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Measurement of Pen Pressure of Offline Signatures Using 3D Digital Microscopy and Its Utility in Determining Authorship

3D Mikroskop Kullanılarak Çevrimdışı Oluşturulmuş İmzalarda Fulaj Ölçümü ve Aidiyet Tespitinde Kullanılabilirliği

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ABSTRACT

Objective: Two of the most frequently used diagnostic criteria in writing and signature comparisons are the degree of pen pressure and variations in pen pressure. However, in today's practice, this criterion is inferentially evaluated only by naked eye or using image enhancer tools. This situation may cause various results among examiners, and difficulties in judicial procedure in terms of forensic handwriting and signature examinations, which has already been criticized for subjectivity. In this study, it is aimed to measure the depth of the indented pen pressure numerically in offline signatures and to evaluate it more objectively compared to the classical methods.

Methods: Note that 10 male and 10 female subjects participated in this study. Subjects were asked to imitate the signature shown as an example on three different surfaces. This signature was imitated by the subjects three times on different surfaces via free-hand (practise and non practice). Depth measurements were taken from five different points on the signature using a Leica DVM-6 3D Digital Microscope and compared with the genuine signature.

Results: Statistically significant differences were reported at different confidence intervals in comparisons considering different combinations.

Conclusion: In conclusion, aside from similar depth of the indented pen pressure, persistence of dissimilarities in different comparison documents and at different points is an important criterion. It has been revealed that these differences are statistically significant.

Keywords: 3D digital microscope, genuine signature, simulation, pen pressure, none practiced free-hand, practiced free-hand

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*** A part of this study was presented as a poster presentation with the title "Surface Roughness Measurement Techniques Using Pen Pressure Measurement in Signatures and Usability for Determination of Identity" at the 72rd American Academy of Forensic Science Congress, held on 17-22 February 2020.**

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ÖZ

Amaç: Yazı ve imza karşılaştırmalarında en sık kullanılan tanı kriterlerinden biri de baskı derecesi ve baskı derecesi değişiklikleridir. Ancak günümüzde uygulamada bu kriter yalnızca göz ile veya görüntü iyileştirici aparatlar kullanılarak tahmini olarak değerlendirilmektedir. Bu durum, kişiden kişiye değerlendirme farklılıklarının çıkmasına neden olabilmekte ve zaten subjektifliği ile eleştirilen adli yazı ve imza incelemelerinde yargılamada sıkıntılara neden olabilmektedir. Bu çalışmada baskı derecesi derinliğinin offline olarak atılmış olan imzalarda nümerik olarak ölçümü ve daha klasik yöntemlere göre daha objektif olarak değerlendirilebilmesi amaçlanmıştır.

Yöntem: Çalışmaya 10 erkek ve 10 kadın denek katılmıştır. Deneklerden, örnek olarak gösterilen imzayı üç farklı zeminde taklit etmeleri istenmiştir. Bu imza denekler tarafından, her zeminde üçer defa çalışmadan önce ve çalıştıktan sonra taklit edilmiştir. İmzanın üzerinde belirlenen 5 farklı noktadan Leica DVM-6 3D mikroskop ile derinlik ölçümleri alınmış ve orijinal imza ile kıyaslanmıştır.

Bulgular: Farklı kombinasyonlar göz önüne alınarak yapılan karşılaştırmalarda, farklı güven aralıklarında istatistiksel olarak anlamlılık ifade edecek şekilde farklılıklar bulunmuştur.

Sonuç: Sonuç olarak kalem baskı derecesindeki benzerliğin yanı sıra farklı kişilerde, farklı noktalarda kalem baskı derecesinde görülen farklılıklar da önemli bir kriterdir. Bu farklılıklar t-testi uygulanarak incelenmiş ve istatistiksel olarak anlamlılı bulunmuştur.

Anahtar Kelimeler: 3D dijital mikroskop, orijinal imza, taklit, kalem basıncı, bakarak taklit, serbest taklit

INTRODUCTION

It has been discussed for years whether forensic handwriting and signature examinations, which is a specialty within the field of criminalistics sub-division of forensic sciences, provides scientific objectivity both in our country and worldwide. The most important factors in this regard are undoubtedly the high subjectivity due to eyeball examination and the lack of language unity in reporting results (1-5). In this context, using numerical data in forensic handwriting and signature examinations and numerical expression of the results are of great importance in terms of objectivity. It is important to consider the nature of human error as well. Almost all recent scientific studies are performed with this motivation (6-23).

One of the criteria used for determining the authorship in writing and signature examinations is indented writing pen pressure; in other words, the quality and depth of the marks left by the pen on the paper. Indented pen pressure and its depth vary according to degree of pen pressure applied by the writer and/or signer as well as velocity and the quality of the pen and the characteristics of the paper and surface (24,25). In almost all comparisons, depth of indented writing pen pressure, degree of pen pressure and variations in pen pressure were mentioned. This method is used as an indication of whether the document is signed by the same person. However, the fact that they do not show similarity is accepted as one of the indicators that the writings and signatures were not signed or written by the same person when the questioned and comparison documents are considered (26). However, in routine practice, the measurements of depth and variation of indented pen pressure are made either with the naked eye or with the help of some instruments such as magnifiers or Electro Static Detection Apparatus, and no numerical value is expressed in the examinations made on the writings on the paper (27). Because this situation will lead to subjective results that can vary among experts, problems arise both scientifically and in its use in the judicial process in terms of reliability. Real-time pressure measurement is performed with writing and/or signatures collected using tablet or with special pens designated for this purpose (28-32). Li et al. (33) collected online signature samples generated on tablets from 13 female and 35 male subjects and then these signatures were imitated online by three document examiners. When the Pearson's correlation value of the pressure degrees of the genuine and simulated signatures was investigated, the correlation between the genuine signatures and one of the signatures was 0.95; however, the correlation between genuine and simulated signature was found to be 0.26. This study shows that regression analysis can be used to identify whether the signiture is simulated or not. In the study by Mohammed et al. (32) conducted to determine how dynamic elements such as velocity, duration, size, jerk and pressure in online signature vary according to the style of signature and whether these dynamics are affected in the same manner in genuine and simulated signatures, and signatures written with intent to deny; it has been determined that text-based signatures are written using less pen pressure than stylized and mixed signatures. Furthermore, it has been determined that the genuine signatures were signed using more pen pressure than the signatures with intent of denial or forgery. In another study on online signature in which dynamic elements such as velocity, duration, size, jerk and pressure were compared between genuine and simulated signatures, pen pressure was more dominant in original signatures than simulated signatures, whereas natural signature style had an impact on simulated signatures. Furthermore, text-based simulated signatures were reported to have higher pressure than simulated mixed and simulated stylized signatures (34). When the age-related changes in the degree of pressure were examined in 42 subjects including 24 men and 18 women in the signatures collected online; however, the degree of pressure decreased with increased age in men, no significant change was reported in women (35). Although some studies have begun to be carried out, there are almost no experimental studies on numerical pressure measurements of offline signatures. For example, in the 3D analysis study by Gould et al. (23), pressure was measured in microns and its advantages in examining intersecting lines were mentioned. There is a need for studies in this field regarding 3D microscopes that allow non-contact and therefore non-destructive measurement. No similar study was found in the literature research. This study aims to demonstrate the utility of microscopes that used to measure surface smoothness in indented writing impression examination, thus obtaining the values of indented writing examination with numerical measurement of surface smoothness technique in micrometer (µm) and to investigate whether these measurement values can be used in determining authorship.

MATERIALS AND METHODS

One of the authors (female) signed her signature three times on three different conditions (Figure 1). Blue colored ballpoint pen was used for the tests. In the first case, signatures were signed on an A4 size paper placed on a "file with clamps;" in the second case, a unlined A4 size paper of the same type was placed under the paper on which the signatures were signed; and in the third case, two null papers of the same type were placed under the paper on which the signatures were signed. The author's signature will be referred to as the "genuine signature" in rest of the article. Images were taken at 300× magnification using a Leica DVM-6 microscope at specified points (the start, mid, end and turning points of the signiture) on the signature samples (Figure 1), including the author's samples, and their 3D profiles were created for the examination. Marking was made from the two reciprocal sides of the line at the specified points with LAS X software integrated to the microscope used, and the numerical values and graphics were obtained by measuring the depth of 1845 points in micrometers (µm) in the distance between the two marker points. During the measurements, the maximum value given automatically by the software program was taken as the depth value at each point. Minitab was used for the statistical analysis where box plots were plotted. In this study, the relationship between the genuine and simulated signatures was analyzed using SPSS®25 with the independent sample t-test.

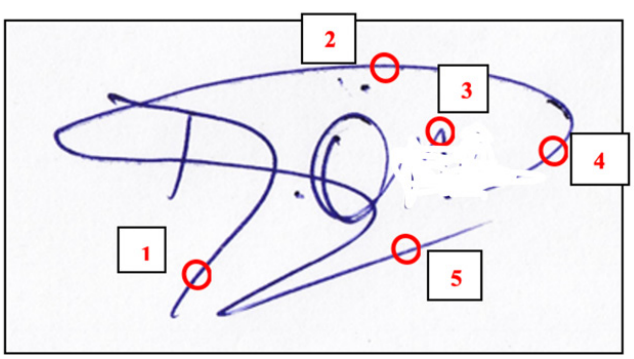

Figure 1. Genuine signature requested from the subjects to be imitated and measured points (The latter part of each signature has been intentionally blurred to protect the anonymity of the author)

Simulated Signatures

Samples were collected by the free-hand method. Ten female and 10 male with university and high school graduates were asked to imitate the author's signature three times on these surfaces using the same brand of pen and paper. Participants firstly, looked at the original signature and imitated the signature without studying it (Figure 2). This will be referred to as the "None practiced free-hand (Npf-h)" in rest of the article.

In the second step for free-hand the same individuals were given 10 min for practicing the author's signatures, and again were asked to imitate three times on three different surfaces (Figure 3). This will be referred to as the "practiced free-hand (pf-h) " in rest of the article.

The depth of 1845 points was measured.

RESULTS

The study was performed on three different conditions, with signatures three times on each surface. Furthermore, the subjects were given 10 min to practice the signature, and then signatures were repeated three times on each surface. These

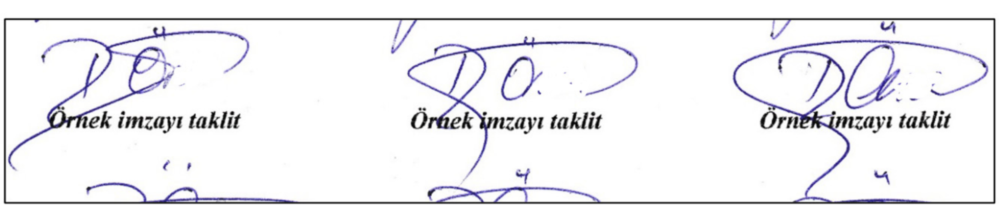

Figure 2. Simulation of the author's signature on a surface by one of the participants none practiced free-hand (The latter part of each signature has been intentionally blurred to protect the anonymity of the author)

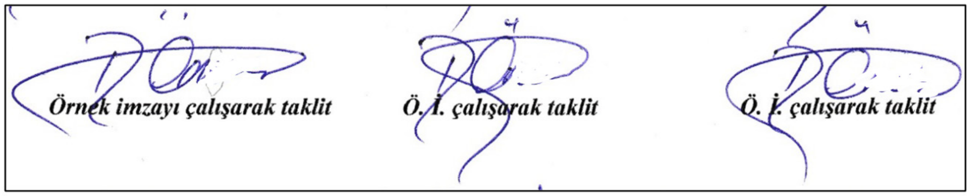

Figure 3. Simulation of the author's signature on a surface by one of the participants practiced free-hand (The latter part of each signature has been intentionally blurred to protect the anonymity of the author)

data were compared with the values at different points of the genuine signature, according to the surface, before and after practice. One of the experimental findings was given in Figure 4 as a representative of the depth results. As per Tables 1 and 2, a statistically significant difference was reported between the mean depth of 8 subjects (4 male and 4 female) at the first point, 5 subjects (3 male, 2 female) at the second point, 13 subjects (6 male and 7 female) at the third point, 7 subjects (2 male and 5 female) at the fourth point and 11 subjects (5 male and 6 female) at the fifth point and the mean depth of the genuine signature.

Tables 3 and 4 show the results of the comparison of genuine signatures with simulations by male and female subjects at different points npf-h and pf-h. A statistically significant difference was reported between the mean depth of 3 subjects (0 male and 3 female) at the first point, 4 subjects (3 male and 1 female) at the second point, 13 subjects (5 male and 8 female) at the third point, 4 subjects (1 male and 3 female) at the fourth point, 3 subjects (1 male and 2 female) at the fifth point in the simulations before practice and the mean depth of the genuine signature. There was a statistically significant difference between the mean depth of 9 subjects (6 males and 3 females) at the first point, 3 subjects (2 males and 1 females) at the second point, 10 subjects (4 males and 6 females) at the third point, 4 subjects (1 male and 3 females) at the fourth point, 2 subjects (0 male and 2 female) at the fifth point in the simulations after practice and the mean depth of the genuine signature.

Tables 5 and 6 show the results of the comparison of the genuine signature with the simulations on different surfaces npf-h and pf-h. In the simulations via npf-h, the first and third points were the most noticeable on the first surface in women. A statistically significant difference was reported between the mean depth of 6 women at the p<0.05 level at the first point,

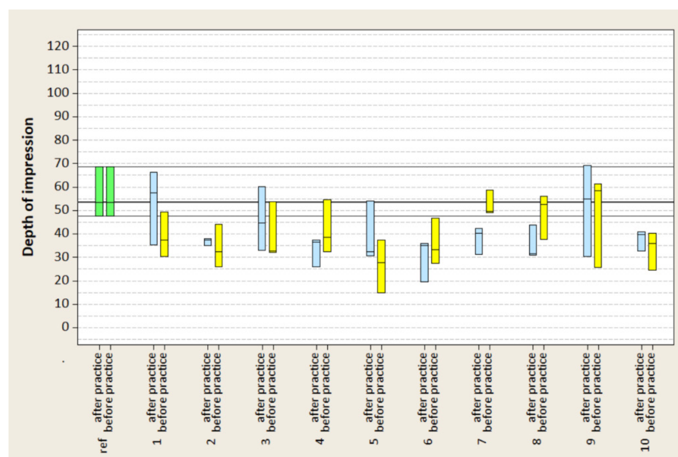

Figure 4. One of the experimental findings as a representative of the depth results

Table 1. Point based evaluation of the simulated signatures by female subjects

N / Point	1	2	3	4	5
F1	2.828 **	-0.609	1.323 *	2.384 **	2.072 **
F2	3.970 **	2.186 **	6.872 **	0.651	-0.114
F3	-7.151 **	-3.574 **	0.224	-0.783	-0.598
F4	0.073	-0.859	6.117 **	1.813 **	2.148 **
F5	1.538 *	-1.486 *	5.361 **	0.658	1.569 *
F6	1.009	-0.139	5.180 **	1.931 **	2.839 **
F7	2.032 **	1.024	4.290 **	2.925 **	1.682 *
F8	0.745	-0.900	3.668 **	3.289 **	0.312
F9	-0.430	-0.537	-1.013	0.943	0.201
F10	0.453	-1.424 *	3.510 **	0.850	2.728 **

** p<0.05, * p<0.10

Table 2. Point-based evaluation of the simulated signatures by male subjects

N / Point	1	2	3	4	5
M1	0.426	0.888	5.248 **	2.656 **	2.450 **
M2	2.008 **	-0.430	2.893 **	0.184	0.652
M3	2.039 **	1.551 *	5.890 **	0.889	-0.459
M4	-1.494 *	-1.723 **	0.120	-1.889 **	-2.018 **
M5	0.121	-2.486 **	-0.748	0.476	1.689 *
M6	-0.139	0.346	0.843	-1.148	1.512 *
M7	-3.072 **	-1.644 *	1.020	-1.356 *	-0.183
M8	-0.401	0.125	6.286 **	0.191	-0.113
M9	-1.697 **	-2.050 **	2.220 **	-1.009	0.421
M10	0.866	1.156	6.311 **	1.613 *	1.689 *

** p<0.05, * p<0.10

Table 3. Comparison of the depths of the simulated signatures in female subjects before and after practice with genuine signatures

Before practice							After practice					
N / Point	1	2	3	4	5		N / Point	1	2	3	4	5
F1	3.458 **	-0.983	2.662 **	2.317 **	2.049 **		F1	1.055	0.489	-0.159	1.084	0.401
F2	3.712 **	2.158 *	4.143 **	0.606	-0.289		F2	1.917 **	0.952	5.464 **	0.340	0.141
F3	-4.110 **	-1.994**	1.327	-0.687	0.007		F3	-6.192 **	-2.986 **	-0.744	-0.399	-0.800
F4	-0.206	-0.754	3.389 **	0.410	1.693 *		F4	0.545	-0.463	5.417 **	2.994 **	1.298
F5	1.158	-1.211	4.595 **	0.660	0.621		F5	0.964	-0.937	3.013 **	0.294	1.540 *
F6	0.476	-0.062	2.925 **	0.697	1.582 *		F6	0.921	-0.145	4.465 **	2.277 **	2.378 **
F7	0.031	0.526	2.038 **	2.329 **	0.739		F7	4.711 **	0.891	4.368 **	1.705 *	1.597 *
F8	0.605	0.251	1.874 **	2.124 **	-0.354		F8	0.422	1.390 *	3.319 **	2.475 **	1.003
F9	-0.861	1.398 *	-0.274	0.066	0.770		F9	-0.897	0.555	-1.204	1.360 *	-0.376
F10	0.124	-0.492	2.406 **	0.956	1.920 **		F10	0.535	-1.477 *	2.417 *	0.179	1.825 **

** p<0.05, * p<0.10

Table 4. Comparison of the depths of the simulated signatures in male subjects before and after practice with genuine signatures

	Before practice						After practice					
N / Point	1	2	3	4	5		N / Point	1	2	3	4	5
M1	0.198	0.001	4.868 **	3.009 **	2.328 **		M1	0.415	1.255	2.795 **	1.024	1.160
M2	0.309	0.618	2.300 **	0.243	-0.223		M2	3.169 **	-1.178	1.685 *	0.046	1.188
M3	0.684	2.029 **	3.882 **	0.130	-0.244		M3	2.329 **	0.307	4.404 **	1.420 *	-0.375
M4	0.052	-1.627 *	-0.118	-0.434	-1.119		M4	-2.110 **	-0.764	0.326	-2.194 **	-1.672 *
M5	-0.082	-2.189 **	-1.082	0.758	1.048		M5	0.291	-1.285	0.002	-0.032	1.275
M6	0.209	2.366 **	0.240	-0.959	1.618 *		M6	-0.400	-0.885	0.996	-0.680	0.511
M7	-1.389 *	0.711	0.673	-0.559	1.131		M7	-3.039 **	2.302 **	0.739	-1.286	-1.051
M8	-0.705	0.357	5.341 **	0.020	-0.126		M8	-0.001	-0.085	3.622 **	0.345	-0.023
M9	-0.618	-0.644	1.342 *	-0.199	0.195		M9	-1.826 **	-2.196 **	1.710 *	-1.175	0.406
M10	-0.647	0.546	3.351 **	0.680	2.157 *		M10	2.098 **	1.047	6.009 **	1.672 *	0.500

** p<0.01, * p<0.05

4 women at the p<0.05 level and 7 women at the p<0.10 level at the second point and the mean depth of the genuine signature. In the simulations made after practicing, the third point was the most noticeable on the first surface in men. At the third point, a statistically significant difference was reported between the mean depth of 5 men and the mean depth of the genuine signature. In the simulations made without practicing, second and third points were the most noticeable on the second surface in women. A statistically significant difference was found between the mean depth of 4 women at the p<0.05 level, 6 women at the p<0.10 level at the second point and 6 women at the p<0.10 level at the third point and the mean depth of the genuine signature.

In the simulations via npf-h, the second, third and fourth points were the most prominent on the second surface in men. A statistically significant difference was found between the mean depth of 4 men at the p<0.05 level and 5 men at the p<0.10 level at the second point, 2 men at the p<0.05 level, 4 men at the p<0.10 level at the third point, and 3 men at the p<0.05 level, 4 men at the p<0.10 level at the fourth point and the mean depth of the genuine signature. In the simulations made npf-h, the second and third points were the most noticeable on the third surface in women. A statistically significant difference was found between the mean depth of 3 women at the p<0.05 level at the second point, 1 woman at the level of <0.05 and 4 women at p<0.10 level at the third point and the mean depth of the genuine signature. In the simulations made npf-h, the second and third points were the most noticeable on the second surface in men. A statistically significant difference was found between the mean depth of 3 men at p<0.05 level, 4 men at p<0.10 level at the second point and 4 men at p<0.05 level, 6 men at p<0.10 at third point and the mean depth of the genuine signature.

Table 5. Comparison of the depth of simulated signatures in women before and after practice on different surfaces and at different points with the original signatures

Before practice								After practice						
N	Point	1	2	3	4	5		N	Point	1	2	3	4	5
F1	1st Surf.	3.906 **	0.006	2.098 *	1.217	1.418		F1	1st Surf.	0.688	1.073	0.306	-0.988	0.364
	2nd Surf.	4.472 **	-1.079	1.570 *	1.880 *	1.084			2nd Surf.	-0.117	-1.783 *	0.657	3.423 **	1.391
	3th Surf.	0.773	-0.191	0.658	0.357	0.696			3th Surf.	1.156	0.686	-0.795	1.160	-0.461
F2	1st Surf.	4.099 **	1.039	2.724 **	0.280	0.176		F2	1st Surf.	4.541 **	1.029	3.121 **	-0.502	0.159
	2nd Surf.	1.705 *	-0.283	1.864 *	-1.506	-0.263			2nd Surf.	0.635	-2.083 *	2.164 **	-0.146	-0.301
	3th Surf.	1.364	5.366 **	1.835 *	1.045	-0.626			3th Surf.	0.687	4.816 **	4.412 **	1.660 *	0.456
F3	1st Surf.	-2.193 **	-0.072	1.791 *	-1.021	0.927		F3	1st Surf.	-7.406 **	-1.540 *	1.054	-0.372	0.713
	2nd Surf.	-2.671 **	-3.416 **	0.321	0.725	-0.082			2nd Surf.	-4.557 **	-7.605 **	-0.805	-0.686	-0.166
	3th Surf.	-2.044 *	-0.781	0.183	0.018	-1.347			3th Surf.	-2.545 **	-0.153	-1.230	0.349	-2.068 *
F4	1st Surf.	0.192	-0.304	1.610 *	-0.767	1.205		F4	1st Surf.	1.444	0.555	3.210 **	1.883 *	0.305
	2nd Surf.	0.990	-1.470	2.013 *	0.261	0.903			2nd Surf.	-0.277	-2.818 **	2.275 **	5.993 **	1.566 *
	3th Surf.	-0.715	0.403	1.818 *	1.972 *	0.410			3th Surf.	0.151	2.025 *	3.066 **	1.044	0.970
F5	1st Surf.	2.512 **	-0.352	3.312 **	0.080	0.479		F5	1st Surf.	0.936	0.718	1.798 *	-0.168	1.216
	2nd Surf.	1.381	-2.036 *	2.135 *	0.495	-0.002			2nd Surf.	0.388	-1.477	0.817	1.019	1.095
	3th Surf.	-0.361	-0.061	1.869 *	0.525	0.622			3th Surf.	0.454	-1.465	2.708 **	-0.165	0.043
F6	1st Surf.	0.759	-0.369	2.456 **	-0.650	0.608		F6	1st Surf.	4.470 **	-0.007	3.213 **	1.098	1.813 *
	2nd Surf.	-0.225	0.086	1.718 *	5.372 **	1.120			2nd Surf.	0.318	-2.316 **	3.071 **	3.796 **	1.543 *
	3th Surf.	0.421	0.663	0.595	0.755	0.943			3th Surf.	-0.075	1.937 *	1.530	0.754	0.269
F7	1st Surf.	0.117	0.474	0.586	1.674 *	0.551		F7	1st Surf.	4.048 **	0.461	2.594 **	-0.118	1.824 *
	2nd Surf.	-1.866 *	-1.534 *	0.824	1.430	-0.092			2nd Surf.	3.453 **	-1.026	1.720 *	3.586 **	1.071
	3th Surf.	0.862	4.448 **	2.616 **	1.080	1.088			3th Surf.	1.667 *	2.108 *	2.830 **	1.593 *	-0.413
F8	1st Surf.	3.016 **	0.592	0.918	1.226	0.859		F8	1st Surf.	1.016	-0.304	2.797 **	1.207	0.800
	2nd Surf.	-0.940	-2.182 **	1.305	5.079 **	-0.067			2nd Surf.	0.111	-2.761 **	1.494	1.989 *	1.054
	3th Surf.	0.082	1.032	0.646	0.414	-2.046 *			3th Surf.	-0.16	-1.178	1.234	1.229	-0.461
F9	1st Surf.	2.699 **	-1.238	0.623	-0.872	1.023		F9	1st Surf.	2.062 *	0.405	0.395	0.588	0.938
	2nd Surf.	-1.402	-2.787 **	-1.916 *	0.602	0.358			2nd Surf.	-0.643	-0.789	-1.096	8.246 **	-0.125
	3th Surf.	-1.244	0.232	0.482	0.470	-0.368			3th Surf.	0.408	2.518 **	-1.583 *	0.483	-2.164 **
F10	1st Surf.	0.041	0.341	2.933 **	-0.341	1.491		F10	1st Surf.	1.007	0.294	2.770 **	0.056	1.331
	2nd Surf.	0.129	-2.385 **	0.593	0.565	0.754			2nd Surf.	-0.316	-2.388 **	1.231	0.525	1.171
	3th Surf.	0.054	2.133 **	1.305	1.283	0.846			3th Surf.	0.249	-0.084	0.598	-0.018	0.219

** p<0.01, * p<0.05

In the simulations via npf-h, the third point was the most noticeable on the first surface in women. At the third point, a statistically significant difference was found between the mean depth of six women at the $p<0.05$ level and seven women at the $p<0.10$ level and the mean depth of the genuine signature. In the simulations made after practicing, the third point was the most noticeable on the first surface in men. At the third point, a statistically significant difference was found between the mean depth of four men at the $p<0.05$ level and five men at the $p<0.10$ level and the mean depth of the genuine signature.

In the simulations made after practicing, the second and the fourth points were the most noticeable on the second surface in women. A statistically significant difference was found between mean depth of five women at the $p<0.05$ level, seven women at the $p<0.10$ level at the second point, five women at the $p<0.05$ level, six women at the $p<0.10$ level at the fourth point and the mean depth of the genuine signature.

In the simulations via pf-h, the second and third points were the most noticeable on the second surface in men. A statistically significant difference was reported between the

Table 6. Comparison of the depth of simulated signatures in women before and after practice on different surfaces and at different points with the original signatures

Before practice							After practice						
N	Point	1	2	3	4	5	N	Point	1	2	3	4	5
M1	1st Surf.	3.547 **	0.912	3.074 **	1.447	2.010 *	M1	1st Surf.	0.848	1.237	3.830 **	0.857	1.682 *
	2nd Surf.	-0.040	-2.956 **	2.453 **	5.335 **	0.854		2nd Surf.	1.680 *	0.210	1.129	2.869 **	0.130
	3th Surf.	-1.012	1.672 *	2.141 **	1.105	0.948		3th Surf.	-0.554	0.815	0.684	-0.011	0.171
M2	1st Surf.	1.491	0.735	-0.297	0.424	0.531	M2	1st Surf.	2.747 **	-0.534	0.933	-0.435	1.687 *
	2nd Surf.	-0.831	-0.334	1.980 *	0.246	-1.189		2nd Surf.	1.822 *	-3.223 **	2.064 *	-0.540	0.079
	3th Surf.	0.587	1.139	6.125 **	-0.237	0.171		3th Surf.	1.609 *	0.441	0.178	1.365	0.429
M3	1st Surf.	-0.492	2.093 *	2.191 **	0.604	1.036	M3	1st Surf.	2.014 *	1.225	3.026 **	0.538	0.488
	2nd Surf.	-0.75	-0.732	1.858 *	-0.311	-0.241		2nd Surf.	0.635	-0.522	1.742 *	0.451	-1.443
	3th Surf.	1.401	3.730 **	2.064 *	0.204	-1.960 *		3th Surf.	1.398	-0.218	2.685 **	1.217	-0.084
M4	1st Surf.	-0.020	0.637	-0.227	0.634	0.385	M4	1st Surf.	-0.694	-0.438	0.024	-2.519 **	-0.099
	2nd Surf.	0.132	-5.380 **	-0.846	-2.285 **	-0.516		2nd Surf.	-2.014 *	-1.106	1.190	-0.439	-0.747
	3th Surf.	0.017	-1.082	1.296	-0.429	-2.260 **		3th Surf.	-0.593	0.315	-1.156	-0.853	-2.347 **
M5	1st Surf.	0.419	0.547	1.031	0.829	0.529	M5	1st Surf.	-0.244	-1.216	-0.512	0.186	0.884
	2nd Surf.	0.398	-3.365 **	-0.479	0.532	1.116		2nd Surf.	-0.952	-2.910 **	0.725	-2.172 **	0.643
	3th Surf.	-0.603	-1.471	-1.744 *	0.003	-0.050		3th Surf.	1.217	2.500 **	-0.211	1.122	0.477
M6	1st Surf.	-0.311	1.655 *	2.619 **	-0.132	1.280	M6	1st Surf.	-0.007	0.713	1.142	0.556	0.309
	2nd Surf.	-2.026 *	-0.093	-0.598	-9.063 **	0.696		2nd Surf.	-0.915	-1.369	0.793	0.039	0.583
	3th Surf.	1.071	3.986 **	-0.912	-0.144	0.526		3th Surf.	-0.027	-1.841 *	-0.151	-1.475	-0.233
M7	1st Surf.	-0.726	1.115	0.761	-0.483	1.216	M7	1st Surf.	-3.660 **	-1.215	0.190	-1.853 *	-0.587
	2nd Surf.	-5.698 **	-1.084	0.226	-1.231	0.845		2nd Surf.	-2.387 **	-3.921 **	0.236	0.064	-0.157
	3th Surf.	0.531	1.421	0.052	0.335	-0.391		3th Surf.	-0.994	-1.569 *	0.785	-0.332	-1.009
M8	1st Surf.	2.074 *	1.438	4.108 **	0.373	1.813 *	M8	1st Surf.	4.661 **	2.166 **	1.860 *	0.873	1.403
	2nd Surf.	-1.092	-1.843 *	2.061 *	1.873 *	-0.263		2nd Surf.	-1.012	-1.625 *	1.608 *	-0.566	-0.375
	3th Surf.	-0.474	0.812	2.765 **	-0.471	-1.275		3th Surf.	0.209	-0.189	2.430 **	0.330	-0.749
M9	1st Surf.	1.634 *	1.807 *	2.213 **	0.770	1.752 *	M9	1st Surf.	0.228	0.286	3.964 **	-0.617	1.032
	2nd Surf.	-3.854 *	-3.335 **	0.159	-0.487	-0.720		2nd Surf.	-1.398	-1.766 *	0.855	0.405	0.710
	3th Surf.	0.101	0.821	0.325	-0.468	-0.756		3th Surf.	-2.215 *	-2.531 **	-0.712	-1.215	-1.886 *
M10	1st Surf.	1.251	-0.365	1.485	-0.481	1.185	M10	1st Surf.	0.537	0.331	3.257 **	0.024	1.280
	2nd Surf.	-1.036	-0.518	1.182	0.351	1.457		2nd Surf.	2.060 *	-2.345 **	2.301 **	4.252 **	1.138
	3th Surf.	-0.795	2.322 **	3.593 **	1.456	0.834		3th Surf.	1.290	3.753 **	4.911 **	1.079	-1.328

** $p<0.01$, * $p<0.05$

mean depth of four men at the $p<0.05$ level, six men at the $p<0.10$ level at the second point, two men at the $p<0.05$ level, four men at the $p<0.10$ level at the third point and the mean depth of the genuine signature. In the simulations via pf-h, the second and fourth points were the most noticeable on the third surface in women. A statistically significant difference was found between the mean depth of two women at the $p<0.05$ level, five women at the $p<0.10$ level at the second point, four women at the $p<0.05$ level, five women at the $p<0.10$ level at the third point and the mean depth of the genuine signature.

In the simulations via pf-h, the second and third points were the most noticeable on the third surface in men. A statistically significant difference was reported between the mean depth of 3 men at the $p<0.05$ level, 5 men at the $p<0.10$ level at the second point, 3 men at the $p<0.05$ level at the third point and the mean depth of the genuine signature. In Table 7, the comparisons between the mean depth values of all simulated signatures before and after practice and the mean depth of the genuine signature are shown regardless of the surface and point difference. Accordingly, in female subjects, the mean depths of simulated signatures of 8 subjects were reported to be statistically significantly different compared to that of the genuine signature. In male subjects, mean depth of three subjects and five subjects at the $p<0.05$ level were reported to be statistically significantly different than those of the genuine signature.

In Table 8, there are comparisons between the mean depth values of all simulated signatures on three different surfaces npf-h and pf-h and the mean depth of the genuine signature, regardless of the surface and point difference. Accordingly, the mean depths of three subjects (1 male and 2 female) at the $p<0.01$ level and nine subjects (3 male and 6 female) at the $p<0.05$ level were found to be statistically significantly different in the simulated signatures signed before practice. In addition, the mean depths of nine subjects (4 males and 5 females) at the $p<0.01$ level and 12 subjects (5 males and 7 females) at the $p<0.05$ level were reported to be statistically significant in the simulated signatures signed after practice.

In Table 9, the comparison of the simulated signatures made by male and female subjects on different surface npf-h and pf-h with the genuine signature depth is given. Accordingly, the mean depth of the simulated signatures signed without practicing belonging to 10 subjects (5 males and 5 females) on the first surface, 5 subjects (3 males and 2 females) on the second surface and 4 subjects (1 male and 3 females) on the third surface were found to be statistically significantly different than that of the genuine signature. The mean depths of the simulated signatures signed after practicing belonging to 11 subjects (5 males and 6 females) on the first surface, 4 subjects (1 male and 3 females) on the second surface, 7 subjects (3 males and 4 females) on the third surface were statistically significant compared to the that of genuine signature.

Table 7. Comparison of the mean depth values of the simulated signatures none practiced free-hand and practiced free-hand and the mean depth of the genuine signature regardless of the surface and point difference

N	t-value	Person	t-value
F1	2.717**	M1	4.851**
F2	4.526**	M2	2.347*
F3	-3.688**	M3	3.640**
F4	3.710**	M4	-2.526*
F5	2.714**	M5	-0.643
F6	4.415**	M6	0.409
F7	4.764**	M7	-1.877
F8	3.009**	M8	1.766
F9	-0.403	M9	-1.019
F10	2.546*	M10	4.765**
** p<0.01, * p<0.05			

Table 8. Comparison of the mean depth values of the simulated signatures on 3 different surfaces none practiced free-hand and practiced free-hand and the mean depth of the genuine signature regardless of the surface and point difference

None practiced free-hand			Practiced free-hand			None practiced free-hand			Practiced free-hand	
N	t-value		N	t-value		N	t-value		N	t-value
F1	2.914**		F1	1.036		M1	4.073**		M1	2.817**
F2	3.391**		F2	2.980**		M2	1.698		M2	1.607
F3	-1.739		F3	-3.413**		M3	2.058*		M3	3.117**
F4	1.720		F4	3.748**		M4	-1.216		M4	-2.367*
F5	2.329*		F5	1.563*		M5	-0.933		M5	0.092
F6	2.193*		F6	4.202**		M6	0.911		M6	-0.340
F7	2.281*		F7	4.647**		M7	0.307		M7	-2.834**
F8	1.813		F8	2.459*		M8	1.265		M8	1.220
F9	-0.670		F9	0.100		M9	0.016		M9	-1.435
F10	2.403*		F10	1.539		M10	2.548*		M10	4.253**
** p<0.01, * p<0.05										

Table 9. Comparison of signatures simulated none practied free-hand and practiced free-hand on different surfaces with genuine signature

None practiced free-hand						Practiced free-hand					
N	Surface	t-value	Person	Surface	t-value	N	Surface	t-value	N	Surface	t-value
	1st Surf.	2.784 **		1st Surf.	4.056 **		1st Surf.	0.411		1st Surf.	3.541 **
F1	2nd Surf.	1.297	M1	2nd Surf.	1.727 **	F1	2nd Surf.	1.115	M1	2nd Surf.	1.560 *
	3th Surf.	1.112		3th Surf.	1.449 *		3th Surf.	0.375		3th Surf.	0.237
	1st Surf.	2.373 **		1st Surf.	0.695		1st Surf.	1.414 *		1st Surf.	0.894
F2	2nd Surf.	0.946	M2	2nd Surf.	0.343	F2	2nd Surf.	0.459	M2	2nd Surf.	0.416
	3th Surf.	2.630 **		3 th Surf.	1.193		3th Surf.	3.804 **		3th Surf.	1.410 *
	1st Surf.	0.132		1st Surf.	2.112 **		1st Surf.	-0.857		1st Surf.	2.512 **
F3	2nd Surf.	-1.823 **	M3	2nd Surf.	0.221	F3	2nd Surf.	-2.915 **	M3	2nd Surf.	0.670
	3th Surf.	-1.352 *		3th Surf.	1.520 *		3th Surf.	-1.974 **		3th Surf.	2.395 **
	1st Surf.	0.492		1st Surf.	0.372		1st Surf.	2.569 **		1st Surf.	-1.364 *
F4	2nd Surf.	1.472 *	M4	2nd Surf.	-1.785 **	F4	2nd Surf.	1.257	M4	2nd Surf.	-1.115
	3th Surf.	1.081		3th Surf.	-0.946		3th Surf.	2.621 **		3th Surf.	-1.603 *
	1st Surf.	2.153 **		1st Surf.	1.319 *		1st Surf.	1.793 **		1st Surf.	-0.198
F5	2nd Surf.	0.835	M5	2nd Surf.	-0.924	F5	2nd Surf.	1.204	M5	2nd Surf.	-0.958
	3th Surf.	1.012		3th Surf.	-1.592 *		3th Surf.	0.085		3th Surf.	1.162
	1st Surf.	0.587		1st Surf.	1.922 **		1st Surf.	3.239 **		1st Surf.	1.074
F6	2nd Surf.	2.131 **	M6	2nd Surf.	-0.729	F6	2nd Surf.	2.714 **	M6	2nd Surf.	-0.053
	3th Surf.	1.209		3th Surf.	0.728		3th Surf.	1.387 *		3th Surf.	-1.419 *
	1st Surf.	1.303		1st Surf.	0.810		1st Surf.	2.496 **		1st Surf.	-2.179 **
F7	2nd Surf.	-0.216	M7	2nd Surf.	-0.807	F7	2nd Surf.	2.306 **	M7	2nd Surf.	-1.131
	3th Surf.	3.041 **		3th Surf.	0.542		3th Surf.	3.138 **		3th Surf.	-1.642 *
	1st Surf.	1.938 **		1st Surf.	3.325 **		1st Surf.	2.108 **		1st Surf.	3.137 **
F8	2nd Surf.	1.033	M8	2nd Surf.	0.270	F8	2nd Surf.	1.439 *	M8	2nd Surf.	-0.992
	3th Surf.	0.198		3th Surf.	-0.283		3th Surf.	0.731		3th Surf.	0.717
	1st Surf.	0.372		1st Surf.	3.214 **		st Surf.	1.272		1st Surf.	1.625 *
F9	2nd Surf.	-1.115	M9	2nd Surf.	-2.429 **	F9	2nd Surf.	-0.577	M9	2nd Surf.	-0.577
	3th Surf.	-0.255		3th Surf.	-0.236		3th Surf.	-0.322		3th Surf.	-3.280 **
	1st Surf.	1.746		1st Surf.	1.005		1st Surf.	2.152 **		1st Surf.	2.163 **
F10	2nd Surf.	0.132	M10	2nd Surf.	0.902	F10	2nd Surf.	0.158	M10	2nd Surf.	2.551 **
	3th Surf.	1.730		3th Surf.	2.583 **		3th Surf.	0.502		3th Surf.	2.569 **

** p<0.01, * p<0.05

DISCUSSION

Signatures generated online seem advantageous in terms of simultaneous detection of dynamic properties such as speed, size, degree of pressure, fluency and duration. However, despite the increase in digitalization, offline handwriting and signature examinations are still very common due to the use of paper. Our findings show that when the depths of the pen stroke due top en pressure of the simulated signature for each point were compared with the genuine signature regardless of the difference depending on the surface conditions and npf-h and pf-h, in fact, significant differences occur at p<0.05 and p<0.01 level at each point, which can be used in diagnosis. In our opinion, these findings show that depth of the indented pen pressure can be used in diagnosis. At the third point, it was determined that this difference reached its maximum, and the mean depth of 13 subjects at p<0.05 level and 14 subjects at p<0.01 level were reported to be statistically significantly different than those of the genuine signature (Figure 1, Tables 1-2). The reason for seeing such a difference at the third point needs to be further investigated. The peculiarity of the point here is that it coincides at the middle of the signature with a sharp turn. Therefore, it is possible that the pressure exerted could be the lowest at this location. For this point, it can be thought that different degrees of pressure are applied by different individuals while creating curls. When the depths of the signatures simulated npf-h and pf-h were compared with the genuine signatures for each point regardless of the surface types, it cannot be said that the depths of the simulations made after practicing are closer to the genuine signature, provided that they are the same at five points. Due to its short duration, practicing did not contribute to the subjects, on the contrary, it had a negative effect. There should be a longer practice time for free-hand simulation. The subject must thoroughly memorize the signature and then sign it in an automated manner. It has also been revealed here that this cannot be achieved with short-term studies. Undoubtedly, the surface becomes important when examining an offline signature in terms of determination of the authorship. One of the biggest disadvantages in forensic writing and signature examinations is that it may not be known on what surface the signature under examination was made. For this reason, it is important to take the comparison samples on different surfaces as much as possible, if the numerical depth differences are to be used in the comparison as was carried out in this study. Our findings show that the mean depth of the simulated signatures are statistically significantly less or higher than the genuine signature for different points, also for simulations made on different surfaces. Therefore, it would be reliable to consider negative findings rather than positive findings in the examination of simulations made with comparison samples taken on different surfaces to determine authorship. When the mean depth values of all simulation signatures of the subjects npf-h and pf-h were compared with the mean depth of the genuine signature regardless of the surface and the point, the mean depth of 8 subjects in females, 3 subjects in males at the $p<0.01$ level, and 9 females and 5 males at $p<0.05$ level were found to be statistically significantly lower or higher than the genuine signature. The number of subjects with differences is quite high. The significance value ($p<0.01$) is quite high, so it would be appropriate to use it in determining the authorship. Regardless of the surface and the point, the comparison of the mean depth values of all simulated signatures npf-h and pf-h to those of the genuine signature revealed a difference in 3 subjects at the $p<0.01$ level in simulated signatures via npf-h, and in 9 subjects in simulated signatures via pf-h. In the signatures via practiced free hand, it is again encountered that there are differences in more subjects. As a matter of fact, a difference at the level of $p<0.05$ was found in 9 subjects for signatures simulated npf-h, and in 12 subjects pf-h. Regardless of the point difference, when the mean depth values of the simulated signatures made on three different surfaces npf-h and pf-h and the mean depth of the genuine signature were compared, a statistically significant difference was found in a significant number of subjects, which is a very important finding. These differences remained high in all three surfaces. As a matter of fact, in the simulations npf-h, the depth values of 10 subjects (5 females, 5 males) at $p<0.05$ level, 11 subjects (5 females, 6 males) at the $p<0.10$ level on the first surface, 5 subjects at $p<0.05$ (2 females, 3 males), 6 subjects (3 females, 3 males) at $p<0.10$ level on the second surface, 4 subjects (3 females, 1 males) at 95% confidence interval and 8 subjects (4 female, 4 male) at 90% confidence interval on the third surface differ statistically from the genuine signature. In the simulations pf-h, the depth values of 11 subjects (6 females, 5 males) at the $p<0.05$ level, 14 subjects (7 females, 7 males) at the $p<0.10$ on the first surface, 4 subjects at the $p<0.05$ level (3 female, 1 male), 6 subjects (4 females, 2 males) at $p<0.10$ level on the second surface, 7 subjects (4 females, 3 males) at $p<0.05$ level, and 12 subjects at $p<0.10$ level (5 females, 7 males) on the third surface differ with the genuine signature.

CONCLUSION

The depth of pen pressure of any signiture is important. It needs to be determined in detail becuase it has the potential to reveal whether it is forgery or not. However, the depth is not a constant variable, unfortunately it has the potential to vary depending on the condition such as the hardness of the surface. Pen pressure is one of the criteria used in discriminating genuine from simulated signatures. It should be evaluated together with other criteria and a decision should be made accordingly.

In conclusion, aside from similar depth of the indented pen pressure, persistence of dissimilarities in different comparison documents and at different points is an important criterion. It has been revealed that these differences are statistically significant. When comparing the depth of the indented pen pressure, it is better to use numerical values (quantitatively) as in this study, not eyeball estimate (qualitatively). It should be noted that the degree of pen pressure is one of the diagnostic criteria used in Forensic Handwriting and Signature Examinations and should be accompanied by other criteria when considering inclusion or exclusion.

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ETHICS

Ethics Committee Approval: Approval for the current study was granted by the Istanbul University, Social and Human Sciences Ethics Committee (approval no: 13/11/2019-257799).

Authorship Contributions

Concept: G.Ç., Design: G.Ç., Data Collection or Processing: D.Ö.K., Analysis or Interpretation: D.Ö.K., G.Ç., Literature Search: D.Ö.K., Writing: D.Ö.K., G.Ç.

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