FORENSIC EXAMINATION OF PRE AND POST CONDITIONED HANDWRITING IN OSTEOARTHRITIS PATIENTS: A STATISTICAL APPROACH

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Abstract:

Handwriting refers to a person's own writing style, which includes writing letters, words, and sentences with a pen or pencil on paper or another writing surface. Handwriting is influenced by various conditions throughout life. The prominent conditions that affect the handwriting are diseases, body injuries, drugs, writing tools, surfaces, body postures, etc. Many research studies have been reported where handwriting was found to be affected by various disease conditions. In line to the previously reported cases, the present research has been conducted to study the impact of osteoarthritis (OA) on handwriting features. Osteoarthritis (OA) is a joint disorder that can cause discomfort, stiffness, and pain. As the illness can affect any joint in the body; hips, knees, and hands are the most commonly affected body parts. In Osteoarthritis conditioned most of the patients have difficulty to grip a pen or pencil and unable to write because it causes discomfort, stiffness, and a limited range of motion in the afflicted joints.

In present research study, pre- and post-conditioned OA handwriting features were qualitatively and quantitatively compared. The study also included a statistical analysis in pre- and post-conditioned OA handwriting feature which was analyzed by paired t-test. It is assumed that the study will demonstrate difference in both handwriting conditions of an individual and may show the range of deviations. The outcome of the study may help the forensic document expert and lawyers in similar cases.

Keywords: Handwriting examination, disguised writings, individual characteristics, osteoarthritis, disease writings.

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Introduction:

Handwriting is the most advanced skill that is achieved by the human hand. The hand is a very complex and delicate structure, having 27 bones, 27 joints, and more than 40 muscles (Thomassen, 1983). The interphalangeal and metacarpophalangeal joints between the fingers' bones enable the flexibility and extension of the fingers, which are essential for directing the movement of a writing tool. Osteoarthritis is a joint degenerative disease that affects the joints, particularly those in the hands, hips, knees, and spine. It is characterized by the gradual deterioration of the cartilage that cushions the ends of bones within a joint, resulting in pain, stiffness, and decreased mobility. (Zhang, 2010; Altman, 1991; Østerås N, 2017; Marshall, 2018, October 10; Lane, 2011; Litwic, 2013).

Osteoarthritis: most of the patients have finger joints that make it difficult to grip a pen or pencil and write because it can cause discomfort, stiffness, and a limited range of motion in the afflicted joints. The physical control required for writing by hand is known to be significantly impacted by physiological conditions like osteoarthritis (OA) (Huber, 1999). As a result, the handwriting may alter, taking on different characteristics like smaller letters, shakiness, and uneven word spacing. Osteoarthritis patients have a challenging time writing for long stretches of time (Saini K. , 2015).

While multiple studies have shown that illness and aging have a major impact on handwriting (Osborn, 1929 ; Quirke, 1930; Brewester, 1932; Baker, 1955; Hilton, 1956; 1977; Harrison, 1966), this study aims to examine the qualitative impacts of osteoarthritis on handwriting characteristics. The data would be determined a statistically to study the impact or deviation in handwriting in a post-diseased condition from a pre-diseased condition.

Methods and Materials:

To conduct the study of the effects of OA on the handwriting of an individual in pre- and post-OA conditions, 10 individuals with OA were identified and selected to participate. These are the subjects that approached several rheumatology, physiotherapy, and affiliated institutions. Interested patients were given a comprehensive explanation of the study before taking samples of their handwriting used for research. A verbal, informed consent was taken. Each patient was requested to provide a small piece of handwriting before OA condition that served as control or reference samples. A set of handwriting samples was gathered and produced in accordance with the preconditions for the study objective. The individuals were instructed to write the same content as in reference handwriting so as to standardize the material substrate. No guidelines were provided regarding the writing style or manner; instead, the subjects were given reference writing samples to help them create the same content. The chronology between the pre-diseased condition and fresh handwriting samples (post disease OA) ranges from 3 to 4 years. No samples were selected beyond this time period. The handwriting samples were provided on unruled A4 sheets; similarly, the post-disease condition handwriting was also collected on a similar type of A4 sheet. For the collection of samples, OA patients were requested to sit comfortably on the chair, and a hard-surfaced table was provided to them. Then they were requested to provide samples on an A4 unruled blank sheet with a blue ballpoint pen with same content as in admitted samples. All samples (pre-diseased and post-diseased) were analyzed on the basis of general handwriting characteristics (Table 1).

Alignment: The vertical positioning of written text on a page or line in handwriting.

Letter formation: A letter formation is the act of forming each individual letter in a legible and regular way.

Rhythm: The pattern or flow of movements a writer makes to form letters and words.

Tremors: An involuntary movement or shaking of the hand or fingers, which can cause the written text to appear shaky or uneven.

Connecting Strokes: The lines or strokes that link one letter in a word to the next.

Slant: The angle at which the written word is angled or tilted in relation to the horizontal baseline.

Initial and Terminal strokes: The strokes or lines used to properly establish the start and finish of a letter or word.

Spacing between the lines: The amount of existing space between each horizontal line of written text on a page.

Spacing between the words: The amount of space between each word on a line of text.

Size: The physical dimensions of the written text, which includes the height and width of each letter.

Pen lifts and pen pauses: A pen pause is a small pause in the motion of the pen or pencil when writing, usually in between individual letters or phrases. On the other hand, the raising of a pen or pencil off the paper in between words or phrases is referred to as a pen lift.

For statistical analysis paired *t*-test between the pre-conditioned and post-conditioned OA

handwritings on Graph Prism software was used for the analysis. The qualities of the handwriting were classified along with variables (BO and AO) and separated into three categories, "0", "1 and "3" for statistical analysis. The categories were given to handwriting samples (BO and AO) that demonstrated the changes in the handwriting of an individual from pre-conditioned OA handwriting to post-conditioned OA handwriting. (Table 1)

S. N o	Handwriting Characteristics	Code	Code along Variables	Categorization of characteristics		
				Category 1	Category 2	Category 3
1	Rhythm	RY	RY_BO/RY_AO	0=Good	1=Bad	2=Combination
2	Tremors	TM	TM_BO/TM_AO	0=Present	1=Absent	N. A
3	Pen lifts	PL	PL_BO/PL_AO	0=Present	1=Absent	N. A
4	Pen Pauses	PP	PP_BO/PP_AO	0=Present	1=Absent	N. A
5	Retouching/over writing	RO	RO_BO/RO_AO	0=Present	1=Absent	N. A
6	Speed	SP	SP_BO/SP_AO	0=Slow	1=Medium	2=Fast
7	Initial and terminal strokes	IT	IT_BO/IT_AO	0=Tapered/ Sharp	1=Blunt/Tre mulous	N. A
8	Connecting strokes	CS	CS_BO/CS_AO	0=Smooth	1=Tremulou s/Angular	N. A
9	Size	SZ	SZ_BO/SZ_AO	0=Small	1=Medium	2=Large
10	Slant	SN	SN_BO/SN_AO	0=Forward	1=Vertical	2=Backward
11	Spacing between words	SW	SW_BO/SW_AO	0=Narrow	1=Medium	2=Wide
12	Spacing between lines	SL	SL_BO/SL_AO	0=Medium	1=Narrow/ Wide	N. A
13	Alignment	AM	AM_BO/AM_AO	0=Straight	1=Descendi ng	2=Ascending
14	Letter Formation	LM	LM_BO/LM_AO	0=Regular	1=Irregular	N. A
Variables: Pre-conditioned OA Handwriting (Before Osteoarthritis) = **BO** Post-conditioned OA Handwriting (After Osteoarthritis) = **AO**						

Table 1: Handwriting characteristics and variables that were chosen for the study were categorised and coded for statistical analysis.

Result and Discussion
1. Alignment
In pre-conditioned OA handwriting samples, the writing has a straight and ascending alignment with respect to the page, whereas in post-conditioned OA handwriting samples, the writing has an ascending and descending alignment with respect to the page. Therefore, out of 10 post-conditioned OA handwriting samples, 04 samples showed descending alignment, 05 samples showed ascending alignment and whereas 01 sample showed no change in alignment as compared to their reference samples. (Fig 1)

2. Letter formation
Individuals in pre-conditioned OA handwriting samples made round and smooth letters, whereas in post-conditioned OA handwriting samples, individuals were unable to make round and smooth letters. Out of 10, 08 samples showed deterioration in letter formation, and the other 02 samples showed no deterioration in post-conditioned AO handwriting samples as compared to the reference sample. (Fig 1)
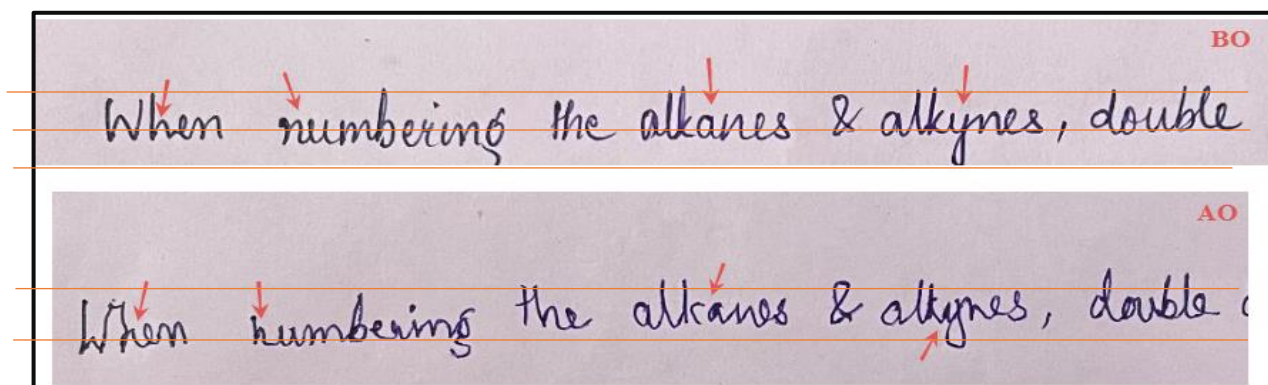
Fig 1: BO showing straight alignment and good rhythm, AO showing ascending alignment and poor rhythm. Red arrows showing deteoriation in letter formation.

3. Rhythm

In pre-conditioned OA handwriting samples, a good rhythm showing smoothness, speed, and consistency of the strokes has formed letters and words. But in post-condition OA handwriting, irregular rhythm showed uneven letter appearance, and inconsistency in strokes was involved in word and letter formation. Therefore, out of 10 samples, 06 samples showed overall deteoriation and poor rhythm while other 04 samples showed combination of good and poor rhythm as compared to reference samples. (Fig 1)

4. Tremors

In pre-conditioned OA handwriting samples, no tremors were observed, while in post-conditioned OA handwriting samples, tremors were present on multiple occasions. Almost at every type of stroke in post-OA-conditioned handwriting samples, uniform tremors were seen as uncontrollable and sudden strokes. Tremors were observed in 08 out of 10 samples when compared to the reference sample. On the other hand, only 02 samples didn't show the tremors. (Fig 2)
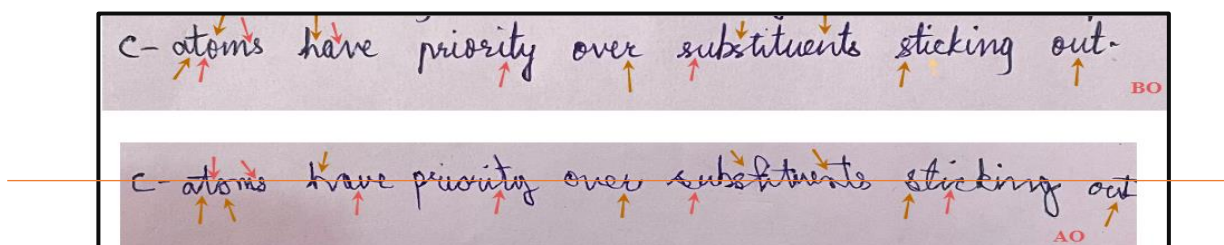

Fig 2: BO, red arrows showing no presence of tremors and yellow arrows showing smooth connecting strokes. AO, red arrows showing presence of tremors and yellow arrows showing deteriorated connecting strokes.

5. Connecting Strokes

Connecting strokes are observed to be smooth, angular, curvy, and rhythmic in nature in pre-conditioned OA handwriting samples, whereas connecting strokes are observed as uneven, tremulous, and irregular in post-conditioned OA handwriting samples. Out of 10 post-conditioned OA handwriting samples, 09 samples showed tremulous and irregularly connected strokes, while the other 01 sample showed smooth connecting as compared to reference samples. (Fig 2)

6. Slant

It has been observed that the variation in slant characteristics of samples S1–S10 remained constant, and there was a slight change in slant that

was unnoticed in post-conditioned OA handwriting samples compared to pre-conditioned OA handwriting samples.

7. Initial and Terminal strokes

In pre-conditioned OA handwriting samples, having tapered, blunt, and distinct initial and terminal strokes means that they are not too thick or too light. In post-conditioned OA handwriting samples, initial and terminal stokes are blunt, tremulous, and thick at the initial and terminal point; out of 10 AO samples, 07 samples showed blunt and thicker strokes, and 03 samples showed tremulous initial and terminal strokes. (Fig 3)
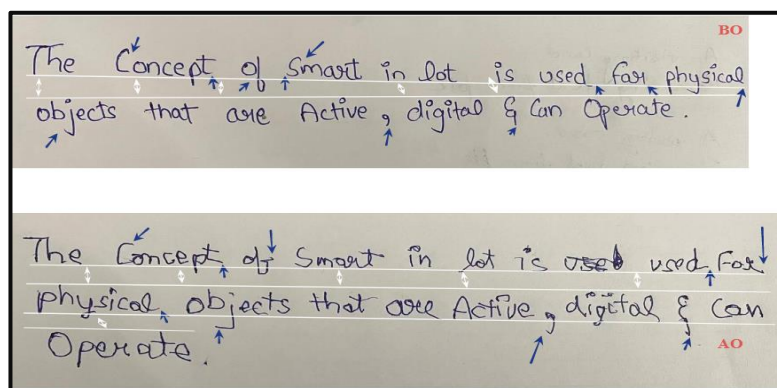
Fig 3: In BO and AO, white arrows showing spacing between lines. Blue arrows showing variation in initial and terminal strokes.

8. Spacing between the lines

In pre-and post-conditioned OA handwriting samples, spacing between lines was observed as medium, wide, and narrow. In post-condition OA hand writing, 09 samples had medium spacing, and 01 sample had wide spacing between lines. (Table 3 and Fig 3)

Spacing between Lines	Pre-conditioned OA Handwriting	Post-conditioned OA Handwriting
	No. Samples=10	No. Samples=10
Narrow	05	00
Medium	05	09
wide	00	01

Table 3: Variations in spacing between lines of pre- and post-conditioned OA Handwritings.

9. Spacing between the words

In pre-conditioned OA handwriting samples, medium and narrow amounts of spaces between the words were observed. In post-conditioned OA handwriting samples, narrow, medium, and wide spacing between words was observed. However, 01 samples showed wide spacing, and the 09 samples showed medium spacing between the words of the post-conditioned OA handwriting samples with respective its pre-conditioned OA handwriting. (Fig 4)
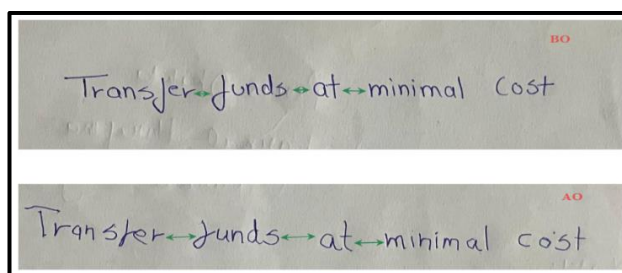

Fig 4: In BO and AO, green arrow showings spacing between the words.

10. Size

In the pre-conditioned OA handwriting samples, size was observed as small and medium. In post-conditioned OA handwriting samples, out of 10 samples, 08 samples showed medium size and 02 samples showed large size. It was discovered that post-conditioned handwriting was larger in size than reference samples. (Table 4 and Fig 5)

Spacing between Lines	Pre-conditioned OA Handwriting	Post-conditioned OA Handwriting
	No. Samples=10	No. Samples=10
Small	07	0
Medium	03	08
Large	00	02

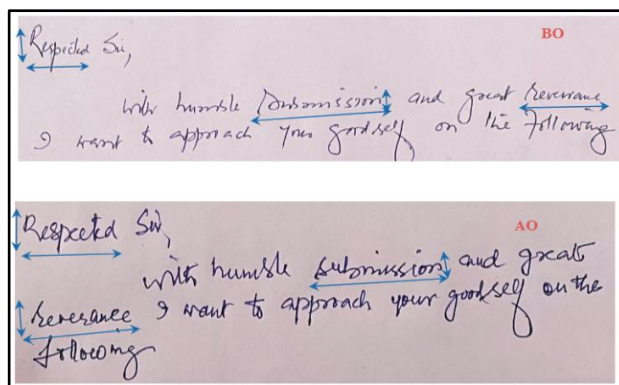**Table 4: Variation in size of pre-and post-conditioned OA**

Fig 5: In BO and AO, blue arrows showing size variations.

11. Pen lifts and pen pauses

In pre-conditioned OA handwriting samples, an individual had a good line quality feature, which results in no unintentional or uncertain pen lifts being observed. In post-conditioned OA hand writing samples, an individual had difficulty forming the letters and words which resulted in major pen lifts and pen pauses. All 10 post-conditioned OA handwritings had more pen lifts and pen pauses as compared to the pre-conditioned handwritings. (Fig 6)
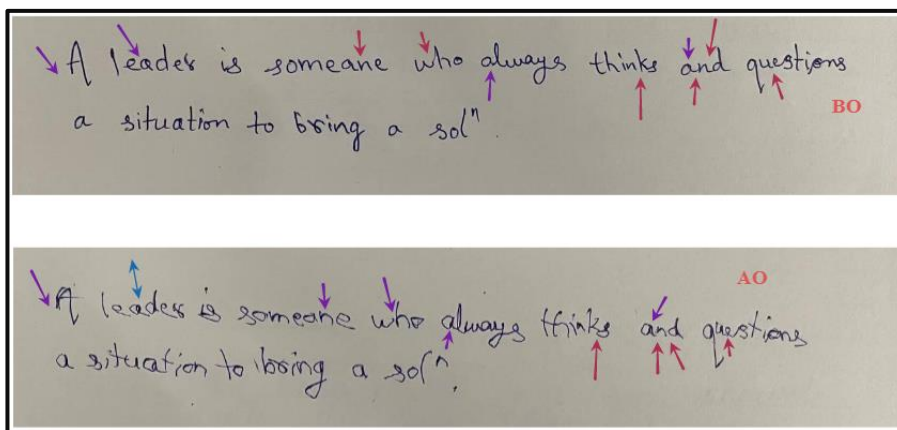

Fig 6: BO, purple arrows showing absence of pen lifts and red arrows showing no pen lifts. AO, purple arrows showing presence of pen pauses and red arrows showing pen lifts.

In a qualitative analysis, the handwriting samples of pre- and post-OA conditions were compared with each other. The result has been intreputed and shown in Fig 1-6. The characteristics demonstrated the deviation in general handwriting characteristics between each OA and its respective BO. It was observed that the characteristics in post-conditioned OA handwritings that were affected are rhythm, tremor, initial, terminal, and connecting strokes; overall size; spacing between words and letters; alignment; letter formation; writing speed; pen pauses; and pen lifts. There was no change observed in slant, retouching and overwriting.

In a statistical analysis, the result for the paired t-test of post-conditioning OA handwriting showed the significant effect of OA ($p < 0.05$) on various handwriting characteristics.

The paired t-test analysis showed a significant difference in rhythm between pre- and post-conditioned OA handwriting (M = -1.4, SD = 0.5164, t-value = 8.573, df = 9, and p value = <0.0001). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed a significant difference in tremors between pre- and post-conditioned OA handwriting (M = 0.8, SD = 0.4216, t-value = 6.000, df = 9, and p value = 0.0002). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed a significant difference in pen lifts between pre- and post-conditioned OA handwriting (M = 0.8, SD = 0.4216, t-value = 6.000, df = 9, and p value = 0.0002). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed a significant difference in pen pauses between pre- and post-conditioned OA handwriting (M = 0.9, SD = 0.3162, t-value =9.000, df = 9, and p value = <0.0001). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed an insignificant difference in retouching and overwriting between pre- and post-conditioned OA handwriting (M = 0.3, SD = 0.483, t-value = 1.964, df = 9, and p value = 0.0811). This indicated that the intervention had a negative effect on the outcome measure.

The paired t-test analysis showed a significant difference in speed between pre- and post-conditioned OA handwriting (M = 1.4, SD = 0.5164, t-value = 8.573, df = 9, and p value = <0.0001). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed a significant difference in initial and terminal strokes between pre- and post-conditioned OA handwriting (M = -0.6, SD = 0.5164, t-value = 3.674, df = 9, and p value = 0.0051). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed a significant difference in connecting strokes between pre- and post-conditioned OA handwriting (M = -0.9, SD = 0.3162, t-value = 9.000, df = 9, and p value = <0.0001). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed a significant difference in size between pre- and post-conditioned OA handwriting (M = -0.9, SD = 3162, t-value = 1.000, df = 9, and p value = <0.0001). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed an insignificant difference in slant between pre- and post-conditioned OA handwriting (M = 0.1, SD = 0.3162, t-value = 1.000, df = 9, and p value = 0.3434). This indicated that the intervention had a negative effect on the outcome measure.

The paired t-test analysis showed a significant difference of spacing between words in pre- and post-conditioned OA handwriting (M = -0.6, SD = 0.5164, t-value = 3.674, df = 9, and p value = 0.0051). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed a significant difference in spacing between lines of pre- and post-conditioned OA handwriting (M = 0.4, SD = 0.5164, t-value = 2.449, df = 9, and p value = 0.0368). This indicated that the intervention had a positive effect on the outcome measure.

The paired t-test analysis showed a significant difference in alignment between pre- and post-conditioned OA handwriting (M = -0.9, SD = 0.7379, t-value = 0.7379, df = 9, and p value = 0.0039). This indicated that the intervention had a positive effect on the outcome measure.

The statistical analysis data presented clearly accurately in the Table 5.

Pair	Variables	Mean	Std. deviation	*t* (test statistic)	df (degree of freedom)	Sig. (two-tailed) (p-value)
Pair 1	RY_BO/RY_AO	-1.4	0.5164	t=8.573	df=9	<0.0001
Pair 2	TM_BO/TM_AO	0.8	0.4216	t=6.000	df=9	0.0002
Pair 3	PL_BO/PL_AO	0.8	0.4216	t=6.000	df=9	0.0002
Pair 4	PP_BO/PP_AO	0.9	0.3162	t=9.000	df=9	<0.0001
Pair 5	RO_BO/RO_AO	0.3	0.483	t=1.964	df=9	0.0811
Pair 6	SP_BO/SP_AO	1.4	0.5164	t=8.573	df=9	<0.0001
Pair 7	IT_BO/IT_AO	-0.6	0.5164	t=3.674	df=9	0.0051
Pair 8	CS_BO/CS_AO	-0.9	0.3162	t=9.000	df=9	<0.0001
Pair 9	SZ_BO/SZ_AO	-0.9	0.3162	t=9.000	df=9	<0.0001
Pair 10	SN_BO/SN_AO	0.1	0.3162	t=1.000	df=9	0.3434
Pair 11	SW_BO/SW_AO	-0.6	0.5164	t=3.674	df=9	0.0051
Pair 12	SL_BO/SL_AO	0.4	0.5164	t=2.449	df=9	0.0368
Pair 13	AM_BO/AM_AO	-0.9	0.7379	t=3.857	df=9	0.0039

Table 5: Results of the paired t-test with mean differences between "BO" and "AO," standard deviation, significance (two-tailed), t-values, and degree of freedom from statistical analysis of the handwriting characteristics of OA individuals

Discussion

Diseases or disorders affecting the joints and bones of the hands are a common cause of pain, stiffness, swelling, and other disabilities that can have a significant impact on patients' handwriting. There are various diseases that can affect the hands, as well as the symptoms they induce and their impact on patient handwriting. It has been noticed in previous studies that straight and curved strokes, loops, and word and letter formation displayed tremors due to the limited mobility of motor function in diseased patients. Pen lifts and pen pauses were mostly observed as a result of joint pain. Due to stiffness in joints, diseased patients displayed tremulous connecting strokes, variations in initial and terminal strokes, deteoriation in rhythm, and poor quality. It has been observed that in diseased handwritings, deviations were present in size, spacing, alignment, and speed due to difficulty gripping the writing instrument. Hands are complex structures made up of bones, joints, ligaments, tendons, and muscles that can be affected by a variety of illnesses, including

rheumatoid arthritis, osteoarthritis, gout, carpal tunnel syndrome, and others. Pain, swelling, stiffness, reduced range of motion, deformities, and other limitations are common symptoms of joint and bone illnesses in the hands, depending on the kind and severity of the ailment. Several symptoms can have an impact on a patient's handwriting. It has been observed in diseased handwritings, deviations were present in size, spacing, alignment, and speed due to difficulty gripping the writing instrument (Altman, 1991; Hilton, 1956; 1966; Sulner, 1966; Koppenhaver, 2007; Saini K. , 2015; Saini K. &., 2019)

In present study, it was observed that due to discomforting stiffness, pain, and swelling in hand joints, OA patients showed difficulty forming round and curved letters and displayed tremors in connecting strokes and letter formation. It was also observed that size and spacing have increased in post-conditioned OA patients' handwriting than pre-conditioned OA handwritings. The qualitative and statistical analysis of pre- and post-OA handwritings has displayed a significant deviation in handwriting features. In such cases, deviated should not be treated as forged.

Conclusion

In present study, the quantitative and statistical analysis demonstrated a significant result in deviation of handwriting characteristics of post-conditioned OA handwriting from pre-conditioned

OA handwriting such in alignment, tremors, size, spacing between words and letters, rhythm, and formation of words and letters. Document examiners can use these statistical data and deviations to determine the author of a document or whether it has been a forged. As a result, this study contributes in the field of forensic science by emphasising the need of taking data science into account while examining handwriting samples. Furthermore, research can be conducted with same statistical analysis on same disease with large number of samples from different age groups with incubation period that individual had served with disease.

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