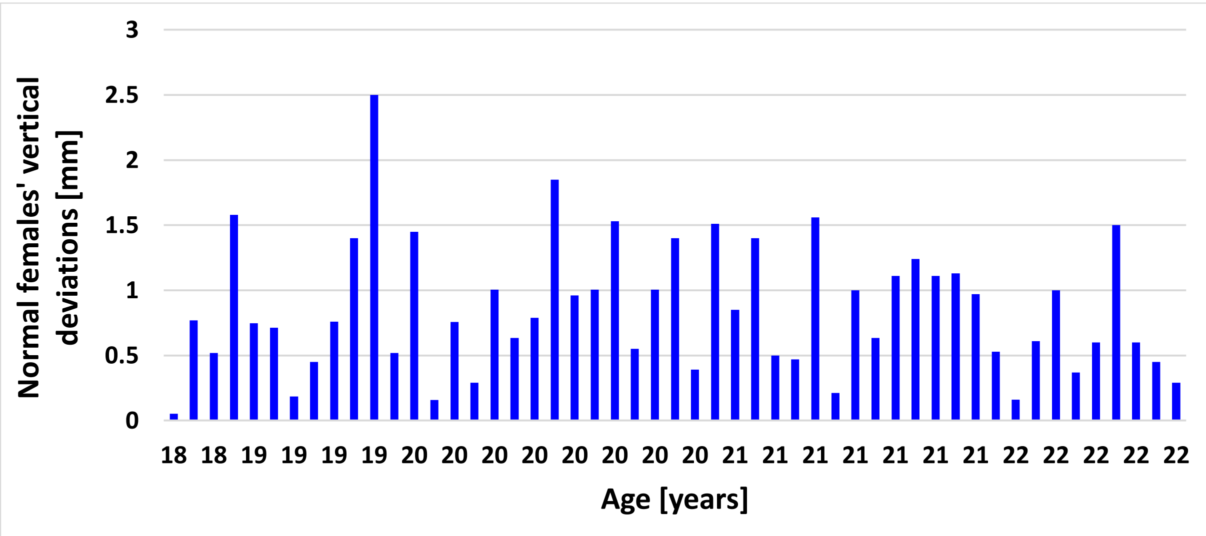

Fig. 3. Vertical deviation of all normal females as a function of age.

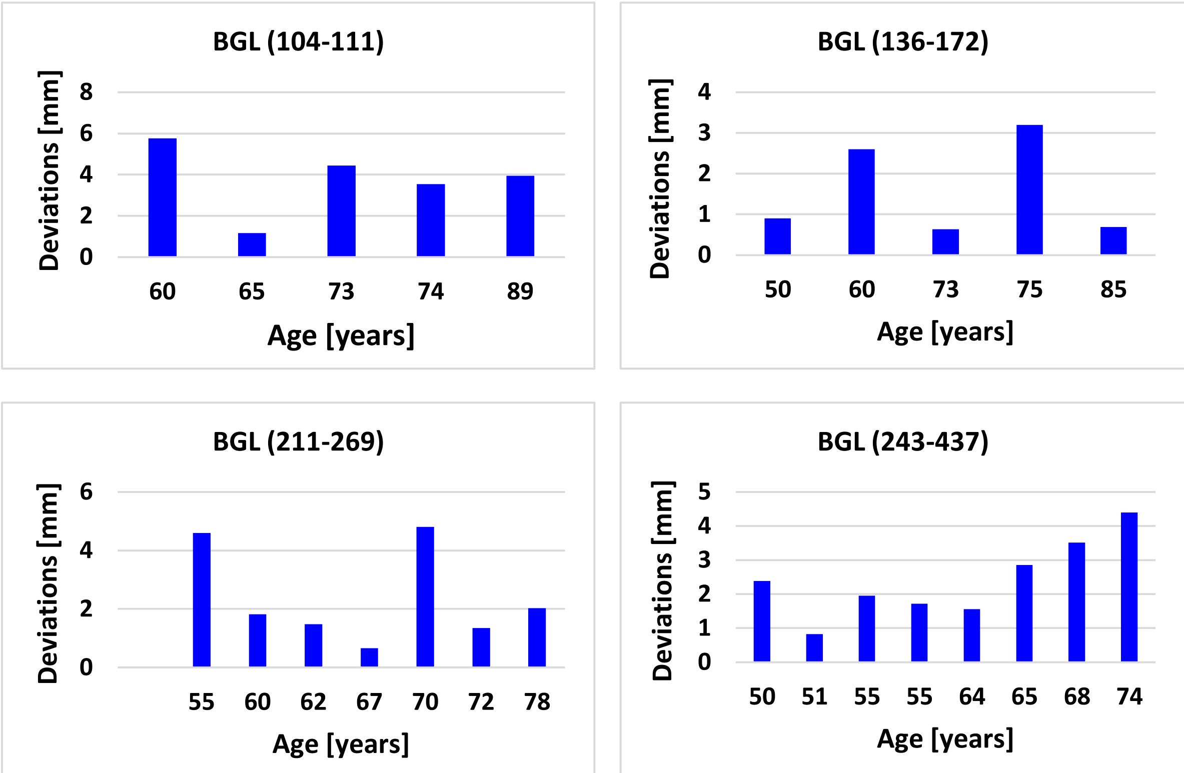

Fig. 4. Vertical deviation of diabetic females' as a function of age for different age groups measured within very narrow BGL intervals.

In Fig. 4 - which represents diabetic females vertical deviations - the effect of BGL was eliminated by taking a group of individuals with BGL in a narrow range (104 - 111). As can be seen, the mean deviation was at 3.77 mm for the age group of 60-89 years. Other groups have mean values of deviations rising in value as shown above. Subjects aged 50 to 85 years whose BGL was between 136 to 172, had mean deviation of 1.6 mm, while group aged 55 to 78 years whose BGL was between 211 and 269 had a mean deviation of 2.1, and the last group aged 50 to 74 years, whose BGL between 243 to 437 had a mean deviation of 2.39 mm. It might be questioned of whether this hand deterioration is due to age or diabetes; therefore, a second parameter is investigated, namely the relation between vertical deviation and BGL for diabetes.

From Fig. 5, it can be seen that deviation varies between 0.9 and 2.3 mm for diabetic subjects aged 50 to 55 years and having a BGL mean value of 323 points, while deviation varies between 1.1 and 5.7 mm for diabetic subjects aged 60 to 65 years and having a BGL mean value of 186 points. The deviation varies between 0.6 to 4.8 mm for diabetic subjects aged 67 to 73 years and having a BGL mean value of 202 points, while deviation varies between 0.68 to 4.4 mm for diabetic subjects aged 74 to 89 years and having a BGL mean value of 184 points. The minimum and maximum range of vertical deviation as a function of BGL stayed the same as those measured as function of age since it the test is the same but with different parameter.

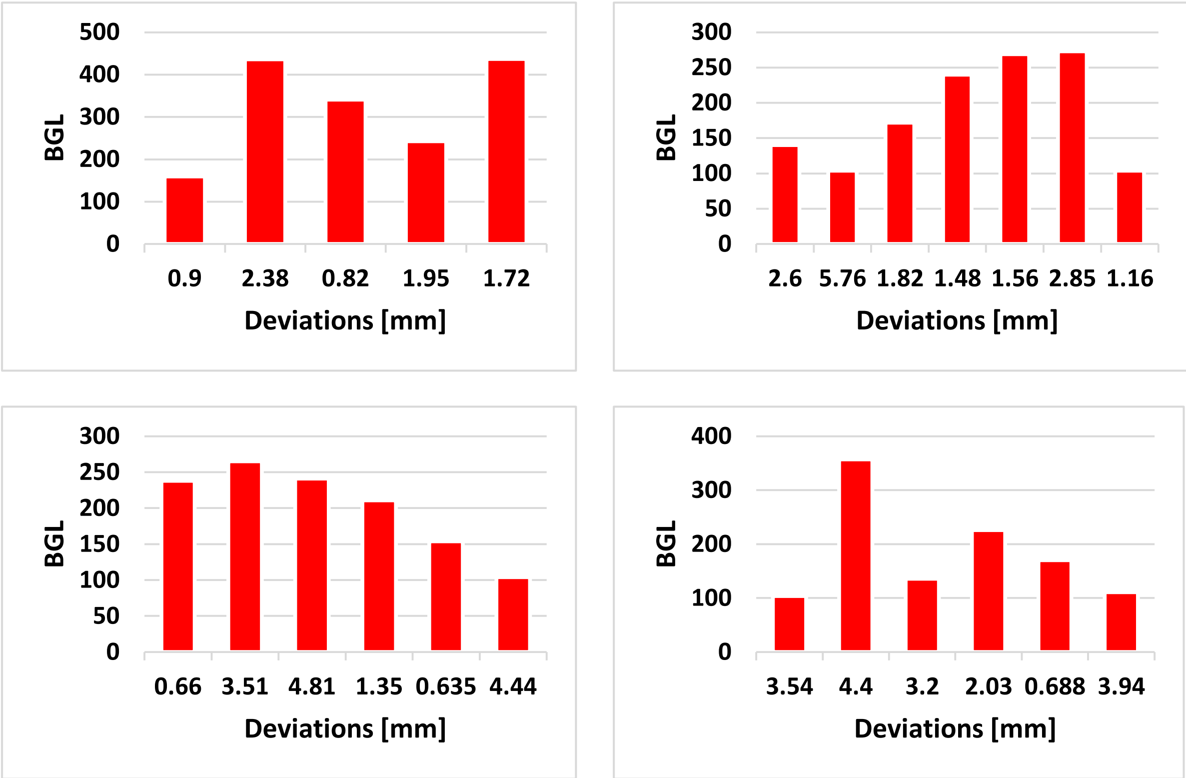

Fig. 5. Vertical deviation of diabetic females as a function of BGL.

Fig. 6 shows the vertical deviation of all normal males as a function of age while Fig. 7 shows diabetic males vertical deviation as a function of age for different age groups measured within very narrow BGL intervals and Fig. 8 shows vertical deviation of diabetic males as a function of BGL.

Minimum and maximum vertical deviations for normal males were at 0.01 mm and 2.3 mm with a mean value of 0.86 mm, and standard deviation of 0.48 mm, and the correlation coefficient between age and deviation is equal to 0.057 which is a low value; therefore, age has not affected the results as the age group is very much of similar age which agreed with previous results found for normal females as shown in Fig. 6.

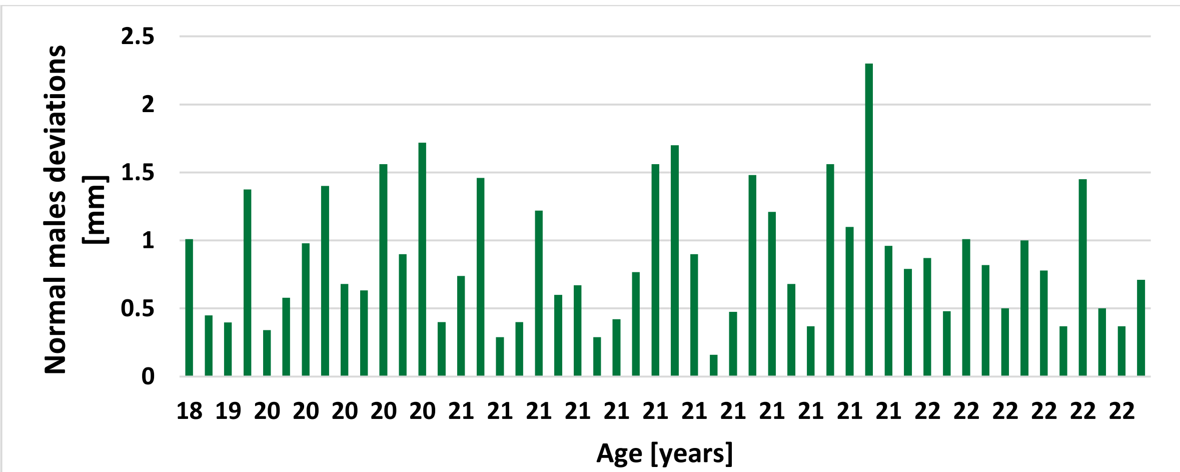

Fig. 6. Vertical deviation of all normal males as a function of age.

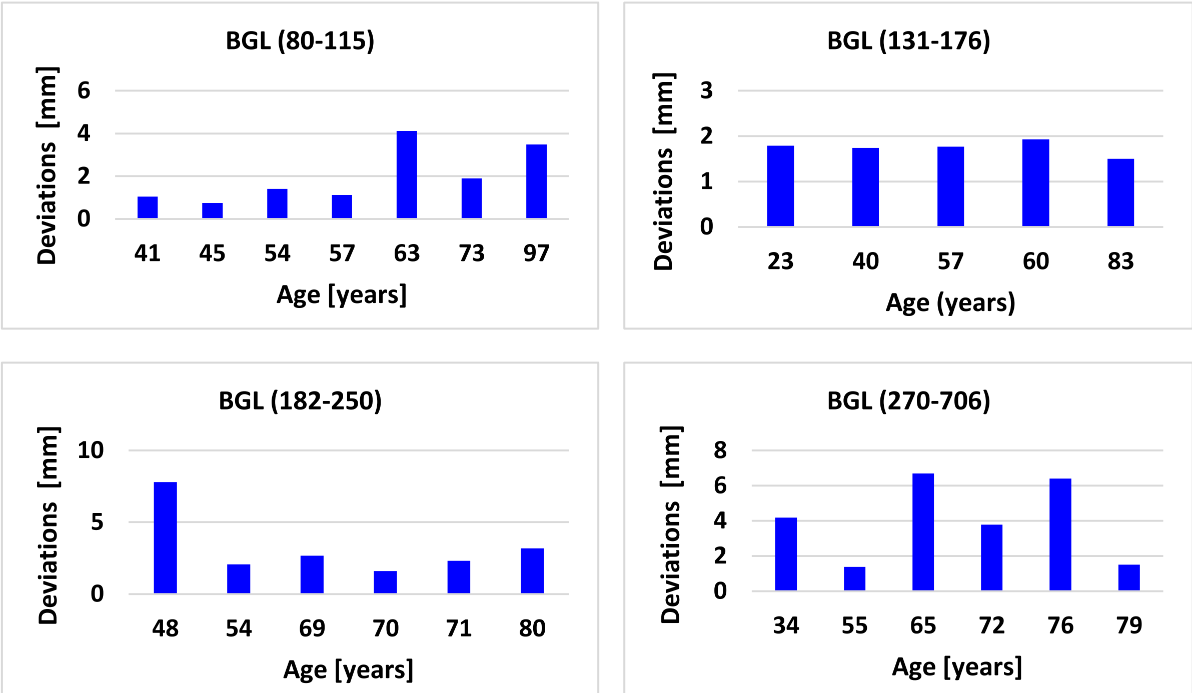

Fig. 7. Vertical deviation of diabetic males as a function of age for different age groups measured within very narrow BGL intervals.

In Fig. 7, the effect of BGL was eliminated by taking a group of individuals with BGL in a narrow range such as (80-115). The mean deviation was at 1.97 mm for age group 41-97 years. Subjects aged 23 to 83 years whose BGL was between 131 to 176, had mean deviation of 1.74 mm, while group aged 48 to 80 years whose BGL was between 182 and 250 had a mean deviation of 3.27, and the last group aged 34 to 79 years, whose BGL between 270 to 706 had a mean deviation of 3.99 mm.

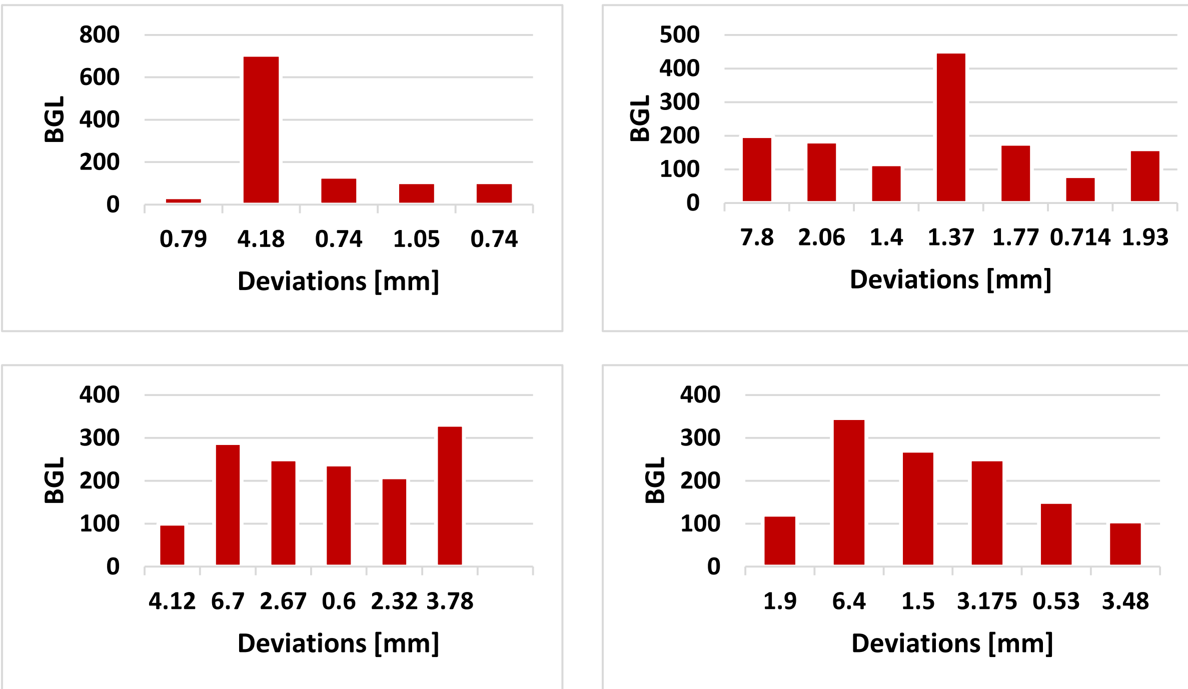

Fig. 8. Vertical deviation of diabetic males as a function of BGL for different age groups.

From Fig. 8, it can be seen that deviation varies between 0.79 and 4.18 mm for diabetic subjects aged 23 to 45 years with BGL whose mean value is 216 points, while deviation varies from 0.7 to 7.8 mm for diabetic subjects aged 48 to 60 years with BGL whose mean value is 194 points. The deviation varies between 0.6 and 6.7 mm for diabetic subjects aged 63 to 72 years with BGL whose mean value is 235 points, while deviation varies between 0.53 to 6.4 mm for diabetic subjects aged 73 to 97 years with BGL whose mean value is at 207 points. Minimum to maximum range of vertical deviation as a function of BGL for diabetic males was found to be the same as that for age.

Fig. 9 shows the mean values of vertical deviation as a function of state of health and gender and Fig. 10 shows the standard deviation (STD) of the vertical deviation as a function of state of health and gender.

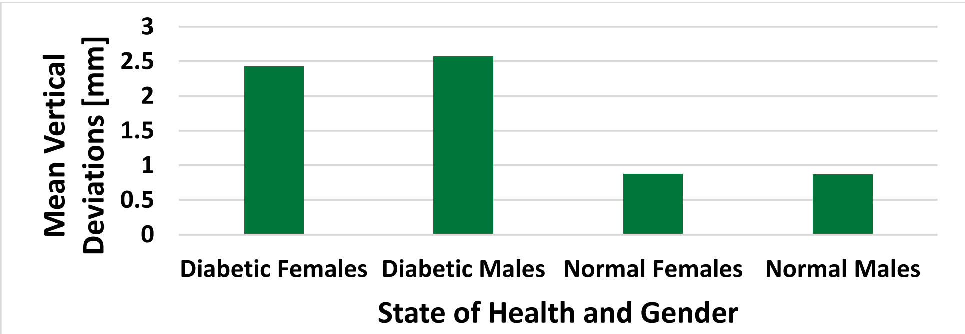

Fig. 9. Mean values of the vertical deviation as a function of state of health and gender.

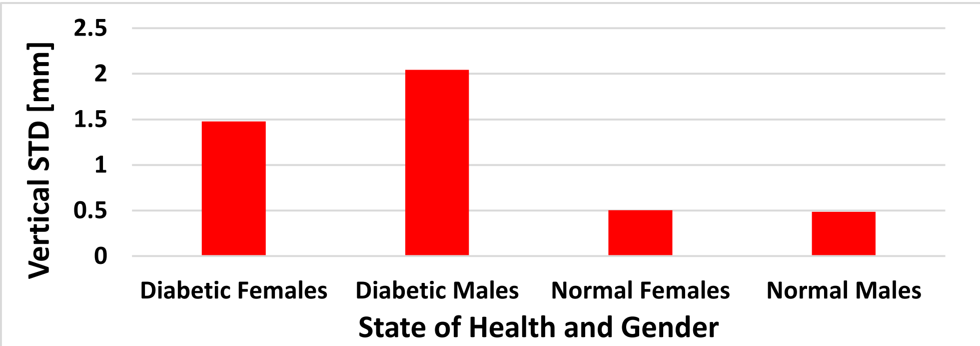

Fig. 10. Vertical deviation STD as a function of state of health and gender.

The minimum and maximum vertical deviations for diabetic females were at 0.63 mm and 5.76 mm with a mean value of 2.42 mm and a standard deviation of 1.47 mm. It was noticed that the subjects' age has a large effect on the results; i.e., the deviation increases for older subjects compared to younger ones. This is not surprising since older people find difficulties in moving their extremities. As can be seen from these results, the ratio of deterioration for the mean value of the hand movement between diabetic and normal females is 2.78-fold. Undoubtedly, the higher this ratio is the more sever is the effect of diabetes on hand movement. The ratio of deterioration for diabetic to normal males was found to be approximately 2.988.

Minimum and maximum vertical deviations for diabetic males were equal to 0.53 mm and 7.8 mm with a mean value of 2.57 mm and a standard deviation of 2.04 mm. As can be seen from this result, the ratio of deterioration for the mean value of the hand movement for diabetic males when compared to normal males is 2.98-fold higher. This value is also higher than that measured for females, indicating that females had better hand tracking compared to males. In both cases, the high values for means emphasize the severity that diabetes has on hand motion. The correlation coefficient between age and deviation is equal to 0.157 which is a low value. The aforementioned results are justified as older people generally tend to be less responsive in terms of motion. This may be because the subject feels uncomfortable and intended to conduct the test as swift as possible and not being keen on how perfect their hand is tracing the line; therefore, high deviations were obtained.

It can be said that BGL in general worsened hand movement only when the mean was approximately three times that of normal males. Correlation coefficient is equal to 0.369 which indicates the strong dependence of deviation on BGL and the state of health. In both cases, females hand movement is better than that of males. So, hand movement is also a function of gender in this type of movement as revealed by the results depicted in Fig. 9. It is clear that diabetics have higher variability and spread than normal subjects as shown in Fig. 10. This is an indication of how the disease affects people at different degrees. At the same time it strengthens the idea behind taking normal subjects of similar age characterized by having a small degree of spread. This emphasizes that healthy young aged subjects behave in a similar manner and - in general - they have very good hand response and small deviation; consequently, they can give a base line for reference results. Gender parameter had a clear effect on deviation when it is considered separately. Females have less deviation than males. This can be explained by the tendency of females to produce a more accurate and near perfect movement than males and due to their patience while conducting the experiment. It was found that age also had a bad effect for diabetic subjects since older subjects were found to be less responsive and unable to control their extremities as good as younger subjects.

3.2. Horizontal Hand Movement

The results of horizontal hand movement are depicted in Figs. 11 – 16. The minimum and maximum horizontal deviations for normal females as a function of age were at 0.037 mm and 2.77 mm with a mean value of 1.1 mm, and standard deviation of 0.6 mm as shown in Fig. 11. Correlation coefficient between age and deviation is equal to 0.25. This value of correlation indicates that horizontal deviation is affected by age.

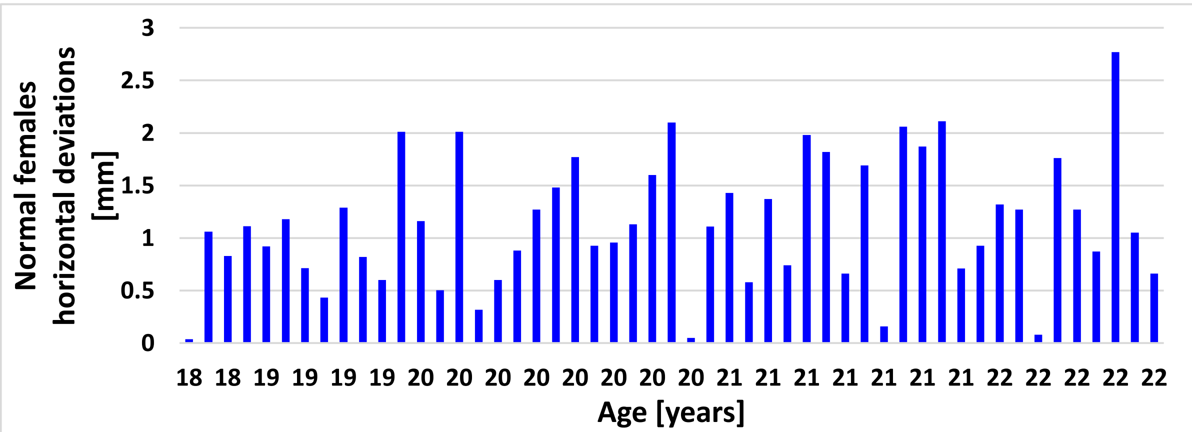

Fig. 11. Horizontal deviation of all normal females as a function of age.

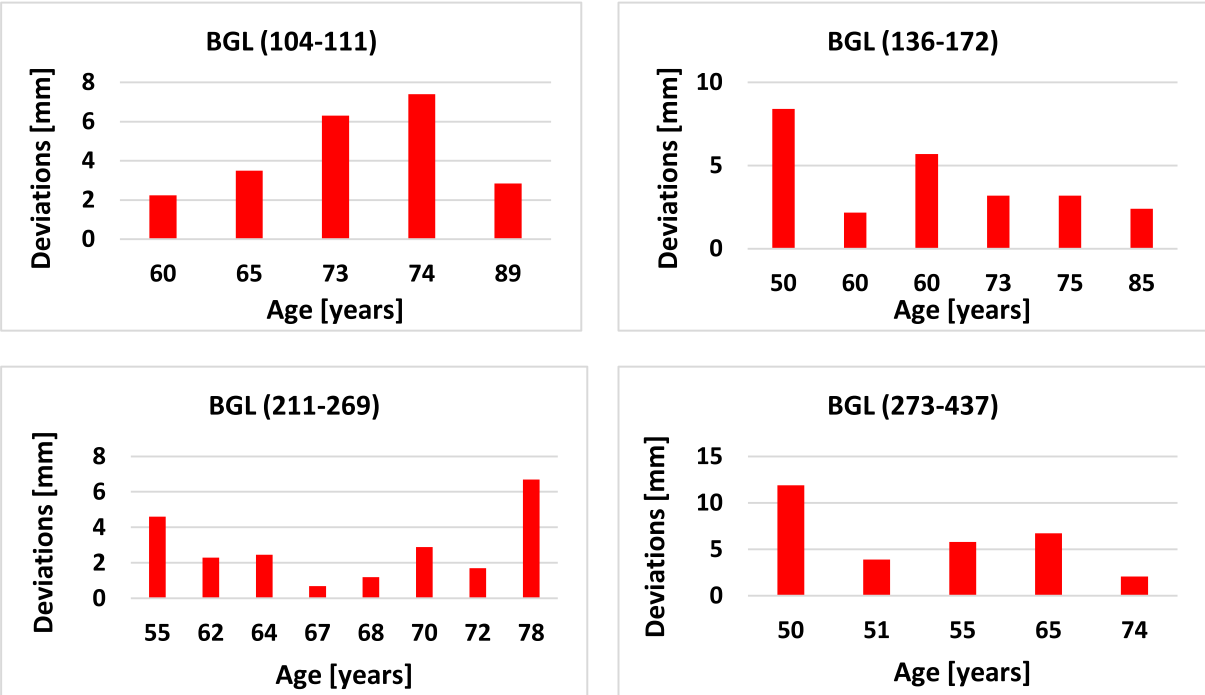

Fig. 12. Horizontal deviation of diabetic females as a function of age for different age groups measured within very narrow BGL intervals.

In Fig. 12, the effect of BGL was eliminated by taking a group of individuals with BGL in a narrow range such as (104 to 111), the mean deviation was at 4.46 mm for age group 60 to 89 years. Subjects aged 50 to 85 years - whose BGL was between 136 and 172 - had mean deviation of 4.17 mm, while group aged 55 to 78 years whose BGL was between 211 and 269 had a mean deviation of 2.81 mm. The last group aged 34 to 79 years, the BGL of which lies between 273 and 437 had a mean deviation of 6.07 mm.

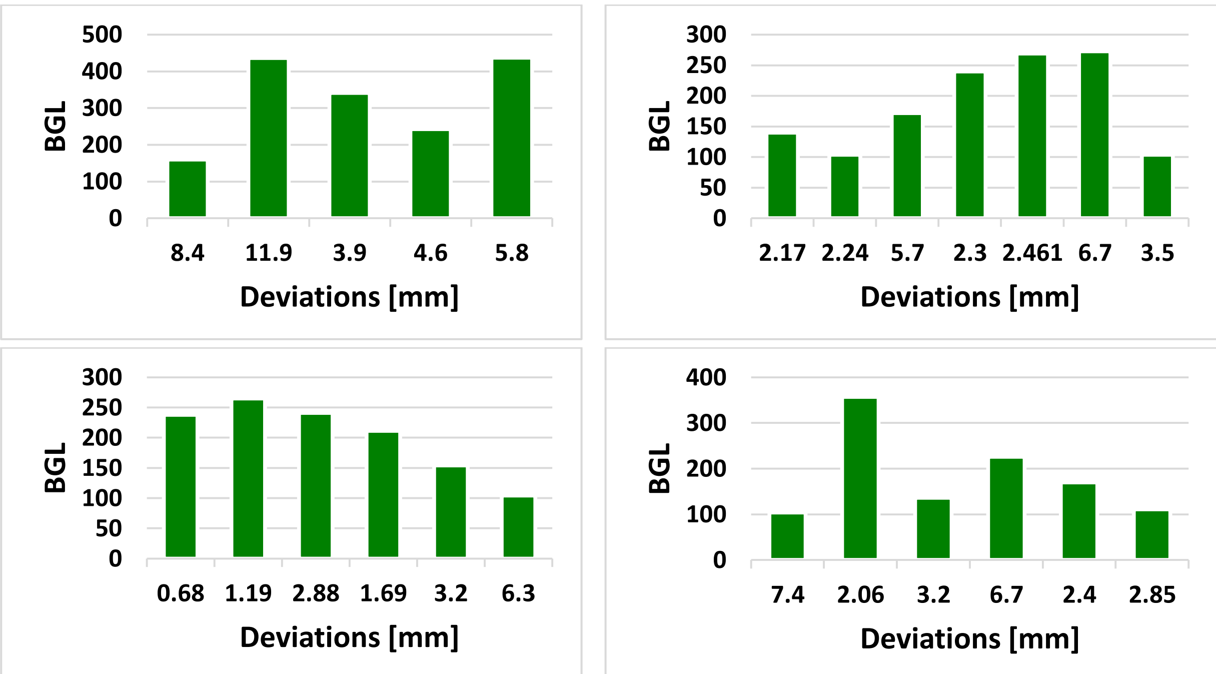

Fig. 13. Horizontal deviation of diabetic females as a function of BGL for different age groups.

From Fig. 13, it can be seen that deviation varies between 3.9 and 11.9 mm for diabetic subjects aged 50 to 55 years with BGL mean value of 323 points, while deviation varies between 2.17 and 6.7 mm for diabetic subjects aged 60 to 65 years with BGL mean value of 186 points. The deviation varies between 0.68 to 6.3 mm for diabetic subjects aged 67 to 73 years with BGL mean value of 202 points, while deviation varies between 2.06 to 7.4 mm for diabetic subjects aged 74 to 89 years with BGL mean value of 184 points.

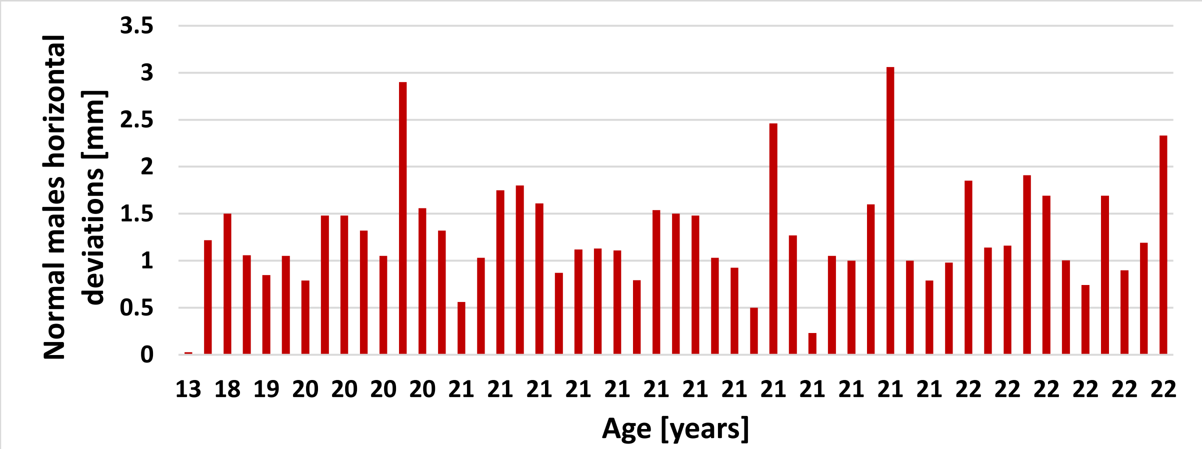

Fig. 14. Horizontal deviation of all normal males as a function of age.

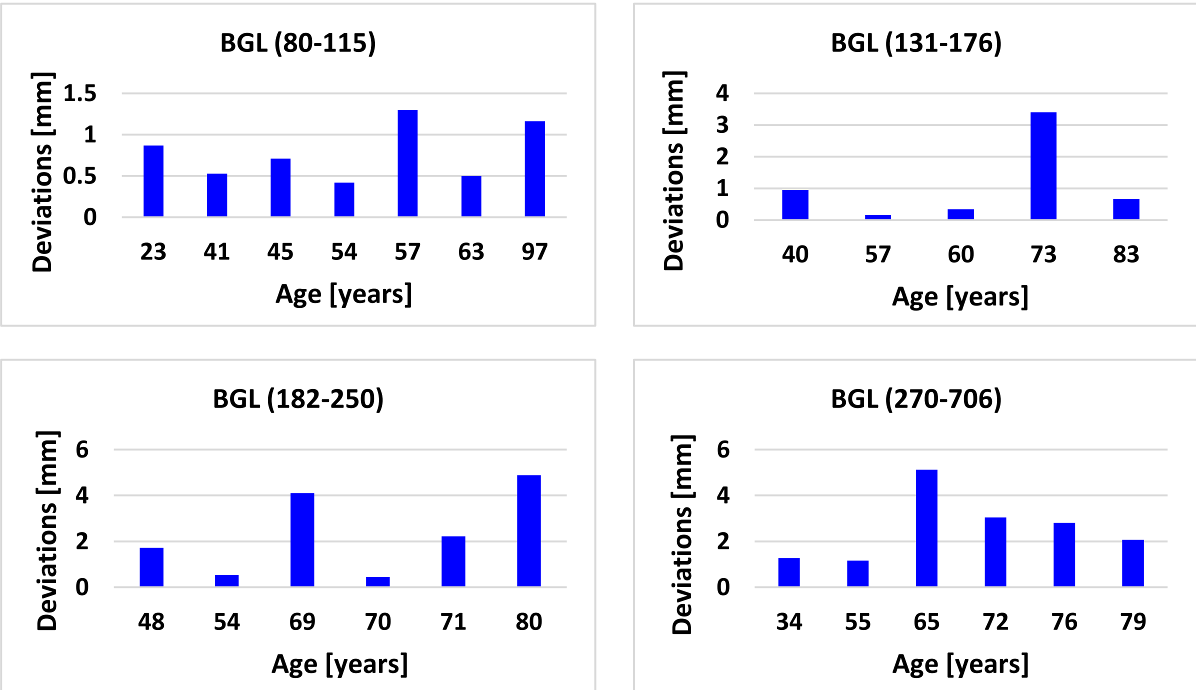

Fig. 15. Horizontal deviation of diabetic males as a function of age for different age groups measured within very narrow BGL intervals.

In general, minimum and maximum horizontal deviations for diabetic females as a function of age were at 0.68 mm and 11.9 mm with a mean value of 4.17 mm and standard deviation of 2.68 mm. From these results, the ratio of deterioration for the mean value of the hand movement between diabetics and normal females is 3.79-fold while the ratio of deterioration for diabetic to normal males was approximately 1.29. Undoubtedly, the higher this ratio is, the more sever is the effect of diabetes on hand movement. Correlation between deviation and age is equal to 0.37 which concludes that age is the decisive factor in deteriorating hand movement. The effect of BGL was also investigated and the results showed that the minimum to maximum range of horizontal deviation as a function of BGL for diabetic females stayed the same as that obtained for age because these are different parameters, although they are of the same subjects who took the same test. Fig. 13 shows that BGL in general worsened hand movement only when the mean - which was approximately four times that of normal females - is considered. Correlation coefficient between deviation and BGL was 0.23 which emphasizes the effect of BGL on deteriorated hand movement.

Minimum and maximum horizontal deviations for normal males were at 0.02 mm and 3.06 mm with a mean value of 1.3 mm and standard deviation of 0.57 mm as shown in Fig. 14. The correlation coefficient between age and deviation was equal to 0.10 which is a very low value. An indication of an almost independent relation of deviation on age was noticed because this is a very tight age range meant to give the study a base line.

Fig. 15 - which represents diabetic males' horizontal deviations as a function of age - a BGL in the range (35 to 115) had a mean deviation that equals 0.78 mm for the age group ranging from 23 to 97 years. Subjects aged 40 to 83 years - whose BGL was between 131 and 176 - had mean deviation of 1.1 mm, while group aged 48 to 80 years – with BGL between 182 and 250 - had a mean deviation of 2.31 mm. The last group aged 34 to 79 years with BGL ranging between 270 and 706 had a mean deviation that is equal to 2.57 mm. The deterioration ratio for the mean value of the hand movement in this case is 1.29-fold higher than that for females, which indicates again that females had better hand tracking than males. This value emphasizes the severity diabetes has on hand motion. Correlation coefficient between deviation and age is equal to 0.39 which indicates direct proportionality between the two parameters. The minimum to maximum range of horizontal deviation as a function of BGL for diabetic males stayed the same as before.

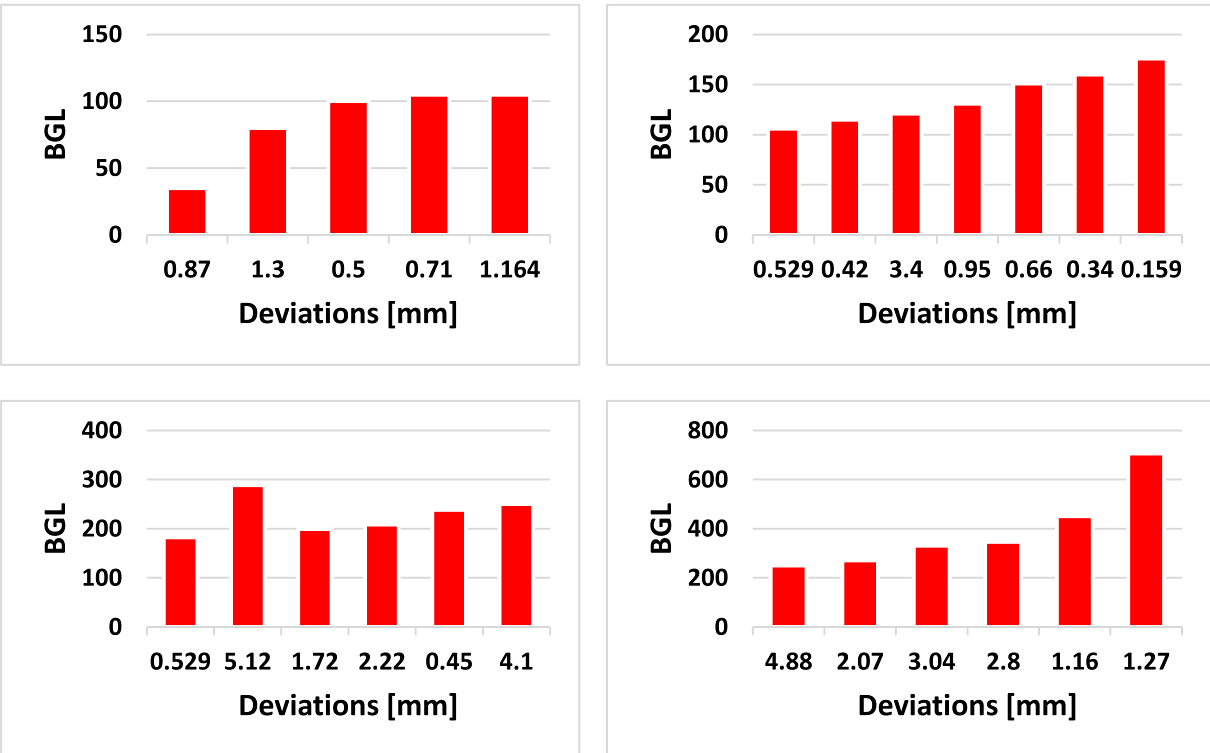

Fig. 16. Horizontal deviation of diabetic males as a function of BGL for different age groups.

From Fig. 16 it can be seen that deviation varies between 0.5 and 1.3 mm for diabetic subjects aged 23 to 45 years with BGL mean value of 106 points, while deviation varies from 0.16 to 3.40 mm for diabetic subjects aged 48 to 60 years with BGL mean value of 137 points. The deviation varies between 0.45 to 5.12 mm for diabetic subjects aged 63 to 72 years with BGL mean value of 227 points, while deviation varies between 1.16 and 4.88mm for diabetic subjects aged 73 to 97 years with BGL mean value of 392 points. Deviations of horizontal hand movement increased as BGL increased for diabetic males, with a correlation factor of 0.26.

Fig. 17 exhibits the horizontal deviation mean values as a function of state of health and gender while Fig. 18 depicts the horizontal deviation STD as a function of state of health and gender. These two figures reveal that diabetic subjects have high mean value of horizontal deviation compared to normal subjects indicating a deteriorated hand movement. The obtained high values of STD confirm that data is well spared around the mean in the case of diabetics compared to that for normal subjects who had small spread and hence low variability in their hand movement. This confirms that this disease affects people hand movement.

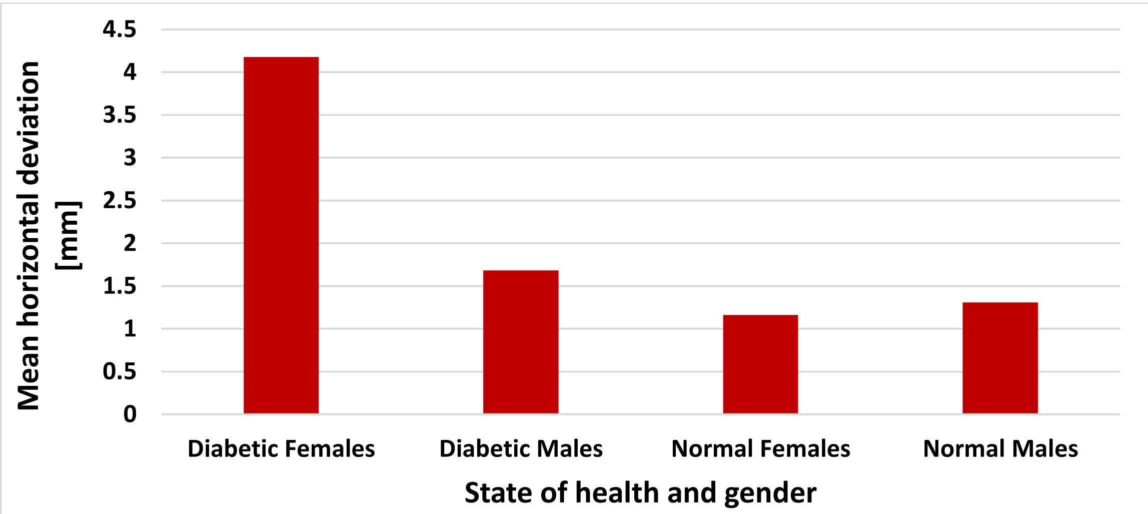

Fig. 17. Mean values of horizontal deviation as a function of state of health and gender.

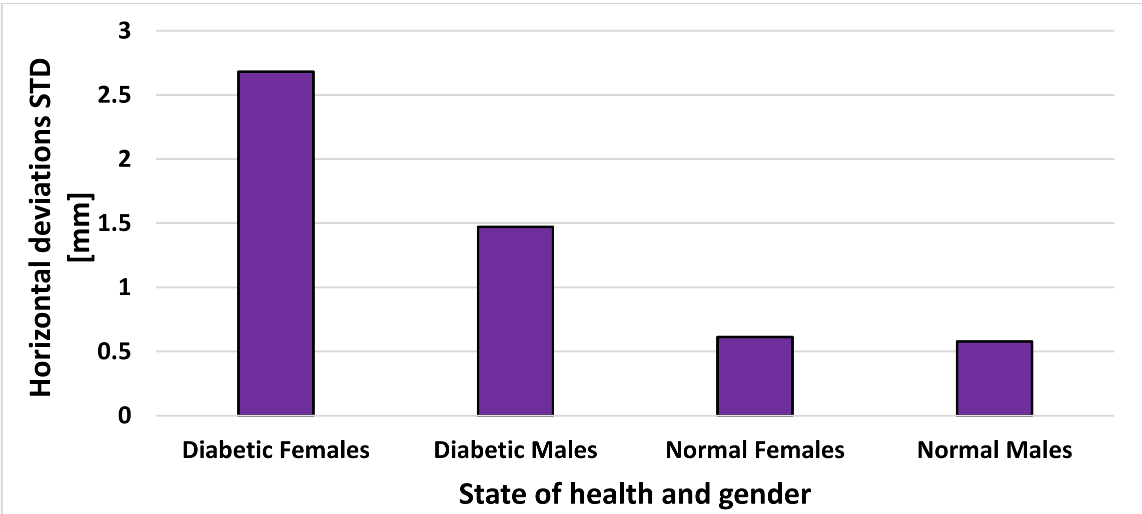

Fig. 18. Horizontal deviation STD as a function of state of health and gender.

3.3. Deviations' Comparisons

A comparison between the vertical and horizontal deviations is depicted in Figs. 19-21. In these figures NFVD denotes normal female vertical deviation, NFHD: normal female horizontal deviation, NMVD: normal male vertical deviation, NMHD: normal male horizontal deviation, DFVD: diabetic female vertical deviation, DFHD: diabetic female horizontal deviation, DMVD: diabetic male vertical deviation and DMHD: diabetic male horizontal deviation.

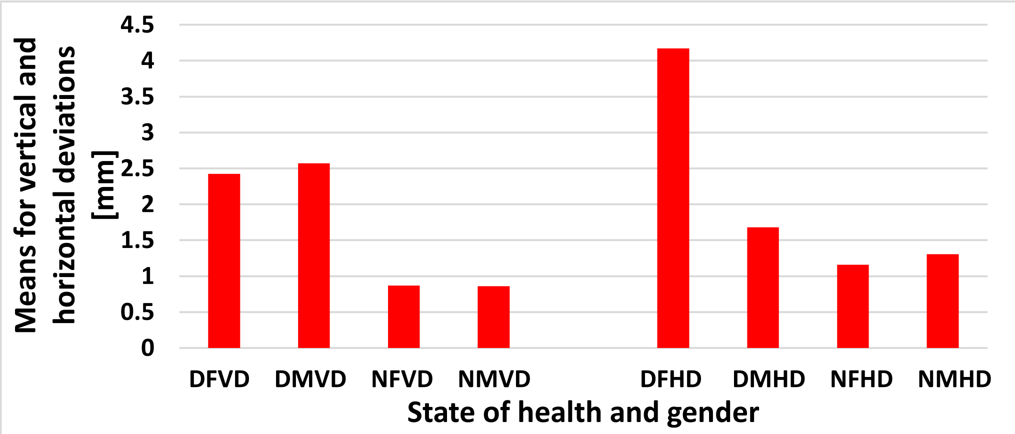

Fig. 19. Mean values of vertical and horizontal deviations with as a function of state of health and gender

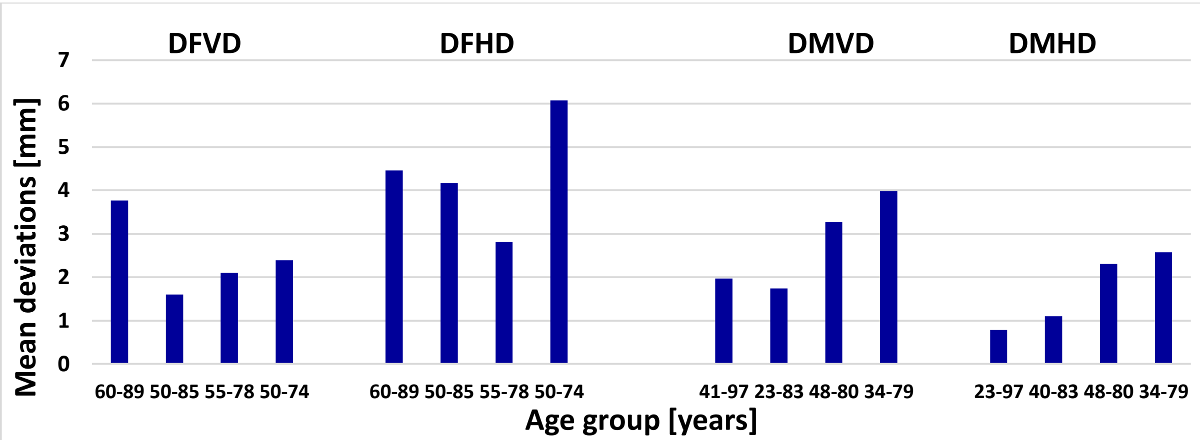

Fig. 20. Mean values of deviations for different age groups for vertical and horizontal tracking.

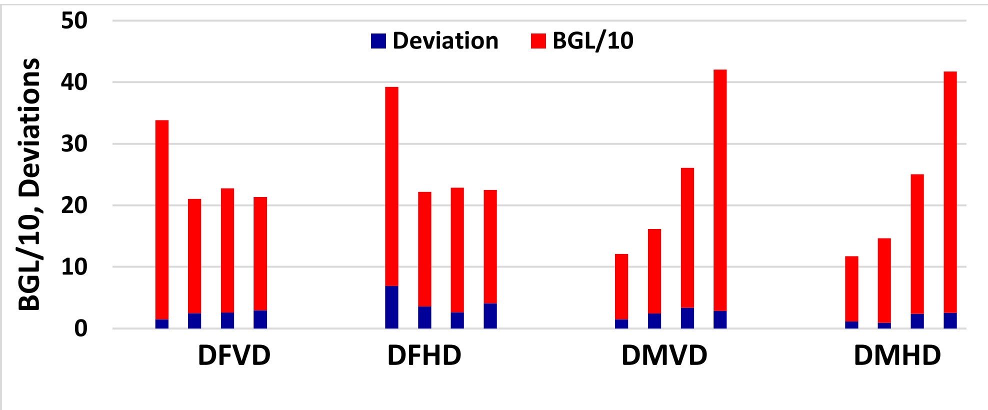

Fig. 21. Mean values of BGL (divided by 10) and deviations for different age groups for vertical and horizontal tracking.

Fig. 19 gives comparative mean values of deviations with state of health and gender for both vertical and horizontal tracking. It can be seen that diabetic mean deviations are higher than normal mean deviations and normal females perform better with vertical hand movement except for the first group with lowest BGL. Males had the lowest deviations for horizontal tracking. Fig. 20 constitute a comparative graph for mean values of deviations for different age groups for vertical and horizontal tracking and Fig. 21 represents a comparative graph for mean values of BGL (divided by 10) and deviations for different age groups for vertical and horizontal tracking. It can be seen that females have less deviations particularly when vertical tracking was considered, while males have less deviations when horizontal tracking was considered.

Fig. 22 presents a comparative pi-chart of correlation of deviations with state of health and gender for both vertical and horizontal tracking and summarizes the findings for all groups.

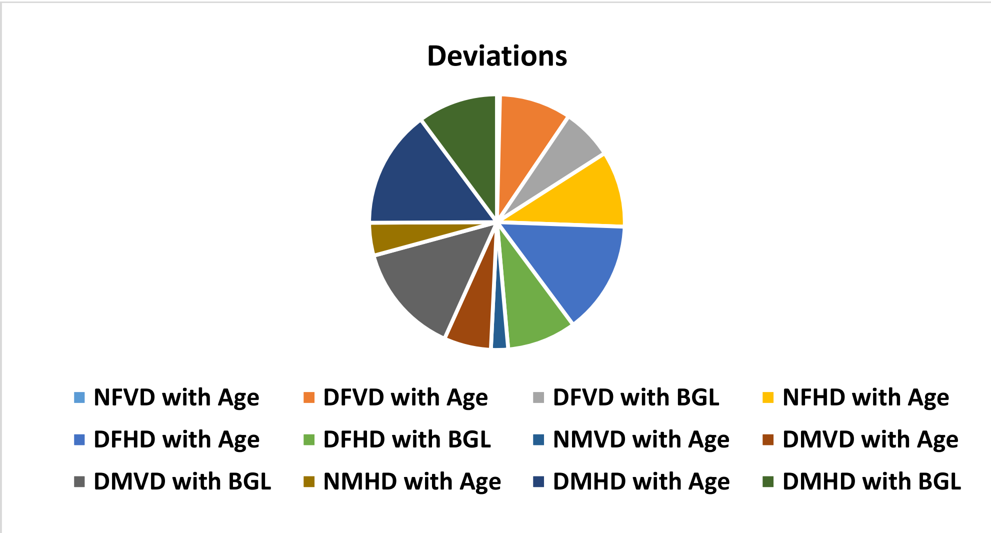

Fig. 22. Correlation of deviations with state of health and gender for both vertical and horizontal tracking.

This figure confirms the results of other researchers and shows the consistency with those reported by Mota et al. who noticed that the severity of hand deviation increases with diabetes [19]. Fig. 22 also affirms the results of Rosenbloom who reported that limited joint mobility for diabetics' mellitus indicates increased risk for microvascular disease [20]. It also assures other researchers' results such as Kudsi et al. [21] who gave confirming results of the diabetes effects on hand movement and mentioned that the numbers of diabetes mellitus cases are increasing worldwide and they are the major cause of chronic damage - to many body organs like the shoulders and the hands - such as limited joint mobility and several other conditions.

4. CONCLUSIONS

A suitable setup for the evaluation of vertical and horizontal deviations from prescribed horizontal and vertical tracks was presented. It took into consideration the effects of certain parameters such as BGL, gender and age.

Mean values of vertical and horizontal deviations for the diabetics were larger than those for normal subjects and were worsened to a large degree by diabetes BGL. Female subjects had better tracking results than male subjects and older aged subjects showed more deviations than younger ones.

The ratio of deterioration in vertical hand deviation between diabetics and normal females is 2.78, while the ratio of deterioration for diabetic to normal males is approximately 2.988. The ratio of deterioration in horizontal hand deviation between diabetics and normal females is 3.79, while the ratio of deterioration for diabetic to normal males was approximately 1.29.

The software prepared by the authors can be easily used on any personal computer and modified to measure the deviation produced while conducting vertical and horizontal tracking. It can be used to find out how perfect the hand is moving as a personal diagnostic tool.

Chief advantages of this system - over other systems - are that it is fully computerized, easy to use and non-invasive. In future, tests may be performed using an application on a mobile phone.

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