Effect of Visual Feedback on the Static and Kinematic Characteristics of Handwriting

Michael Pertsinakis [1,2]

Abstract: *Research on visual feedback has not produced consistent results to show how visual feedback or the lack, thereof, influences individual handwriting characteristics. A two-pronged approach was designed to investigate the degree of this influence. For this purpose, samples of signatures as well as cursive and block text, written with and without visual feedback, were collected from 40 volunteers and imported into a PC via a pen tablet, using an electronic inking pen. The data was analyzed in a handwriting movement analysis software module specially designed for this research that was added to the software MovAlyzeR by Neuroscript LLC. Two forensic document examiners (FDEs) independently analyzed samples from the two groups (samples executed with normal visual feedback versus the group of samples executed without visual feedback). They found no fundamental differences between these two groups. Their analyses also demonstrated that a large number of similarities existed in the general design of the allographs (alternative forms of a letter or other grapheme) and in the pictorial aspects, regardless of the complexity of the samples. In the cursive and block handwriting, four main qualitative characteristics were linked to the absence of visual feedback: change of overall size, non-uniformity of left margins, change of baseline alignment, and inclusion of extra trajectories. The statistical analysis verified the above findings. The comparative analysis also suggests that gender, educational level (above high school) and handedness create an insignificant influence on the individual characteristics of writing produced with and without visual feedback. The only notable exception is the relationship between signature duration and educational level. The volunteers with a medium education level showed a significant increase in duration while signing their names without visual feedback in comparison to those with higher education levels. The combination of the above findings suggests that handwriting is not fundamentally influenced by visual feedback.*

Reference: Michael Pertsinakis (2017). Effect of Visual Feedback on the Static and Kinematic Characteristics of Handwriting. J. Forensic Document Examination, Vol 27, pp. 5-21.

Key Words: Digital handwriting, Factors that influence handwriting, Kinematics, Visual feedback, Signatures

1. Introduction

The motor skill of handwriting is influenced by numerous extrinsic (e.g., physiological constraints, genetic factors, handedness, medications, etc.) and intrinsic (e.g., imitation, mental state of the writer, fatigue, etc.) conditions and factors, contributing to the individuality of handwriting (Huber and Headrick, 1999). Ellen (2006) stressed that the forensic document examiner (FDE) should gather as much information about the medical history of the alleged writer, the physical condition, the alleged writing stance, as well as the existence of special conditions that occurred in the environment at the time the handwriting was produced. Ellen reasons that some factors can change

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the individual's writing so drastically that it may be impossible to make an accurate comparison between the person's normal and abnormal writing, causing serious problems for an FDE who works on such a case (Miller, 1987). Srihari et al (2002) reported several factors that may influence handwriting: age, ethnicity, handedness, handwriting method learned, the contents of the written text, the writing instrument, the nature and the material of the document and changes in the neuromotor system of the writer over time. Among these factors high importance is given to physiological conditions that can affect handwriting to a degree that makes accurate comparison between the genuine and the questioned handwriting difficult or even impossible (Hilton, 1969).

In case of visually impaired writers the literature is not unanimous as to whether reduced visual feedback will create significant changes in the individual's handwriting characteristics. There is also no consensus as to which individual characteristics are affected when visual feedback is reduced, and to what extent changes in visual feedback could limit conclusions by FDEs or lead to erroneous conclusions. Huber and Headrick (1999) suggest that the principal disadvantage of a visually impaired writer is the reduction of feedback information on the handwritten result. This in turn may restrict the writer from using references as to the form, length, and location of pen strokes. This may result in "square writing", exaggerated size of letters, difficulty in maintaining a straight baseline, increase in vertical spacing between lines of writing, considerable amount of retracing and overwriting, inconsistency of spacing between letters and words, hesitation marks at the beginning of letters, lack of fluency and appearance of writing tremor due to hesitation and decreased speed of execution, avoidance of pen lifts (e.g. Plimmer et al, 2011, Meulenbroek & Van Galen, 1989.). Researchers Morikiyo and Matsushima (1990) identified letter duplications, insertion of pen strokes, and increase of writing size when there is a lengthened delay of visual feedback.

Teulings (1989) suggested that the handwriting motor system is an open-loop system because the performance of handwriting is largely independent upon internal and external feedback. Ellis (1982) also states that feedback processing is unlikely, due to the very small time of execution of the strokes. However, Caligiuri and Mohammed (2012) challenge the time delay hypothesis of the open-loop motor system by referencing the research of Evarts and Tanji (1974), who suggest that the sensory-motor kinesthetic feedback loop could be realized in less than 50 ms .

Therefore, it is likely that at least some writing can be executed as a familiar motor program that requires no reafferent cues (Kelso, 1982; Schmidt, 1982). Agreeing with the above findings, Van Galen et al. (1988) and Smyth and Silvers (1987) proposed that visual feedback plays a monitoring role mainly in the multi-stroke level, but less during the level of execution of a single stroke. Marquardt et al. (1999) propose that the distortion of visual feedback does not directly slow down open-loop movements to allow control of the motor output in a closed-loop mode.

The present study examines whether visual feedback affects the static and dynamic characteristics of handwriting and pinpoints the specific characteristics that are affected by the absence of visual feedback.

2. Methodology

Forty healthy educated adults that included 20 females and 20 males participated. Their ages ranged from 22 to 65. Three participants were left-handed. All volunteers were Greek citizens who resided in various locations of Greece. The majority of them were recruited from the Greek island of Crete. All participants were proficient in Greek cursive and block script. The volunteers possessed educational levels spanning from medium (i.e., high school) to very high (i.e., PhD). Volunteers who had not achieved a high school diploma were excluded to eliminate partial illiteracy as a factor that would affect handwriting proficiency. Before the experiment, the volunteers completed a questionnaire regarding their age, residence, gender, health condition, handedness, and education. The informed consent procedure was approved by the ethics commission at Staffordshire University and the University Hospital of Heraklion, Crete, Greece. Participants gave written permission that their specimens of signatures and handwriting could be anonymously used for research, presentations, and publications. Table 1 presents the demographic characteristics of the volunteers.

The participants wrote on an unlined sheet of paper placed on top of an opaque pen tablet (Wacom Graphire CTE-440 with accuracy of 0.01 cm and

Experiment Participants – Total: 40 subjects					
Female	20	**Male**	20		
Righthanded	37	**Lefthanded**	3		
18-30 yo	21	**31-43 yo**	16	**44-70 yo**	3
Medium Educational Level	7	**Higher Educational Level**	33		

Table 1. Demographic Characteristics of the Volunteers, detailing gender, handedness, age and education level.

sampling rate of 100 Hz), with an active area of 5” x 4” (12.7 cm x 10.16 cm), using an electronic inking pen (Wacom EP200) with a normal blue ballpoint cartridge. The sheet of paper was held in place by the participant’s non-writing hand. The pen tablet was connected to the USB port of a Lenovo T43p laptop with MS Windows XP operating system. The experimental procedure and the recording of the pen movements were executed using Neuroscript MovAlyzeR handwriting movement software (Version 6.1.), which was selected because of its functionality, scientific documentation, detailed measurement and ability to record and analyze dynamic characteristics of handwriting, such as duration and velocity (e.g., Pantelyat et al, 2014; Johnson et al, 2015; Ketcham and Rodriguez 2007; Mohammed et al, 2010).

The volunteers were asked to produce handwriting under the following conditions: Condition 1 -Cursive writing with normal visual feedback. The volunteers wrote in cursive and under normal visual feedback a Greek “pangram”, which is a sentence that includes all letters of the Greek alphabet (“**ζαφείρι δέξου πάγκαλο βαθών ψυχής το σήμα**” [*Receive this beautiful gem, which signifies the deepest sentiments of my heart]*) (3 trials). Condition 2 - Cursive writing with visual feedback suppressed using a blindfold that obscured all light (3 trials). The volunteer was instructed to start writing in the central left part of the tablet. After each trial, the experimenter slid the sheet of paper on the tablet to create empty space. The researcher made sure that the blindfold was positioned correctly before each trial. Condition 3 - Block writing with normal visual feedback. The volunteers wrote the same pangram in block handwriting (3 trials). Condition 4 - Block writing without visual feedback. The volunteers wrote the same pangram in block handwriting while vision was obstructed using a blindfold (3 trials). Condition 5 - Signature under normal visual feedback (10 trials). Condition 6 - Signature with visual feedback suppressed using a blindfold that obscured all light (10 trials). The signatures were labeled as symbolic (consisting only of non-grammatical trajectories), holographic (consisting of legible letters), or mixed (containing both legible letters and illegible symbols). These same categories have also been referred to as *stylized*, *text based*, and *mixed* (Found & Bird 2016, Mohamed et al, 2011). The trials were blocked per condition while the sequence of conditions was at random per participant.

Prior to the experiment, each volunteer was familiarized with the concept of the experiment by the experimenter. They performed a few exercise trials by placing signatures with the electronic pen on the tablet with and without visual feedback. Each trial started by a 400 Hz tone of 200 ms. The recording started when the pen touched the tablet. When the volunteer finished the trial and lifted the electronic pen for more than 2 seconds, a 800 Hz tone of 200 ms was generated. The beginning of each new condition was signaled by a double audio cue. In addition to the audio cues at the beginning of each trial, which commenced when the experimenter hit the Enter button, the volunteers were guided verbally through the experiment. The volunteers were told to use their normal speed, using their habitual writing stance and pencil grip, while seated comfortably in a quiet place at a well-illuminated desk. The volunteers could not see the computer screen, so they focused only on the sheet of paper on the pen tablet, and the directions of the experimenter. The samples were written on

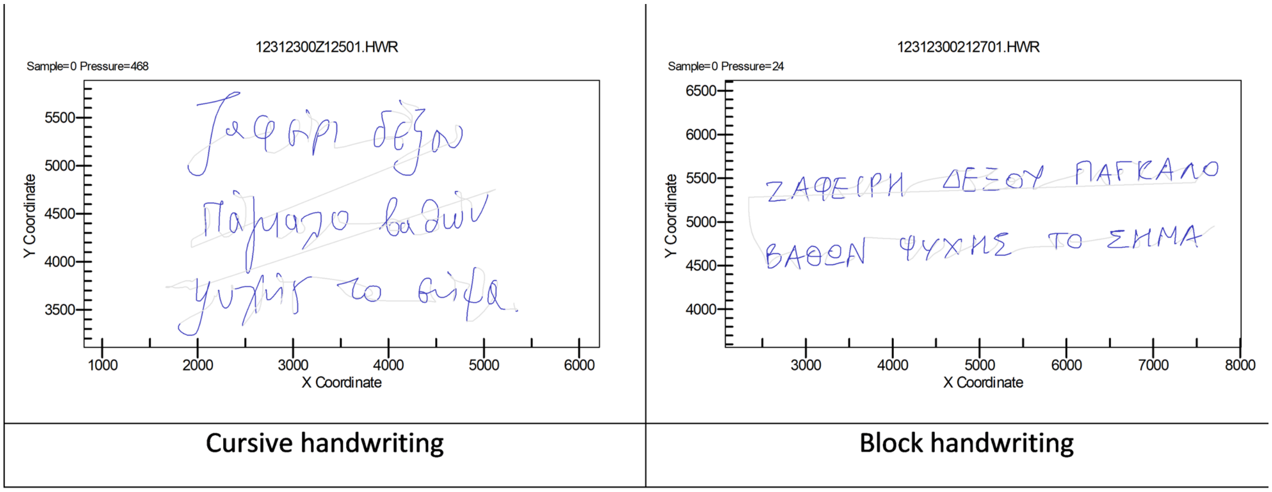

Figure 1. The dictated pangram written in cursive and in block letters.

unlined A4 paper to give the volunteer the freedom to utilize the habitual size of signature and to avoid any possible influence that a lined paper would impose. A ballpoint pen was provided since it is the most commonly used writing instrument. In addition, stereoscopic examinations of writings with ball point pens more clearly show stroke direction, striation lines, and pictorial characteristics than the examination of strokes executed by other kind of pens (e.g., felt tip or gel) (Ellen, 2006).

To avoid any researcher bias the following software settings were established during the creation of the experiment and were not changed during data collection and analysis: The horizontal and vertical coordinates were low-pass filtered using the complex Fast Fourier Transform (FFT) followed by a frequency-domain filter at 12 Hz and a sinusoidal transition band between 5.1 Hz and 18.9 Hz, followed by the inverse FFT (Teulings & Maarse, 1984). The entire trial from the start of the pen movement (e.g., after the pen touched the tablet and the pen movement started) until the end of the pen movement (e.g., when the pen was lifted or the pen movement stopped) was regarded as one segment.

Specifically, the written text, which was previously memorized by the participants, was also dictated at a speed that matched the volunteer's own writing speed. The pangram also has the advantage of being one of the shortest Greek sentences of its kind (Sarantakos, 2014), while enabling the researcher to cover the full spectrum of the Greek alphabet (cursive and block letters), as well as to examine the interword and interlinear distances. Figure 1 presents a pangram written in cursive and in block letters. Both images are depicted in raw data. The grey lines represent the aerial movements of the inking pen above the paper sheet.

After recording all samples via the tablet, a bottom-up analysis took place for each trial, condition, participant and group. First, while the volunteer was still present, each trial was inspected for possible discontinuities (e.g., where the pen was lifted beyond the maximum proximity height). For all the discontinuities found, a visual examination took place using a 10-power Regula Batlija Ltd magnifier to investigate possible differences between the writing on the paper and the recorded data. In cases where a trial was performed erroneously (e.g., the writer did not finish the trial), the experimenter could decide to rerecord this single trial. This procedure ensured that each trial was performed correctly. Afterwards, the consistency of the trials for each condition was examined. To do so, all trials within the same condition were compared. The comparison was in terms of the pictorial as well as the dynamic representation focusing mainly on the pattern of durations, absolute average velocity and pressures. The purpose of this comparison was to detect outliers in all trials per condition; however, no such outliers were discovered.

3. Results

3.1. Results regarding the analysis of signatures

Independently executed by two FDEs, forensic comparison of the volunteers' signatures between the visual feedback and the non-visual feedback conditions showed many similarities. No fundamental differences were found in terms of the construction and the general pictorial image of the allographs, the slant, the connecting strokes, the main directions of the pen-down trajectories, the line quality, the relative positions and orientation of the signatures. This lack of fundamental differences was observed in all three types of signatures (symbolic, holographic, and mixed type) and in all levels of signature complexity. This means that the complexity of a signature is not dependent on the visual feedback. In the present research, no signature simplification occurred under the condition of no visual feedback, thus agreeing with Teulings' et al. (1989) remark that well trained handwriting is produced by an open loop motor program. Conversely, the execution of the signature is a highly automated process. Furthermore, the forensic comparison shows a lack of differences along with many similarities regardless of gender, handedness, and educational level (from high school until PhD level), signifying that the motor program used for signature execution is not influenced by these factors. In summary, no distinctive characteristics were found which the expert could exploit to identify –or even hypothesize- the visual feedback condition during which a questioned signature was written. Some of the similarities between the two conditions are illustrated in Figure 2.

The collected data of duration (in seconds), absolute, horizontal and vertical size (cm), average pressure (z), road length (cm), average absolute velocity (cm/s) and slant (radians) were statistically analyzed using the statistics analysis software SPSS (Version 21). Significant differences were found in duration under visual feedback (Mean 2.08 s and Standard Deviation (SD) 1.17 s), duration without visual feedback (2.27 ± 1.27 s; $t(39) = -4.16$, $p<0.001$, $r=0.55$), Average Absolute Velocity under visual feedback (10.49 ± 5.39 s) and Average Absolute Velocity without visual feedback (9.56 ± 4.68 s; $t(39)=4.22$, $p<0.001$, $r=0.56$). The educational level of the volunteer significantly influenced the duration of execution. In both subgroups, the execution without visual feedback takes more time. However, in the subgroup of subjects with a medium level of education, the duration increases significantly ($df=1$, $F=10.08$, $Sig.=0.003$). A suggested explanation is that

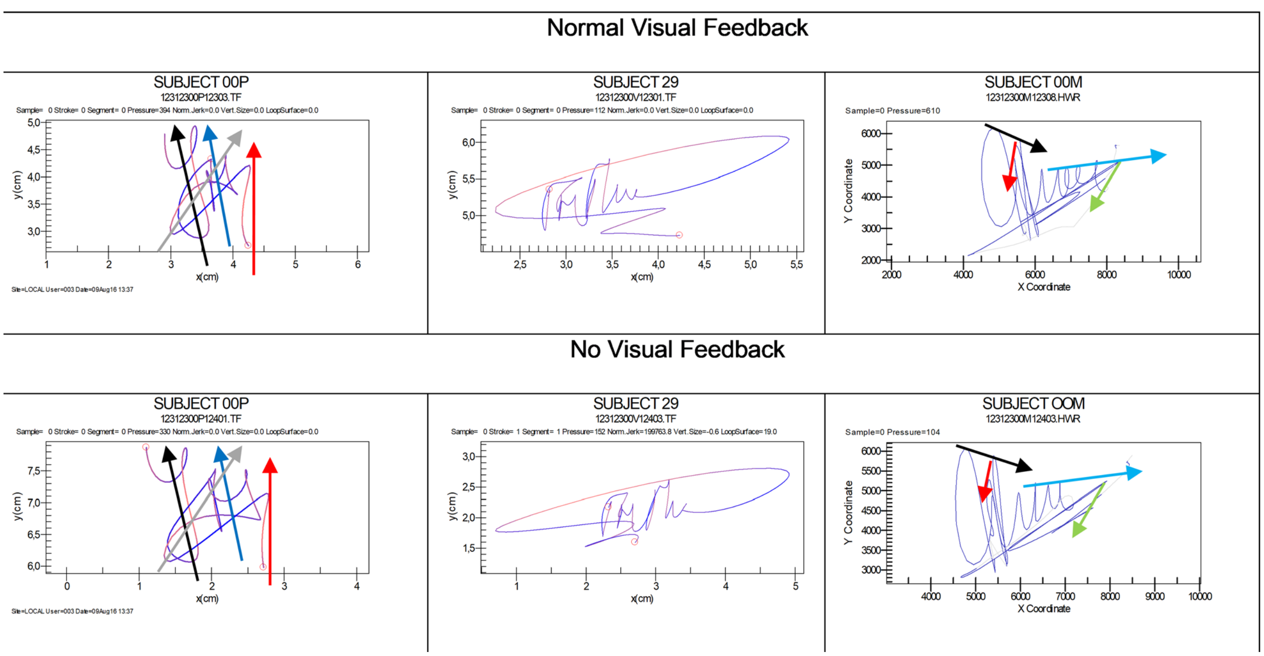

Figure 2. In subject 00P the arrows show the slants of parts of the signature, while in subject 00M the alignment of the parts of the signatures is compared. Subject 29 executes a signature, whose high complexity is not affected by the loss of visual feedback.

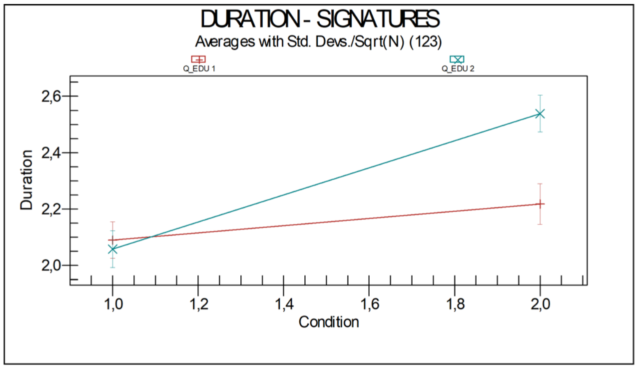

Figure 3. The subjects react significantly differently to the loss of visual feedback, depending on their educational level, in the Duration in Signatures [Edu 1=high education level, Edu 2=medium educational level].

a higher level of education is often connected with a more recurrent execution of the signature. This repetition creates a higher degree of automation, so larger parts of the executed signature are regarded as one allograph and, as such, are faster retrieved and executed. Therefore, if two signatures of the same overall size and complexity belong to two different individuals, one who often practices it and one who does not, the signature from the former will be divided into fewer memory units than that of the latter. Consequently, the retrieval and storage in the buffer area, until the "go" sign of the execution occurs, will be faster. Figure 3 shows a chart of duration vs condition 1 (normal visual feedback) and condition 2 (absence of visual feedback). Both subgroups present the overall same averages in condition 1, but in condition 2 the medium level subgroup shows a distinctive delay in the execution.

3.2. Results regarding the analysis of cursive and block handwriting

The forensic comparison between the two groups of cursive handwriting (samples executed with normal visual feedback versus samples executed without visual feedback), focusing on general design, line quality, size, connections, spacing, slant and alignment, shows lack of fundamental difference in all pictorial characteristics of both groups, regardless of the complexity of the handwriting samples. The same findings apply for the comparison of the block handwriting. Such an experiment of cursive handwriting is presented in Figure 4.

These findings take into consideration that the dictated pangram is a semantically peculiar text, that the participants had a small amount of time to practice and that–unlike signatures- it was not an automated action. In fact, this text consists of many different and independent motor units and, therefore, the motor program had to proceed to a far larger number of memory unit retrievals and storages, thus minimizing automation. The dictated text both in its cursive and block form manifests a far larger number of pen stops than the signatures, and occupies larger vertical and horizontal space. The hand has to

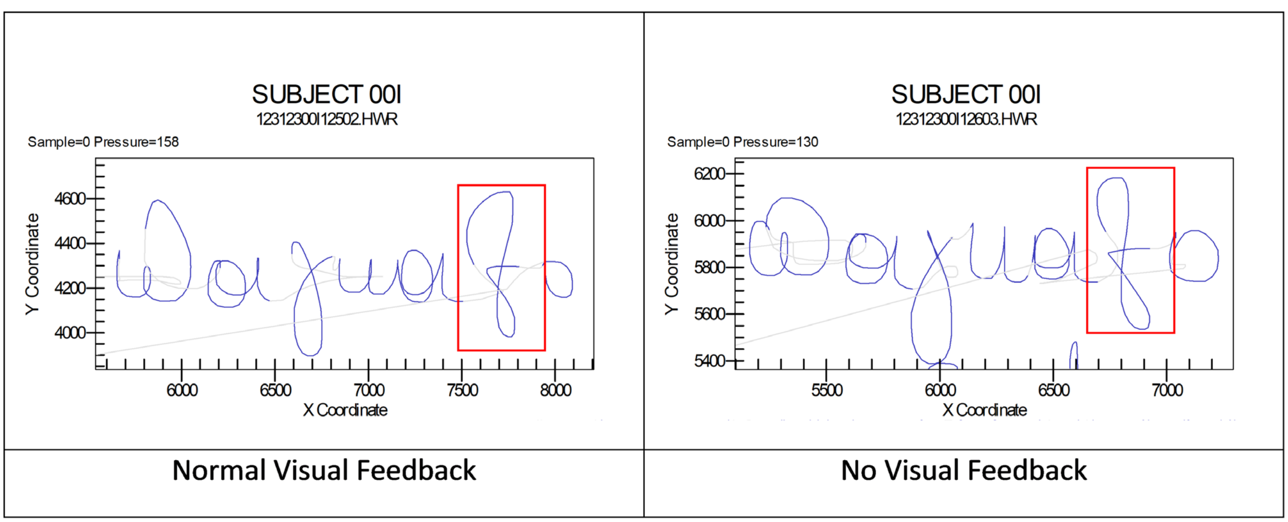

Figure 4. Amongst the large numbers of similarities, it is worth mentioning the rare allograph with the pictorial image of the number 8 that corresponds with the letter λ (see red rectangle). The unusual design of this allograph is similar in both conditions.

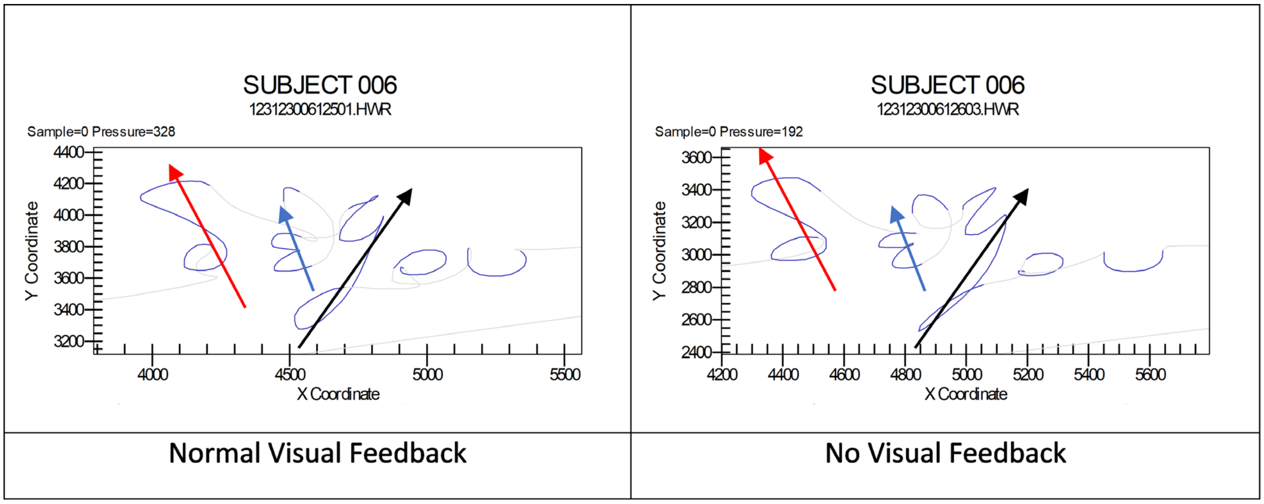

Figure 5. The three arrows illustrate the slants in three letters. No fundamental difference is observed.

travel in both dimensions for longer duration and to create a multitude of unknown air trajectories. This suggests that both cursive and block handwriting manifest significantly less automation compared to the execution of signatures.

Even with a minimization of automation, the forensic comparison executed independently by two FDEs showed no fundamental differences along with distinct similarities in all the individual characteristics that were analyzed. The general design of the handwriting remained the same. The line quality showed no evidence of becoming poorer. The findings of this comparison replicate those of the signatures. Since the factor of automation is minimized, these similarities can be attributed solely to the fact that the motor program, which executes handwriting, is not significantly affected by the exterior factor of visual feedback. Figure 5 illustrates the similarities of the characteristic of slant between a cursive sample written with and without visual feedback.

The lack of fundamental differences was not linked in any way with handwriting complexity or writing maturity of the individual. This suggests that the complexity of a handwriting sample is not specifically compromised by the absence of the visual feedback. In Figure 6, the cursive handwriting of subject 012 is analyzed. This female righthanded writer, with a higher educational level, manifests a complex handwriting with highly individualized characteristics. The inspection of the general design of the allographs in these two conditions shows lack of fundamental differences. It is worth noticing the trajectories that create the letter **α** (see blue arrow), the anticlockwise connection of the letters **ε** and **ι** (see red arrow) and the elaborated construction of the letter **ψ** (see black arrow). The analysis of pen stops and aerial movements of pen (as shown by the grey lines) revealed that the hand made the same type of movements, while it was hovering over the document, in both conditions (Dewhurst et al, 2016). This is especially evident in the letters **υ** and **ν** at the end of the first and second line of the text, where the pen lifts and makes an aerial trajectory to the first letter of the next line. Proceeding to the examination of block handwriting, samples written with and without visual feedback were compared. Apart from the similarity of the general design, the replication of fine detail is also evident. In the grey rectangle, once again, the anticlockwise connection between the letters E and I is presented. The individual peculiarities of exaggerating the finishing trajectories of certain letters is retained, even when the participant had no visual feedback (red and blue arrows). Also worth mentioning is the similarity in the air strokes: the black arrows in Figure 5 show the last trajectory of the writing sample that, in both conditions, involves a clock wise in-air hook-like trajectory.

Finally, the forensic comparison of the handwriting samples, in accordance to that of the signature sampless, shows that the pictorial elements are not affected by gender, handedness or educational level (considering medium and higher education

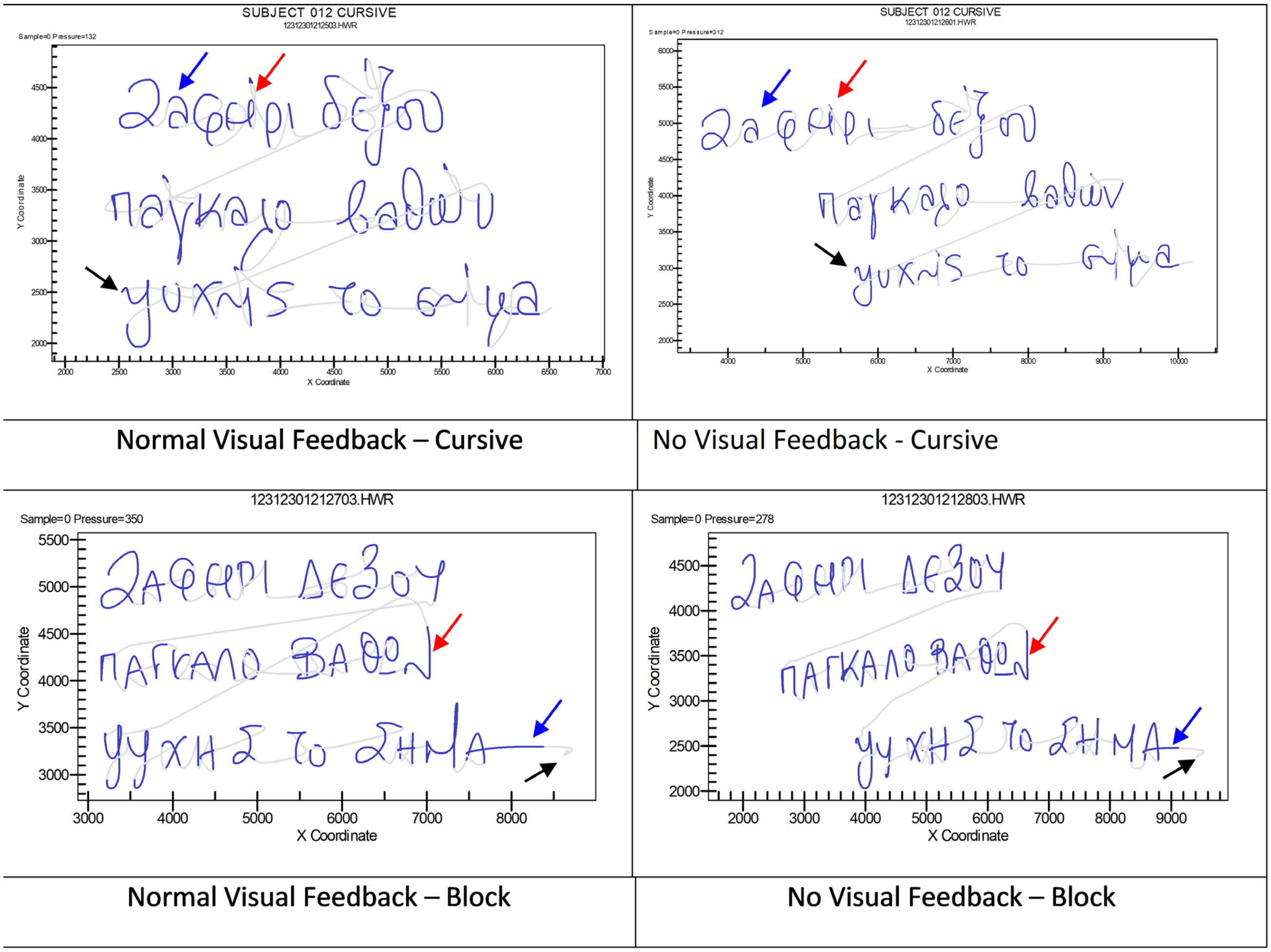

Figure 6. The similarities in the two conditions in cursive and block handwriting are presented.

levels). This uniformity of the findings suggests that the execution of signatures, as well as cursive and block writing, is based on a single motor program used to produce a diverse variety of results.

As stated by Huber & Headrick (1999), the loss of visual feedback interferes in the macromanaging of handwriting. It specifically decreases the ability of the writer to align the letter that is currently produced to letters that were already produced, as will be demonstrated in Figure 7. This absence of feedback regarding the exact position of the previous letters shows some common characteristics, which could be used as flags to indicate absence of visual feedback. The qualitative analysis shows the existence of four main flags that are linked with handwriting execution without visual feedback. These are a) change of overall size, b) non uniformity of left margins, c) change of baseline alignment and d) inclusion of extra trajectories. It must be stressed that these flags do not, by themselves, constitute signs of forgery as they are merely qualitative clusters of common characteristics perceived in the samples created without visual feedback. They are limited in quality and scope, and do not constitute fundamental and unexplained differences.

3.2.1 First Qualitative Flag - Change of overall size

Verifying the reference point provided by the previously executed letter on the left of the currently drawn one does not pose a problem. Since this letter was executed immediately before the current one, the writer simply continues keeping the dominant hand in the same horizontal alignment. This is supported by the experimental findings since on no occasion did the executed letter err fundamentally from the letter to the left. However, the alignment to the reference

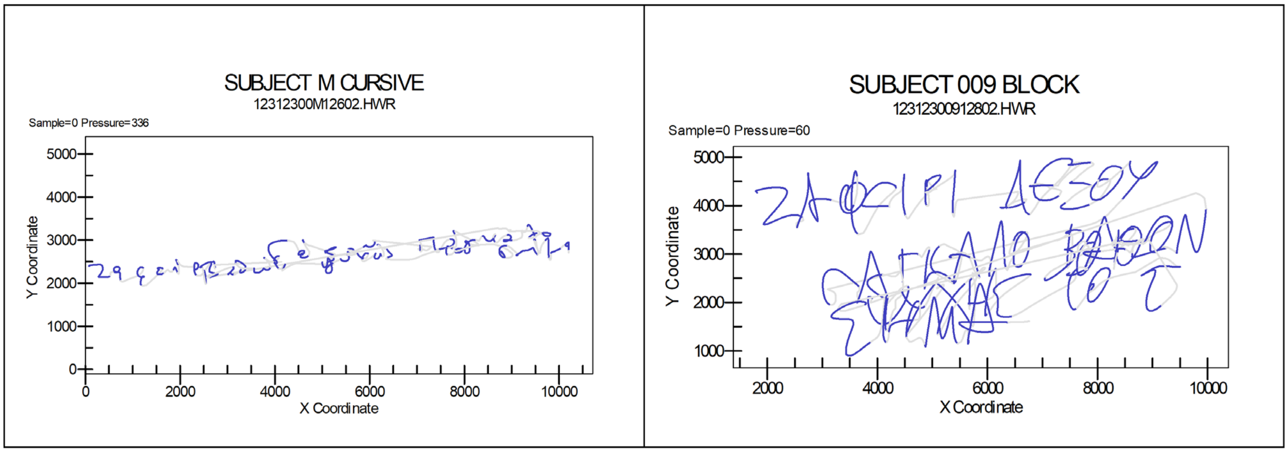

Figure 7. Two cases of extreme reduction of interlinear distances in the condition of no visual feedback, that led to overwriting in cursive (left image) and block (right image) letters.

point of the letter above is far more demanding. In this case, the hand that executes the trajectories has already moved down a line, therefore any attempt of artificial alignment, as well as any mnemonic aid, is minimized. Two basic mechanisms applied by the writer to overcome the spatial loss, due to the inability to use the two reference points, were investigated: enlargement and reduction of the size of handwriting sample executed without visual feedback. Both the enlargement and the reduction may refer to any pictorial characteristic pertinent to size and spacing. No correlation was found between the choice of the one mechanism over the other and the gender, educational level, or handedness of the volunteer.

Specifically, the mechanism of reduction could lead to vertical overwriting, since the vertical reference point is totally ignored and overlapping between the two lines could be exaggerated, as presented in Figure 7. In such cases, legibility is compromised.

10 out of 40 writers (25%), who did not show any vertical overwriting in condition 1, proceed to a certain degree of overwriting in condition 2 in cursive writing (from light to major overwriting), while the same effect was demonstrated in 4 writers in block handwriting (10%).

By the same token, the mechanism of enlargement could reach its extremities in trials like the one pictured in the Figure 8 where the writer divided the second single line into two (one placed under the other). Out of 40 subjects this phenomenon was noticed in 4 participants in the case of block handwriting (10%), and in two participants in the case of cursive writing (5%).

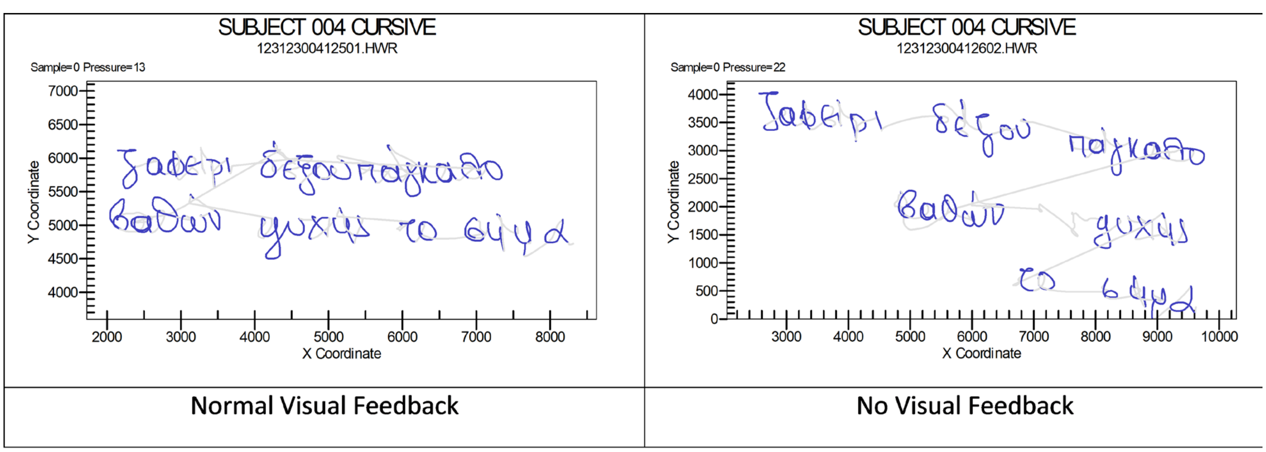

Figure 8. A case of extreme increase of interlinear distance in the condition of no visual feedback, with the added characteristic of dividing the second line of the text into two.

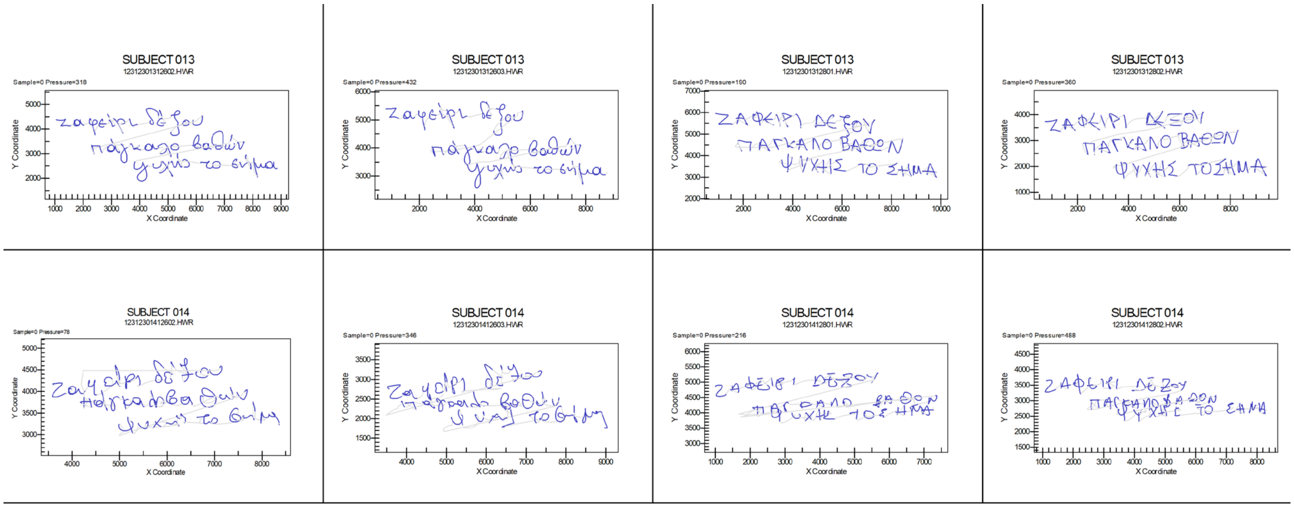

Figure 9. Examples of stability in the positioning of the subsequent lines in the condition of no visual feedback.

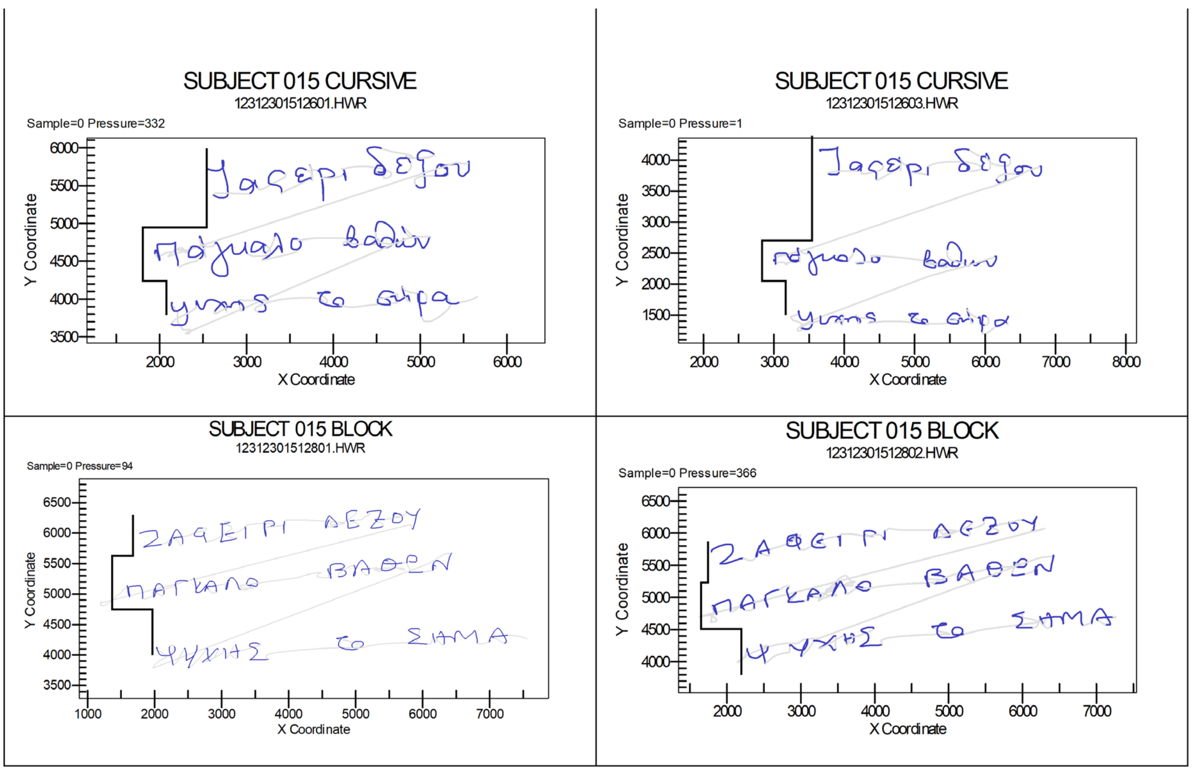

Figure 10. Examples of stability of margin positioning.

3.2.2 Second Qualitative Flag – Non uniformity of left margins

A second flag that is linked with handwriting execution under no visual feedback is the non-uniformity of left margins. For writers who position the left margins uniformly in normal visual feedback conditions, only six participants out of 40 (15%) manifested uniformity in all of their trials in cursive handwriting without visual feedback. No participant (0%) did the same in block handwriting. The major tendency of this non-uniformity is when the writer positions the second (or third) line further to the right of the previous line.. This positioning towards the right is not linked with the handedness of the writer

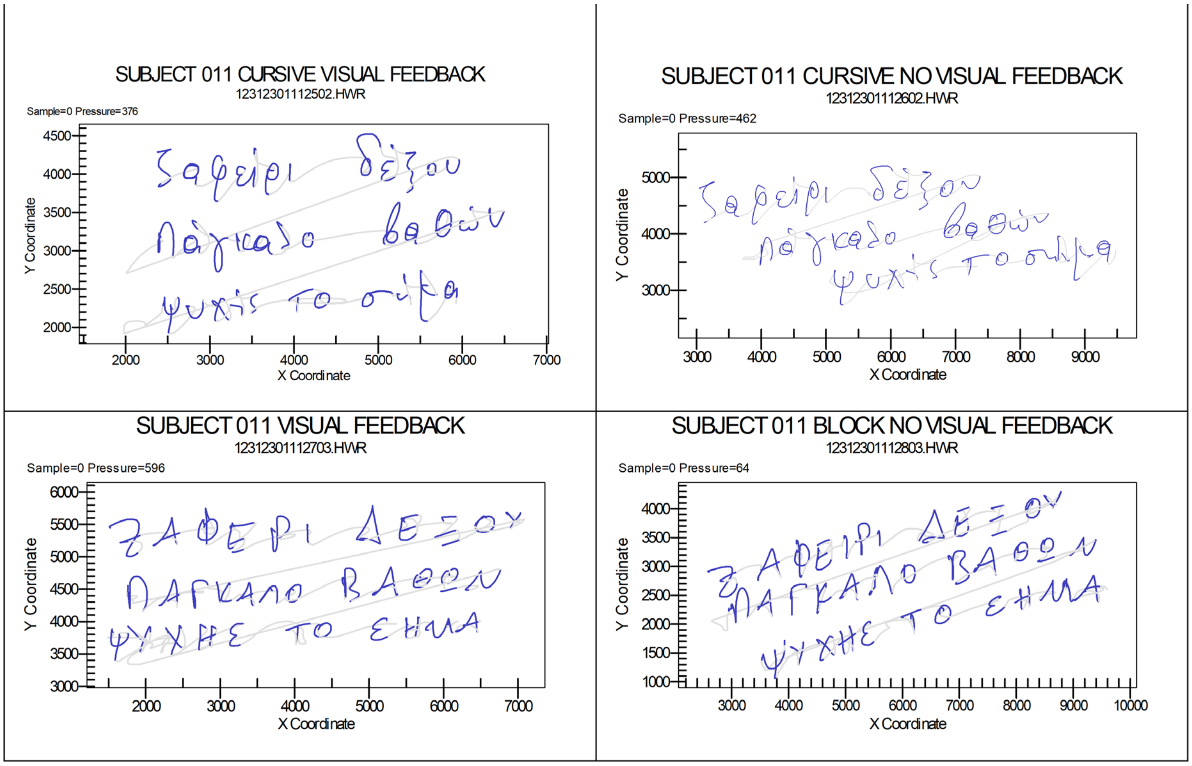

Figure 11. Uniformity of baseline alignment change in both cursive and block handwriting.

and tends to be stable, suggesting that the allograph positioning at the start of each line (and therefore the aligning with the above line) is not coincidental, but scripted in the motor program that is executed. Figure 9 shows a number of examples of stability in the positioning of subsequent lines.

It is interesting to note that the tendency of utilizing stable patterns remains even when the margin is moved towards the left of the document, as presented in Figure 10. Subject 015 is a right-handed female. No explanation related to her handedness could be proposed to answer why she positioned the margins to the left and retained this position when writing without visual feedback. Even more interesting, at the start of the third line in all the samples she places the initial letter to the right again. This complex and peculiar execution is very stable and highly individualized.

3.3.3 Third Qualitative Flag: Change of baseline alignment

Fifteen participants changed their baseline alignment to a noticeable degree in cursive handwriting

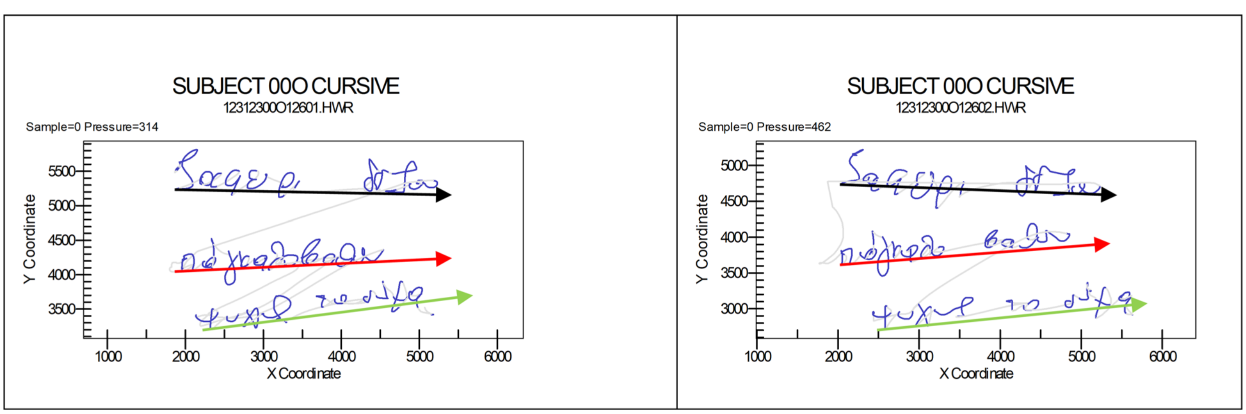

Figure 12. An example of repeatability in both conditions of an individualized baseline alignment.

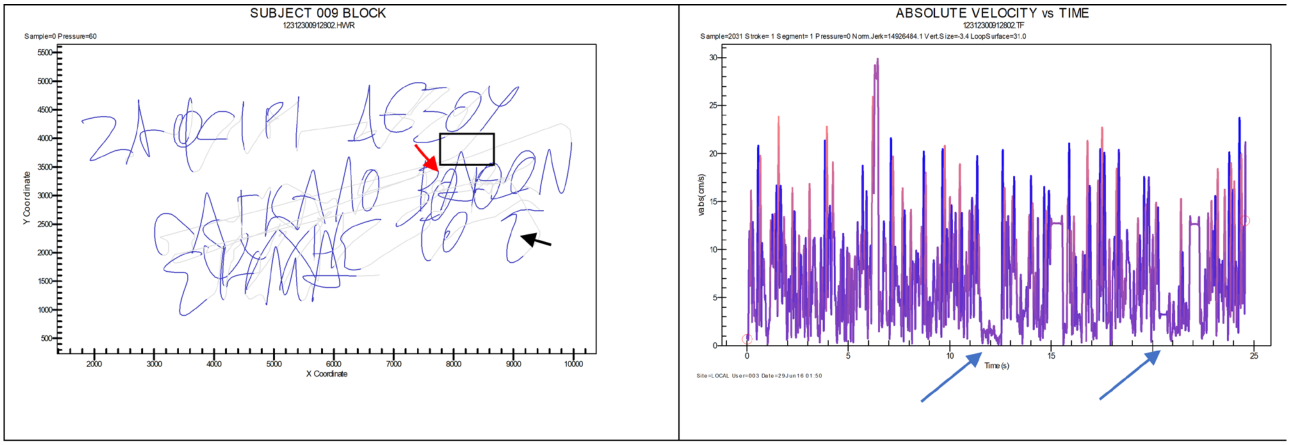

Figure 13. An example of addition of extra letters in the condition of no visual feedback.

(37.5%), and 14 participants showed a noticeable change in the baseline alignment in block handwriting (35%). The baseline alignment moved upwards in 53% of the changes in cursive and in 50% of the changes in block handwriting. In two occasions, both upward and downward baseline alignments were noticed in the same handwriting sample in block handwriting. The change of baseline alignment tends to be uniform in both cursive and block handwriting, as presented in Figure 11. Therefore, in all situations where volunteers modified the baseline alignment in both cursive and block handwriting, they tended to slant in the same direction.

The change in baseline alignment is not related to handedness. The changes tend to be replicable in most trials. This applies even in samples where complex and highly individualized baseline slant compilations appear, as is demonstrated in Figure 12, where the sample manifests three different baseline alignments, one per line. This phenomenon is replicated in each trial.

3.3.4 Fourth Qualitative Flag: Inclusion of extra trajectories

Two writers when writing cursive (5%) and six writing block (15%) inserted extra trajectories in

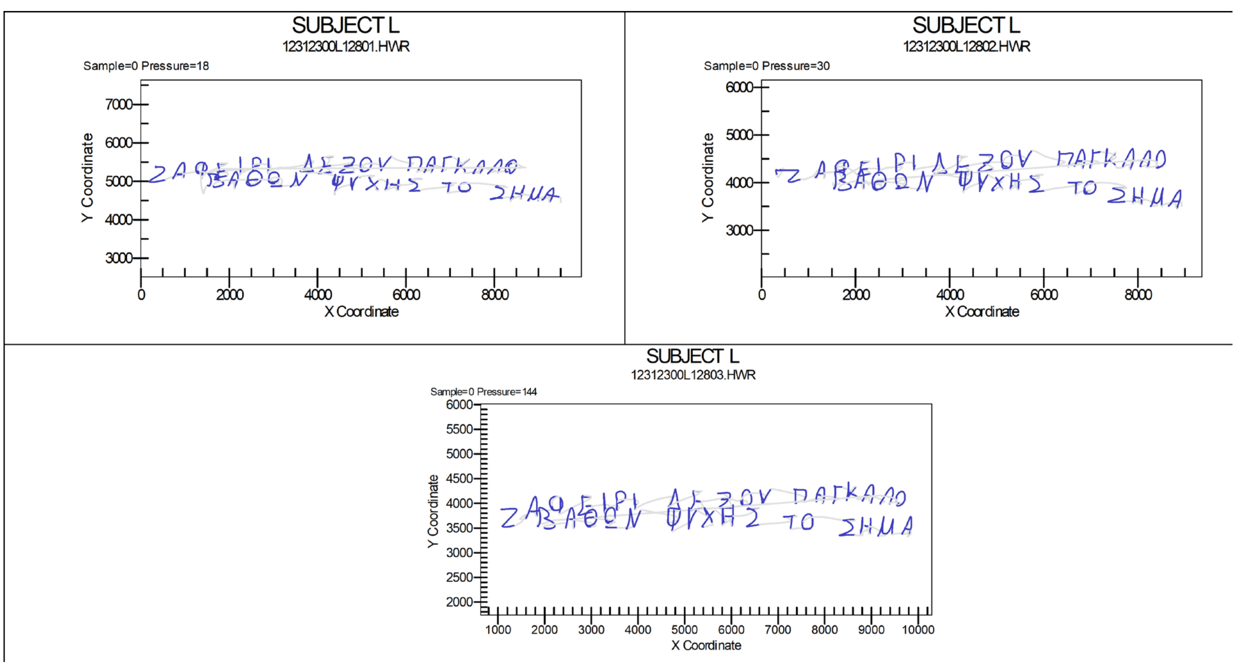

Figure 14. Duplication of a highly individualized relation of baseline alignment, intra-word alignment, and allograph positioning in three samples of block handwriting with no visual feedback.

the dictated handwriting sample. The trajectories may consist of a letter that does not belong in the executed word, a duplication of the last trajectory of the currently executed allograph or an addition to an already existing allograph. In Figure 13 we can see the inclusion of the allograph O in the block letter **ΒΑΘΩΝ** (see red arrow) and the duplication of the letter **Σ** in the word **ΣΗΜΑ** (see black arrow). The kinetic analysis shows that after the creation of the letter **O** and the first **Σ** (that is after the creation of the extra letter and before the execution of the second letter), absolute velocity drops and the writing instrument makes erratic trajectories hovering over the document. In the absolute velocity vs time graph, the time period from 11.10 sec to 12.54 sec (that is the sequence after the creation of letter O) and the time period from 20.04 sec to 20.68 (that is the sequence after the creation of the first **Σ**) shows that absolute velocity decreases (see blue arrows).

To summarize, the mechanisms that a person chooses to compensate for lack of visual feedback do not appear random, but tend to be repeated and consistent. This occurs even in instances of complex compositions of baseline alignments, overwriting, non-uniformity of margins and general design of the allographs, where this highly individualized combination is replicated in each trial. In Figure 14, the duplication of a complicated and individualized

Individual Characteristics	Mean	S.D.	t-test	r	Comments
Duration 1 - sec	18.06	3.33	0.62	---	The absence of visual feedback does not significantly influence the duration of the cursive handwriting.
Duration 2 - sec	17.92	3.24			
Vertical Size 1 - cm	-1,81	0.62	0.004	0.44	The absence of visual feedback influences significantly the vertical size of the cursive handwriting sample, since it decreases during no visual feedback.
Vertical Size 2 - cm	-2.19	0.93			
Slant 1 - rad	0.01	0.06	0.004	0.44	The absence of visual feedback influences significantly the slant of the cursive handwriting sample, since it decreases during the condition of no visual feedback.
Slan 2 - rad	-0.07	0.19			
Absolute Size 1 – cm	6.41	1.54	<0.001	0.60	The absence of visual feedback influences significantly the size of the cursive handwriting sample, since it increases during condition of no visual feedback.
Absolute Size 2 – cm	7.47	1.67			
AvAbsVelocity 1 – cm/s	3.86	0.87	0.20	---	The absence of visual feedback does not significantly influence the average absolute velocity of the cursive handwriting.
AvAbsVelocity 2 – cm/s	3.76	0.80			
Roadlength 1 - cm	68.18	13.99	0.14	---	The absence of visual feedback does not significantly influence the roadlength of the cursive handwriting.
Roadlength 2 - cm	66.21	14.91			
HorizontalSize 1 – cm	6.08	1.67	0.001	0.51	The absence of visual feedback influences significantly the slant of the cursive handwriting sample, since it increases during the condition of no visual feedback.
HorizontalSize 2 – cm	7.01	1.84			

Table 2. Presentation of the t-test results for cursive handwriting (normally distributed data).

Individual Characteristics	Mean	S.D.	Wilcoxon signed-rank test	R	Comments
AvPenPressure1 - z	137.05	39.21	<0.001	0.42	The absence of visual feedback influences significantly the pressure of the cursive handwriting sample, since it increases during no visual feedback.
AvPenPressure2 - z	151.83	33.54			

Table 3. Presentation of the Wilcoxon signed-rank test results for cursive handwriting (non-normal distributed data).

Individual Characteristics	Mean	S.D.	t-test	R	Comments
Duration 1 - sec	19.58	3.19	<0.001	0.53	The absence of visual feedback influences significantly the duration of execution of the block handwriting sample, since it increases during this condition.
Duration 2 - sec	20.59	3.58			
Vertical Size 1 – cm	-1,64	0.82	0.006	0.42	The absence of visual feedback influences significantly the vertical size of the block handwriting sample, since it decreases during during this condition.
Vertical Size 2 – cm	-2.12	0.98			
Roadlength 1 - cm	78.00	21.28	0.61	---	The absence of visual feedback does not significantly influence the roadlength of the block handwriting.
Roadlength 2 - cm	79.12	20.95			

Table 4. Presentation of the t-test results for block handwriting (normally distributed data).

relation of baseline alignment, intra- word alignment, and letter positioning is shown.

This repeatability of such complex constructions may be linked with an open loop motor program that is used to create signatures and handwriting. This motor program is not influenced at a trajectory level by the loss of visual feedback and is able to produce repeatable and legible results.

The collected raw data of the individual characteristics of duration (in seconds), absolute, horizontal and vertical size (cm), average pressure (z), road length (cm), average absolute velocity (cm/s), and slant (radians) were statistically analyzed using the statistics analysis software SPSS (Version 21). The analysis of cursive handwriting suggests that in the absence of visual feedback and average pen pressure is significantly increased as an attempt of the writer to reinforce the kinesthetic feedback received from the friction between the writing instrument and the document. The absolute and the horizontal sizes are both increased significantly in the condition of no visual feedback, while the vertical size is reduced. Slant is also changed significantly, as was suggested in the forensic comparison. Roadlength[1] does not significantly change. This is expected since, as noted in the forensic comparison, the complexity of handwriting did not fundamentally change between the two conditions, while the simplification of the letter design or the omission of letters is a rare occurrence. Table 2 shows the results of the influence of visual feedback in the individual characteristics of cursive handwriting, for normally distributed data.

The analysis of block handwriting shows that the majority of the findings are similar to those of cursive handwriting. Average pen pressure is significantly increased. The absolute and the horizontal sizes

Individual Characteristics	Mean	S.D.	Wilcoxon signed-rank test	R	Comments
AvPenPressure1 – z	400.95	106.16	0.009	0.29	The absence of visual feedback influences significantly the average pen pressure of the block handwriting sample, since it increases during this condition.
AvPenPressure2 – z	420.42	101.62			
HorizontalSize1 – cm	6.76	2.19	0.002	0.35	The absence of visual feedback influences significantly the horizontal size of the block handwriting sample, since it increases during this condition.
HorizontalSize2 – cm	7.74	1.93			
Slant 1 - rad	-0.05	0.36	0.001	0.37	The absence of visual feedback influences significantly the slant of the block handwriting sample, since it decreases during the condition of no visual feedback.
Slant 2 - rad	-0.12	0.26			
Absolute Size 1 – cm	7.27	1.58	<0.001	0.45	The absence of visual feedback influences significantly the absolute size of the block handwriting sample, since it increases during this condition.
Absolute Size 2 – cm	8.36	1.45			
AvAbsVelocity 1 – cm/s	4.01	0.99	0.036	0.23	The absence of visual feedback influences significantly the average absolute velocity of the block handwriting sample, since it decreases during this condition.
AvAbsVelocity 2 –cm/s	3.88	0.87			

Table 5. Presentation of the Wilcoxon signed-rank test results for block handwriting (non-normal distributed data).

increase significantly in condition 2, while the vertical size and slant are reduced. Duration is significantly increased while average absolute velocity is decreased, a finding that corresponds to the results for signatures. Finally, the roadlength does not change significantly. Table 4 shows the results of the influence of visual feedback in the individual characteristics of block handwriting for normally distributed data.

Educational level (above high school degree) and gender create an insignificant influence in the individual characteristics of writing produced with and without visual feedback. The findings of this study show that subjects react in the same manner to loss of visual feedback, regardless of their educational level or gender.

4. Discussion.

The combination of the above findings suggests that all types of writing (signature, cursive and block handwriting) are governed by a single major open-loop motor program, which is not significantly influenced by outside factors. No evidence was found that visual feedback is a factor that intervenes fundamentally in the procedure of allograph execution. On the contrary, both forensic and statistical evidence suggest that visual feedback is mainly linked with the inspection and the correction of the overall outcome of the handwriting process and not with the execution of each allograph. Since the lack of visual feedback decreases the ability of the writer to inspect and correct the result of the handwriting process, the final outcome may manifest a number of pictorial and kinetic distortions. However the degree of these distortions is limited and their extent is localized and minimized, so that they cannot be regarded as fundamental differences when compared to normal handwriting of the same individual.

The handwriting samples from both conditions manifest a strong body of complex and individualized similarities, with the simultaneous lack of fundamental differences, thus belonging to the same variation group. The comparative analysis suggests that gender, educational level (above high school level) and handedness have an insignificant influence on individual characteristics, strengthening the theory of an all inclusive open-loop system that is not influenced by extraneous factors. The only factor that may influence this motor program is the degree of automation in the execution of the allographs. This especially applies in frequently executed and highly skilled signatures, since in such cases larger parts of the signature are regarded as one allograph and as such, are faster retrieved and executed.

References

Caligiuri, M.P. and Mohammed, L.A. (2012). The neuroscience of handwriting. CRC Press, New York.

Dewhurst, T.N, Ballantyne, K.N. and Found, B. (2016). Empirical investigation of biometric, non-visible, intra-signature features in known and simulated signatures. Australian Journal of Forensic Sciences, 48, 659-675.

Ellen D. (2006). Scientific Examination of Documents-Methods and Techniques. CRC Press, New York.

Ellis A. W. (1982). Spelling and writing (and reading and speaking). In A.W. Ellis (ed.) Normality and pathology in cognitive functions. London Academic Press.

Evarts, E.V. and Tanji, J. Gating of motor cortex reflexes by prior instruction. Brain Research 71:479-494, 1974.Found, B. J. & Bird, C. (2016). The Modular Forensic Handwriting Method, Journal of Forensic Document Examination/Special Issue, 26, 7-62.

Found, B. J. & Bird, C. (2016). The Modular Forensic Handwriting Method, Journal of Forensic Document Examination/Special Issue, 26, 7-62.

Hilton, O. (1969). Consideration of the writer's health in identifying signatures and detecting forgery. Journal of Forensic Science, 14 (2), 157-166.

Huber, A. & Headrick, A.M. (1999). Handwriting Identification: Facts and Fundamentals. Boca Raton, CRC Press.

Johnson, B. P. Phillips, J. G. Papadopoulos, N. Fielding , J. Tonge, B. and Rinehart, N. J. (2015). Do children with autism and Asperger's disorder have difficulty controlling handwriting size? A kinematic evaluation. Research in Autism Spectrum Disorders Vol. 11, 20–26. doi:10.1016/j.rasd.2014.11.001.

Kelso, J.A.S. (ed) (1982). Human motor behavior. Hillsdale, NJ.

Ketcham, C.J. Rodriguez, T.M. and Zihlman, K.A. (2007). Targeted aiming movements are compromised in nonaffected limb of persons with stroke. Neurorehabil Neural Repair, Sep-Oct Volume? 388–397.

Marquardt, C. Gentz, W. and Mai, N. (1999). Visual control of automated handwriting movements. Exp Brain Res. 128 (1), 224-228.

Meulenbroek, R.G.J. and Van Galen, G.P. (1989). The production of connecting strokes in cursive writing: Developing co-articulation in 8 to 12 year-old children. In Plamondon, R. Suen, C.Y. and Simner, M. (Eds.), Computer recognition and human production of handwriting. Singapore: World Scientific.? – is this a second source or a continuation?

Miller, L. S. (1987). Forensic examination of arthritic impaired writings. Journal of Police Science and Administration, 15 (1), 51-55.

Mohammed, L.A, Found B., Caligiuri M. and Rogers D. (2011). The Dynamic Character of Disguise Behavior for Text-based, Mixed, and Stylized Signatures. Journal of Forensic Sciences, 56 (s1), 136- 141.

Morikiyo Y and Matsushima T. (1990). Effects of delayed visual feedback on motor control performance. Percept Motor Skills, 70 (1), 111-114.

Pantelyat, A. Freedman, R. Pawlowski, S. Kesari, A. Wilkinson, J. Duda, J. and Morley J. (2014). Quantitative Motor Assessment in Parkinson's Disease (PD) with the MovAlyzeR® Digital Writing Tablet. Neurology, 82 (10), Supplement P3.072.

Plimmer, B. Reid, P. Blagojevic, R. Crossan, A. and Brewster, S. (2011). Signing on the tactile line: A multimodal system for teaching handwriting to blind children. ACM Trans Comput-Hum, Vol. 18 (3), Article No. 17.

Sarantakos, N. (2014). Δε βυθιζω φρικτά γκλομπ ψυξης (τα πάντα γύρω από τα παντογράμματα), www.sarantakos.com/language/pantogram.htm,.

Schmidt, R.A. (1982).The Schema Concept, Chapter 9 of Human Motor Behavior: An introduction. Psychology Press; 1st Edition, Hillsdale, New Jersey

Smyth M.M. and Silvers, G. (1987). Functions of vision in the control of handwriting. Acta Psychologica, 65 (1), 47-64.

Srihari S.N., Cha S. H., Arora H. and Lee S. (2002). Individuality of handwriting. Forensic Science, 7 (4), p. 1-17.

Teulings, H.L., & Maarse, F.J. (1984). Digital recording and processing of handwriting movements. Human Movement Science, 3, 193-217.

Teulings, H.L., Thomassen A.J.W. and Maarse F.J. (1989). A description of handwriting in terms of main axes. In R. Plamondon C.Y. Suen & M. Simner (Eds) Computer recognition and human production of handwriting, World Scientific Publ. Co., Singapore, 193-211.

Van Galen, G.P., Smyth M.M. and Meulenbroek R.G.J. (1988). The monitoring of repetitive stroking patterns under visual and non-visual guidance of handwriting. In R. Plamondon, C.Y. Suen, J.-G. Deschesnes & G. Poulin (Eds.), Proceedings of the Third International Symposium on Handwriting and Computer Applications.

Endnote:

1. *Roadlength* is the pictorial characteristic of the length of the trajectory of eg a letter from its beginning to its end. It is also called *tracelength*. Roadlength is usually measured through software such as MovAlyzeR®