Effect of visual feedback on the static and kinetic individual characteristics of handwriting

By

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Declaration

I declare that while registered as a candidate for the research degree, I have not been a registered candidate or enrolled student for another award of the University or other academic institution.

I declare that no material contained in the thesis has been used in any other submission for academic award and is solely my own work.

Michael Pertsinakis

Abstract

It has been previously established that handwriting is a motor skill defined in a two-dimensional spatial domain, consisted of three major levels through which the motor units that contain the letter trajectories are retrieved from their motor memory storage and translated into a process of muscle commands via muscle adjustments. As soon as individuals start learning how to write they are introduced to a writing system common to a group of writers connected by geographic, academic, temporal, national or occupational links. As the writing ability evolves, writers distance themselves from the class system, that they were taught, develop peculiarities in handwriting and acquire personal writing characteristics, the so called individual characteristics of handwriting, which are considered the backbone of forensic handwriting identification. Handwriting is influenced by a number of genetic, physiological and biomechanical factors. Some factors can change the individual's writing so drastically that it may be impossible to make an accurate comparison of the person's normal writing with the person's abnormal writing causing serious problems for forensic document examiners. However the research regarding the visual feedback is partially contradictory regarding the degree of its influence on the individual characteristics. A two-pronged approach was designed in order to investigate the degree of this influence: Samples of signatures, cursive and block handwriting written with and without visual feedback were collected by 40 volunteers and were imported in a PC via an opaque pen tablet using an electronic inking pen. The data was stored and analyzed in a handwriting movement analysis software module specially designed for this research, that was attached in the software MovAlyzeR by Neuroscript LLC. Peer reviewed forensic comparison by a forensic document examined (FDE) between the two groups (that is the group of samples executed with normal visual feedback versus the group of samples executed without visual feedback) shows total lack of significant differences between samples of the two different conditions and the existence of a large corpus of similarities in the design and the pictorial aspect, regardless of the complexity of the samples. Focusing on the cursive and block handwriting, six traits linked to the absence of visual feedback where found: change of overall size, non uniformity of left margins, change of slant, avoidance of pen lifts, inclusion of extra trajectories and decrease of line quality. Furthermore, it was established that the absence of visual feedback by itself cannot lead a trained FDE to an erroneous conclusion. The statistical analysis shows that visual feedback significant influences the duration and average absolute velocity of the signature execution, since the signature is executed more slowly under no visual feedback. Further analysis of the cursive handwriting shows that without visual feedback there is a significant increase in absolute and horizontal size as well as average pen pressure and a decrease in slant and vertical size while in block handwriting there is a significant increase in absolute and horizontal size, average pen pressure as well as duration and a decrease in slant, average absolute velocity and vertical size. The comparative analysis suggests that the factors of gender, educational level and handedness creates an insignificant influence during the comparison of the two conditions of the researched individual characteristics, with the only notable exception of the relationship between signature duration and educational level due to automation and its results in the memory retrieval program of the allographs. 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 visual feedback -no evidence was found that visual feedback intervenes significantly in the procedure of allograph execution, but is mainly linked with the auxiliary order of macro-managing, inspection and possibly correction of the overall outcome of the combination of the above allographs.

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Abbreviations

In the text below the abbreviation “F.D.E.” stands for Forensic Document Examiner.

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Chapter 1 - The neuromuscular aspect of handwriting and its implication in the field of Forensic Handwriting Examination

1.1. Introduction

Five years ago, a document presenting the Last Will and Testament of a deceased individual was examined by the researcher after the mandate of the Court of First Instance in Heraklion, Crete, Greece. The prosecutor submitted a number of comparison documents allegedly written by the deceased, which exhibited writing structures fundamentally different to the handwriting in the questioned document. The defendants replied that the testator wrote and signed the will, while suffering from extreme opacification of the eye retina caused by cataracts, which limited severely the vision, and attributed the dissimilarities found to that factor. They also presented documents from a public hospital, which documented the existence of blindness caused by cataracts. After the conclusion of the literature review, it was evident that there was insufficient literature pertinent to the effect of visual feedback in handwriting and surprisingly the literature regarding the importance of this factor in the phenomenon of handwriting was to a large degree self-contradictory and in many instances problematical by methodological standards. Furthermore it was based more on qualitative findings and less on quantifiable data.

Using this case as a springboard, this study aims to determine whether the lack of visual feedback causes substantial and statistically significant influence in the static and kinetic individual characteristics of handwriting. Moreover it seeks to examine the degree of importance of this factor and the limitations it may cause during the forensic analysis. Finally it investigates whether the influence of the absence of visual feedback could create effects in the handwriting that may jeopardize the results of the forensic comparison and lead a forensic document examiner (FDE) to an erroneous conclusion.

The research strives to investigate the questions above in a fully quantifiable manner, removing researcher bias by a) the use of a highly acclaimed handwriting analysis software with pre-set features and b) the use of “four eye principle” peer review analysis of the forensic findings. Furthermore, the methodology described contributes to the creation of a scientific blueprint, by utilizing modern scientific principles, techniques and equipment, through which the effect of a great number of variable and invariable factors of the motor control system of handwriting can be objectively investigated.

This chapter is a general introduction to handwriting as a neuromuscular activity. It describes the modern models of graphomotor activity, the various characteristics of handwriting, the difference between class and individual characteristics and the factors that influence handwriting. An extended presentation of the influence of vision and vision impairment conditions on handwriting will take place and a literature review will follow. Finally, the research questions will be articulated.

1.2. Motor control aspect of handwriting

In this section the basic elements of the neurophysiology of handwriting, the motor control aspect of it and the hierarchy of its levels will be addressed.

The human nervous system is complex, organizing and controlling a multitude of automatic and programmed behaviors. It is divided into the Central Nervous System (CNS), consisting of the brain and the spinal cord, and the peripheral nervous system (PNS), consisting of the bundle of nerves that start from the spinal cord and run through the body (Carter, 1998; Caligiuri and Mohammed, 2012). Handwriting control involves many areas of the central and the peripheral nervous systems. In the brain three cortical regions are involved with handwriting: a) **Brodmann area 4**, which refers to the primary motor cortex of the human brain and is located in the posterior portion of the frontal lobe. Brodmann area 4 is part of the precental gyrus, b) **Brodmann area 5,** which is part of the parietal cortex in the human brain and is involved in somato-sensory processing and association and c)

Brodmann area 6, which is occupied by the premotor cortex and is located within the frontal lobe of the brain just anterior to the primary motor cortex. While not fully investigated it may play a role in planning movement, in the spatial and sensory guidance of movement, in understanding the actions of others and in using abstract rules to perform specific tasks (Jenkins et al, 2000). In Figure 1 an image of the brain is presented with Brodmann areas numbered.

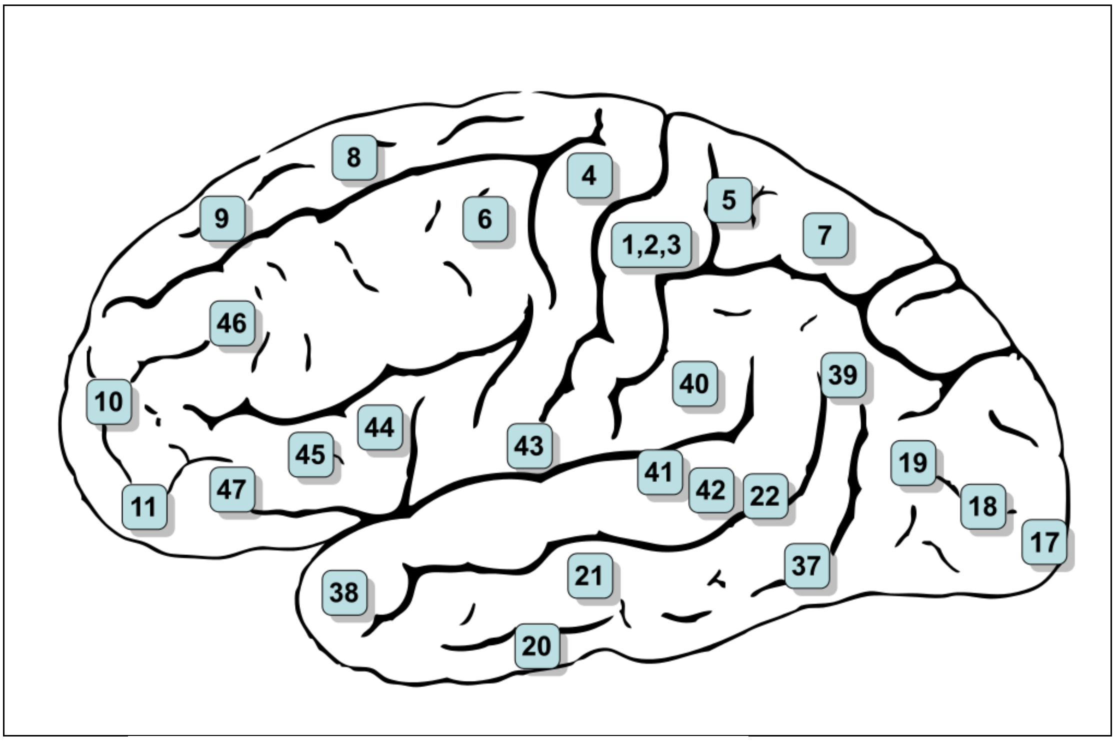


Figure 1. Image of the brain with Brodmann areas numbered.

Handwriting viewed as a motor skill is defined in a two-dimensional spatial domain. The control aspect of this skill is generated top-down from higher order, well defined and invariant linguistic representations (Teulings, 1988) whereas the more variable features are probably related to the parameters derived at the lower levels (Teulings and Schomaker, 1993). Ellis (1982) proposed a macroscopic generic model, locating handwriting and speech as two paths to a main “cognitive system”. The handwriting path is depicted as follows:

The Graphemic Buffer

Where the creation of the grapheme code takes place. A grapheme is the smallest semantically distinguishing unit in a written language, analogous to the phoneme of the spoken language. The grapheme code is then sent to

The Allographic long-term Store

Where for each grapheme a pertinent allograph is retrieved. The allograph is any graph that is a representation of a grapheme. The next station in the path is

The Allographic Buffer

Where each allograph is temporarily stored. The consequent storage of each allograph creates an allographic code, which describes the depiction of the grapheme **but not its execution.** The code is then sent to

The Graphic Motor-Pattern Store

Where the pattern of its execution is retrieved. The next point in the path is

The Graphic Motor-Pattern Buffer

Where the pattern of grapheme execution is temporarily stored until it is realized in the outer world by

The Neuro-Muscular Execution Component

Where the graphs are executed and thus manifested in the outside world.

Thomassen and Van Galen (1992) noted that the handwriting motor program is abstracted, based on the high degree of consistency in the form of an individual's script when the person is using different limbs.

Based on the above model, Teulings (1988 and 1996) describes the handwriting-motor system according to three major levels, largely equivalent to the lowest three levels of Ellis's model: the long-termed motor memory storage, the long-term memory retrieval and the translation process of muscle commands via muscle adjustments, using as a further basis the theoretical findings of van Galen (1980) and Sanders (1983), which contributed to the formalization of each of the aforementioned levels. Handwriting is not executed one element at a time but through a concurrent activation of various levels of hierarchy (Van Galen et al, 1989).

Since the understanding of this theoretical model is of paramount importance in the understanding of handwriting, especially regarding the possible influence that not controllable factors have on it, the three levels of this model will be extensively reviewed.

1.2.1. The Long-Term Motor Memory

Some kind of long-term motor memory that contains the essential information on elementary handwriting movement patterns is imperative and handwriting cannot be generated without it (Teulings, 1988). This information, that has been input via learning and experience, is used by the motor programs creating handwriting patterns. Keele(1968) defines a motor program as "*a set of muscle commands that are structured before a movement sequence begins and that allow the entire sequence to be carried out uninfluenced by peripheral feedback*" while Smidt et al (1979) describe it as "*as an abstract memory structure containing codes capable of being transformed into patterns of movement*". The information that is stored in this level is generalized, meaning that it is not represented in terms of concrete muscle contractions or joint flexions (Teulings et al 1986), has certain invariant properties and is divided into spatial, temporal and kinetic forms. While Denier van der Gon and Thuring (1965), Viviani and Terzuolo (1982) and Wing (1978) suggest that the motor programs consist mainly of temporal information, Teulings, Thomassen and van Galen (1986) confirmed experimentally what among others Morasso (1981) and Russel (1976) suggested, that is the spatial information, ie the spatial characteristics, the topological structure and the stroking sequence, that mainly populates the long-term motor memory. This information is stored as units and is retrieved in the next level. However it is debatable whether any single pattern of movement is represented in the motor memory or that this pattern is created by the combination of some motor memory units, e.g. it is highly improbable that a whole word could consist a memory unit, with the possible exception of brief, highly practiced sequences like a signature (Teulings, 1988). Therefore the best candidate of a memory unit is a single stroke, that is a movement between two successive points of high curvature, as it has been shown that "*these segmentation points can be conveniently found, by searching for relative minima of the absolute velocity as a function of time"* (Thomassen and Teulings, 1985), however complete letters can be regarded as units too (Teulings, Thomassen, van Galen,1983) depending on certain factors like the simplicity of the allograph and the experience of the writer (van Galen et al, 1988, Hulstijn and Van Galen, 1988). Therefore there is no clear-cut answer to the question "what is the unit that is stored in the long-term motor memory" since it can vary from a single stroke to a single letter and a signature.

1.2.2. The Long-Term Memory Retrieval

After selection, each aforementioned memory unit is retrieved. Experimental evidence (Sternberg et al 1978, Ellis 1982, Rosenbaum et al 1984) suggests that the movement sequence, after its retrieval and before its execution, is stored in a buffer and thus is executed as a whole after a "go signal". When this "go signal" is given, the units are transferred to the next model by groups and not individually. By that mode, the execution of handwriting is more fluid and faster, enabling cursive writing. However Thomassen and van Galen (1992) comment that since the speed of execution of each unit rarely is faster than 80 ms there is sufficient time for retrieval of each unit individually even without the aforementioned buffer.

1.2.3. Motor Adjustment Phase

In the long-term motor memory only the essential information is stored. The movement information, which is essential in the creating of the graph, is created in the motor adjustment level. Thus the size, the slant and the relative stroke duration is organized here. This peripheral level of the model is due to the neuromuscular limitations posed by the anatomical structure of the human body, e.g. the minimum time of joint or muscle contraction etc. Judging from the nature of the biomechanical structure of the human body and the multitude of its complexities, a basic description of handwriting in the biomechanical level in terms of two main axes has been proposed (Teulings, Thomassen and Maarse, 1988). These two main axes correspond to the wrist-joint and the finger-joint movements and are parallel to them, an idea which is well accepted (Denier van der Gon and Thuring, 1965, Plamondon and Lamarche, 1986). The wrist-joint axis creates fast movements with little spatial error, since it allows only two degree of freedom [dorsal/palmar flexion and ulnar/radial abduction]. The finger-joint axis is slower and manifest more spatial errors due to the fact that the thumb and index finger both possess four degrees of freedom [one for each of the two peripheral joints (flexion/extension) and two for the proximal one (flexion/extension and adduction/abduction)], while the rest of the fingers do not move independently.

1.3. Class and Individual Characteristics of Handwriting

As soon as an individual starts learning how to write they are introduced to a writing system, which is common to a group of writers connected by geographic, academic, temporal, national or occupational links. In the majority of circumstances this writing system is the copybook style that is learned in elementary school. Any introductory writing system is called a class system since it defines not an individual but a whole class of writers. The class system manifests class characteristics, aspects, elements or qualities of writing that situate a person within a group of writers, or that give a written communication a group identity (Huber and Headrick, 1999). Within geographical regions there are groups of children that learn handwriting at approximately the same period of time in identical ways and methods so that one might expect that their handwritings at that time present the characteristics of the respective copybook system they were taught and are almost identical (Al-Hadrami, 2013). Class characteristics can only be associated with a group and not with a single individual (Saferstein, 1995).A class system may be very broad or very narrow (Levinson, 2001). Figure 2 illustrates the broad class system of the copybook style that the Greek educational system taught elementary school children during 1980s versus the narrow one of the extravagant style of handwriting that the fans of extreme heavy metal use when writing the name of their favorite groups).

Class Systems	
	
Greek Copy Book Style	Black Metal Style

Figure 2. Greek copybook style handwriting versus extreme heavy metal band handwriting.

However, as the writing ability evolves and the person ages (Naider et al, 2007) , writers distance themselves from the class system that they were taught (e.g. the copybook style learned in elementary school) and develop peculiarities in handwriting and acquire personal writing characteristics, which are considered the backbone of identification (Hilton, 1992). This group of handwriting features, specific only to an individual’s handwriting, are called individual characteristics and can be defined as those discriminating elements that serve to differentiate between members within any or all groups (Huber and Headrick, 1999). Hilton (1992) defines individual characteristics as those that are highly personal or peculiar and are unlikely to occur in other instances. This individuality, he continues, rests on the very important maxim that each person has consistent handwriting, which is distinct from the handwriting of any other individual, provided that there is enough writing material present.

Vos et al (2000) mentioned that from the moment people start learning to write, they introduce deviations from the model writing system taught. The extent of these deviations increases as the writing style becomes more personalized, due to experience and practice, resulting in a style which is the product of many factors including the model system, artistic skill, perceptual ability, muscular control, nature of employment, frequency of writing and exposure to the writing of others. This individual writing style develops from childhood to adolescent years and beyond. Summarizing the above, an individual's handwriting due to aforementioned reasons deviates from the copybook style and the class characteristics that are common for all individuals of the same age, location and situation, and because of these deviations from the norm the handwriting comparison and identification is possible.

In accord with the above, Morris (2000) states that these characteristics are peculiar to the writing of a particular individual and constitute his or her writing habits. Furthermore, he stresses that these features are responsible for creating the handwriting characteristics of the writer and are used to distinguish between writings and writers.

1.4. Factors influencing handwriting

It has been established that handwriting is an individual human behavior, influenced by genetic, physiological and biomechanical factors of the human body and affected by learning processes (Hecker,1993). The combination of these factors as well as the strong interaction between handwriting process and external factors like writing surface, writing medium and overall conditions of writing defines handwriting as a unique psychomotor activity which can never be exactly duplicated by others or by the same individual. Based on the above principles lies the maxim that states that "no two writings of the same material by different individuals are identical" (Hilton, 1992).

The phenomenon of handwriting as a motor skill is influenced by numerous conditions and factors, some in the majority of times outside the control of the individual [e.g. physiological contstrains, genetic factors, handedness, medication etc]. Other variables to a certain degree controlled by the writer [e.g. imitation, mental state of the writer, fatigue]

(Huber and Headrick, 1999). Specifically, Caligiuri and Mohammed (2012) state that a number of factors like neurological diseases, psychotropic medications and aging influence the motor aspect of handwriting disrupting the procession of the aforementioned handwriting program. It has been frequently stressed (eg. Dines, 1998; Ellen,2005) that the FDE should gather as much information about the medical history of the alleged writer, their physical condition, the alleged writing stance, as well as the existence of special conditions that occurred in the environment (freezing cold, unstable surface etc) at the time the handwriting was produced. Some factors can change the individual's writing so drastically that it may be impossible to make an accurate comparison of the person's normal writing with the person's abnormal writing causing serious problems for forensic document examiners (Miller, 1987). Furthermore while any comparison material can be of some importance, the expert should always search for contemporary material written under the same circumstances, especially within periods that handwriting is unlikely to change due to aging or neuromuscular disorders (Kelly and Lindblom, 2006). Furthermore, common knowledge dictates that an expert should try to locate equivalent documents to compare, (hence the maxim “compare like to like”) for example ask for comparison material written in cheques if the disputed handwriting is written on a cheque. As Kelly and Lindblom note (2006): “*No writing prepared under such unusual conditions should be depended on exclusively for comparison with writing done under more normal circumstances, although it can often serve as a valuable supplement*”. Finally the experts should be cautious in relying mainly on genuine comparison material produced before the alleged date of the sample under inspection, to minimize the risk of self-disguised comparison material.

A graphic example of how certain factors can change the signature of an individual has to do with the signature that Guy Fawkes, a member of the Gunpowder Plot in 1605, placed in a confession document right after the end of torture session at the hands of his captives (Fraser, 2003). The comparison of this signature with the group of his normal signatures cannot lead to any scientific conclusion, since there are too few common elements to be compared. Therefore the FDE would note that there is a large number of differences, but being unable to attribute them and recognizing that the questioned signature (the signature after the torture) is not written under normal circumstances, due to the high level of tremor and low line quality, cannot render any conclusion that either connects or disengages these two signatures that are presented in Figure 3.

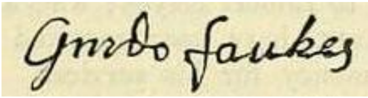
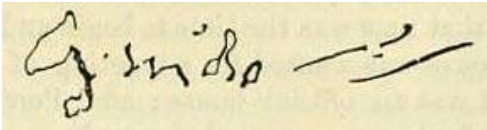
	
Natural signature of Guy Fawkes	Signature of Guy Fawkes after torture

Figure 3. Comparison between a natural signature of Guy Fawkes written under normal circumstances and a signature after a session of torture.

Shrihari et al (2002) report several factors that may influence handwriting: age, ethnicity, handedness, the system of handwriting learned, the content of the text written, the writing protocol (that is written from memory, dictated or copied out), the writing instrument, the nature and the material of the document and changes in the handwriting of the writer over time. Bradley (1986) points to several factors, for instance the writer's emotions, motivations, perceptual abilities, physiology, intellectual development, muscle, skeletal and nervous system. Koppenhaver (2007) added that mental illness, emotional states, moods and physical handicaps are also factors that may influence handwriting. Furthermore, Baxter (1966) noted that a person may deliberately change their handwriting to some extent. However, Huber and Headrick (1999) emphasized that different factors can influence different people in a different manner and they compiled an impressive list with controllable and not controllable variables. For an understanding of this concept the most important of these variables are discussed below, while an extended section regarding the health related factors that influence handwriting afterwards is given in par. 1.5.

1.4.1. The controllable variables of handwriting

As controllable factors are regarded those that the writer control to some extent and has adopted by choice (Huber and Headrick 1999). The basis of these factors are the following:

1. Imitation. In order to illustrate this factor, the music calligraphy of Johann Sebastian Bach and Anna Magdalena Bach comes to mind (Jarvis, 2010), which due to imitation from his wife "...*for a long time Anna Madgalena's manuscripts were mistaken for autographs..*.". Furthermore, Hecker (1993) presents the changes in handwriting that a young German girl presented after she was influenced by the so called black-power movement in USA. As a result of that fixation certain features of her handwriting characteristics changed in order to mimic the class characteristic of the ghettos areas in USA, as illustrated in Figure 4.

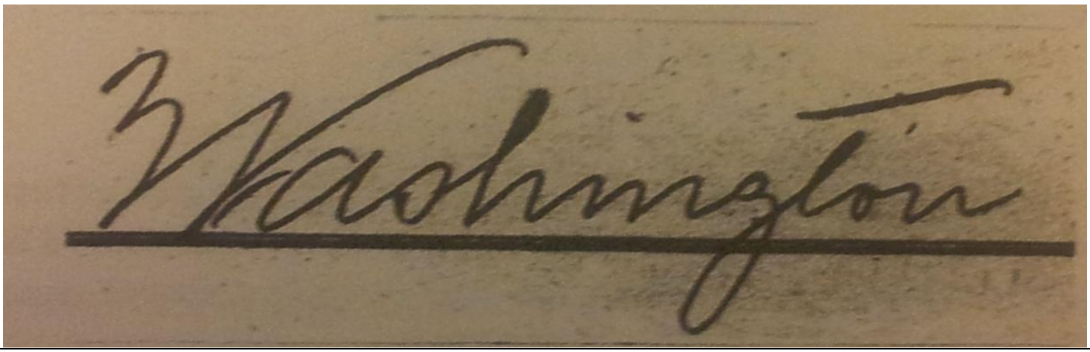


Figure 4. The "Black W" or "3-W", written on an envelope received from Brazil.

2. Circumstantial variables: These are factors that vary according to the circumstances of the execution of writing. There are six major circumstantial factors underlined: the writing medium (Masson, 1985; Masson, 1992; Goonetilleke et al, 2008), writing posture (Grant, 1974, Bradley, 1986), writing space (Bey and Ryan, 1998), writing surface and support (Totty, 1981) and writing environment (Huber and Headrick, 1999).

3. Induced states of the writer: These are variables that relate to the effect of alcohol, drugs, pharmaceuticals, hypnosis, fatigue and physical stress (concentration) on handwriting (McNally, 1974; Kelly and Lindblom, 2006 ; Koppenhaver, 2007).

B. The not controllable variables influencing handwriting

Not controllable factors are regarded these that are not normally under the control of the writer. These factors are:

1.The class system the writer used (Huber and Headrick, 1999): As Osborn noted (1929) “Through all these changes (that a person’s writing undergoes) the original system will to some extent visibly protrude”. These class systems can be classified as national, cultural and occupational and influence heavily the characteristics of the handwriting. Turnbul et al (2010) investigated the class characteristics of Polish people writing in English aiming to identify class characteristics that distinguish Polish handwriting from English handwriting. Cheng et al in 2005 researched the English handwriting of three main racial groups in Singapore and Katsaridou (2009) investigated the class characteristics of the English handwriting of Greek people. These studies aimed to identify common class characteristics based on nationalities and to investigate the possibility of identifying the geographical origin in which the writer was taught to write.

2. The mental state of the writer: States like emotional stress, nervousness and mental instability can have an effect on the handwriting by influencing the fluency of its execution (Girouard, 1986).

3. Senility and Infirmity: During the senility phase of the writer, the handwriting degenerates, writing tremor manifests and the line quality is reduced (Hilton, 1969; Rosenblum and Livneh-Zirinski, 2008 et al). Kelly and Lindblom (2006) mentioned that

advanced age could cause greater variations in handwriting as it is generally accompanied with declined health.

4.Medication: Medication has been suggested as the cause of changes in writing (Gilmour and Bradford, 1987). Taking as an example Haase's investigation of the relationship between the therapeutic response to an neurological agent and the handwriting changes that are produced (1961), five major handwriting changes were suggested: stiffening, cramping, size reduction, a lessening of slant and shakiness. Further researches (Hart, 1985 ; Glogowaski et al, 1963) also suggested that the medication is an influential factor.

5.Genetic reasons: The possibility of writing similarity due to genetic relationship has been suggested (Stevens, 1964; Munch, 1987; Gamble, 1978), although the findings are not yet conclusive.

6. Organically related illnesses: A large corpus of literature regarding the effect of illnesses, such as Alzheimer's disease (Schroetter et al, 2003; Balestrino et al, 2012), arthritis (Miller, 1987), celebral palsy (Beacom, 1968; Bumin and Kavak, 2010), multiple sclerosis (Wellingham-Jones, 1991; Rosenblum and Weiss, 2010) and Parkinson's disease (Morrish et al, 1996; Bryant et al, 2010), in handwriting has been built the last 50 years.

1.5. Physiological constraints as not controllable factors influencing handwriting, focusing on the writing of visually impaired individuals.

Physiological factors can significantly affect handwriting. Miller (1987) refers to a list of such factors: *"injuries and deformities directed to the phalanges, metacarpals and arm, and arm of the writing hand; diseases and injuries affecting muscles, ligaments and joints of the writing hand…."*. Furthermore it is stated (Hilton, 1969) that such physiological constraints may alter the handwriting so much that any accurate comparison between the normal and the abnormal handwriting is impossible. Harrison (1958) notes that the loss of muscular control may render a signature unrecognizable and urges the expert when faced a signature which allegedly was written in such extreme conditions to search for contemporary material. However he doesn't specify which physiological factors affect which characteristics of the handwriting.

It is a common ground that while the majority of experts have the unshakeable belief that physiological factors can create a huge deterioration in the handwriting, the literature can sometimes be very vague. Eg. Morris (2000) simply states that "*Some temporary impediments may affect writing more than permanent ones, but it depends upon the writer and the nature of the temporary impediment*."

Focusing further on the subject of the handwriting of visually impaired individuals it must be noted that the vision is linked with the notion of visual acuity, that is the acuteness or clarity of vision, which is dependent upon optical and neural factors. The most prominent of these are (i) the sharpness of the retinal focus within the eye, (ii) the intactness and functioning of the retina, and (iii) the sensitivity of the interpretative faculty of the brain (Cline et al, 1997). If an individual manifests a low score of visual acuity, their vision is compromised (this will be discussed further in the next chapter). The loss of visual acuity can be caused by disorders such as myopia, congenital blindness, hyperopia, optic atrophy, retinitis pimentosa, glaucoma, macular degeneration (Duane, 1989), retinal degeneration, albinism, cataracts (Pertsinakis et al, 2010), muscular problems that result in visual disturbances, corneal disorders, diabetic retinopathy, congenital disorders, and infection as well as caused by brain and nerve disorders.

From a forensic aspect, it is suggested (Huber and Headrick, 1999) that the principal disadvantage of a visual impaired writer is the lack or partial loss of feedback information. This in turn restricts the writer from using references as to the form, length and location of strokes and causes the manifestation of the following characteristics (Dines, 1998; Lindblom, 1983; Walton, 1997; Plimmer et al, 2011):

- High probability of manifestation of "square writing" with flattened letter bases since such type of letters are generally more easily constructed than the curved ones. The size of the letters may be increased.
- Difficulty of maintaining a constant baseline and avoiding merging lines of writing, which can cause an increase in vertical spacing between lines of writing or present intersections with other writings of printed materials.
- Considerable amount of retracing and overwriting.
- Inconsistency of spacing between letters and words.
- Manifestation of hesitation marks at the beginning of letters.
- Lack of fluency and appearance of writing tremor due to hesitation and decreased speed of execution.
- Stunting of letter designs, especially the upper and lower loops.
- Avoidance of pen lifts, which can lead to possible absence of "i", "j" etc dots as well as the hyphenation marks, "t" crossings etc.
- The degree of the impairment is analogous to the degree of the manifestation of the above characteristics. The less severe the impairment, the greater the chance is that the handwriting will not display features indicative of visual impairment.
- Abnormal handwriting.
- Poor control of the number of stroke repetitions or letter repetitions (Lebrun & Rubio, 1972).
- Connecting strokes are more sensitive to withdrawal of visual feedback (Meulenbroek & Van Galen, 1989).

However, there has not been any common opinion about consistent characteristics that can be associated with vision impairment of any particular origin or nature. Lindblom (1983) notes that "*Although some research has been done which considers the handwriting of the blind, there is little that deals with various levels of visual impairment.*" Huber and Headrick (1999) point to the critical distinction that the characteristics of handwriting may diverge to a certain extent depending on whether the loss of eye sight took place before or after the person learned to write and note that a well practiced signature will retain its best quality even if the vision is lost, especially if the impairment took place after writing automation was established.

1.6. The hypothesis of the limited need of visual feedback

It is noted that a large number of forensic researchers focus on the handwriting of the blind (Todd, 1965), the various aids designed to help visually impaired writers and the comparison procedure when the questioned document is allegedly written by a writer with compromised visual feedback (Beacom, 1967; Bleuschke, 1968; Lindblom 1983; Morgan and Zilly ,1991). However, an ongoing debate in the field of graphonomics is focused on whether sensory feedback is necessary in the execution of a learned motor task. Scientists mainly from the field of cognitive psychology theorize (Keele and Summers, 1976) that the aforementioned handwriting motor system is an open loop system, [i.e. a system that encloses rapid movement sequences which can be executed without feedback], resulting from an abstract motor program. Therefore *"…the performance of handwriting is largely independent upon internal and external feedback"* [both visual and proprioceptive feedback] (Teulings, 1988), as well as friction, gravity, inertia, instructed speed, size of the allographs, muscles and limbs involved (Teulings, 1996). Ellis (1982) , whose model was discussed in section 1.2., included open feedback loops, and Glencross (1977) suggested that since kinesthetic feedback requires approximately a 100 ms delay, feedback processing is unlikely due to the very small time of execution of the strokes. This time-delay theory has been challenged however by Evarts and Tanji (1974) who suggest that the sensory-motor feedback loop could have a delay of less than 50 ms. Keele and Summers (1976) present another argument in favor of the open loop motor control while observing deafferentiated experimental monkeys, who no longer had access to peripheral vision, and however were able to execute learned movement sequences in a relative normal pattern. This suggests that learned movement sequences may be encoded in a motor program as a series of movement units encoded without the need of peripheral feedback, while any kinesthetic feedback has at a maximum a limited role in the monitoring for corrective actions. Agreeing with the above Van Garner et al (1988) and Smyth and Silvers (1987) proposed that a) visual feedback plays a monitoring role mainly in the multistroke level, but less during the level of execution of a single stroke and b) the speed of writing seems little affected by the absence of visual feedback, while Schomaker, Thomassen,and Teulings (1989) suggest that visual feedback monitors, in fact, only the baseline and lineation levels. Agreeing with the above Marquardt et al (1999) concurs that a distortion of visual feedback does not directly slow down open-loop movements to allow control of the motor output in a closed-loop mode. 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). It is suggested (Van Doorn and Keuss, 1992) that the withdrawal of vision does not impair the handwriting in a noticeable manner. This is based on two hypotheses. The first is that vision is not needed during the act of writing. Micro-analyses should then reveal that spatial as well as temporal writing features are identical in conditions of vision and no vision. Alternatively, it is possible that vision is needed during the act of writing, but that without visual feedback possible errors and inaccuracies have to be prevented by other means. Assuming that the latter would place an extra demand on movement control, this should be revealed by an increase in processing time. Later experiments (Van Doorn and Keuss, 1993) suggested that as a result of the lack of visual feedback the production of a letter took more time and resulted in larger letter trajectories. Furthermore, under no vision movement time and trajectory size of acceleration and deceleration phases of a stroke movement increased. However, these findings are not unanimous. 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. Furthermore, Teulings, Contreras-Vidal, Stelmach and Adler (1997) in their research regarding the correlation between visual feedback and Parkinson micrographia stated that while the elderly controls seemed to make little use of visual feedback, the patients with Parkinson's disease rely on the visual feedback of previous or of ongoing strokes to program subsequent strokes and thus this recursive feedback may play a part in the progressive reductions in handwriting size found in Parkinsonian micrographia. The last finding is backed up also by Ondo and Satija (2007), who noticed that in the "off" medicine group of the parkinsonian patients, eye closure increased the writing length by 14.0 +/- 10.1% ($P < 0.05$) from a mean of 69.1 to 77.7 mm [range -14% to +73%]. Finally, the examination of the handwriting performance in the absence of visual control in writer's cramp patients, their level of automatization is not impaired (Chakarov et al, 2006).

On the other hand other researchers maximize the importance of visual feedback: Skillful use of the hand under visual guidance is an integral part of handwriting, suggesting that the extent of the eye's guidance differentiates spontaneous scribble from skilled imitation of symbols (Kellogg, 1969). Arter et al (1996) state that visual feedback is needed for the execution of handwriting and therefore errors will occur on the condition of its absence. In agreement with them, Benbow (1995) states that “In manuscript writing the hand's output depends almost entirely upon the input and ongoing guidance of the visual system” while Camhill and Case-Smith (1996) state that skillful use of the hand under visual guidance is an integral part of handwriting. Slavin et al (1996) noticed different degrees of the effect of visual feedback according to the age of the writer. Van Galen et al (1989) suggest that lack of visual feedback reduces the speed of handwriting and attribute it to the notion that visual monitoring in handwriting “is especially relevant to the clearance of the memory buffer.”

Focusing on the pictorial aspect of handwriting, Morikiyo and Matsushima (1990), in their research about the effects of delayed visual feedback on motor control performance found that the most frequent kinds of error were the type of insertion of line elements or letter duplication and the fact that the size of written letters increased with lengthening delays of visual feedback. Lovelace and Aikens (1990) noticed that while writing with their eyes shut, the volunteers have a tendency to increase the size of the letters. Furthermore the orientation with the document was lost. However they concluded that the visual analysis showed no consisted discrimination of writing based on the presence or the absence of visual input while writing, regardless of the age of the writer and they justified these findings by suggesting that the handwriting performance without visual feedback can be kinesthetically controlled and thus skilled motor activity of handwriting appears to require little visual guidance at any age. Any age-related decline in the accuracy of hand movements made in the absence of visual guidance would appear to be small in magnitude, occur very late in life, and perhaps to be related to decline of health or to memory components of the task.

Summarizing the above, a proposal arises that each individual stroke is lightly influenced (if at all) by visual feedback, which is later utilized mainly in order to monitor the spatial correlation of the strokes and their positions. However this proposition is still debatable (Caliuguri and Mohammed, 2012). Keele and Summers (1976) even went to the extent to support that feedback plays a limited role in the ongoing error monitoring for corrective actions, a rather bold statement, that was challenged by Abbs and Winstein

(1990) and van Galen and Weber (1998), stressing the rich variability and adaptivity both in speech and handwriting execution.

1.7. Critical Review of Literature

On a preliminary level, the contradictory nature of the above findings is apparent. From the one side a part of the literature supports that vision and its loss influences handwriting in a gradual but important way, while other findings suggest that handwriting is a closed system and therefore the existence or lack of outside factors is mostly irrelevant. The last findings also contradict the common belief of many FDEs, who perceive the influence of visual feedback as of potentially great importance: One of the first questions that an expert ask the mandates is whether the alleged writer suffered from any eye disease at the time of the writing of the last will and testament and as stated above FDEs strive to gather contemporary comparison material, which will be affected by the same visual factors. Furthermore, the theory of limited effect contradicts the common understanding and the "scientific gut feeling" that vision and handwriting are two intertwined phenomena and that the visual feedback is essential for monitoring the creation of handwriting motor control system. The experimental part of the thesis examines both sides of the argument and whether behind this apparent difference, there is a common ground. Furthermore, there is no consensus to which individual characteristic is affected, if any, and if the extent of these changes could limit the conclusions of the expert or even contribute to an erroneous conclusion.

The planning and writing of this thesis used literature focused on the following aspects:

<u>1.7.1. The basic principles and scientific advances in the fields of Forensic Document Examination.</u>

While “standing on the shoulders of these giants”, the contemporary researcher has the opportunity to re-examine the fundamentals in a more mature manner. It is a rewarding experience to see the budding of the relatively new science of forensic document examination from its first steps (Osborn, 1929; Harrison, 1958), how it was forged through its biggest challenges and trials – as they where iconized by the cumulative decisions of the U.S. Supreme Court in Daubert, Joiner and Kumho Tire during the 90s (known collectively as the Daubert Trilogy) (Kelly and Lindblom, 2006)- and how it emerged as a fully peer-reviewed discipline (Huber and Headrick, 1999; Hecker, 2000; Köller, Nissen, Rieß & Sadorf, 2004).

<u>1.7.2. Methodology of forensic research on medical patients in general, focused on visually impaired patients</u>.

The methodology used by other researchers while investigating the relation between handwriting and other medical conditions, such as arthritis, Alzheimer’s, Parkinson’s was reviewed. The aim was to critically appraise the proposed methodology regarding the volunteer inclusion criteria, the methods of comparison and the manner of expressing the level of differentiation, if any, between the samples. Its findings are already discussed.

A further important point that often emerges in forensic research is the matter of writing maturity and the automation of handwriting that this creates (Dines, 1998). A well practiced signature, especially a symbolic one with few if any stops of the writing medium, that possesses a high line quality, may supply little evidence of the nature or the extent of any visual impairment, particularly if the vision loss occurred long after writing habits had been established. In order to investigate the possible effects of loss of visual feedback, methods should be devised that overcome the interference of automation in the process of handwriting.

However, apart from these general notions, the exact quantification of the consequences of this loss/lack of vision on the individual characteristics of handwriting and how this can lead to erroneous conclusions in a forensic report has not been addressed as is summarized by Huber and Headrick (1999) "Writings of the individual **may acquire** attributes easily confused with symptoms of spurious writing" pinpointing the possibility of danger of an erroneous conclusion in a forensic report, which could lead to a false verdict of the court. It must be always stressed that forensic science is the application of empirical science in the service of the Law and therefore assists the court to render a correct decision and as such, its importance lies not on a theoretical basis but on its sheer power to claim an individual guilty or not. From the roots of graphology –a primitive semi-science that evolved to forensic document examination- erroneous findings that resulted erroneous court decisions still plague the reputation of the forensic discipline. For example Vasilios Zisiadis, a known legalist in Greece states (1993) among other things: "The forensic document expert rarely can attest, even with a relative certainty, about the genuineness of a signature or a document." and in a footnote he continues "The forensic handwriting report was the cause of the legal error against the French captain Dreyfus". It is sad to see such statements being published in the most prominent legal publishing house in Greece and it is very easy to utterly demolish such accusations by the sheer weight of modern peer-reviewed evidence (Found and Rogers, 2003): a large number of forensic handwriting validation studies have been published (Kam et al, 1997; Found et al, 1999; Kam et al, 2001; Sita et al, 2002) which provide statistical support of the proposition that the expertise is demonstrable. Furthermore, the New Zealand Police Document Examination Section engaged further detailed studies (Found et al, 2001). Currently, a large number of organizations are providing a series of blind trials and collaborative exercises (e.g. the annual ENFHEX collaborative exercise for European laboratories of forensic document examinations) where the experts work on monitored cases. Finally, the hypothesis that there is no difference between trained FDEs and lay people in the examination of writing samples has been clearly confuted (Kam et al, 1994.)Thus it is necessary that forensic scientists should strengthen the methodology of their research to fend off the multitude of attackers.

1.7.3. Findings of neurosciences, graphonomics and cognitive psychology regarding the relationship between vision and writing.

As stated in section 1.6. the relation between vision and the temporal and spatial control of handwriting is well investigated in the field of cognitive psychology. However, in the majority of such papers, it is noticeable that the “similarities” or “differences” are claimed as such by non FDEs. However when facing a questioned writing sample the layman faces two big methodological issues. Firstly they cannot distinguish between similarity and difference. This focuses mainly on their inability to compare non obvious elements like inter-allograph ratio. On the other hand even if they correctly pinpoint a difference, they are not scientifically equipped with the knowledge and experience to declare that this difference is significant and therefore the specimen is forged, the difference is accidental or that in fact it is not a difference at all but an until now unseen natural but genuine variation. This gets much worse in research regarding impaired vision since they have to deal with abnormal writing. Therefore it is necessary that the results of such research should be reviewed by a forensic document expert, who is the only certifiably competent person to distinguish between the similarity and the significant difference. However, in a large number of papers reviewed the researchers have no forensic background nor did they cooperate with a forensic document expert so, even if their efforts are commendable, their findings can be sometimes easily disputed.

In a summary, the critical appraisal of the existing literature stresses the following:

- The need of a scientific inclusion protocol of the possible participants is paramount, through which a thorough isolation of any potential contamination will take place.
- The study of automation of handwriting and how it may affect the investigation of a specific factor.
- The need for thorough comparison based on a correct scientific methodology, which is based on a peer reviewed, quantifiable methodology. For this research a two pronged analysis was designed based on a) a qualitative peer reviewed analysis based upon the "four eye principle" of the Forensic Document Examination Discipline and b) a a quantitative and statistical analysis with the use of movement analysis software with pre-set settings (see chapter 3).

1.8. Research Question and Goals

Literature review shows the multitude of factors that may influence handwriting. However specifically regarding visual impairment and the loss of visual feedback the suggestions were contradictory and inconclusive. Furthermore the required quantification of findings is lacking. The present research aims to show whether visual feedback does not significantly change the static and kinetic individual characteristics of handwriting (null hypothesis) or that it does to a significant degree (alternate hypothesis). Providing that the alternative hypothesis is correct the research further aims a) to pinpoint the individual characteristics that are affected by the absence of visual feedback, b) to proceed to comparative analysis based on gender, handedness and education level and c) to investigate whether the absence of visual feedback could jeopardize the results of the comparison done by an FDE and lead to an erroneous conclusion. Furthermore it strives to present a methodology that provides a variety of details as well as secures the validity of the findings and could be used as a blueprint to further forensic research in the future.

Chapter 2 - Vision, Human Eye and Visual Feedback

2.1. Introduction to the human eye and the crystalline lens

The human eye has as a primary goal to allow vision and can distinguish up to 10 million colors (Judd, Deane B.; Wyszecki, Günter, 1975). Its further auxiliary goals are to effect the adjustment of the size of the pupil, to regulate the hormone melatonin and to entrain the body clock and the circadian rhythms (Zimmer, Carl,2012). This highly sophisticated organ offers an almost 180 degree vision (95° away from the nose, 75° downward, 60° toward the nose, and 60° upward) which raises to almost 270 degrees when we take into consideration the eyeball rotation of about 90° (Seedhouse, 2015).

Three transparent layers constitute the human eye, which enclose a transparent structure. The outmost layer is named fibrous tunic and consists of the cornea and sclera. The cornea is the smaller segment of this layer and is circa 8 mm in radius. It is fused on the sclera, the larger segment, which is circa 12 mm in radius. These two segments are connected with the circular shaped limbus. The term "corneosclera" is often used to describe this region (Dorland, 2011). The iris and the pupil are situated beneath cornea and are evident on casual inspection, because of the transparency of the cornea (Gold, D.H. ; Lewis R. 2002) . The middle layer is called vascular tunic and consists of the choroid, the ciliary body, and the iris. Finally, the innermost layer is the retina, which gets its circulation from the vessels of the choroid as well as the retinal vessels (Gold, D.H. ; Lewis R. 2002). Inside these three layers lies the aqueous humour, a gelatinous plasma-like fluid, the vitreous body, which fills the space between the lens and the retina, and the flexible crystalline lens. The three layers of the human eye and the aqueous humour are presented in Figure 5.

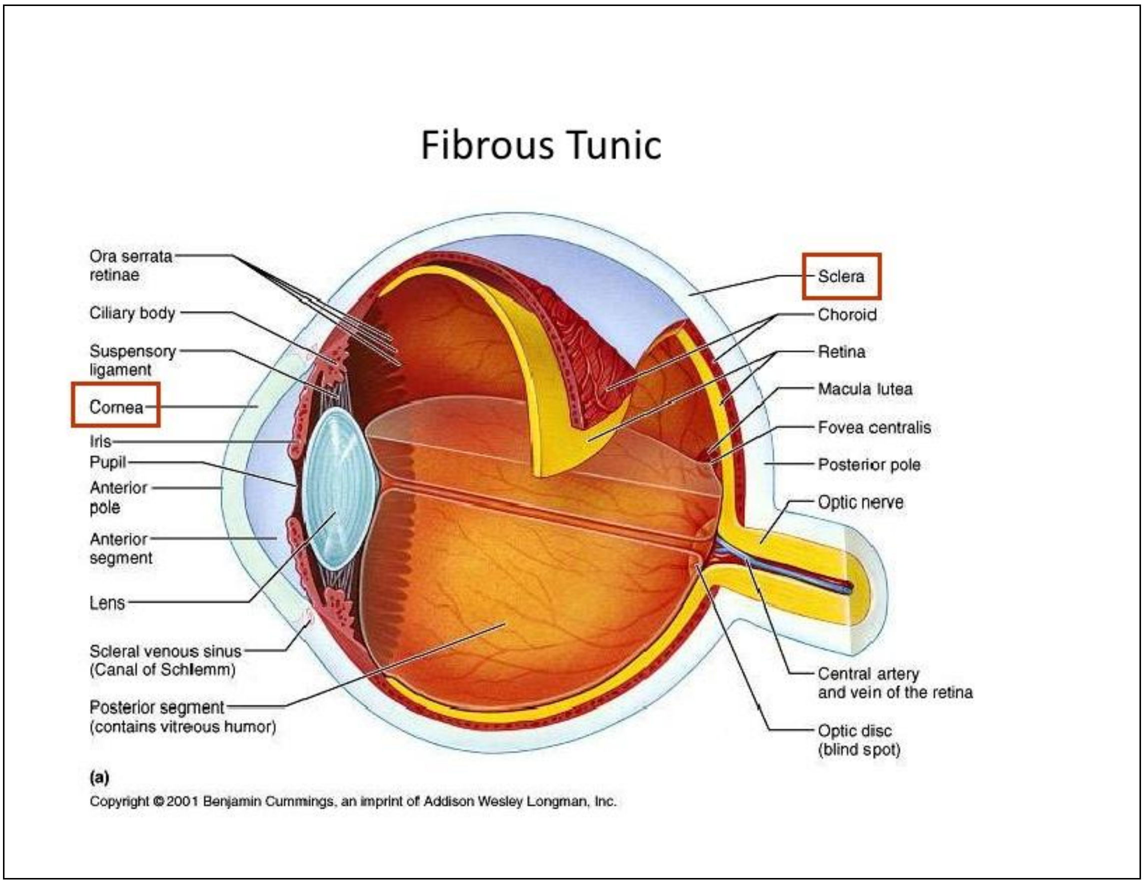


Figure 5.The three layers of the human eye and the aqueous humour.

The lens is part of the anterior segment of the eye, where the iris is also located, which regulates the amount of light entering into the eye. The lens is suspended in place by the suspensory ligament, a ring of fibrous tissue that attaches to the lens at its equator and connects it to the ciliary body (Forrester J, Dick A, McMenamin P, Lee W,1996). Posterior to the lens is the vitreous body, which bathes it along with the aqueous humor.

The healthy lens is a transparent, biconvex structure. Its primary function is to transmit the incident light and to focus it on the retina, providing the eye with a focusing refracting power of 20+ diopters [diopter is the unit of measurement of the optical power of a lens, that is of the degree to which a lens converges or diverges light](Slamovits, 1993). The lens has an ellipsoid, biconvex shape, while the anterior surface is less curved than the posterior (Duker, Myron. Yanoff, J. S., 2008). Details of the human lens are presented in Figure 6.

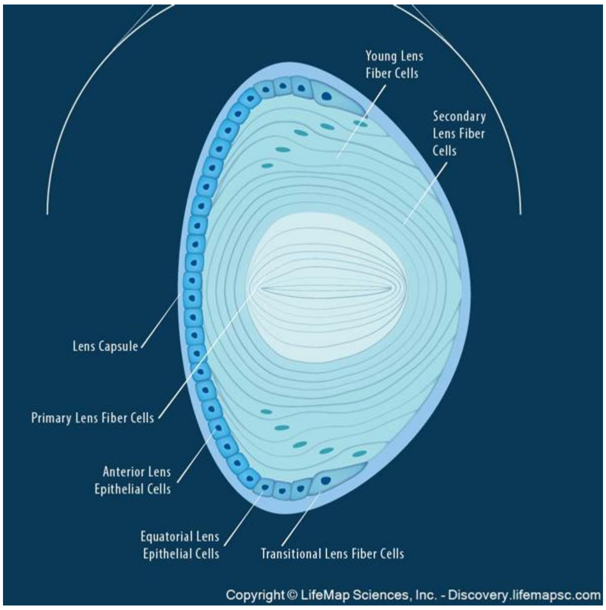


Figure 6. Details of the human lens.

The lens regulates the focal distance of the eye so that it can focus on objects at various distances, thus allowing a real image of the object seen to be formed on the retina, and therefore its work is similar to the focusing of a photographic camera – a procedure called "accommodation" (Watson, 2012). Accommodation is achieved by the alteration of the shape of the lens, due to the action of the zonular layer, a ring of fibers connecting the ciliary body with the lens. The shape of the lens can alter much more easily during childhood while it becomes less mutable with age, while after circa the 40th year of a person's life, the mutability is radically declined. In Figure 7 the details of accommodation are presented: In cases where distant vision is desired the ciliary muscles are relaxed and the crystalline lens is on minimum strength, since the parallel light rays from a distant object don't require as much refraction as those from a close object.

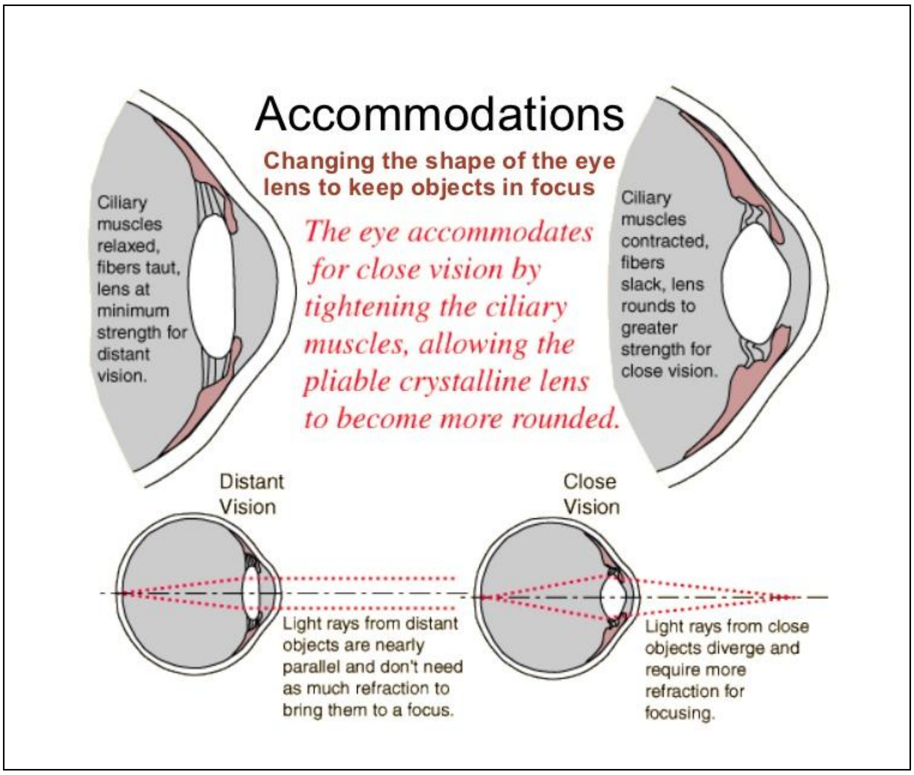


Figure 7. Details of the procedure of accommodation of the human lens

Another utility of the lens is to block the majority of ultraviolet light in a wavelength of 300-400 nm, thus defending the retina from potential harm - it is interesting to note that people suffering from aphakia, that is missing a lens, allegedly can see ultraviolet light as whitish blue or whitish-violet (David (Hambling D,2002). The lens is composed over 90% by the water-soluble proteins called crystallins (Hoehenwarter, Klose and Jungblut R., 2006) and the great majority located are α-, β-, and γ-crystallins, a distinction based on the order they elute from a gel filtration chromatography column (De Jong, Hendriks, Mulders, bloemendal, 1989). They are vital for maintaining the index of refraction of the lens and of its transparency, due to the high-molecular weight aggregates that gather in the lens fibers (Andley, 2006). On the other hand, the absence of mitochondria and other light-scattering organelles in the lens fiber is also important for keeping the transparency of the lens.

The lens has three main parts: the lens capsule, the lens epithelium, and the lens fibers. The lens itself lacks nerves, blood vessels, or connective tissue (Duker and Yanoff 2008). Figure 8 presents a schematic diagram of the lens and its major parts.

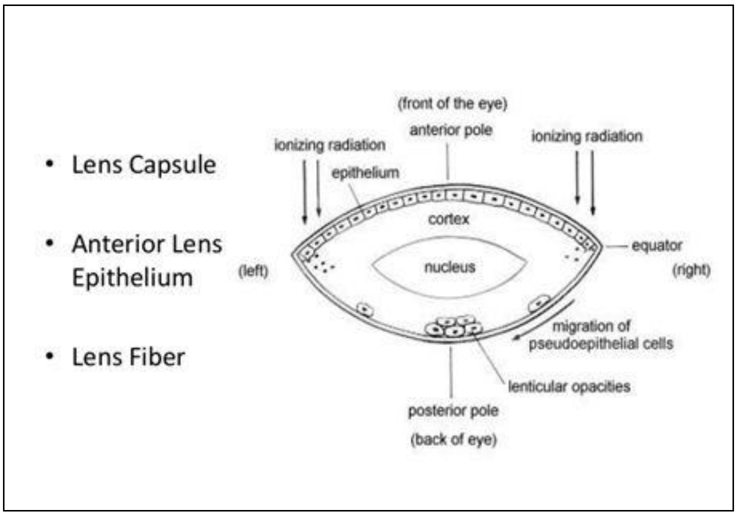


Figure 8. Structure of the human lens.

The lens Capsule is a smooth transparent viscous membrane consisted of IV-type collagen and sulfated glycosaminoglycans (GAG), which spread over the cells of the epithelium and surround the lens (Forrester, Dick, McMenamin and Lee, 1996). Inside the capsule the lensic materials are easily altered during the accommodation procedure. Its frontal side is far thicker than the back, since accommodation utilizes the frontal side far more, and overall varies from 2 to 28 mm in thickness, being thicker in the equator (Forrester, Dick , McMenamin and Lee. 1996). The outer layer of the capsule is connected with the fibers of zonular layer, a ring of fibers connecting the ciliary body with the lens, which are very important in the alteration of the lens during the accommodation phase.

Anterior to the capsule, located before the lens fibers, lies the simple cuboidal lens epithelium (Forrester, Dick , McMenamin and Lee. 1996). Its cells, found only on the anterior side of the lens, are metabolically active and able to interact to all the major cellular activities, including DNA biosynthesis, protein and lipid synthesis of RNA, ATP creation . Furthermore, its cells are able to create new lens fibers (Candia, 2004), which are added to the outer cortex.

The lens fibers, summarily referred to as laminae, stretching from the posterior to the anterior poles, form the bulk of the lens. They are long, thin, transparent cells, firmly packed, with diameters typically 4–7 micrometres and lengths of up to 12 mm (Forrester, Dick , McMenamin and Lee. 1996) kept together via interdigitations and gap junctions of the cells that resemble "ball and socket" forms.

2.2. Visual System – the eye-brain circuit

The main purpose of the visual system is to provide with the capability of processing visual images by the interpretation of the information carried by visual light to build a three dimensional interpretation of the world. As such, the visual system is a highly evolved and complex mechanism, able to form monocular three dimensional representations from a pair of two dimensional projections, to identify objects and shapes, to measure distances and navigate the body in relation with the outer world (Hubel, 1995) .

In the hierarchical order of the information processing (Dragoi, 1997), the visual system consists of the eye, which receives photons traveling from the object through the lens and projects them inversely on to the retina, which in turn sends the data, now turned into an electrical signal by the "photoreceptor" cells, to the corresponding optic nerve with a bandwidth of about 8960 kilobits per second. For comparison, it is stated that guinea pig retinas transfer at about 875 kilobits per second (Reilly, 2006). Visual perception, human's ability to interpret the environment through the information that is contained in the visible light, begins when light lands on the retina and turns into an electric signal by the aforementioned photoreceptor cells (Rodiek, 1988). These cells are divided into two types, rods and cones, named for their shape. Cones are concentrated in the central area of the retina, called “fovea” (Carter, 1998) and are responsible for high acuity tasks like writing and for color identification. Rods are responsible mainly for the night vision and are located into the peripheral regions of the eye. Figure 9 shows a representation of both types of receptor cells.

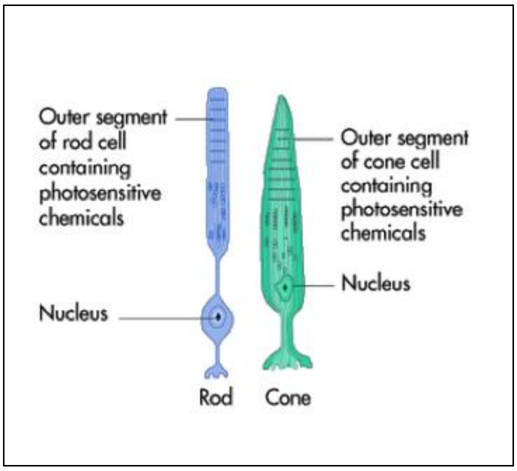


Figure 9. Schematic representation of the photoreceptor cells

The two optic nerves partially cross at a part of the brain called optic chiasm. Information from the right visual field travels in the left optic tract while information from the left visual field travels in the right optic tract. Each optic tract terminates in the lateral geniculate nucleus (LGN) in the thalamus, deep in the center of the brain. The LGN separates visual inputs into parallel streams, one containing color and fine structure, and the other containing contrast and motion. From there the optical information travels to the visual cortex of the brain through a number of axons and neurons called summarily optic radiation. One optic radiation exists in each brain hemisphere. The visual cortex exists in the celebral cortex , above the cerebellum, and is responsible for processing the received visual information (Carter, 1998). It consists of Brodman areas 17, 18 and 19 (see again Figure 1). Both hemispheres of a brain possess a visual cortex- the left hemisphere visual cortex receives signals from the right eye while the right visual cortex from the left. The final part of this process is called the visual association cortex and it is suggested that its main purpose is the recognition and memory of visual objects (Carter, 1998).

The organization of both celebral cortex and visual association cortex is very tangled at birth, due to the hypertrophy of connections of neurons that are separated by experience, into definite columns, therefore the reduction and not the increase of connections improve the infant's visual ability. Experience also plays a major role in the fine-tuning of color perception, face and object recognition as well as the motional and spatial understanding (Banks and Salapatek, 1978 ; Bushnell, 2001).

2.3. Visual Feedback in the context of this research.

When the eye-brain circuit functions normally and the writers are unobstructed by environmental and situational factors (limited light, bizarre writing position, freedom of neck movement in order to point the eyes towards the document etc), they have "normal visual feedback", that is they receive pictorial information regarding the execution of the trajectory, the allograph and finally the whole handwriting sample in real time. On the other hand when there is a severe break in the chain between the executed trajectory, the eye and the brain then the writers have no visual feedback, which in turn means that they receive no real time information about the stroke executions. These breaks can be among others environmental, situational and physiological.

2.3.1. Environmental Constrains of Visual Feedback

The lack of adequate luminosity is the main environmental constrain of visual feedback, since the visual system is based on the reception of photons, which travel from the object and reach the eye. Further environmental constraint can be extreme fog, smoke or in general the existence of any such element on the environment that denies photons' ability to reach the lens.

2.3.2. Situational Constrains

In order for the photons to travel successfully to the lens, the object that emits them should be in the line of sight of the spectator and the eyes of the spectator should be unobstructed. Therefore, a blindfold destroys visual feedback as well as the positioning of the document at a radiant that the human vision cannot reach.

2.3.3. Physiological Constraints

A person's ability to see is linked with Visual Acuity, a term that presents and measures clarity of vision. Visual acuity is linked with physiological factors that influence the optical and neural factors of the eye-brain circuit, e.g. the sharpness of the retinal focus, the sensitivity of the brain faculty or the health of the retina (Cline, Hofstetter and Griffin, 1997). Most common reasons of low visual acuity are myopia, hyperopia, astigmatism, ametropia, detached retina, macular degeneration and cataract (Pavan, 1990; Young, 1991; Livingston, Carson, Taylor, 1995) . If visual acuity is low enough the person is termed legally blind. E.g. the 42 U.S.C. § 416(i)(1)(B) (Supp. IV 1986) .[1] U.S.A. federal statute defines blindness as such: *"[T]he term "blindness" means central visual acuity of 20/200 or less in the better eye with the use of a correcting lens. An eye that is accompanied by a limitation in the fields of vision such that the widest diameter of the visual field subtends an angle no greater than 20 degrees shall be considered for purposes in this paragraph as having a central visual acuity of 20/200 or less."*).

Chapter 3 - Materials and Methods

3.1. Introduction

This chapter describes the methodology of the experiment, its participants, the method used for collecting the handwriting and signature samples and the materials and procedures of the analysis. The specific characteristics under comparison are presented. Finally presentation of the two-pronged analysis will be given.

3.2. Participants

Twenty (20) females and twenty (20) males participated, ranging in age between 22 and 65. All volunteers were Greek citizens, residing in various locations of Greece, while the majority of them was recruited from the island of Crete at the south region of Greece. All participants were proficient in Greek cursive and block writing. The volunteers possessed an educational level spanning from medium (High School diploma) to very high (PhD). Volunteers of lower education were excluded and therefore partial illiteracy as a factor that may influence handwriting was eliminated. All the subjects were healthy and suffered no ailments that might influence handwriting. Before the experiment, the volunteers completed a questionnaire written in Greek language regarding their age, location, gender, health condition, handedness and education level in order to control for factors that may influence handwriting. Table 1 shows the demographic characteristics of the volunteers.

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	

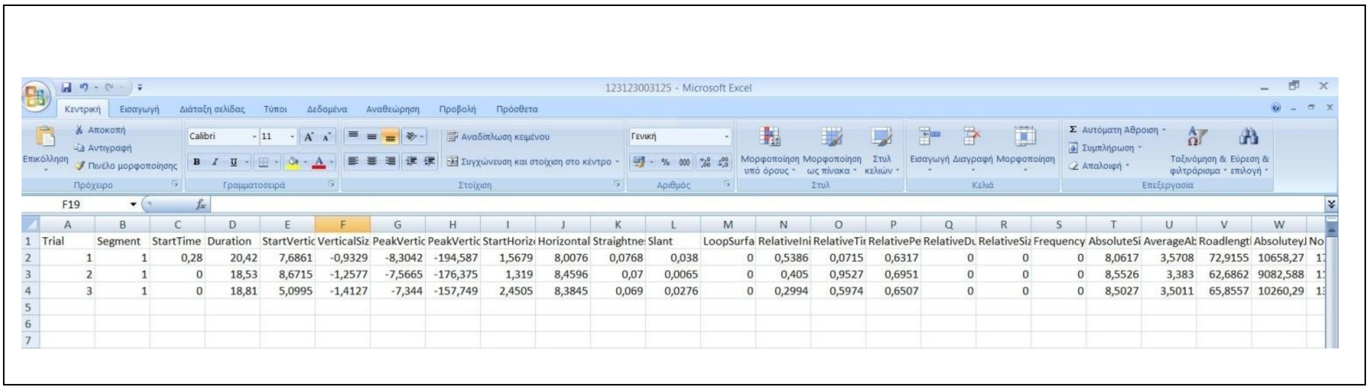
Table 1. Demographic Characteristics of the Volunteers

The screening procedure secured that controllable and not controllable factors that may influence handwriting were eliminated.

The informed consent procedure was approved by institutional Ethics Commission. Participants gave written permission that their specimens of signatures and handwriting will be anonymously used for research, presentations and publications.

3.3. Equipment

The participants wrote on an unlined sheet of paper placed on top of a opaque pen tablet (Wacom Graphire CTE-440 with accuracy 0.01 cm and sampling rate 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 was executed using NeuroScript’s MovAlyzeR handwriting movement software (Version 6.1.). All specimens were analyzed by NeuroScript MovAlyzeR handwriting analysis software, which was selected among other recording software packages, because of its higher functionality, scientific documentation, statistical capabilities, detailed measurement and ability to record and analyze dynamic characteristics such as duration and velocity (e.g., Pantelyat et al, 2014**;** Johnson et al, 2015; Ketcham and Rodriguez 2007; Mohammed et al, 2010). Furthermore MovAlyzeR software exports the data per segment to MS Excel. In Figure 10 part of the segmented findings of the three handwriting samples of Condition 3 of Subject 003 -(cursive handwriting with visual feedback) is shown. Each row lists the data of one sample (called trial). Each column lists one characteristic.



Trial	Segment	StartTime	Duration	StartVertic	VerticalSiz	PeakVertic	PeakVertic	StartHoriz	Horizontal	Straightne	Slant	LoopSurfa	RelativeIni	RelativeTi	RelativePe	RelativeDu	RelativeSiz	Frequency	AbsoluteSi	AverageAb	Roadlengt	AbsoluteyJ	No
1	1	0,28	20,42	7,6861	-0,9329	-8,3042	-194,587	1,5679	8,0076	0,0768	0,038	0	0,5386	0,0715	0,6317	0	0	0	8,0617	3,5708	72,9155	10658,27	[illegible]
2	1	0	18,53	8,6715	-1,2577	-7,5665	-176,375	1,319	8,4596	0,07	0,0065	0	0,405	0,9527	0,6951	0	0	0	8,5526	3,383	62,6862	9082,588	[illegible]
3	1	0	18,81	5,0995	-1,4127	-7,344	-157,749	2,4505	8,3845	0,069	0,0276	0	0,2994	0,5974	0,6507	0	0	0	8,5027	3,5011	65,8557	10260,29	[illegible]

Figure 10. Presentation of the segmented findings of the three handwriting samples of Condition 3 of Subject 003 -(cursive handwriting with visual feedback) in movement analysis MovAlyzeR software.

Using the MovAlyzeR software as a platform, the specific module "Evaluating the Influence of Visual Feedback" was designed and imported.

3.4. Procedure

The volunteers were asked to produce handwriting under the following conditions. The trials were blocked per condition while the sequence of conditions was randomized per participant:

1: <u>Cursive writing with normal visual feedback</u>. The volunteers wrote a Greek "pangram", a sentence that includes all letters of the Greek language ("ζαφειρι δεξου παγκαλο βαθων ψυχης το σημα" [Receive this beautiful gem, which signifies the deepest sentiments of my heart]) in <u>cursive</u> while vision was unobstructed (3 trials).

2: <u>Cursive writing without visual feedback</u>. The volunteers wrote the same pangram in <u>cursive</u> while vision was obstructed using a blindfold. The blindfold was placed by the volunteers before the execution of each trial and was temporarily removed afterwards. The researcher made sure that the blindfold was completely covering the vision and obscured light. The volunteer was instructed to start writing in the central left part of the tablet, while after each trial, the sheet of paper was dragged higher up the tablet to create more empty space (3 trials).

3: Block printing with normal visual feedback. The volunteers wrote the same pangram in block print (3 trials).

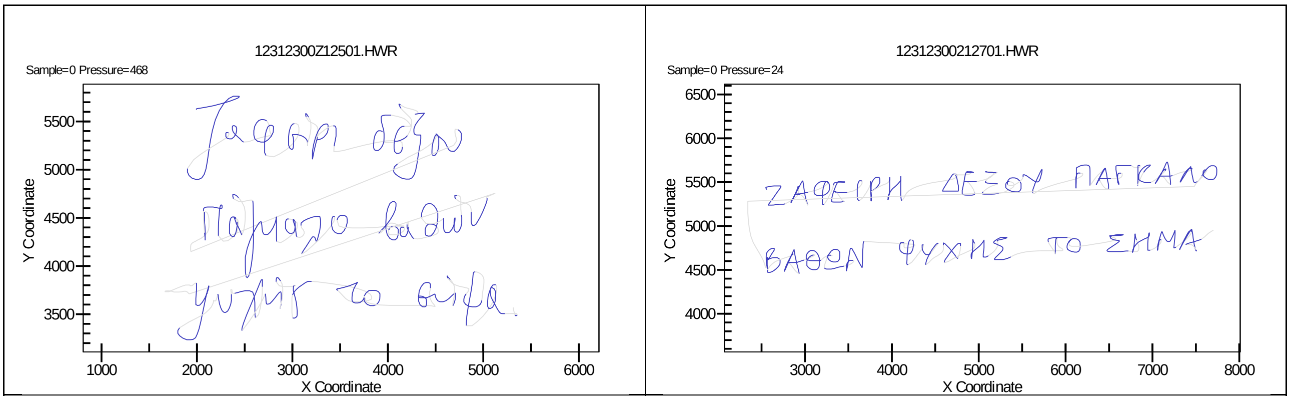
4: Block printing without visual feedback. The volunteers wrote the same pangram in block print while vision was obstructed using a blindfold (3 trials).

5: Signature placing with normal visual feedback. The volunteers were asked to place their own signature that they use in their day to day activities, be it a symbolic, a holographic or a mixed type signature, that is a signature consisted only of non-alphabetic trajectories, of letters or a mixed type which combines non-alphabetic trajectories and letters (10 trials).

6: Signature placing without visual feedback. The volunteers placed their own signature while vision was obstructed using a blindfold (10 trials).

Before the execution of the experiment, each volunteer was familiarized with the concept of the experiment by the experimenter. They were asked to take tests using the tablet and the electronic pen, while they placed their signature and wrote the pangram both with and without visual feedback. Special care was taken so that the volunteers would become familiarized with the pangram both in its cursive and block form. As soon as the volunteers were ready, the experiment was started. Each trial started by a single audio cue. The same tone sounded when the volunteer finished the trial and lifted the electronic pen for more than 2 seconds. 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 write at their normal speed, using their habitual writing stance and pencil grip, while seated comfortably in a quiet environment with plenty of light. The text, which was already memorized by them, was also dictated at them in a speed that matched their writing speed. The pangram enables the researcher to cover the full spectrum of Greek alphabet, in cursive and block letters, as well to examine the interword and interlinear distances and is one of the shortest known such sentence (Sarantakos, 2014). Figure 11 presents 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.



Cursive handwriting	Block handwriting

Figure 11. The dictated pangram written in cursive and in block letters

The experimenter monitored the course of the experiment and the pen movements in real time. His task was double: to survey the volunteer while executing the trial and monitor each progress through the computer screen. As a mnemonic help a popup window emerged at the computer screen at the beginning of each condition, which describes it. Furthermore, at each trial, a very brief description of the current condition was displayed at the top of the screen. The volunteers could not see the computer screen and they solely focused on the sheet of paper, that was placed on the pen tablet, and the directions of the experimenter. The position of the tablet and the document, the grip of the inked pen and the position of the pc monitor is shown in Figure 12.

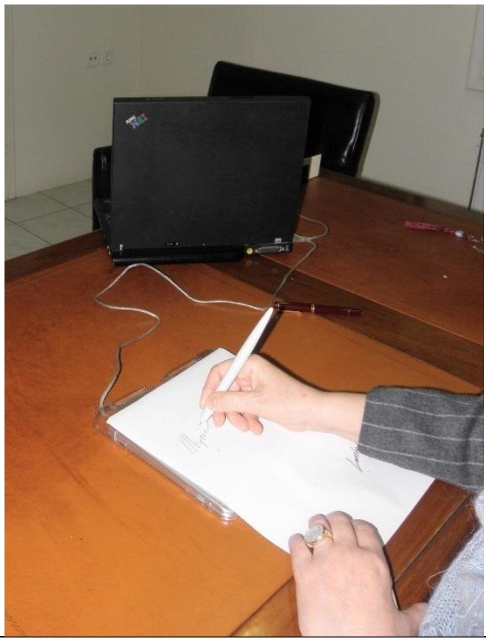
	
A general view of the experiment procedure is presented. Note that the participant has no visual interaction with the pc monitor.	A closer look at the opaque tablet, the writing pen and the paper, on which signature samples are collected.

Figure 12. The position of the tablet and the document, the grip of the inked pen and the position of the pc monitor.

The samples were written in unlined A4 pages in order to give the volunteer the freedom to utilize the habitual size of handwriting and signature and to avoid any possible influence that a lined paper would impose. The choice of ballpoint pen cartridge was made since the stereoscopic examination of stroke direction, striation lines and pictorial characteristics of ball point pen is executed with higher degree of certainty than the examination of strokes executed by other kind of pens (eg felt tip pens or gel pens) (Ellen,2005).

To avoid any researcher's bias the software settings were set during the creation of the experiment and they were not changed during the whole period of sample collection. The parameters used are presented for repeatability reasons:

- The entire trial was regarded as one stroke.
- A last segment was added at any rate.
- The segmentation method of each trial was according to the default settings of the software.

After importing the samples via the tablet a bottom-up analysis took place, starting from each trial, moving to each condition of one subject and concluding to each condition of all subjects:

a) At a preliminary stage each sample was inspected for possible discontinuities, failed importing or simply errors by the subject. For all the discontinuities found, a stereoscopic examination of the sheet of paper took place (using a 10-power magnifier by Regula Batlija Ltd) to investigate possible differences between the writing and the imported data. In such cases both raw and pictorial data were examined. In cases where one trial was created erroneously (e.g. the writer did not finish the sentence) that trial was rerecorded. In summary , at the end of this phase, it was ensured that all imported trials represented fully each sample that the subjects had given.

b) At this stage the consistency of the trials of each condition was examined. In order to do so each trial of a certain condition was compared to the other trials of the same condition. The comparison was pictorial as well as dynamic focusing mainly on the elements of duration, absolute average velocity and pressure. The aim of the comparison was to investigate abnormalities in the spectrum of all trials in each condition. The flagging method for locating such abnormalities used was to investigate significant departures from the natural variations of each trial.

c) When the two above stages were completed, it was certain that the imported samples were consistent and correctly imported. After this, the comparison between selected quantifiable characteristics of the paired conditions took place:

- Condition 1 (C1) -Cursive Writing with Normal Visual Feedback was compared to Condition 2 (C2) -Cursive Writing with Absence of Visual Feedback.

- Condition 3 (C3) -Block Writing with Normal Visual Feedback was compared to Condition 4 (C4) -Block Writing with Absence of Visual Feedback.
- Condition 5 (C5) -Signature with Normal Visual Feedback was compared to Condition 6 (C6) -Signature with Absence of Visual Feedback.

Out of the 6 aforementioned conditions, 3 pairs of comparison were created. On each pair the object of comparison is the same (that is cursive writing, signature or block writing), differentiated by the existence or not of visual feedback. Table 2 (page 71) presents each one of the paired conditions.

3.5. Individual Characteristics under comparison

A comprehensive list of the individual characteristics that were examined, compared and analyzed in this research is presented below.

3.5.1. Static individual characteristics: Due to the nature of forensic examination –that is examining handwriting samples already executed on the document under inspection- the FDEs rarely have the opportunity to examine and analyze the kinetic aspect of the questioned handwriting or signature and mainly focus on the pictorial/static aspect as is described by the traces of ink (or any other writing substance eg carbon, pencil, blood etc) on the document. By examination of the static individual characteristics only limited and qualitative analysis of the kinetic aspects is possible: e.g. the pressure of the writing medium can be described as light or heavy, the speed of execution as fast or slow etc, however the experts examining a static document cannot reach quantitative results regarding the characteristics of the writing sample, e.g. the total duration of the execution, the average absolute velocity etc.

The static individual characteristics that will be examined are:

3.5.1.1. General design of the allographs: This characteristic is related to the general form of an allograph, focusing mainly on the similarity between loops, starting and finishing strokes, angles and curves of the compared samples. This demands a breakdown of the inspected allographs to their fundamental parts, which in turn will be compared. As always, comparison is possible only between comparable allographs. Figure 13 shows specimens taken from the handwriting of eight persons to show the variations in the general design of the common word "the" (Harrison, 1958).

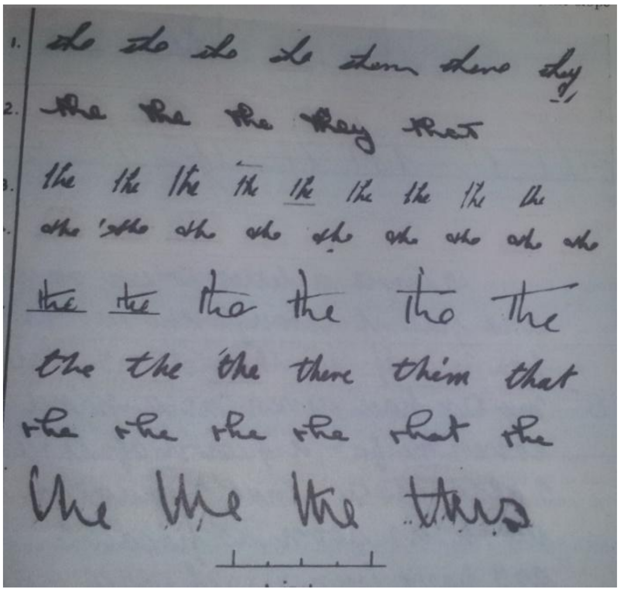


Figure 13. Specimens from the handwriting of eight persons, show the variations in the general design of the common word "the".

3.5.1.2. Line Quality: Line quality is a complex qualitative characteristic that describes the ability of a writer to control the steadiness of their strokes (Dines, 2000). Line quality spans in a spectrum starting from high line quality (smooth, fluent writing) to low quality (erratic-tremorous writing). The importance of this characteristic has been stated by W.R. Harrison (1958): *"It is this defective line quality, only appreciated to the full when visual comparison is* *made with that of a genuine signature, which is one of the most revealing characteristics of forgery...".* Figure 14 illustrates the difference in Line Quality between Writer No.1 (higher line quality, albeit still medium) and No.2 (lower line quality) (Morris, 2000).

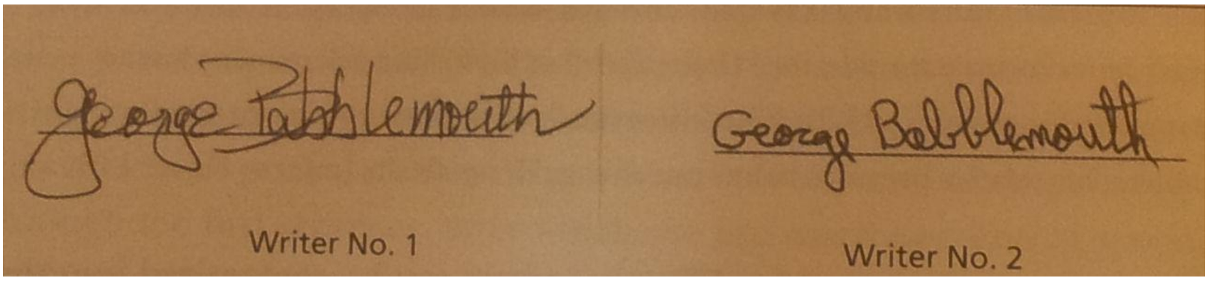


Figure 14. Differences in the level of Line Quality

3.5.1.3. <u>Size of allographs and its sub-elements of horizontal extensions, vertical extensions, road length and intra-allograph ratio</u>: In the literature a number of terms like dimensions, ratios and sizes have been proposed (Huber&Headrick, 1999). This characteristic relates to the absolute size of the vertical and horizontal dimension as well as whether the ratio of the size of the parts which comprise the writing sample has changed [inter allograph ratio]. By examining the three sub elements (horizontal extensions, vertical extensions and intra-allograph ratio) of the characteristic of Size, the researcher can measure and compare absolute characteristics, eg lateral expansions of height, as well as relative characteristics such as ratios/proportions, relative heights etc.

Vertical size is the vertical vector difference between the beginning and the end of a stroke, horizontal size is the horizontal vector difference between the beginning and the end of a stroke and absolute size is the size of a stroke calculated from the vertical and the horizontal sizes in cms. Vertical, Horizontal and Absolute size are pictorial characteristics that can be examined and measured easily from the ink traces on the document. Their pictorial nature and the fact that they can easily be measured –on the contrary to roadlength, which even if it is a pictorial characteristic requires a precision instrument to be exactly measured- positions them as one of the main individual general characteristics that the expert examines during the forensic comparison.

Road length is the length of a writing sample from the beginning to its end, following its trajectory. It is calculated by summing the distances between all consecutive samples or pixels. Figure 15 illustrates the Vertical, Horizontal and Absolute Size as well as the Road length.

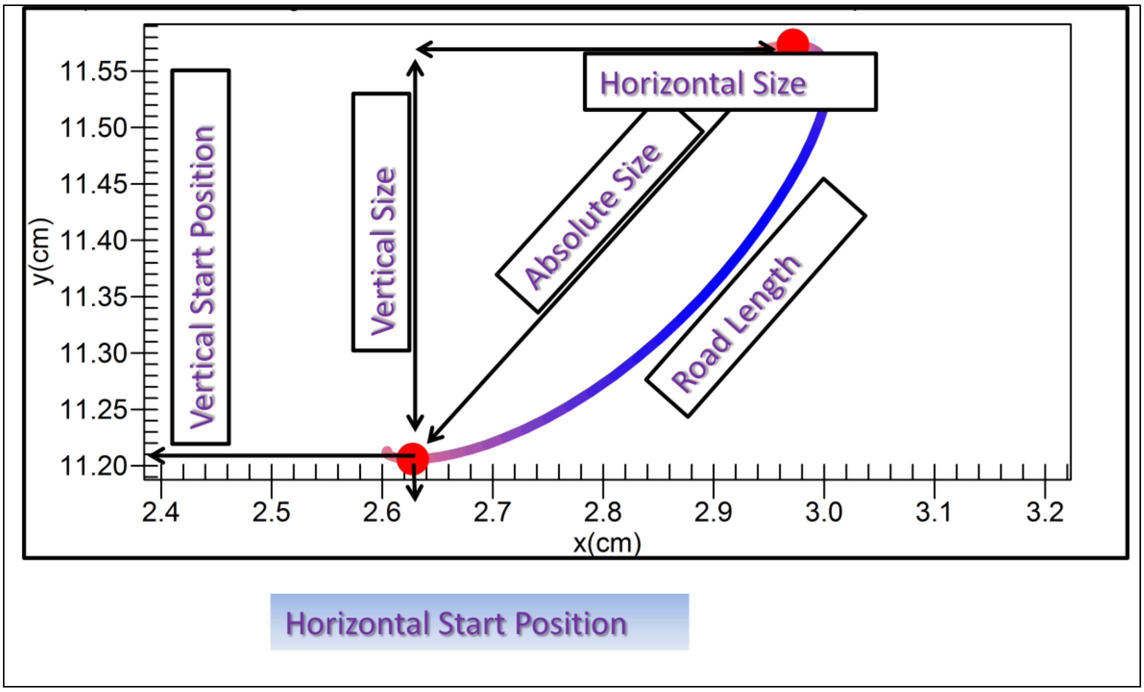


Figure 15. Presentation of Vertical, Horizontal and Absolute Size as well as the Road length.

Road length is not necessarily linked with the overall size of a writing sample since a signature may have a large road length in a small space due to overlaps, retracings and loops. In this research road length is used as a quantified measure of a sample complexity.

The complexity of a handwriting sample is a very important characteristic for discriminating between individuals. Parameters proposed that either singularly or jointly participate in the perceived complexity of the final handwriting sample are the number of turning points in the line (Hardy, 1992; Found et al, 1994; Found et al, 1997) and the total line length over which the turning point occurs among others (Found&Rogers, 2003). Under this scope road length

–with the consideration of the characteristic of absolute size- can be an indicator of complexity: the writing sample with larger road length can be regarded as more complex than another writing sample with the same overall dimensions. Therefore when proceeding to a paired comparison, the difference in road length can be attributed to a difference in complexity, if the absolute size is overall the same. In Figure 16 the connection between road length and complexity is shown: Samples 1 and 2 manifest similar absolute size. However sample 2 is far more complex, since it is consisted of a large number of turning points, when compared to sample 1, which is so simple that it possesses no identifying value whatsoever. This difference in complexity is linked to the quantified difference in road length (sample 1 has a road length of 5.043 cm while sample 2 has one of 14.120.)

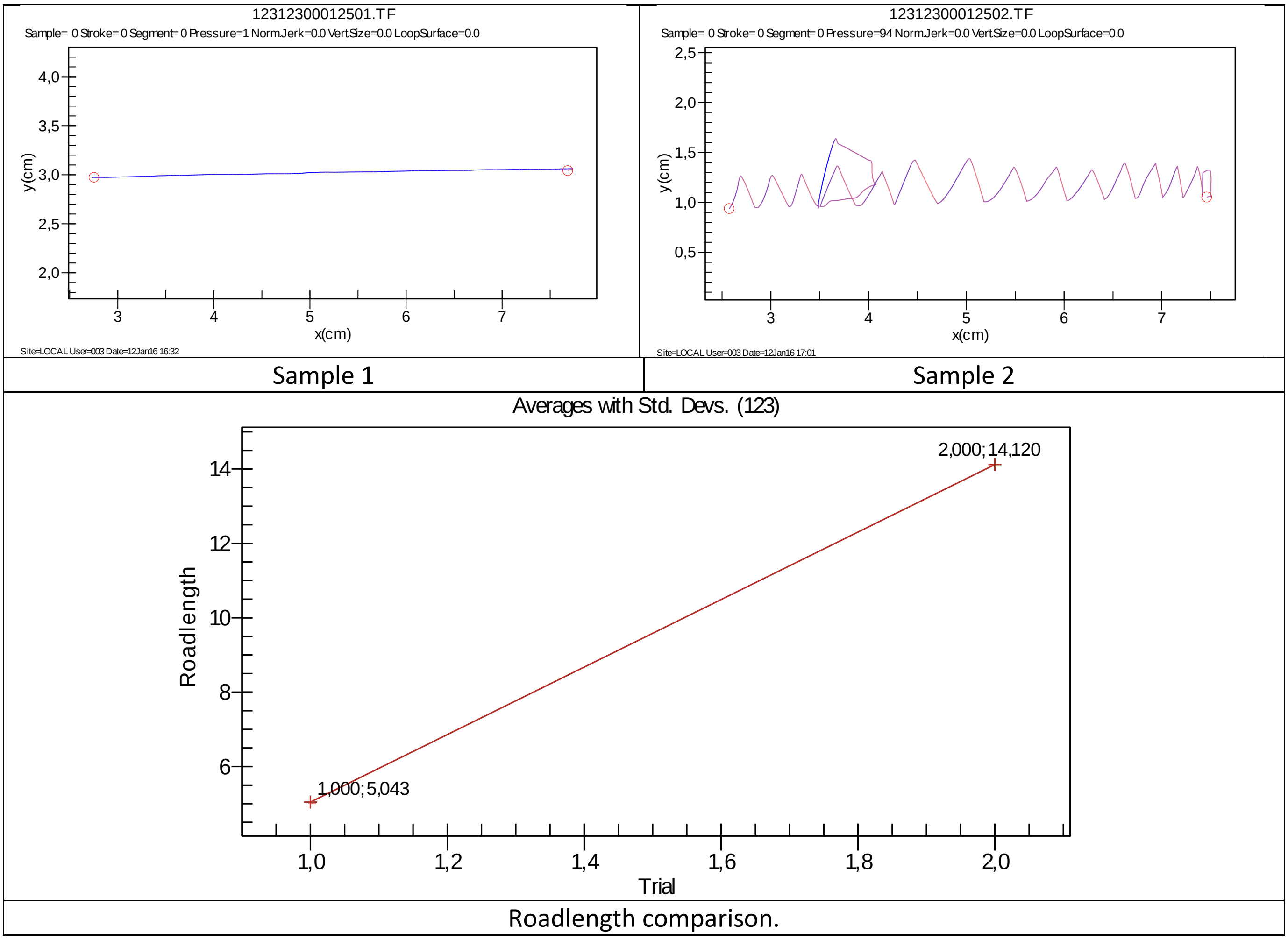


Figure 16. Relationship between complexity and Road length.

3.5.1.4. Arrangement and its sub-elements of Placement, Alignment of the strokes inside the writing sample and Margins: Arrangement is a frequently forgotten characteristic in many comparisons. This also consists of further sub-elements. The sub-element of the placement investigates where the author places the writing sample inside a designated area. The sub-element of the alignment of the strokes inside the writing sample investigates the correlation between the spatial area that allographs occupy. The last sub-element, Margins, is strongly connected with placement and investigates the relation between the allograph and the margins of the specific area. Figure 17 shows an examination of the alignment of neighbouring allographs inside a word.

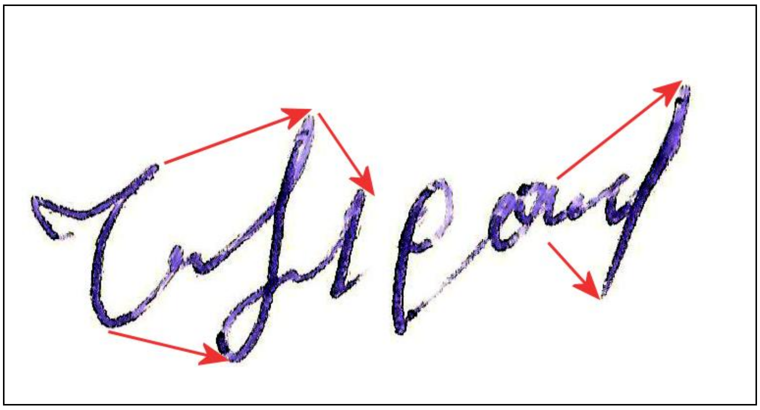


Figure 17. Examination of the spatial correlation between allographs (alignment).

3.5.1.5. Spacing: This includes both intra-word, inter-word and interlinear spacing, that is the absolute as well as relative distance between shapes inside a word, between words and between lines. Furthermore, features like the mixed and uniform spacing are examined here. It must be noted that when inspecting a purely symbolic signature it may not be possible to compare this element. Figure 18 shows examples of intra-word spacing (red line), inter-word spacing (black line) and interlinear spacing (green line).

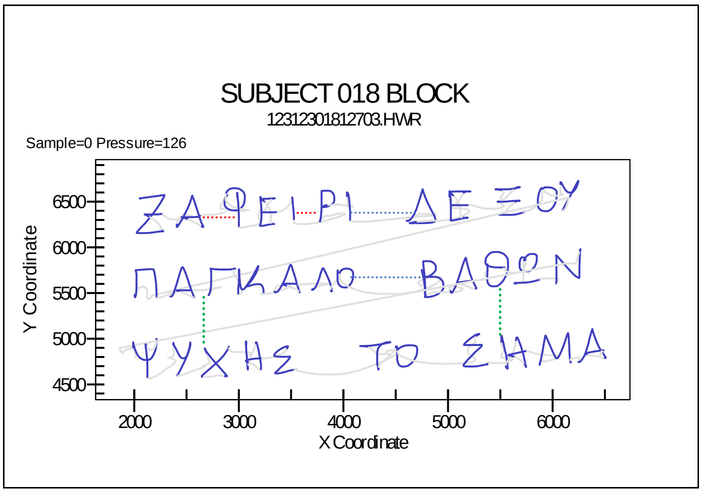


Figure 18. Examples of intra-word, inter-word spacing and interlinear spacing.

3.5.1.6. Slant: This characteristic defines the inclination of allographs relative to the perpendicular to the baseline of the writing and is perceived as the direction of a written sample from the beginning to its ending point (Figure 19).

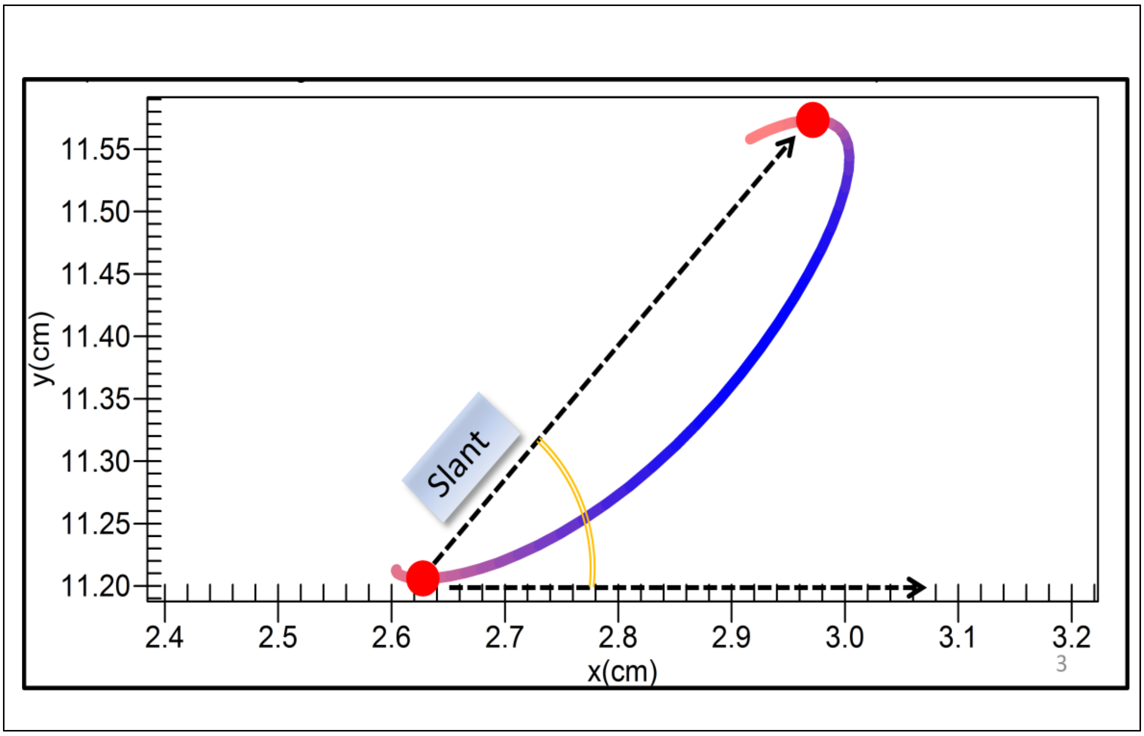


Figure 19. Presentation of the slant

It is very interesting to note that the slant is often changed consciously in attempts of signature disguise, as it is illustrated in Figure 20 in which “A” is an authentic signature. “B” is the simulated version. The difference in slant is prominent (Dines, 1998). Furthermore, slant is one general characteristic prone to erroneous copying by the forger (B. Found & D. Rogers, 2003).

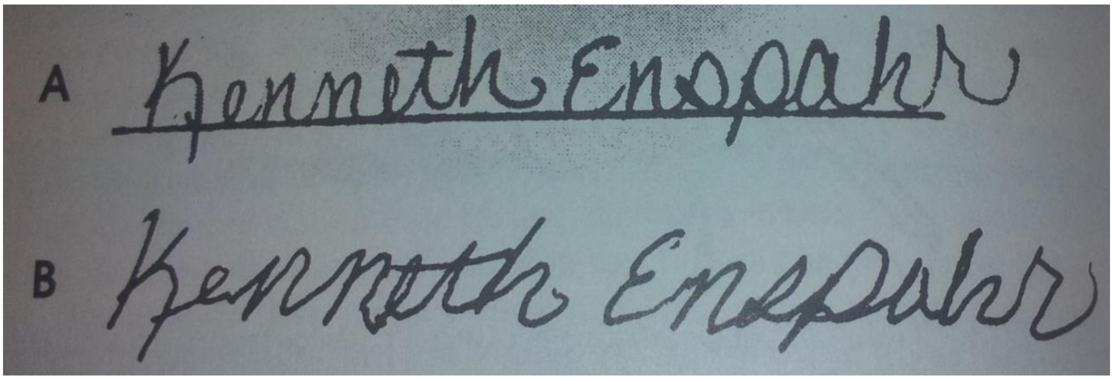
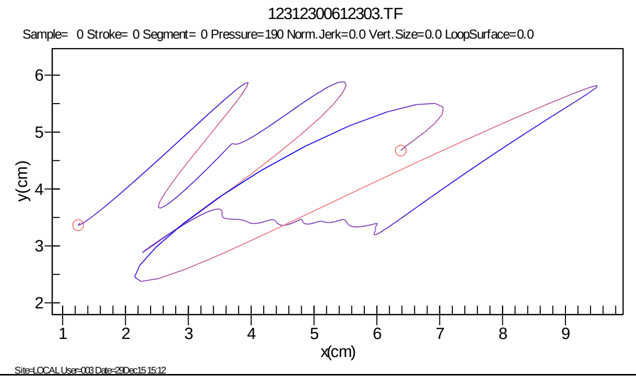


Figure 20. Attempt of signature disguise by changing the slant

3.5.1.7.<u>Extraordinary characteristics</u>: These characteristics encompass all other features which are not described above. Examples of such characteristics are the total alteration of the signature allograph, the transmutation of a signature, created by arbitrary trajectories (symbolic signature) into a signature consisting of letters (holographic signature) and vice versa and the use of other inventions, through which the writer tries to overcome the possible results of loss of visual feedback. In addition the research will examine whether there is homogeneity in the occurrence of such extraordinary characteristics or whether they are used randomly.

3.5.2. **Kinetic individual characteristics:** The use of specialized software provides the researcher the luxury of being able to gather and compare not only the pictorial but also the kinetic (dynamic) aspect of the executed writing sample in a quantifiable manner, as indicated below:

3.5.2.1. <u>Duration</u>: Duration can be defined as the time interval in seconds between the first and the last sample in a stroke. In order to examine the duration of the whole handwriting sample the whole trial (each handwriting and signature sample) was regarded as one stroke. To regulate time functions, the default settings of Fast Fourier Transform algorithm [filter regularity (12) and sharpness (1.75)] were used to convert the signal from the duration domain to the frequency domain using a low pass filter that stops the components that are higher than the cutoff frequency, thus allowing faster and smoother computing. Figure 21 shows an example of analysis of the characteristic of Duration in one signature sample.



Raw image of the signature. Blue lines represent the ascend while red the descend of the writing medium in the document

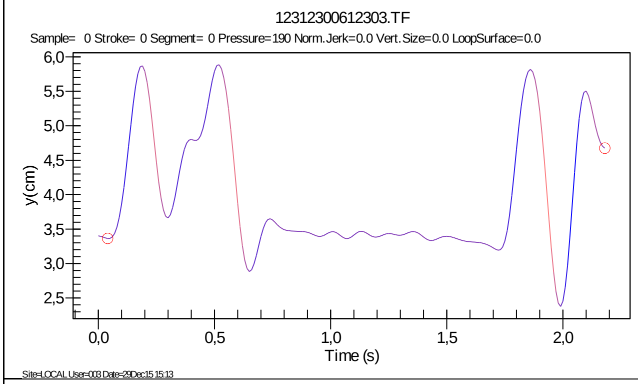


Chart of y coord. Vs Time

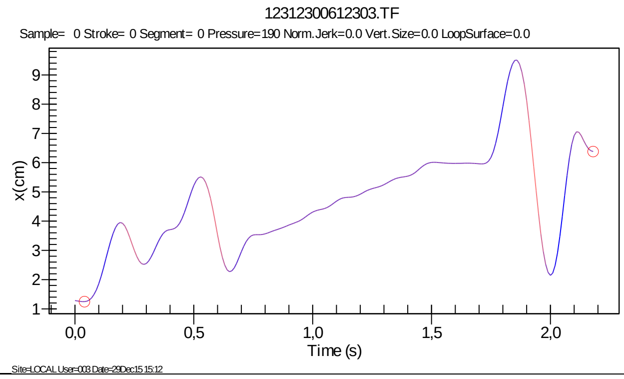


Chart of x coord. Vs Time

Figure 21. Analysis of the characteristic of Duration in one signature sample.

The duration of a handwriting sample is a dynamic characteristic and cannot be examined just by the pictorial analysis of the document. However, the results of this characteristic, that is if the alleged sample was written slowly or swiftly, can be qualitative recognized and compared due to pertinent findings (air lifts, immaterial connections, ink blots etc) (Dines,2005).

3.5.2.2. <u>Average Absolute Velocity</u> : This characteristic relates to the speed of the pen tip on the paper across all samples of a stroke . It is measured in cm/s and as a general rule when analyzing two trials from paired conditions, the higher velocity means lower duration. However, as it will be explained in the next chapter this is not always the case. Figure 22 shows a paired comparison of 3 trials of cursive handwriting written by the same individual. In the first condition the writer has full visual feedback (condition 1 – red charting line) but in the second is blindfolded (condition 2 – blue charting line). Y axis on both charts is the number of trials (3 in total).

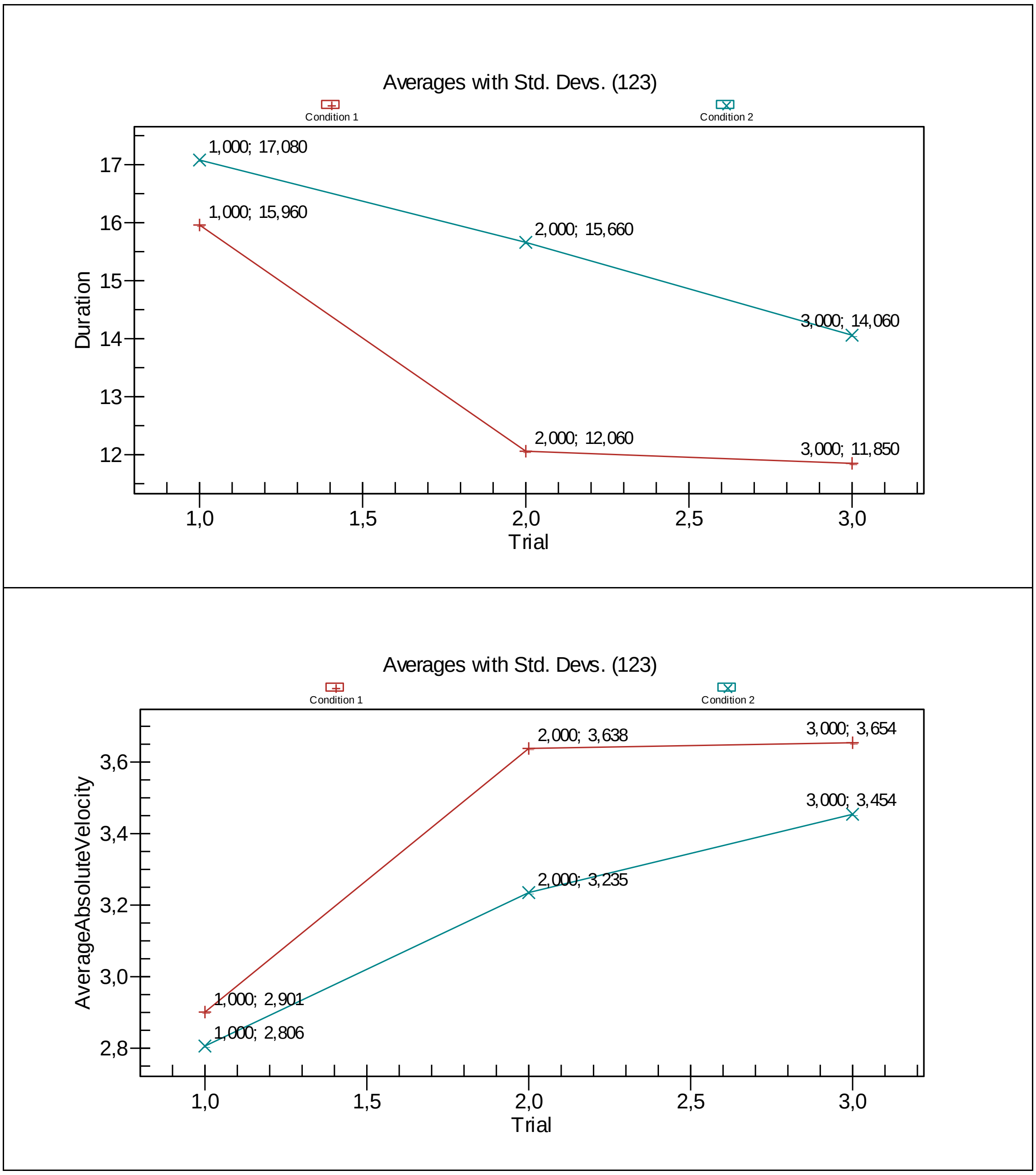


Figure 22. Paired comparison of the Duration and the Average Absolute Velocity of 3 trials of cursive handwriting written by the same individual in condition of visual feedback and absence of visual feedback

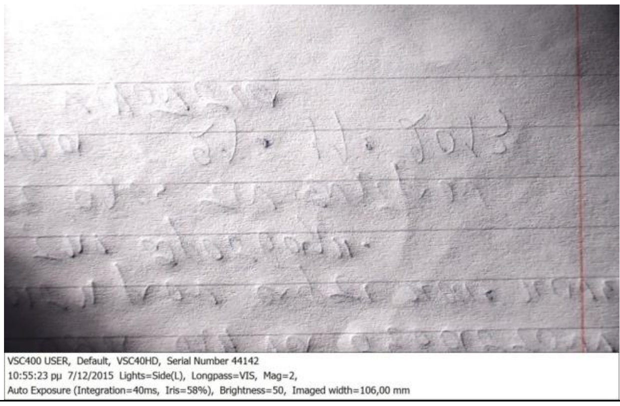
Average absolute speed cannot be examined in a document, however certain evidences (air lifts, immaterial connections, ink blots etc) will help the expert render a qualitative opinion suggesting that the writing sample was executed slowly, in medium speed or quickly. However even the qualitative analysis of this characteristic is very important to the expert, since a significant discrepancy in the individual characteristic of velocity is an indication of forgery (Dines, 1998).

3.5.2.3. Average pen pressure:

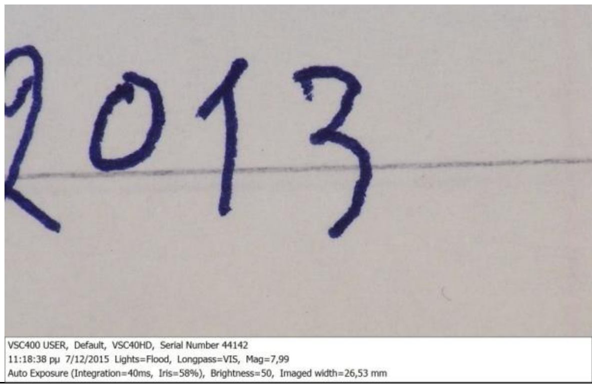
Average pen pressure across all strokes is the pressure that the writing medium exercises in the opaque tablet measured in raw digitizer pressure units (z). MovAlyzeR software records all data that the pen provides in the x and y position (horizontal and vertical position) as well as the z position (direction of the pen axis), through which average pen pressure is provided.

It must be noted that the calibration of the axial pen pressure in the software is essential, since the pen tilt and the internal friction of the cartridge must be taken into consideration (as pressing the pen may require the refill to slide inside the pen barrel) and may show as hysteresis of the pressure (pressure output is increased after a high pressure trajectory) (Teulings, 2013). In order to ensure that no factor may influence the measurement of pressure all the subjects used the same inking pen with the same cartridge and the same type of A4 paper.

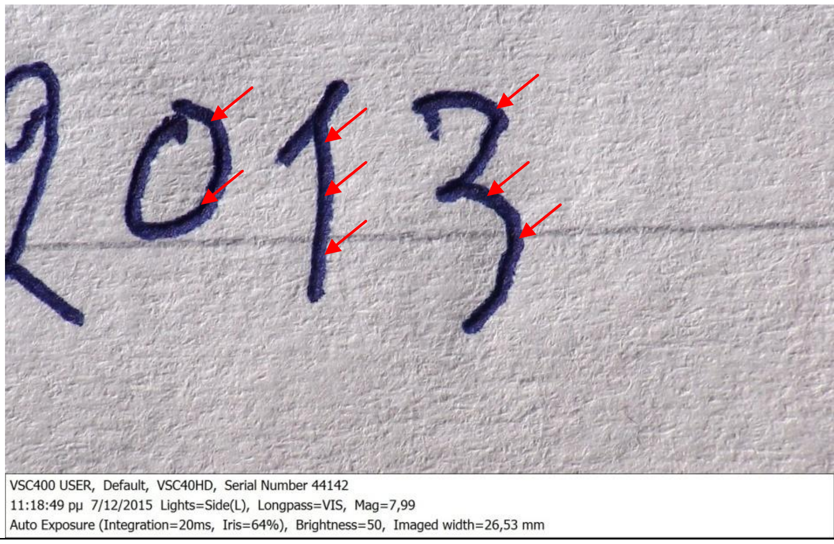
Pen pressure can be only qualitatively examined by the expert, based upon the indentations that the writing medium has left on the document. Based on that, the pen pressure is usually noted as light, medium and strong (Dines, 1998). Figure 23 presents a document written under heavy pressure. It is noted that while direct light is not particularly helpful, oblique light from a cold source is useful for documenting this finding [images taken via Video Spectral Comparator 4000].



The reverse side of the document, illuminated by oblique light



Detail of the handwriting illuminated by direct light. Notice that the pen pressure is not visible.



The same detail illuminated by oblique light. The red arrows pinpoint the indentations.

Figure 23. Examination of writing pressure via Video Spectral Comparator 4000. The red arrows pinpoint some of the indentations created by the writing medium.

3.6.Investigation of the research questions

To answer the questions set on par. 1.8. the examination followed a two-pronged approach:

1. a qualitative peer reviewed analysis based upon the "four eye principle" of the Forensic Document Examination Discipline and 2. a quantitative and statistical analysis with the use of the module "Evaluating the Influence of Visual Feedback" of the handwriting analysis software MovAlyzer.

3.6.1.Introduction to the peer-reviewed forensic analysis using the standard FDE comparison methods (Found & Rogers, 2003)

The subject of research of the discipline of Forensic Document Examination is the investigation of the genuinity or forgery of handwriting. Specifically, Forensic Document Examination is used in order to connect the questioned handwriting with the writer who executed it, through a procedure of analysis, comparison and evaluation of the finding, as well as to disengage it from people who did not execute it. Any type of handwriting is subject to the principles of Forensic Document Examination and as such can be the object of the forensic comparison, as long as there is adequate and pertinent comparison material, in conjecture with the complexity of the questioned handwriting, since complexity is the handwriting element which allows the connection of one piece of handwriting with one and only one writer whilst at the same time eliminating other possible writers, and is one main facet of the individualized aspect of handwriting.

When a question of authenticity or forgery is posed, the FDE collects an adequate quality and quantity of comparison material. Afterwards, the characteristics of each group (the group of questioned handwriting and the group of comparison material) are analyzed, and the findings of this analysis are compared. Therefore it is of paramount importance that the comparison material can fully describe the handwriting habits and elements of the alleged writer at the time of the execution of the questioned sample.

If the comparison manifests only similarities and no fundamental or unexplained differences, taking into consideration the natural variation of both of the above groups (Haggag,1972), then a conclusion of homogeneity/genuineness is established [that is a conclusion that connects the alleged writer with the examined questioned handwriting]. On the other hand, if the existence of fundamental and unexplained differences is established, then a conclusion of disengagement/forgery is reached [that is a conclusion that disconnects the alleged writer from the examined questioned handwriting], regardless the number of similarities (Osborne, 1929; Harrison, 1958;Conway , 1959; Hilton, 1982; Huber and Headrick , 1999).

Fundamental or significant difference is termed as any unexplained difference in the identifying and individualized elements of the questioned handwriting and the comparison material (Huber and Headrick, 1999), that is any unexplained difference between the individual characteristics of the handwritings of the two groups. These differences cannot be taken into consideration as an indication of forgery if they can be explained away by instrinsical factors (physiological constraints, environmental influence etc –see paragraph 1.4A) or not controllable factors (disguise, imitation etc –see paragraph 1.4B). Therefore the differences found due to the weakness of the writer at the time of execution due to senility or due to abnormal position (eg writing standing up, placing the document on a rough wall) or due to the attempt to disguise the natural habits cannot be termed as fundamental and significant. Therefore Osborn (1929) correctly talked of “divergences in amount and quality beyond the range of variation and not attributable to writing or writer conditions.”

Based on this methodological principle, the first part of the analysis includes the forensic examination between the groups executed under normal visual feedback and the groups executed under the absence of visual feedback. Following the standards of ENFSI (European Network of Forensic Science Institutes) and for reason of maximizing verification and objectivity, the comparison and the rendering of conclusions was peer reviewed, following the four-eye principle. Therefore the analysis was conducted separately and independently by two forensic experts. In case of differences of opinion, a third, independent FDE would act as “tie breaker” and his conclusions would be final.

The writer of the thesis proceeded as First Examiner while the roles of Second Examiner and the Tie-Breaker were appointed to members of the laboratory of Questioned Document Studies Chartoularios P.C., associate member of the European Network of Forensic Science Institutes. The writer is positioned as Senior Examiner of this laboratory.

A 7 page long document titled “QUESTIONNAIRE” were given to the first and second examiner (copies of the documents can be found at the appendix B1). Four questions were asked, as seen below:

QUESTION A – Proceed to compare the following pairs in the folder of each subject and notice the existence or not of significant differences.

- **Pair A:** Signatures executed under normal visual feedback vs Signatures executed during the absence of visual feedback.
- **Pair B:** Cursive Handwriting executed under normal visual feedback vs Cursive Handwriting executed during the absence of visual feedback.
- **Pair C:** Block Handwriting executed under normal visual feedback vs Block Handwriting executed during the condition of absence of visual feedback.

QUESTION B – Make a qualitative analysis of the major similarities found in the above comparisons. Analyze per pair. Do you consider these similarities significant?

QUESTION C – Make a qualitative analysis of the major differences found in the above comparisons. Analyze per pair. Do you consider these differences significant?

QUESTION D – Would you regard the above differences as a potential factor for a possible erroneous conclusion of an accredited forensic document examiner?

After the Question A three tables individualized each comparison in signatures, cursive and block handwriting and therefore each examiner had to mark the existence or not of significant differences in each comparison separately. Questions B to D were qualitative and the examiners were urged to elaborate as they saw fit. A digital folder was given to Second Examiner, in which the scanned images of all samples were enclosed, grouped per writer and condition. All personal information were deleted in order to protect the privacy of the volunteers.

3.6.2 Analysis with the use of the software module.

After the conclusion of the forensic analysis, the raw data acquired by the MovAlyzer module –already analyzed bottom-up as examined in par. 3.4. - were compared. The first step was a comparison of the individual characteristics of duration, absolute size, horizontal and vertical size, average pressure, road length, average absolute velocity and slant amongst the total number of subjects in the group of the 40 participants. Afterwards, creating sub groups of gender, handedness and educational level, a comparative analysis took place inside these sub groups. Statistical analysis was conducted using the software's statistical application as well as the statistical software SPSS (version 21) . The statistical tests used are suited to analyze multinomial category variables since the main goal of that part of research is to show a) the nature of relationship between the above mentioned individual characteristics of handwriting (dependent variables) and the two different conditions [condition 1 – visual feedback and condition 2 – no visual feedback], b) to determine whether the three independent variables (gender, handedness and education level) can significantly influence the above relationships. Dependent (paired samples) t-tests were used to test the research hypotheses. Standard error was used as a gauge of the variability between the sample means. Paired samples T-test is a parametric test, based on two assumptions. First that the data follows a normal or Gaussian distribution and second that the data are measured at least at the interval level and therefore if one calculates the differences between the scores of the 2 conditions for each dependent variable, these must be normally distributed. Visual inspection of the distribution and normality tests (Kolmogorov-Smirnov test and Shapiro-Wilk test) were applied to test the assumption of normality (Ghasemi & Zahediasl, 2012). If that assumption was not verified, then the non-parametric Wilcoxon signed-rank test was applied. After the application of either the paired samples t-test or the Wilcoxon signed-rank test, a resulting p-value of less than 0.05 denies the null hypothesis "visual feedback does not significantly change the investigated individual characteristics of handwriting". In the cases where the results were found statistically significant, the effect size (r) was also reported (Coe, 2002) to demonstrate the magnitude of the difference between the two conditions (Sullivan & Feinn, 2012). Afterwards Mixed ANOVA tests were conducted to compare the effects of visual feedback and the absence of visual feedback and the interaction effect between Gender, Educational Level and Handedness in the individual characteristics whose changes were already found significant. In instances that the data did not fulfill exactly the assumptions for conducting the above tests, logarithmic transformations were applied to each dependent variable in its relevant test. The "Sphericity Assumed" dimension was being used in the tests, since when using only 2 levels in the dependent variable, as was the case in this research, sphericity is always assumed by default (Field,2010).

3.7.Summary of procedure

The procedure was described in full detail so the replication of the experiment by another researcher is possible. The two pronged approach is designed to minimize any researcher bias, to solidify the validity of the findings and to produce both qualitative and quantitative conclusions that will provide assistance both to field practitioner and to other researchers. According to the literature research that took place, this methodology provides a great variety of details as well as securing the validity of the findings and could be used as a blueprint for further forensic research in the future.

Chapter 4 - Findings

4.1. Introduction

This chapter describes the findings of the two pronged analysis. In the first sub-chapter (4.2.) the findings of the forensic analysis are presented while in the second (4.3.) there will be a presentation of the digital findings and the statistical analysis with the use of the handwriting analysis software MovAlyzeR and the statistical softwares SPSS (version 21). In each sub-chapter, the findings regarding the signatures are discussed separately of the findings regarding the block and cursive handwriting.

4.2. Findings of the Forensic Analysis

The forensic analysis took place as described in the paragraph 3.6.1., examining and comparing the static individual characteristics (see paragraph. 3.5.A) with the below findings:

4.2.1. Forensic Findings of the comparison of the Signatures

The forensic comparison between the two groups (that is the group of signatures executed with normal visual feedback versus the group executed under the absence of visual feedback) shows the following results:

4.2.1.1. Comparison of the general design of the allographs

The comparison shows a large corpus of significant similarities along with no significant differences in this characteristics. The manner of construction of the allographs, the depiction of the loops and the hooks and the general pictorial image of the samples under no visual feedback belong to the same group of natural variations with the ones with visual feedback. In Figure 24 the comparison between two samples of signatures, the one written in the condition of normal visual feedback and the other in the absence of it) are presented and their similarities are noted.

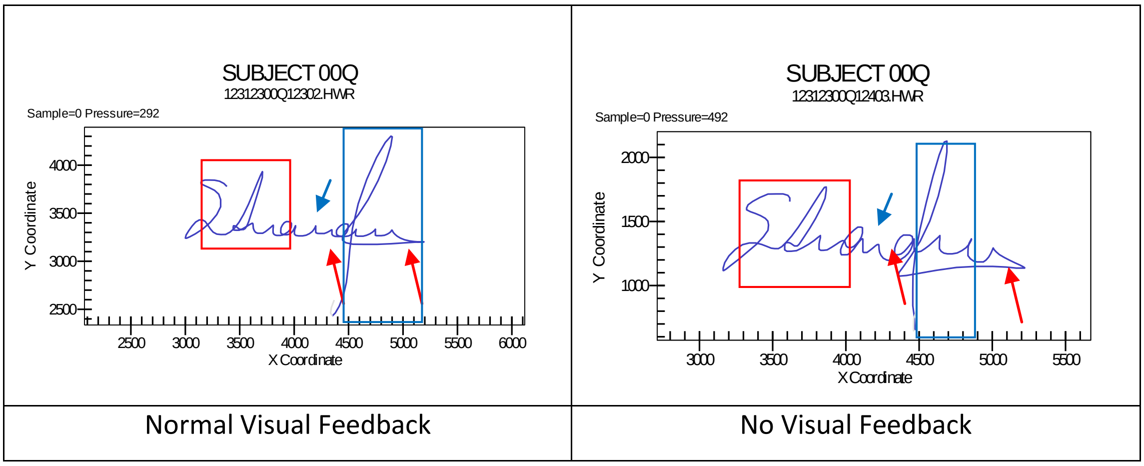


Figure 24. The comparison of these two signatures show that they belong in the same variation group.

Some striking similarities that pinpoint to the common origin of the signatures presented in Figure 24 are: 1. The construction of the initial letter Σ and its connection with the ascended line that is follows with a downward trajectory (red rectangle). 2. The round trajectories that connect the main parts of the signatures (bue arrows). 3) The construction of letter α (red arrow). 4) The vertical looped trajectory (blue rectangle).

4.2.1.2. Comparison of the slant of the allographs

The angle of the axes of letters relative to the baseline (Hilton, 1969) of the samples of condition 2 manifest no significant differences to those of condition 1. In Figure 25 a signature with a complex relation of slants is examined and compares to the sample with no visual feedback.

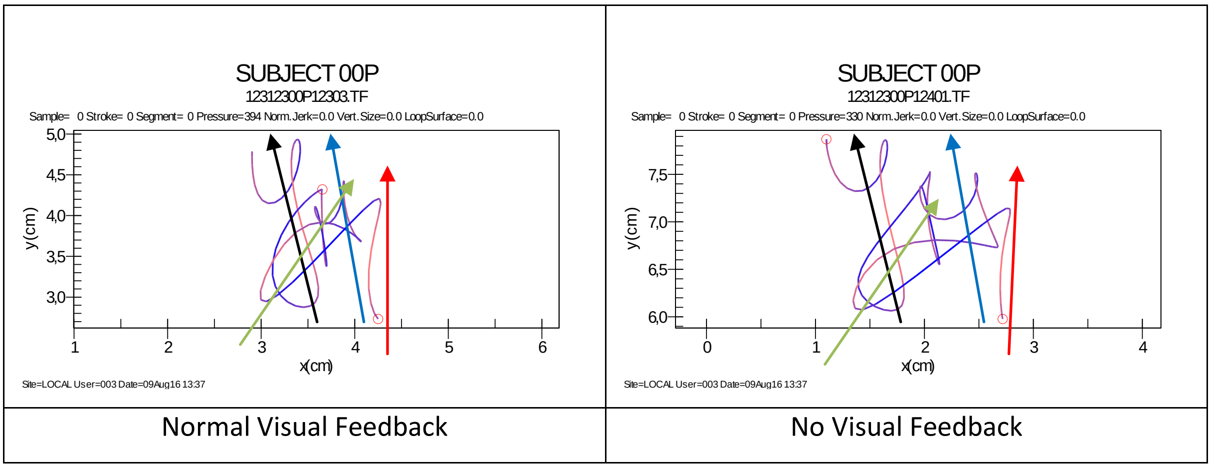
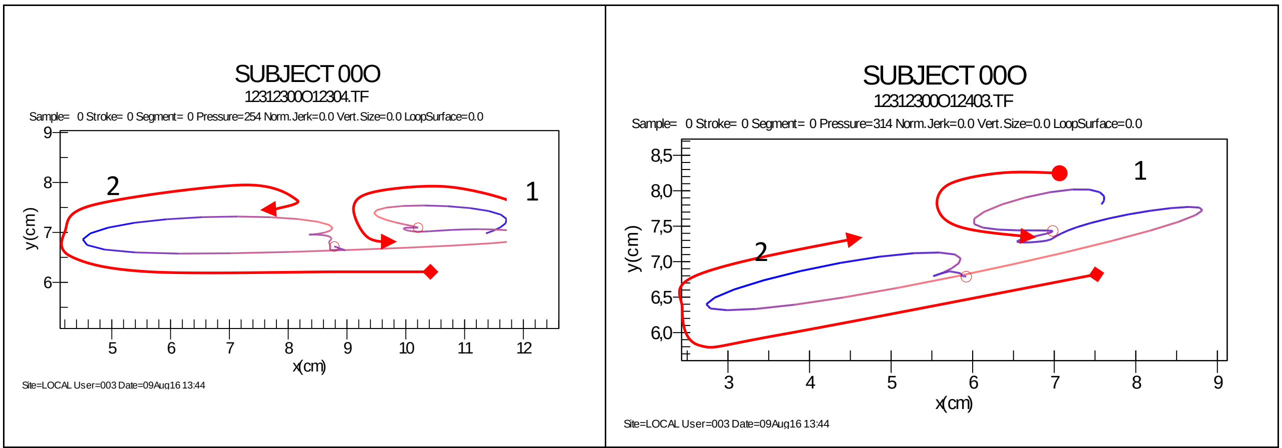


Figure 25. The different arrows show the slants of certain parts of the signature. No significant difference is found on the comparison.

4.2.1.3. Comparison of the connections and direction of trajectory

In this part of comparison two important characteristics will be examined: a) the connections inside a signature, that is the ways that the parts of the signatures are united and the absolute numbers of pen lifts a signature presents and b) the cardinal direction of a trajectory, that is the direction of the beginning to the end of a drawn trajectory. In figure 26 the comparison of a signature with no pen lifts (zero break of connections) and a very bizare direction is presented. Once again all these characteristics of the two conditions enter the same natural variations.

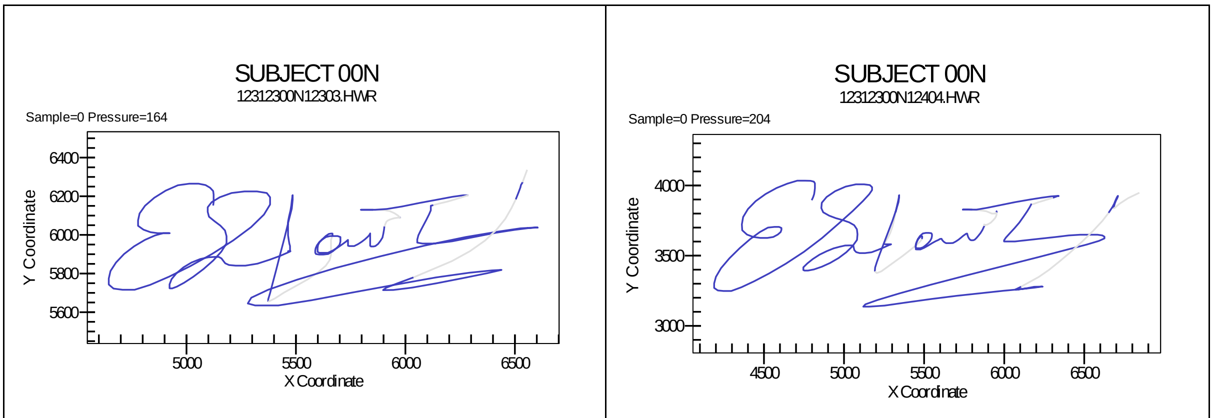


Normal Visual Feedback	No Visual Feedback

Figure 26. In this signature no lift of the pen is noticed and therefore there is no pen stop. The signature is executed in one time unit. The red arrows show the direction of the drawing.

4.2.1.4. Comparison of the line quality

Line quality is not significantly affected by the absence of visual feedback. The controling ability of the writing medium (Dines, 1999) remains at a similar level. In Figure 27 a very fluid signature is compared. The same fluidity is retained in the condition 2. No evidence of tremor, hesitation or instability is found even in the stereoscopical analysis.



Normal Visual Feedback	No Visual Feedback

Figure 27. Comparison of the line quality. The examination of the samples with no visual feedback shows lack of tremor or hesitation.

4.2.1.5. Comparison of the alignment

In this comparison, the parts of a signature are examined and their relation is noticed. In Figure 28 The correlation of specific points in the signature and the relation of their position in it are compared, resulting in a group of significant similarities. This is found in the group of all compared signatures.

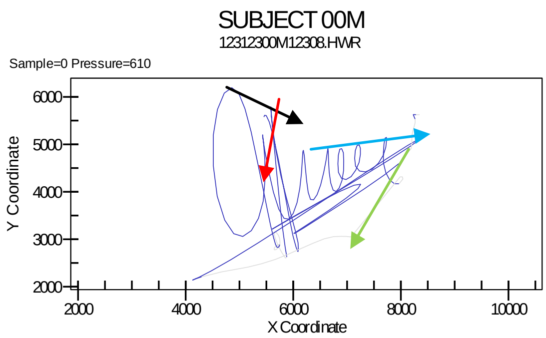
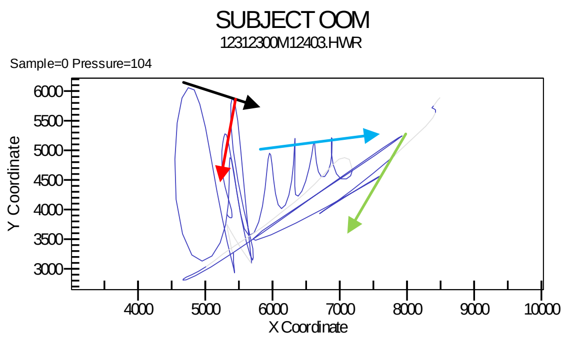
	
Normal Visual Feedback	No Visual Feedback

Figure 28. The arrows show the relationship of the position of certain points in the signature. No significant difference is found.

4.2.1.8. Summary of the forensic findings regarding signatures

The forensic comparison between the two groups (that is the group of signatures executed with normal visual feedback versus the group executed under the absence of visual feedback), focusing on the individual characteristics of general design, line quality, size, connections, spacing, slant and alignment, shows total lack of any significant difference between the groups in all pictorial characteristics, regardless of the complexity of the signatures. The general design of the signature remains the same while with no visual feedback there is no departure from the normal allograph. Line quality –that is the measure of the ability of the writer to control the writing medium (Dines, 1999)- remains at the same level: stereoscopical examination shows no writing tremor or any kind of graphic noise, distortion or hesitation on the signature samples executed without visual feedback. In any way, <u>the signatures executed with and without visual feedback belong in the same group of natural variations</u>.

The lack of differences of that type signifies that any trained forensic document examiner would be able to determine that a signature executed without visual feedback by person x has the same and common origin with a signature executed under normal conditions by the same person, even if the examiner is not aware of the fact that these two signatures where placed under these two different conditions.

It must be stressed that this lack of significant differences in the recruitment pool remains constant regardless the complexity of the signatures and their nature as symbolic or holographic or mixed type. This means that the complexity of a signature is not influenced by the visual feedback: No simplification of the signature was witnessed under the condition of visual feedback, verifying Teuling's remark (1988) of handwriting being a open loop motor program. Based on that assumption, the execution of the signature is manifested as a highly automated action. Furthermore, the forensic comparison shows lack of significant differences along with the manifestation of a strong body of similarities regardless of gender, handedness and educational level (medium and higher), signifying that the motor program used for signature execution is not influenced by these factors.

In Figure 29 two pairs of highly complex signatures are compared : the individual characteristics of each pair fall into the same natural variation pool, signifying the lack of any fundamental difference. This lack of significant differences proves their common origin, i.e. that each pair was created by the same individual writer. It is very interesting to note the degree of similarity of the design of the allographs, to a degree that it is not possible to distinguish which signature belongs to which group [that is which of the two signatures was executed during the absence of visual feedback]. Contrary to expectation, stereoscopical analysis shows that the signatures executed with the absence of visual feedback do not manifest tremor or unnecessary pen stops, lifts and hesitation marks. There are no unnatural curves, the pressure is normal and equally attributed in the trajectories, no significant differences in the vertical or horizontal size and the slants are part of the same group of natural variations. Notice that in this figure the alteration of pressure (as shown with the color of the lines, moving from deep blue –heavy pressure- to red –light pressure) is common in both conditions.

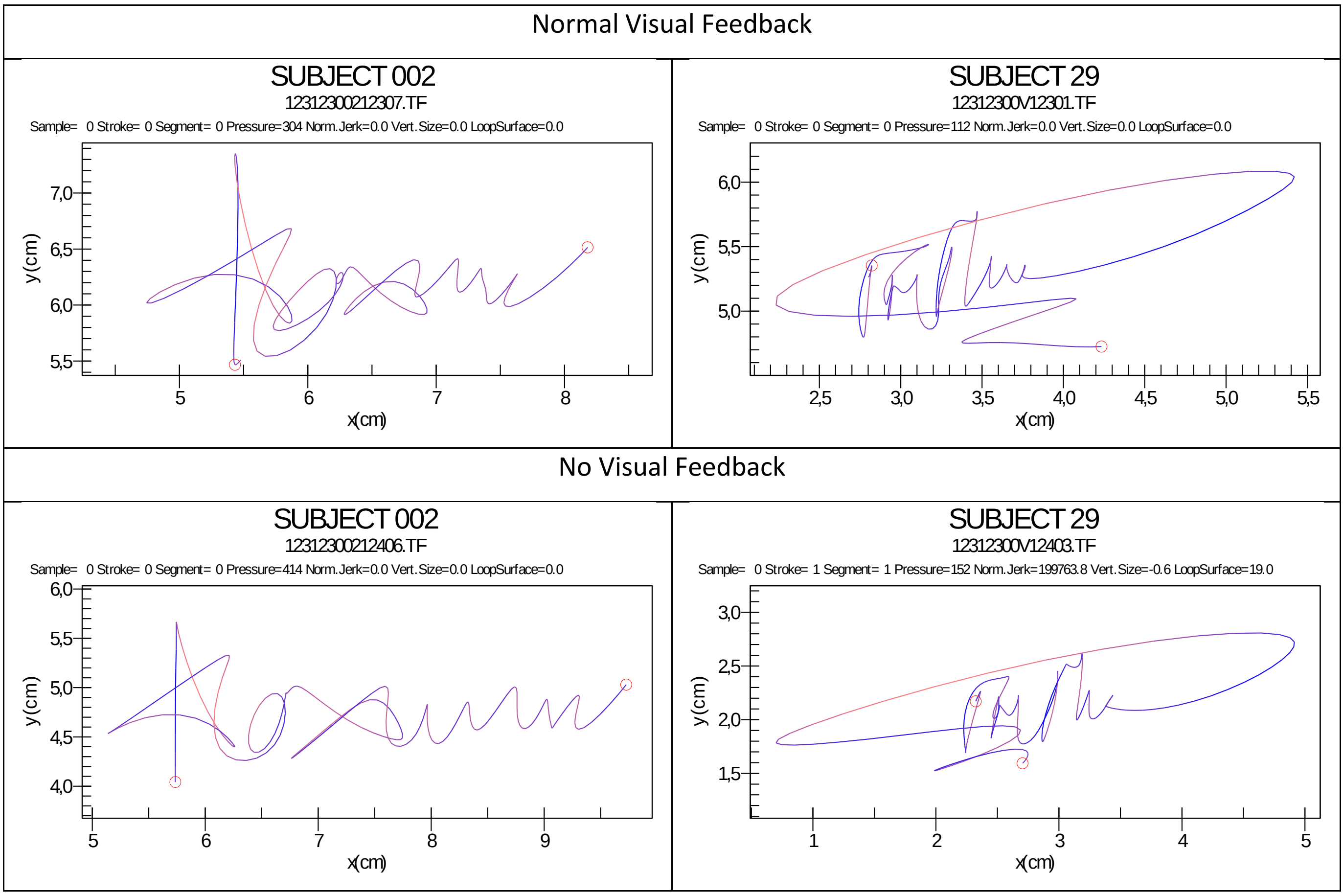


Figure 29. Comparison of two highly complex signatures. Subject 002 is female, while subject 29 is male, both right-handed and of higher education level.

Findings of the same nature apply to holographic as well as symbolic signatures, executed by volunteers of medium educational level, suggesting that the automation is not linked with the type of signature: a signature shows no differences in the condition 2 regardless of whether symbolic, that is consisted of arbitrary and usually joined non-grammatical trajectories, or holographic. Figure 30 shows a signature consisting of disconnected cursive handwriting, executed by a medium level education right-handed male. No significant difference was found in the individual characteristics: General Design, Line Quality as well as Pressure. Pictorial characteristics like slant, horizontal and vertical size as well as spacing all fall inside the natural variations of the writer. During the absence of visual feedback, no grotesque design, tremor, hesitation marks, unnecessary pen lifts were found, showing that the signature written under the condition of absence of visual feedback is normal and belongs fully to the natural variations group of the signature executed by that participant.

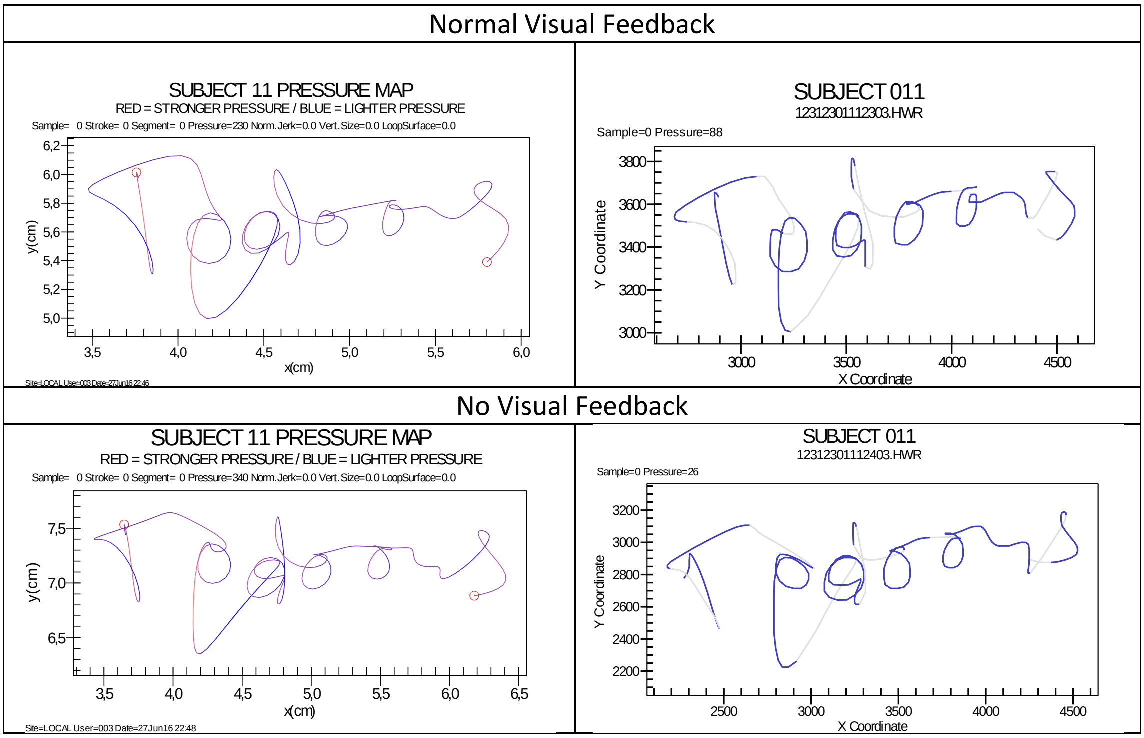


Figure 30. Comparison of signatures executed by a male writer with middle education level.

Therefore, with respect to the execution of signatures no flags of absence of visual feedback were found. This means that no distinctive characteristics were located that the expert could rely upon and identify –or even strongly hypothesize- the condition of visual feedback that the questioned signature was written. Figure 31 presents a highly individualized signature with a high level of complexity. The forensic comparison shows no flags of absence of visual feedback whatsoever – the analyzed pictorial characteristics of the compared samples belong in the same natural variation group.

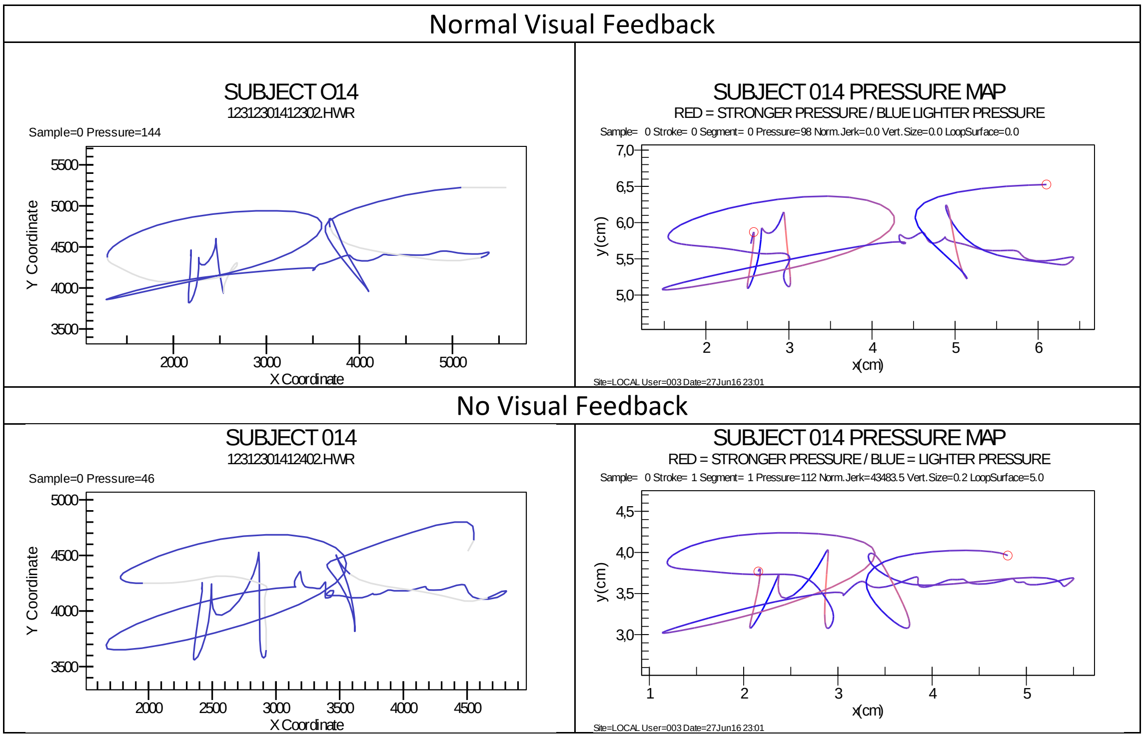


Figure 31. Comparison of highly individualized signatures. The great similarity in general design and the total lack of significant differences signify that the signatures belong in the same group of natural variations of the same writer.

During the verification process, the second examiner (see par 3.6.1.) certified the lack of significant differences. She stated her certainty that the paired signatures came from the same writer, since the identifying elements of the writer were present and any differences could not be considered as significant and she concluded that the presence of individual characteristics and the importance we all know they have in the identification of a writer leave no space for erroneous conclusion. Beyond the vocative admission of the lack of significant differences, it is interesting to comment on her note that "*The above comparisons had as a surprising result the absence of major differences between the signatures executed with visual feedback and the ones without visual feedback.*" , which leads us back to the dichotomy that appears in the pertinent literature and probably in the consciousness of many FDEs about the influence of visual feedback.

4.2.2. Forensic Findings of the comparison of the Cursive and Block Handwriting

The forensic comparison between the two groups (that is the group of signatures executed with normal visual feedback versus the group executed under the absence of visual feedback) shows the following results:

4.2.2.1. Comparison of the general design of the allographs

The comparison of the elements of construction of the allographs was very interesting: all the construction characteristics of the letters of condition 2 were found inside the group of the natural variations in condition 1. In Figure 32 such a comparion of the word πάγκαλο is presented.

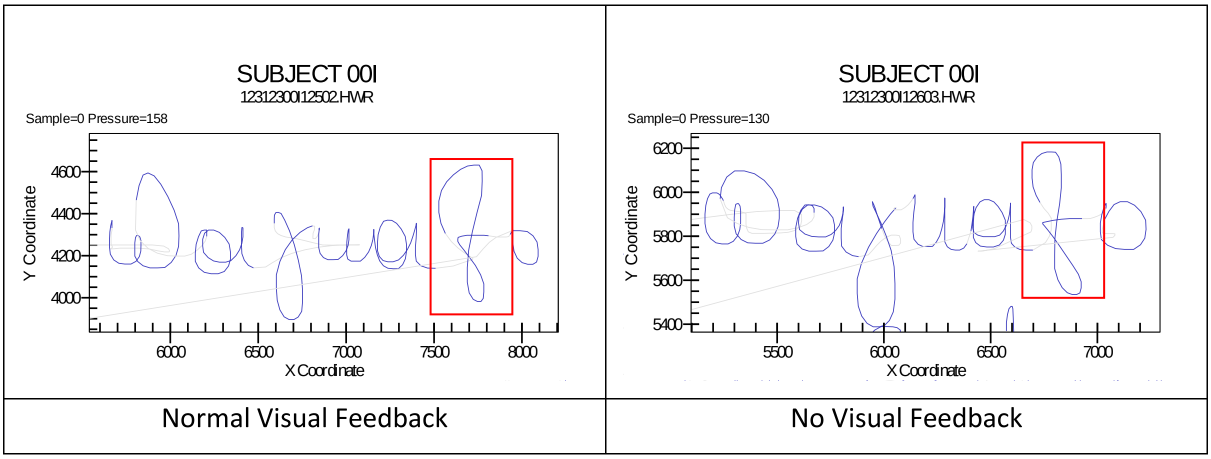


Figure 32. Amongst the large numbers of similarities, it is worth mentioning the rare allograph with the pictorial image of the number 8 that corresponds with the letter λ. This allograph creates a upward loop, then descents, creating a loop at the base of the letter an then, proceeding counterclockwise makes an abrupt turn towards the right part of the word, where it ends (see red rectangle).

4.2.2.2. Comparison of the slant of the allographs

The comparison of the slant of the allographs shows significant constancy, regardless the visual feedback, that is retained in the condition 2. In Figure 33 such a comparison is depicted.

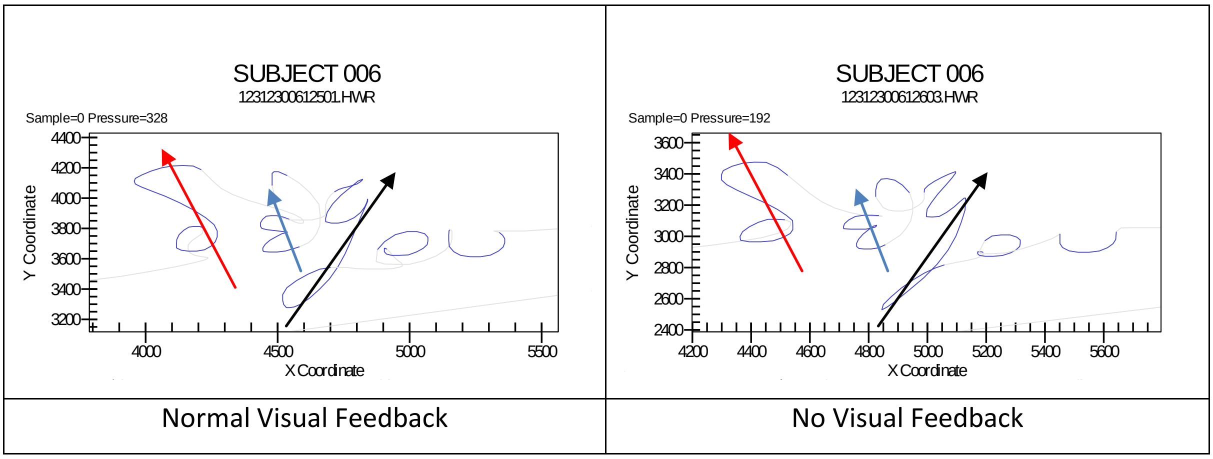
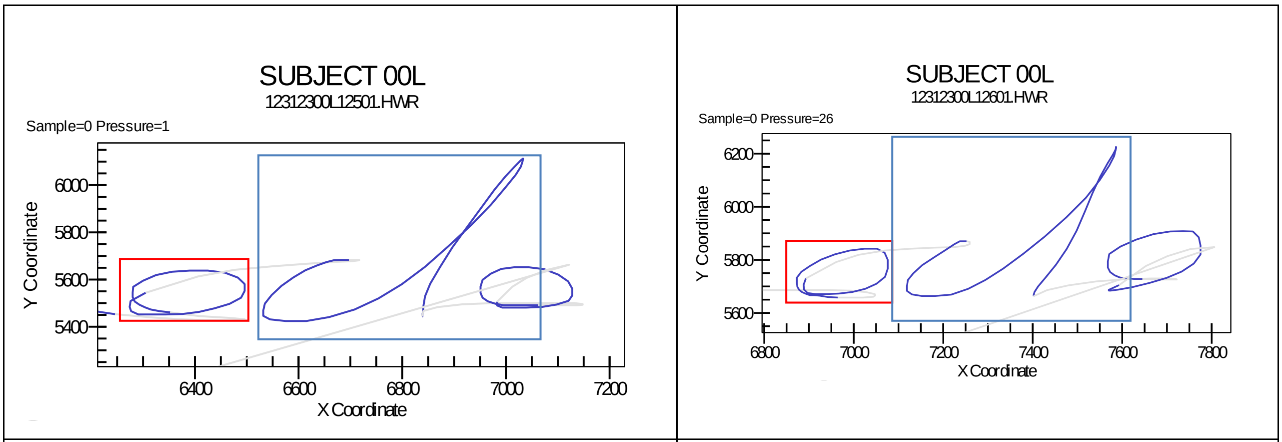


Figure 33. The three arrows manifest the slants in three letters. No significant difference is observed.

4.2.2.3. Comparison of the connections

The comparison shows that a number of very individualised connections, like the one presented in Figure 34, are retained in condition 2, without decreased line quality.

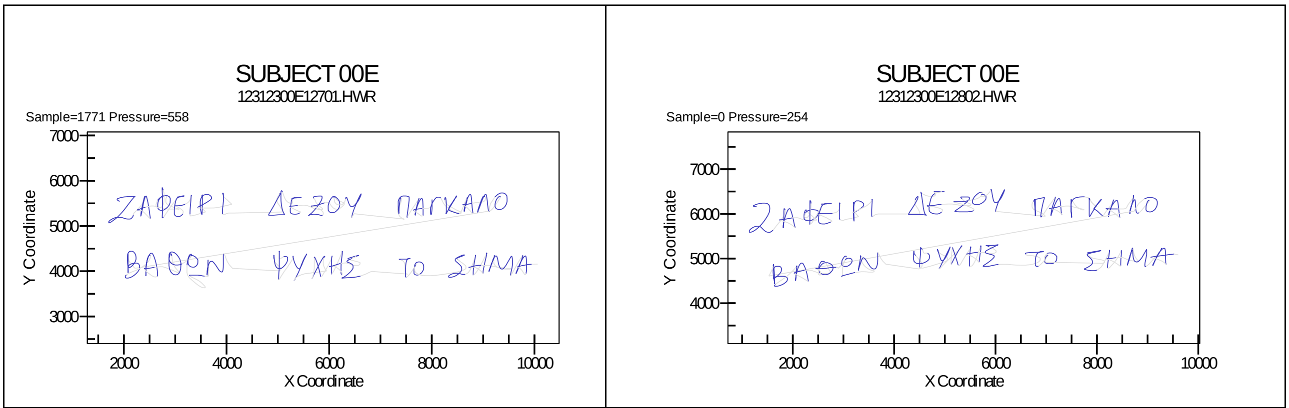


Normal Visual Feedback	No Visual Feedback

Figure 34. This combination of allographs is the letters αλο from the word πάγκαλο. It is noted that α is divided into two parts: the first resembles the letter o (red rectangle) and the second is connected with the letter λ (blue rectangle). This individualized connection remains at both conditions.

4.2.2.4. Comparison of the line quality

Line quality is decreased in certain samples in condition 2 (see par. 4.2.2.14.) However overall, the comparison shows that the degree of this element remains the same in the two conditions, while any differences are not significant. In Figure 35 an example of common degree of fluidity, individualization and automation is noticed.



Normal Visual Feedback	No Visual Feedback

Figure 35. Comparison of the two samples. Line quality remains at the same level in both conditions.

4.2.2.5. Comparison of the alignment

It was found that in second condition a number of highly individualized and complex alignment relations between the letters are maintained, regardless the absence of visibility. In Figure 36 the alignment relations in the word πάγκαλο are examined – the duplication of the letter position in the two conditions is very evident.

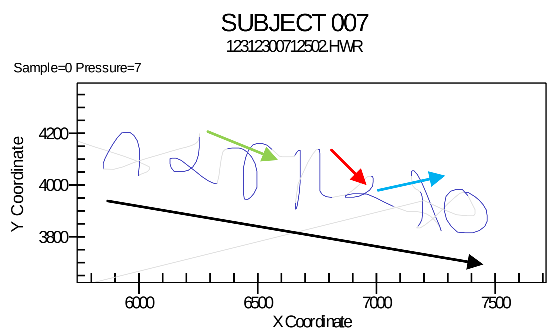
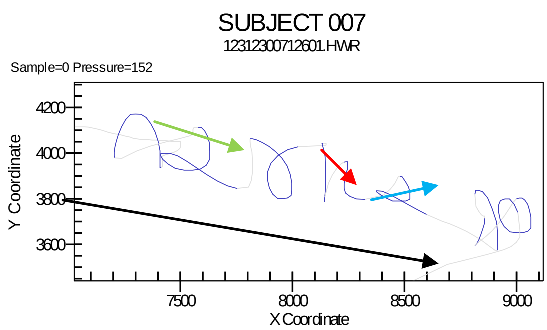
	
Normal Visual Feedback	No Visual Feedback

Figure 36. The arrows present the relations of specific points of the signature. The comparison of the two conditions shows strong similarities, esp. if the complexity of this comparison is taken under consideration.s

4.2.2.8. Summary of the forensic findings regarding cursive and block handwriting

The forensic comparison between the two groups of cursive handwriting (that is the group executed with normal visual feedback versus the group executed under the absence of visual feedback), focusing on the individual characteristics of general design, line quality, size, connections, spacing, slant and alignment, shows total lack of any significant difference in all pictorial characteristics of both groups, regardless of the complexity of examined handwriting samples. The same findings apply for the comparison of the block handwriting.

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 therefore –unlike signatures- it was not an automated action. Using the terminology of paragraph 1.2, 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 travel in both dimensions for longer duration and create a multitude of unknown air trajectories.

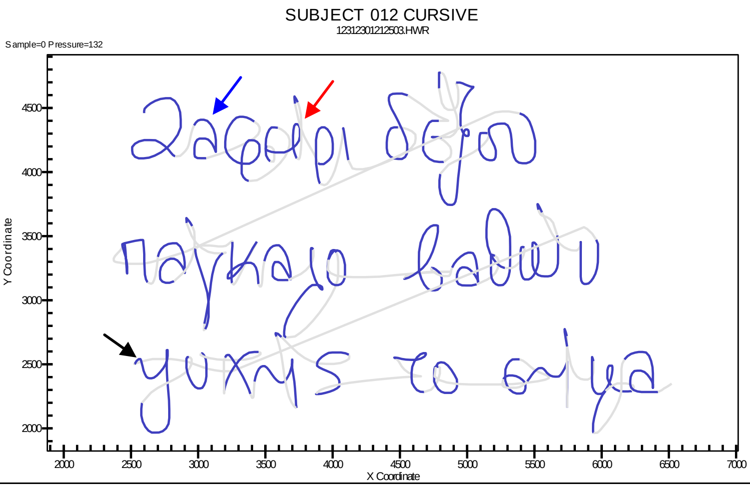
This suggests that both Cursive and Block Handwriting manifest significantly lesser automation when compared to the execution of signatures.

However even by the minimization of automation, the peer reviewed forensic comparison manifested no significant or fundamental differences, while a large group of homogeneity in all the inspected individual characteristics was presented. Once again the general design of the handwriting remained the same while the stereoscopic examination shows no evidence of decline in the line quality. Therefore the finding of this comparison replicated that of the comparison of signatures, i.e. that <u>the cursive and block handwriting executed with and without visual feedback belong in the same group of natural variations</u> and this lack of significant differences, along with the existence of a strong body of similarities, signifies that any properly trained forensic document examiner would be able to determine that handwriting executed without visual feedback by person x has the same and common origin with a handwriting executed under normal conditions by the same person, even if the examiner is not aware of the fact that these two handwriting samples where written under these two different conditions. Since the factor of automation is minimized, this similarity 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.

Once again it was noticed that this lack of significant differences is not linked in any way with the complexity of the sample of handwriting and the writing maturity of the writer. This verifies once again that the complexity of a handwriting sample is not specially compromised by the absence of the visual feedback as a closed loop motor program.

In figure 37 the cursive handwriting of subject 012 is inspected. This female righthanded writer with 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 the total lack of significant 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). Furthermore the inspection of the pen stops and the aerial movements of pen –as shown by the grey lines- show that the hand made the same type of movements while it was hovering over the document in both conditions. 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.

Normal Visual Feedback



No Visual Feedback

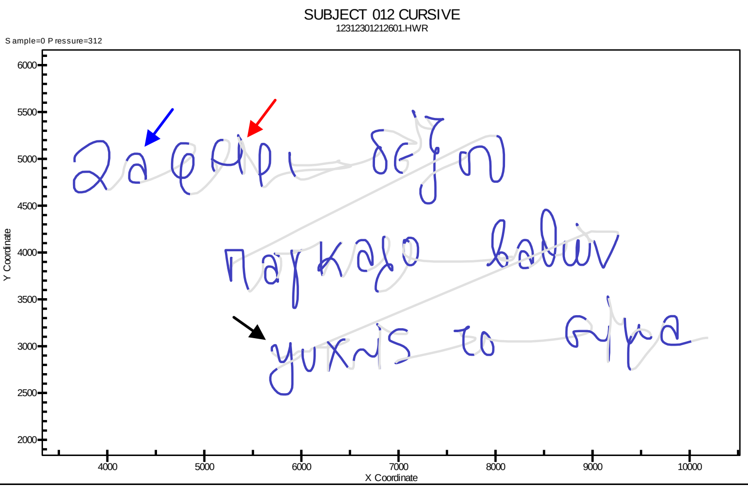


Figure 37. Comparison of the trajectories that create letter α (blue arrow) and ψ (black arrow). Red arrow shows the same construction manner of the connection between the vowels ε and ι.

Continuing the examination of the block handwriting of the same participant, the similarity of the general design is evident. In Figure 38 the comparison between a sample written with visual feedback is compared to a sample written without. Apart of the similarity of the general design, the replication of fine detail is 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). Very interesting is once again the similarity in the air strokes: the black arrow shows the last trajectory of the whole writing sample that in both samples, a clock wise immaterial hook.

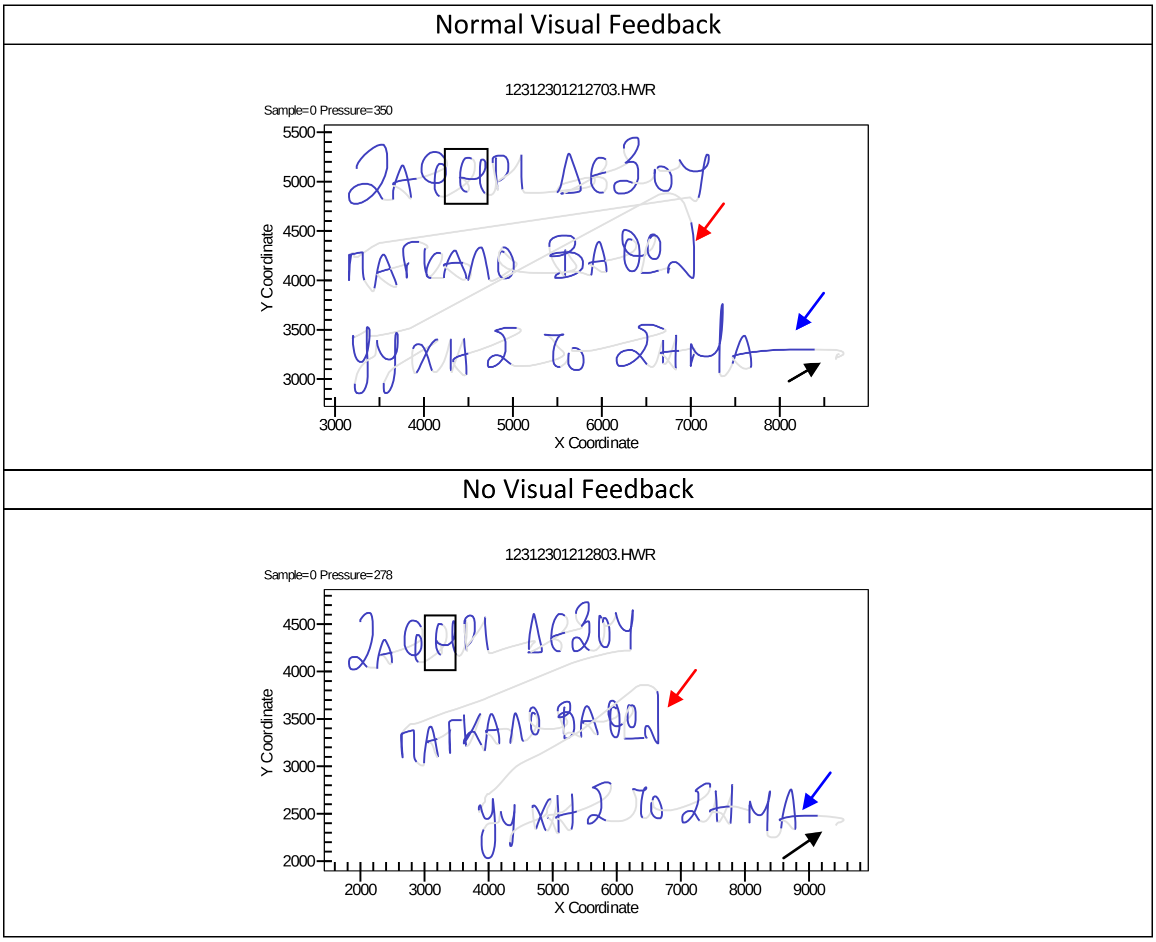


Figure 38. Comparison of block handwriting samples in the two conditions.

The forensic comparison of the handwriting samples in accordance to that of the signature samples shows that the pictorial elements are not affected by the factors of gender, handedness and educational level (medium and higher). This uniformity of the findings suggests that the execution of signatures, cursive and block writing is based on a single motor program, which is used to produce a diverse variety of results.

In Figure 39, the cursive and block handwriting of a medium education level male subject is compared in the two conditions and exhibits no significant differences. Specifically in the cursive handwriting the similarities on the allographs of the letters ξ (blue arrow) and β (red arrow) are noticed while on the block handwriting the intra allograph ratios and intra word alignment of the word ΨΥΧΗΣ (black rectangle) offer a corpus of striking similarities.

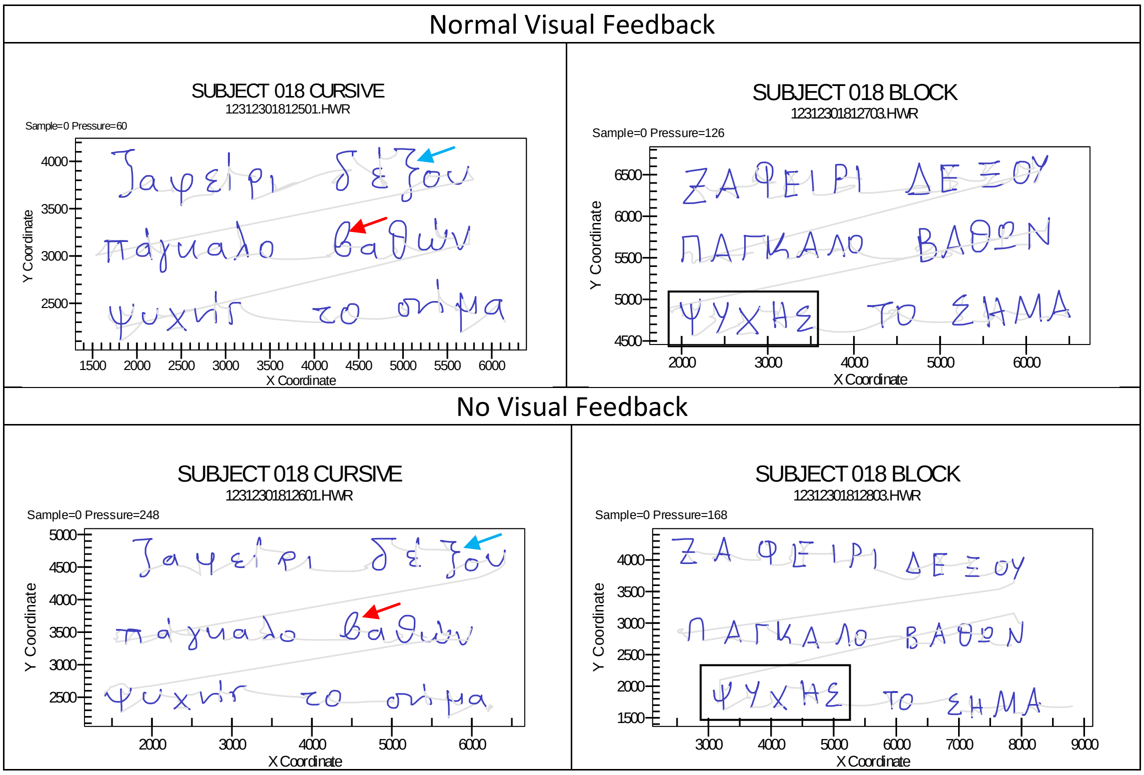


Figure 39. Comparison of both cursive and block handwriting samples in the two conditions.

Based on the above, a trained FDE would not be led into an erroneous conclusion, since no significant difference was found between the outcomes of the two conditions. However as stated correctly by Huber & Headrick (1999), the loss of visual feedback interferes in the macromanaging of handwriting and specifically it decreases the ability of the writer to align the letter that is currently produced to letters that were already produced, as will be demonstrated below. This absence of feedback of the exact position of the previous letters shows some common characteristics that could be used as flags to indicate absence of visual feedback. In fact qualitative analysis shows the existence of six0 flags that indicate the possibility of handwriting execution without visual feedback. These are a) change of overall size, b) non uniformity of left margins, c) change of slant, d) avoidance of pen lifts, e) inclusion of extra trajectories and f) decrease of line quality. It must be stressed that these flags do not constitute signs of forgery – they are qualitative clusters of common characteristics perceived in the samples of Condition 2, that are not “fundamental and unexplained differences”, taking into consideration the natural variations of the sample group of Condition 1.

4.2.2.9. First Flag: Change of overall extension of the sample

Handwriting when compared to signatures manifests trajectories with a lesser degree of automation as well as a greater amount of both pen lifts and aerial movements. This inhibits the macromanagement of the handwriting sample, that is the writer's ability of regulating the spatial placement of the consecutive letters.

Since the Greek language is part of the western Indoeuropean Languages (Bodmer, 1985) the text proceeds from left to right and from top to bottom. The writer positions each letter in accordance a) to the letter on its left and b) to the letter above. Therefore two main reference points are utilized giving the gross coordination of letter placement, which is further influenced by the idiosyncrasies of the writer's individual characteristics of spacing and size. However the verification of the exact location of these two reference points vanishes when the person writes without visual feedback and therefore is forced to utilize both mnemonic and kinesthetic aids regarding the positioning – e.g. using the less dominant hand as an artificial reference point. The verification of the reference point provided by the previously executed letter on the left of the currently drawn one does not pose such 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 significantly from the letter to the left either by overlapping it or by distancing itself from it by a distance outside the natural variations. However, the alignment to the reference point of the letter above is far more demanding: 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. Due to this factor 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%). From these 4 writings, 2 also demonstrated overwriting in cursive.

Figure 40 shows two extreme cases of vertical overwriting. While the vertical reference point is totally ignored and overlapping between the two lines is exaggerated, it is seen that the horizontal reference point is retained.

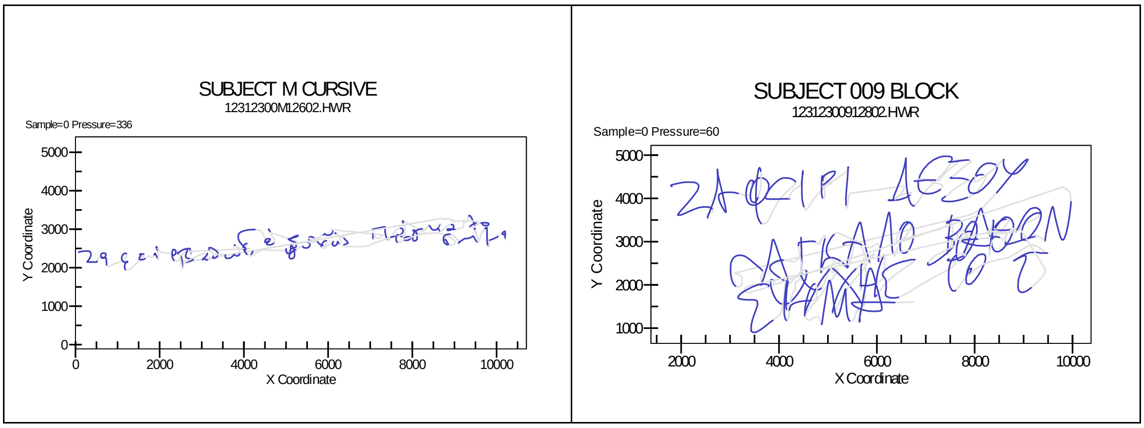


Figure 40. Two cases of vertical overwriting under no visual feedback. Legibility is highly compromised.

Two basic mechanisms used by the writer to overcome the spatial ignorance due to the loss of verification of the two reference points were investigated – the enlargement and the reduction of the size of handwriting sample. Both the enlargement and the reduction may refer to any pictorial characteristic pertinent to size and spacing.

In the enlargement mechanism the writer attempts to create a legible handwriting sample by enlarging the size of the letters, the inter and intra word spacing as well as the interlinear spacing. As shown in Chapter 4b, this mechanism is the most prominent among the writers. It is appraised as a successful strategy of dealing with Condition 2 since it contributes in the legibility of the text and minimizes any danger of overwriting. This mechanism is utilized both in the execution of cursive and block handwriting. In Figure 41 a typical use of this mechanism of enlargement is presented.

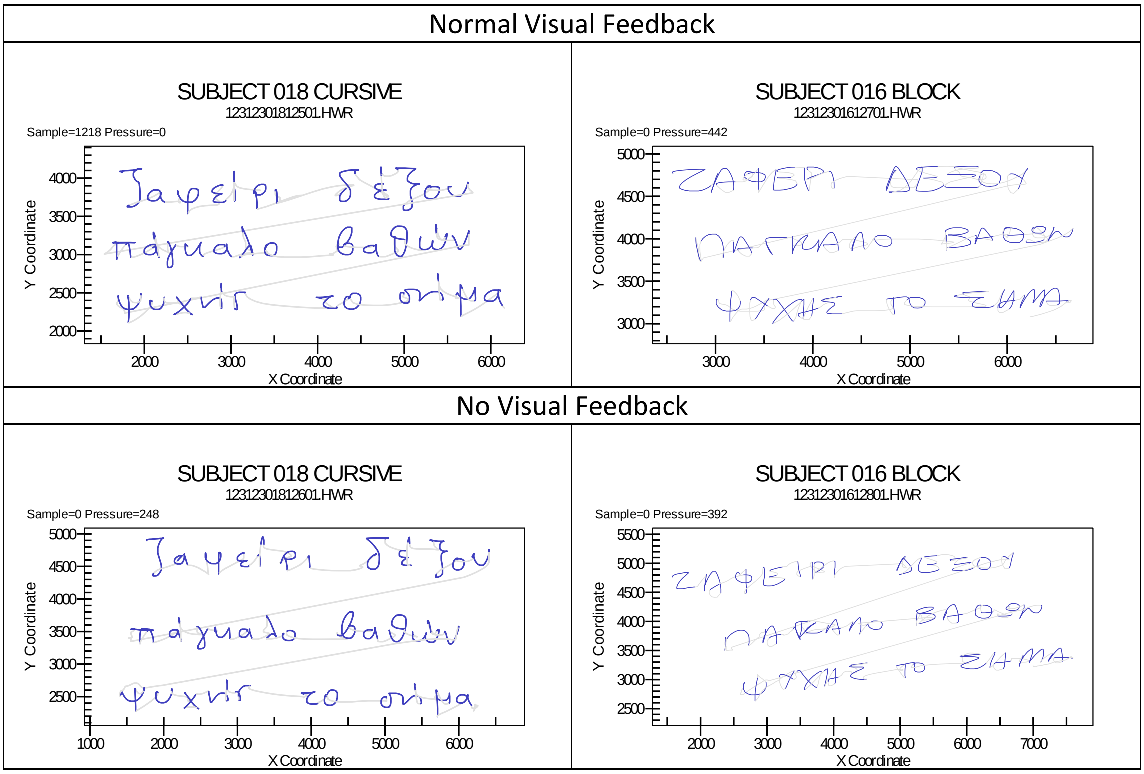


Figure 41. Examples of enlargement of intra and interword spacing as well as interlinear spacing in the condition of no visual feedback.

This mechanism reached its extremities in trials like the one pictured in the Figure 42 where the writer divided the second single line into two, the one under the other, out of the fear that the sample will exceed the horizontal size of the writing area of the tablet.

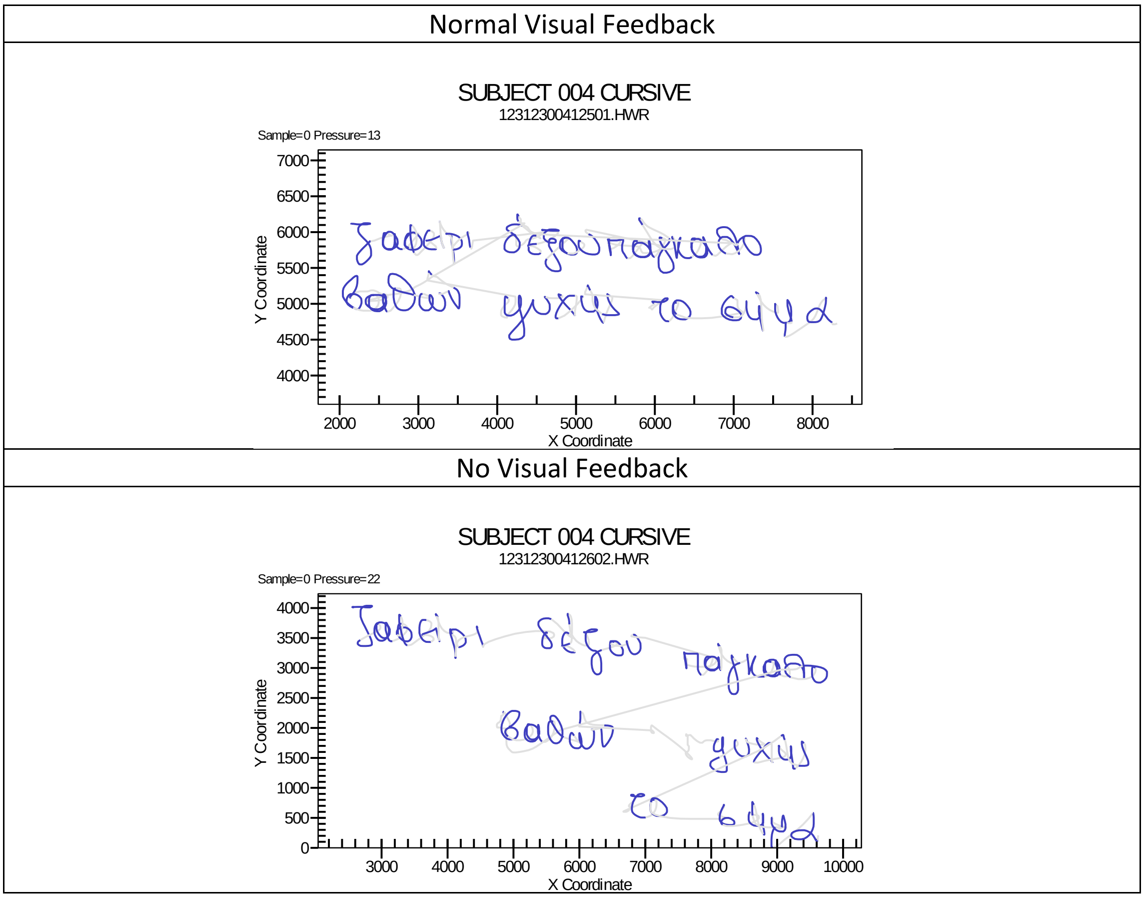


Figure 42. Division of the second line of the text («βαθών ψυχής το σήμα») into two lines.

Out of 40 subjects this phenomenon was noticed in 4 participants in the case of block handwriting (10%) while it was also detected in two of these in cursive writing (5%).

In the second utilized strategy the writer mainly reduces the interlinear spacing between the lines of the handwriting samples, while reduction of intra and inter word spacing and letter size is also noticed. This is a less optimal strategy since due to aforementioned overwriting and loss of line quality, which reduces the legibility of the handwriting sample. In Figure 43 two examples of such overwriting are presented.

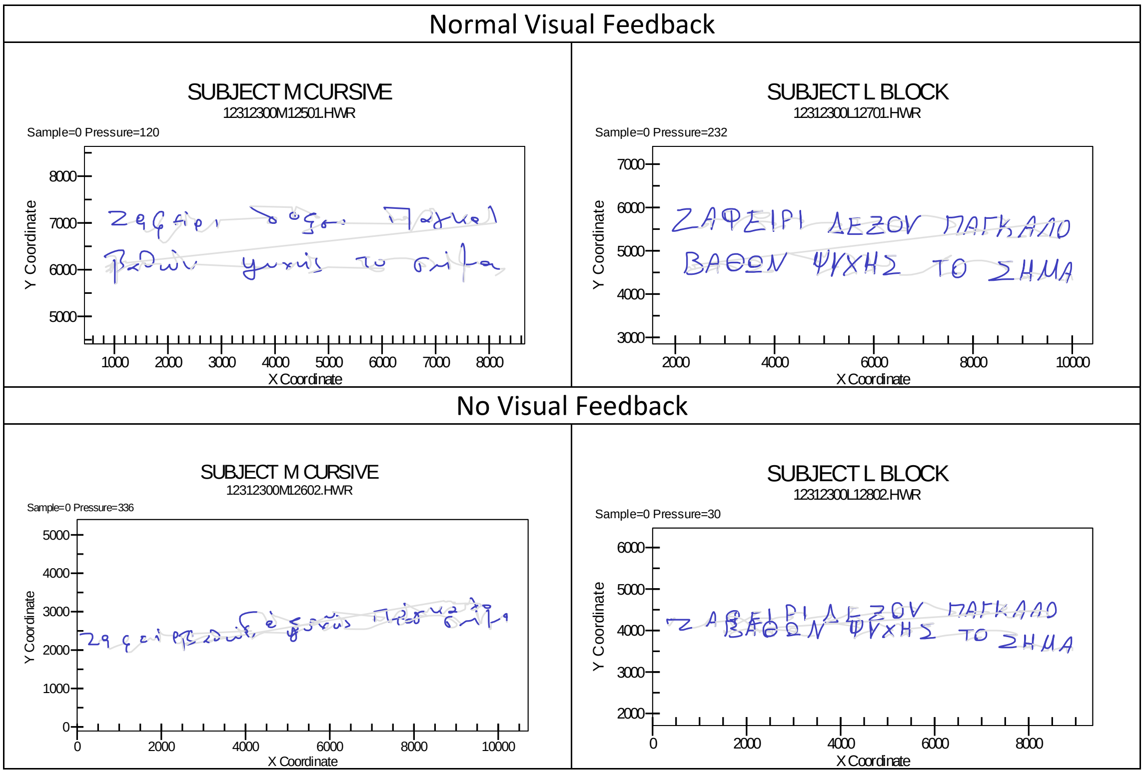


Figure 43. Examples of interlinear spacing reduction in the condition of no visual feedback that results in partial overwriting. Legibility is compromised.

As already stated there is no case of significant overwriting of the left letter of the currently executed text, while forensic analysis shows that in very rare cases the currently executed letter overlaps a minor part of the previously executed letter on its left in Condition 2 unlike Condition 1, as seen in Figure 44 (see red square). In fact in the examination of cursive handwriting there were 9 main cases found in total (on 7 participants) that a minor overlap occurs, while 6 main cases in total (on 5 participants) in block handwriting.

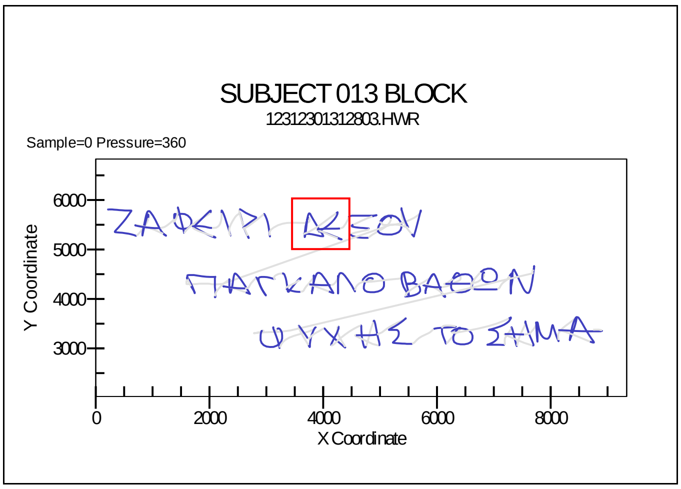


Figure 44. Minor overlap in condition of no visual feedback, where letter E crosses part of the letter Δ.

No correlation between the choice of the one mechanism over the other and the gender, educational level and handedness was found. However it was noticed that the person who chooses the one mechanism over the other will use it both when writing cursive and block handwriting. However, it was also noticed that the writers may tend to educate themselves after each trial, thus making their handwriting more optimal. In Figure 45 two examples of less optimal mechanisms ,where the interlinear space in the condition of no visual feedback were decreased, are observed. Due to this mechanism there are a number of overwritings and the general image and legibility of the samples is compromised. The writers gradually educated themselves by observing after each trial the produced handwriting and making corrections regarding the letter positioning.

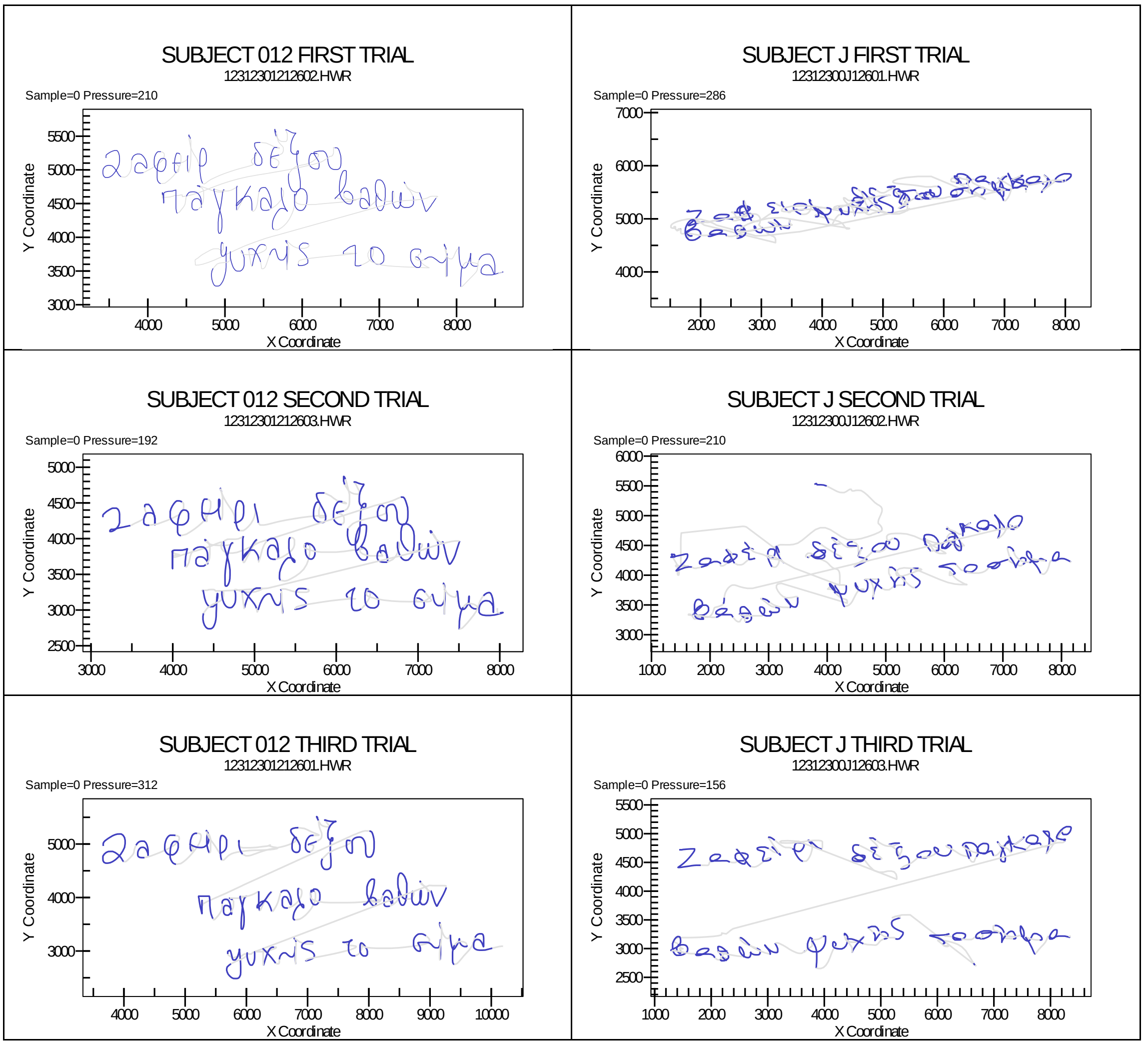


Figure 45. Examples of self-correction of interlinear spacing in the condition of no visual feedback.

4.2.2.10. Second Flag: Non Uniformity of left margins

A second flag that is linked with handwriting execution under the condition of no visual feedback is the non uniformity of left margins in writers who position the left margins of the handwriting samples in a uniform way while having visual feedback: 6 participants out of 40 (15%) manifested uniformity in all of their trials in cursive handwriting, while no participant (0%) did the same in block handwriting.

Figure 46 shows a typical example of non uniformity of left margins in both cursive and block handwriting. Red lines show the uniformity of left margins in condition 1 (normal visual feedback) while blue lines show the non uniformity in condition 2 (no visual feedback).

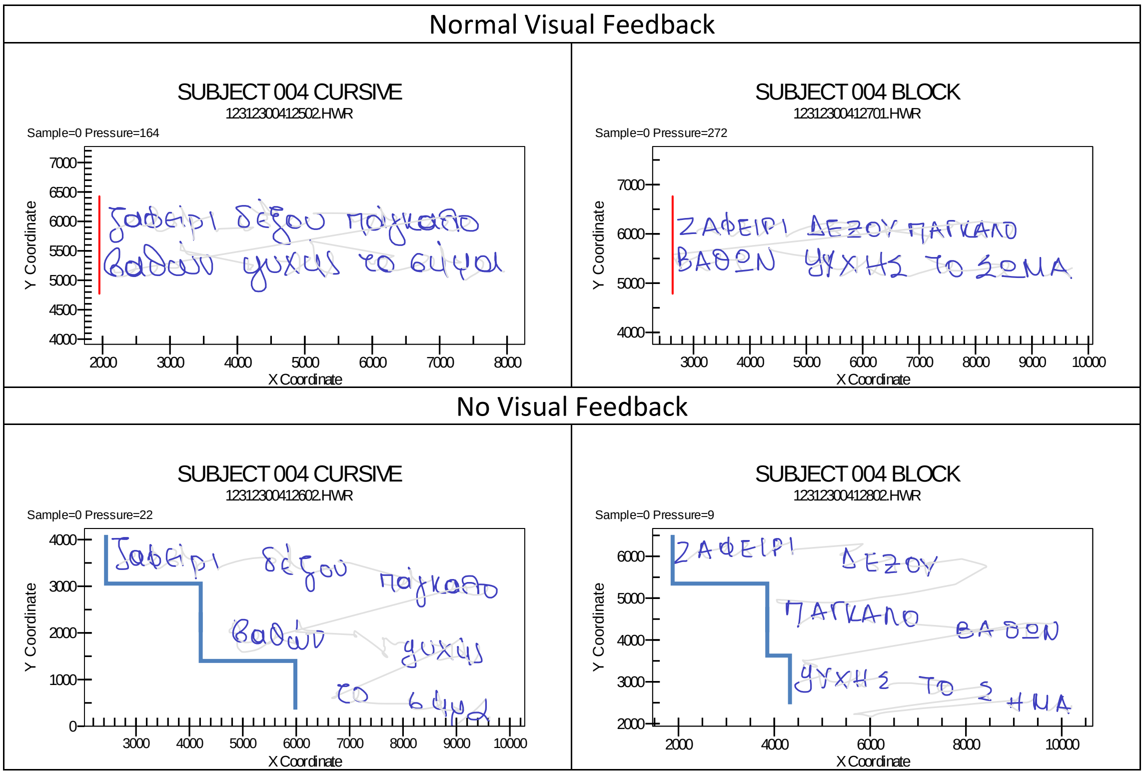


Figure 46. Examples of non uniformity of the left margin in both cursive and block handwriting.

The major tendency of this non uniformity is when the writer positions the second (or third) line further right to where the first one was placed. This positioning towards the right is not linked with the handedness of the writer. In Figure 47 the cursive samples of two participants are demonstrated. Though the handedness is different, the margin positioning under no visual feedback is of the same nature.

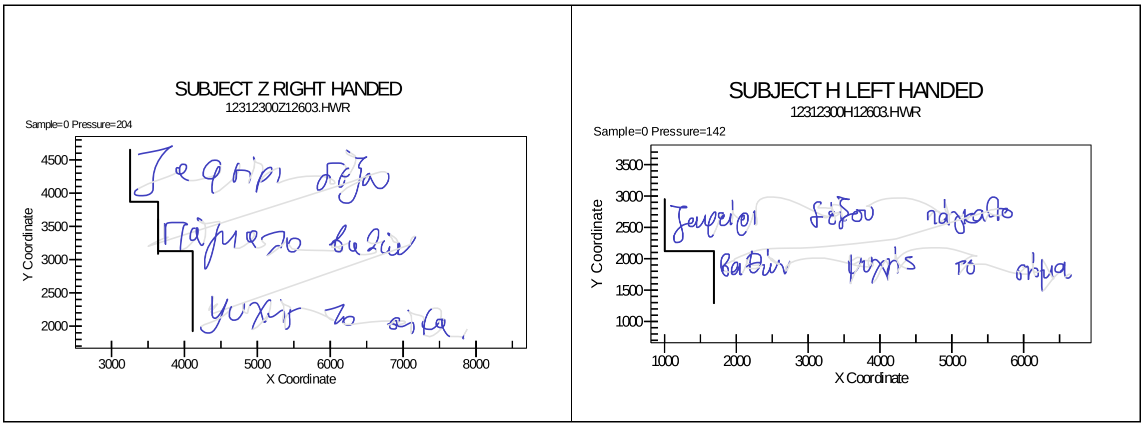


Figure 47. . Examples of non uniformity of the left margin in both handednesses.

This non uniformity of the left margin tends to be stable: 27 of the participants (67,5%) retain the same positioning in all trials in cursive and 18 in block handwriting (45%). This suggests 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 48 shows a multitude of such examples of stability in the positioning of the subsequent lines.

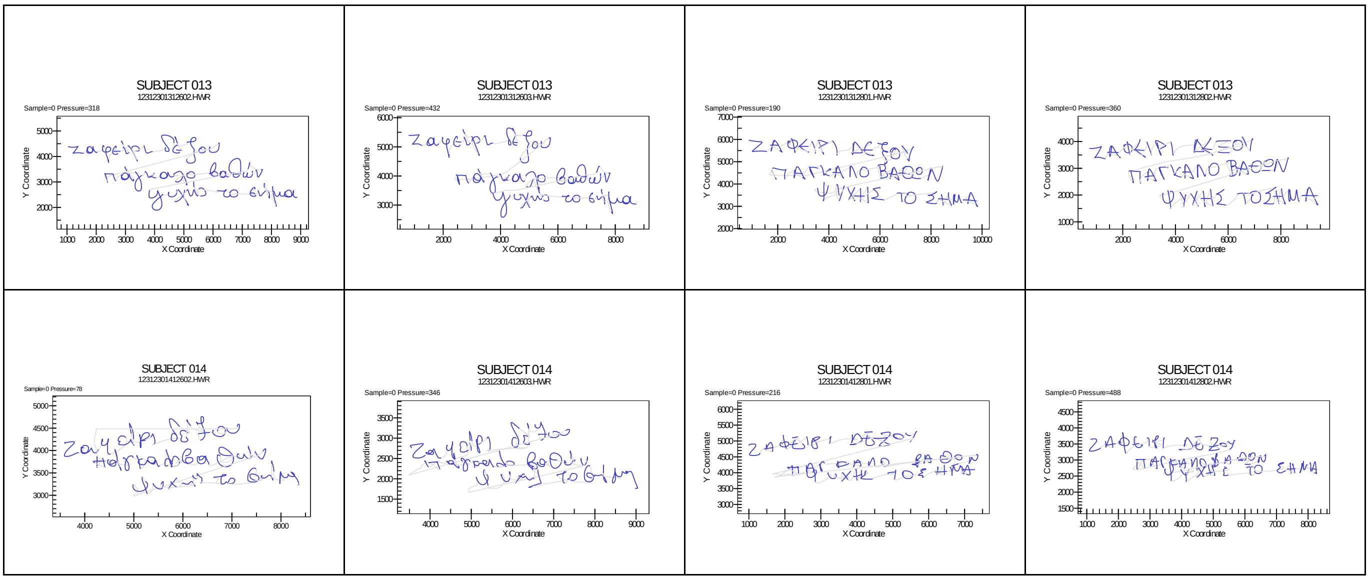


Figure 48. Examples of stability in the positioning of the subsequent lines in condition 2.

It is interesting to note that the tendency of margin stability remains even in the instances where the margin is moved towards the left of the document, as presented in Figure 49.

Subject 015 is a right-handed female and therefore no explanation due to handedness could be proposed to answer why she “chose” to position the margins to the left and retain this positioning. However even more interesting is the fact that in both cursive and block handwriting the middle line is positioned to the left while at the start of the third line in all samples she “corrects” this by placing the initial letter to the right again. This complex and peculiar execution is very stable and highly individualized.

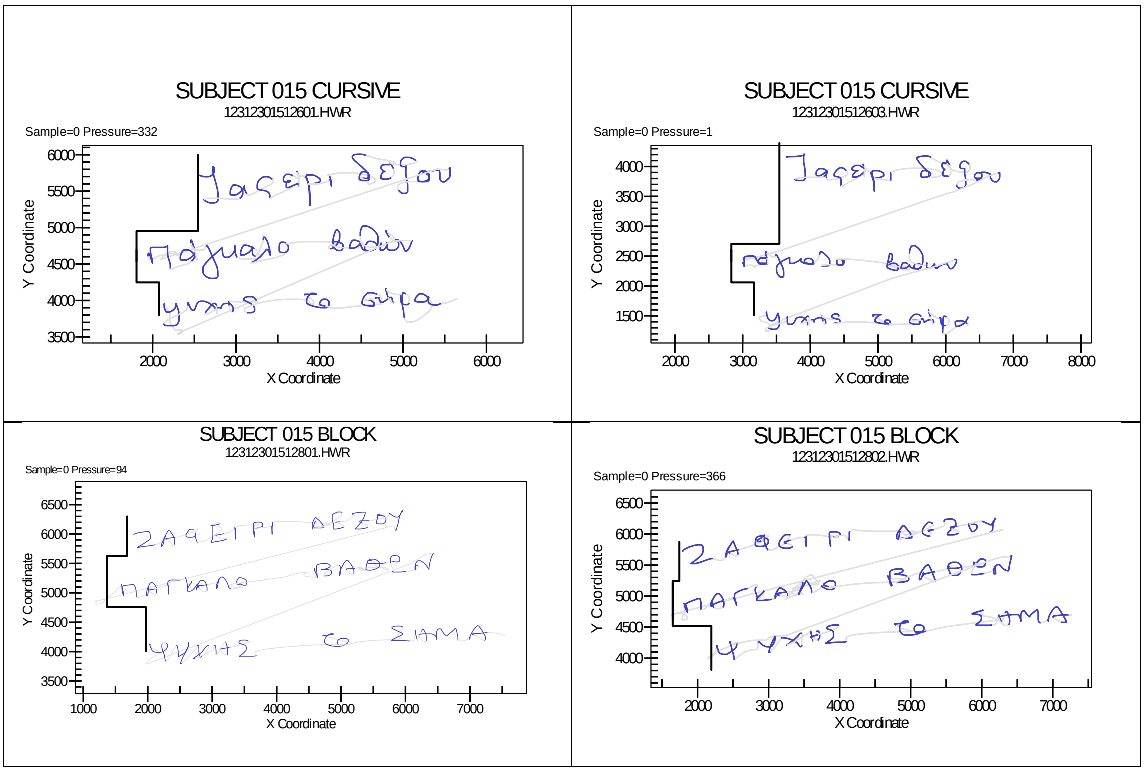


Figure 49. Examples of stability of margin positioning

4.2.2.11. Third Flag: Change of overall Slant

Slant defines the inclination of allographs relative to the perpendicular to the baseline of the writing. It was noticed that 15 of participants change their slants into a noticeable degree in cursive handwriting (37,5%) and 14 in block handwriting (35%). In the 53% of changes in cursive, the slant moved upwards, while in 50% in block. In two occasions both upward and downward slant is noticed in the same handwriting sample in block handwriting. The change of slant tends to be uniform in both cursive and block handwriting, as presented in Figure 50 and therefore in all situations where a participant modified his slant in both cursive and block handwriting, they were both slanted towards the same direction.

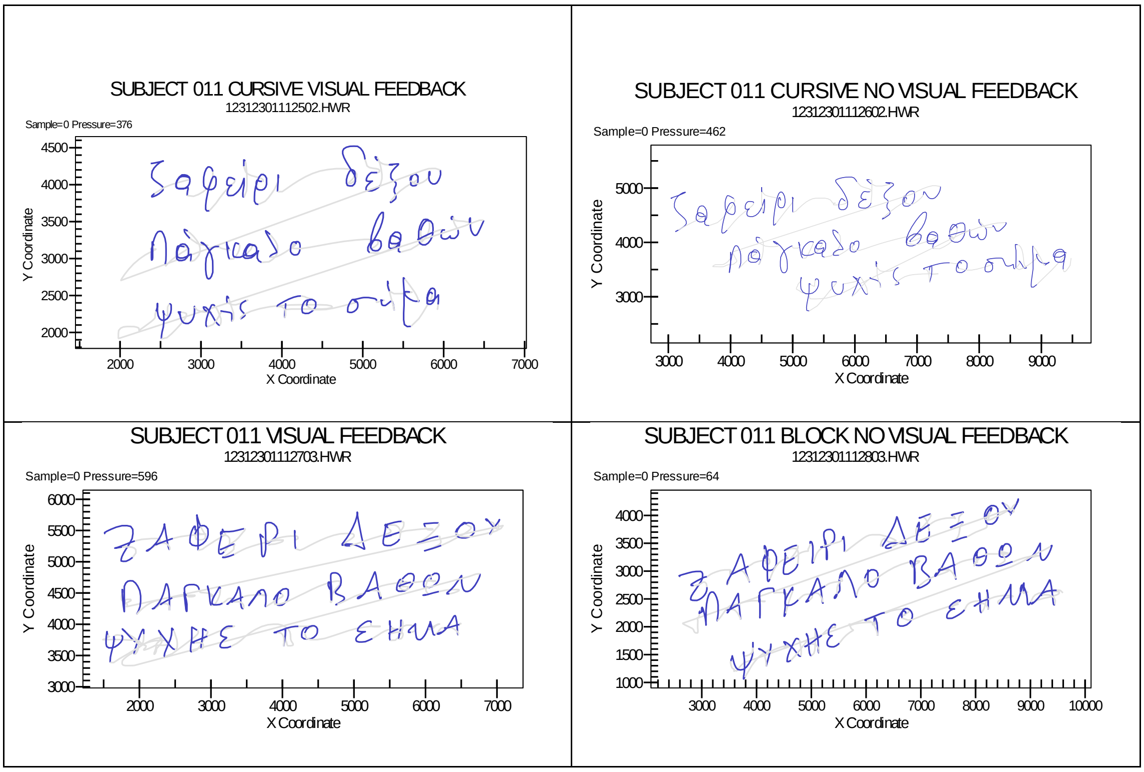


Figure 50. Uniformity of slant change in both cursive and block handwriting.

The change in slant is not related to handedness. However, the changes tend to be replicable in most trials. This applies even in samples where complex and highly individualistic slant compilations appear as is demonstrated in Figure 51, where the sample manifests three different slants, one per line. This phenomenon is replicated in each trial.

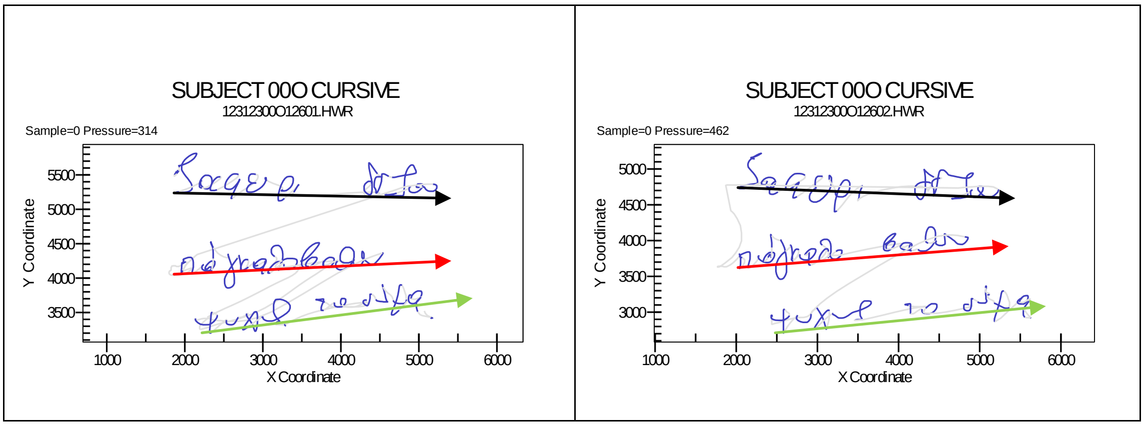


Figure 51. An example of repeatability in both conditions of an individualized slant.

4.2.2.12. Fourth Flag: Avoidance of Pen Lifts

Loss of visual feedback compromises the writer's ability to reestablish the alignment of the executed allograph to the already existing ones. This problem is magnified when the writer breaks the contact of the writing medium and the document by lifting and hovering as it makes an aerial stroke towards the next landing point in the document. The aerial transition denies the writer of the kinesthetic feedback given via pressure.

As a compensation mechanism, it was hypothesized prior the investigation that occasions where the phenomenon of a decrease in pen lifts would be prominent. However, the forensic analysis shows that such instances are not common and rarely correspond to a simplification of the general design of the allographs. The avoidance of pen lifts affects mainly the auxiliary elements of the handwriting, e.g. in the intonation and punctuation signs of the Greek language, and rarely a full allograph. Another method to minimize pen lifts is by transforming semi-material and immaterial connections to material. Therefore, in a handwriting sample in Condition 1 two allographs are connected via an immaterial connection, depicted as pen air lift trajectory-reestablishment of connection to the document. The same connection in Condition 2 may be transmuted to material and therefore the one allograph is connected to the next without any pen lift, by a trajectory drawn on the document. In fact only in one subject (2.5%) the cursive handwriting changed from disconnected to highly connected in Condition 2, in order to avoid the loss of contact. In Figure 52 the absence of the letter l is pointed with a red arrow in the cursive writing of subject 012, who possesses a high level line of quality. Furthermore in the low level line quality of subject 00D it is noticed that the disconnected word βαθ(ών) became connected (see red rectangle), while the disconnected ει became fully connected (black square).

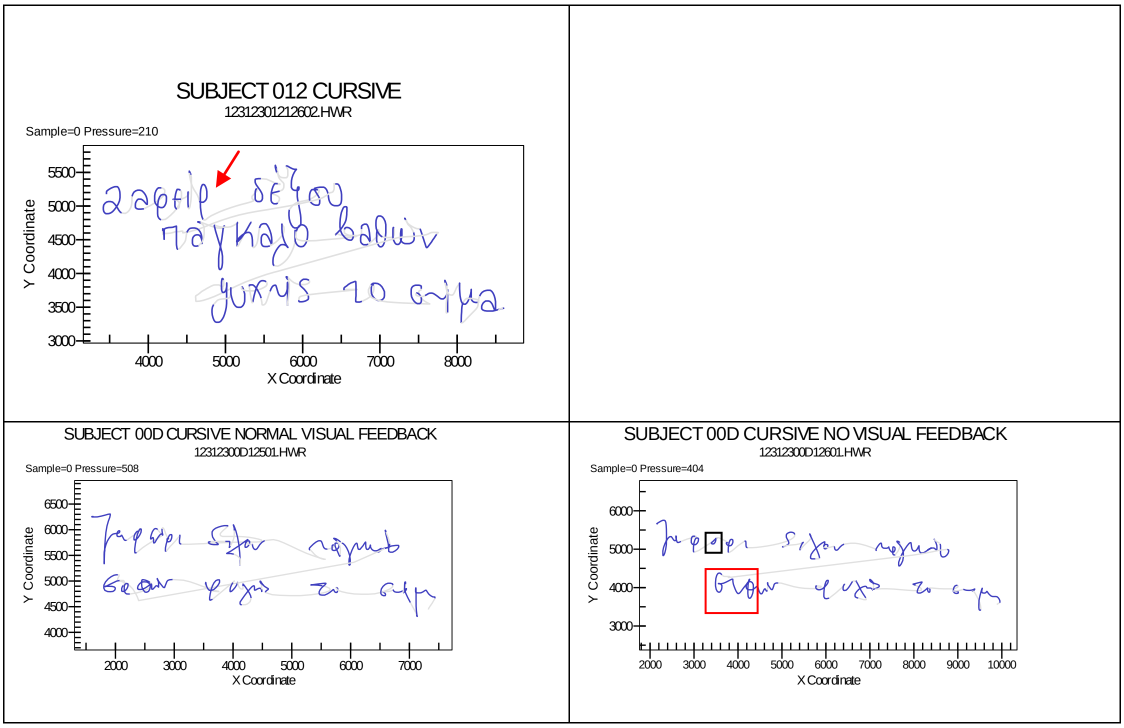


Figure 52. Two examples of pen lift avoidance in the condition of no visual feedback.

Another less prominent occurrence of an immaterial line that is transmuted to a material one is presented inside the red circle in Figure 53.

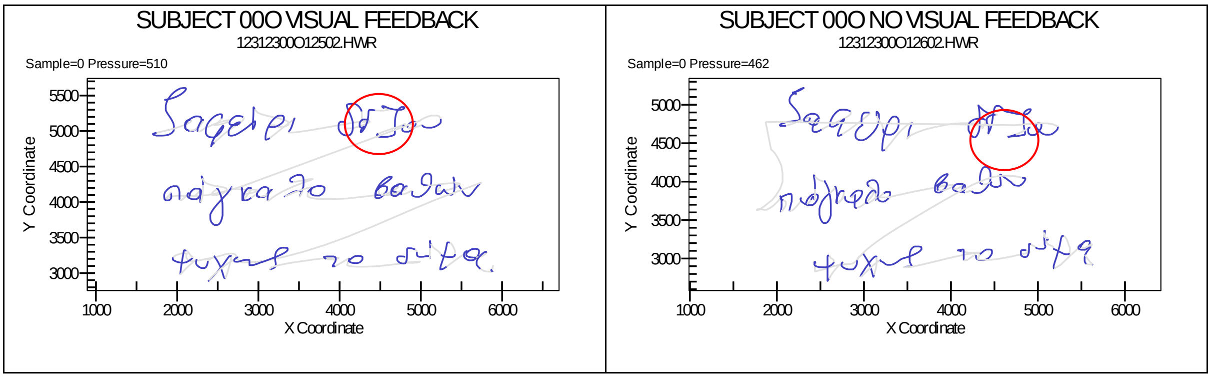


Figure 53. Transformation of an immaterial line to a material one.

4.2.2.13. Fifth Flag: Inclusion of extra trajectories

Two of the writers when writing cursive (5%) and 6 when writing block (15%) inserted extra trajectories in the dictated handwriting sample. The trajectories may be 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 54 we can see the inclusion of the allograph Ο 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 Ο 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 medium 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 Ο) and the time period from 20.04 sec to 20.68 (that is the sequence after the creation of the first Σ) shows the absolute velocity is decreased (see blue arrows).

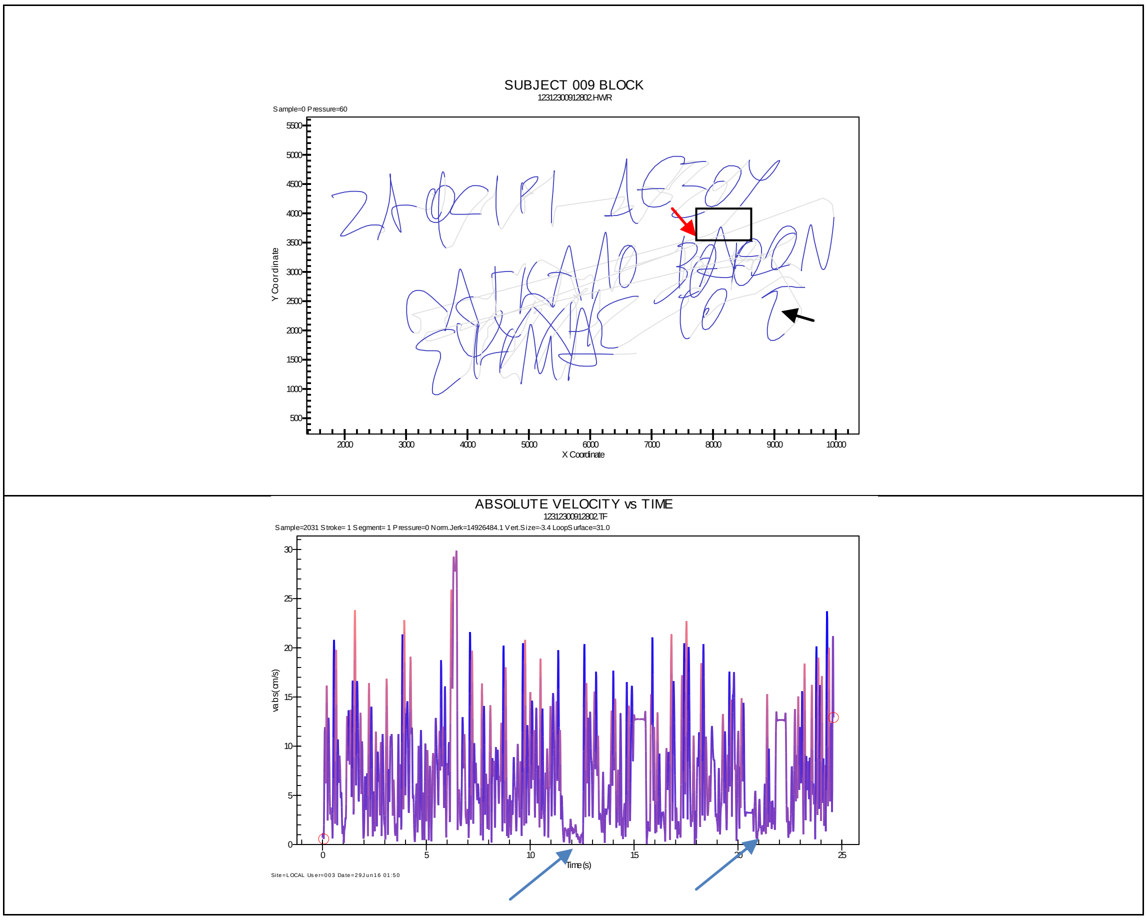
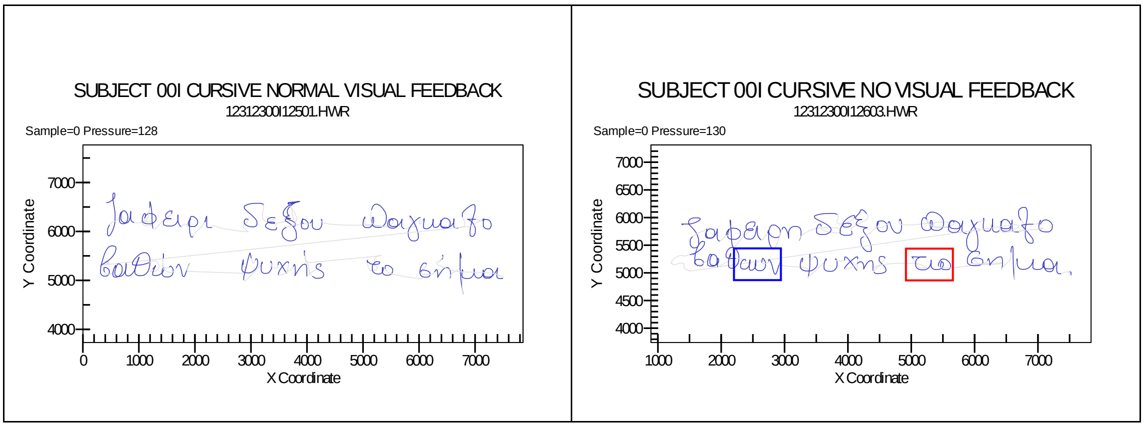


Figure 54. An example of addition of extra letters in the condition of no visual feedback.

In Figure 55 the replication of the previously executed trajectory is presented. In the cursive word βαθών an extra V-shaped trajectory is added next to the letter ω, creating the shape vvv, as is shown in the blue box. Before the duplication of v the absolute velocity is almost zero (from the 14,155 sec to 14,473 sec, with lowest peak 0,013 cm/s).The same phenomenon is noticed in the word το where the anticlock wise o trajectory is duplicated (from the 18,610 sec to 18,800, with lowest peak 0,010 cm/s) as is shown in the red box.



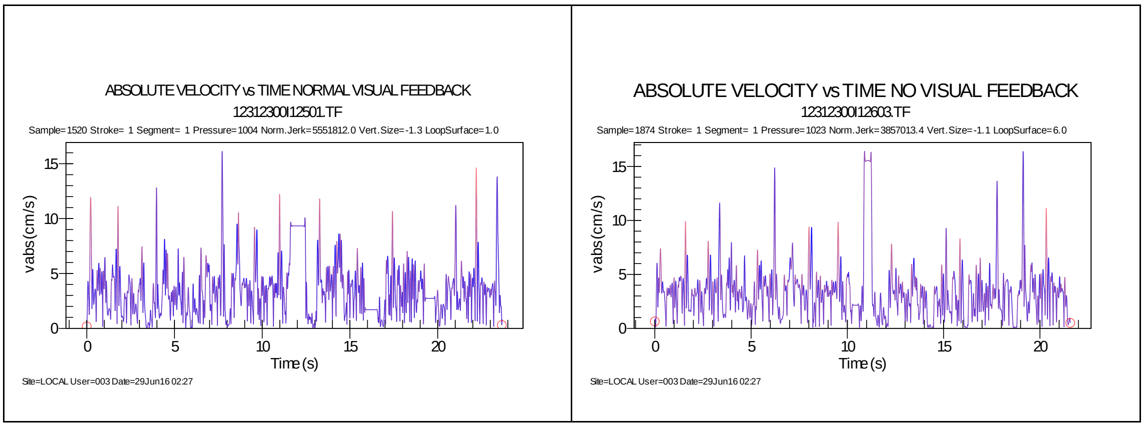


Figure 55. An example of trajectory duplication in the condition of no visual feedback.

The final type of inclusion of an extra allograph is the addition of a trajectory complex that has no utility in a letter and therefore acts as pictorial noise. In Figure 56 part of a block sample is presented. Additional trajectories that have no purpose have been added in the letter Θ (see red arrow) and in the letter ψ (see black arrow).

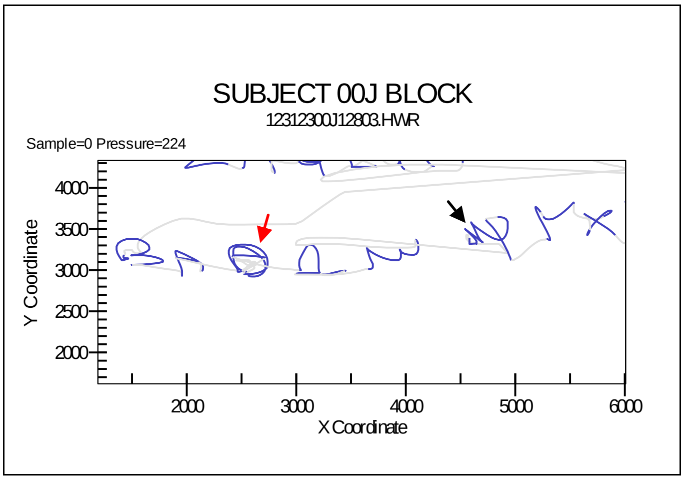


Figure 56. An example of addition on purposeless trajectories in the condition of no visual feedback.

4.2.2.14. Sixth Flag: Decrease of Line Quality

The loss of visual feedback can create a limited decrease of the line quality. This decrease however is not significant: the letters created under the condition of no visual feedback remain fully legible and -as already stated- are part of the group of natural variations of the normal handwriting of the writer. In Figure 57 the writer while writing without visual feedback executes more abrupt and simplistic trajectories and concludes the trial in less time (18,380 sec versus 19,630 sec) than when writing with normal visual feedback. As a result elements of lesser line quality interfere. The letter Ξ (red arrow) and the letter Η (blue arrow) are not fully formed while the loops of the word ΠΑΓΚΑΛΟ (black rectangle) are elongated and bizarre. Furthermore the initial aerial trajectory acts as a medium of navigation (black arrow).

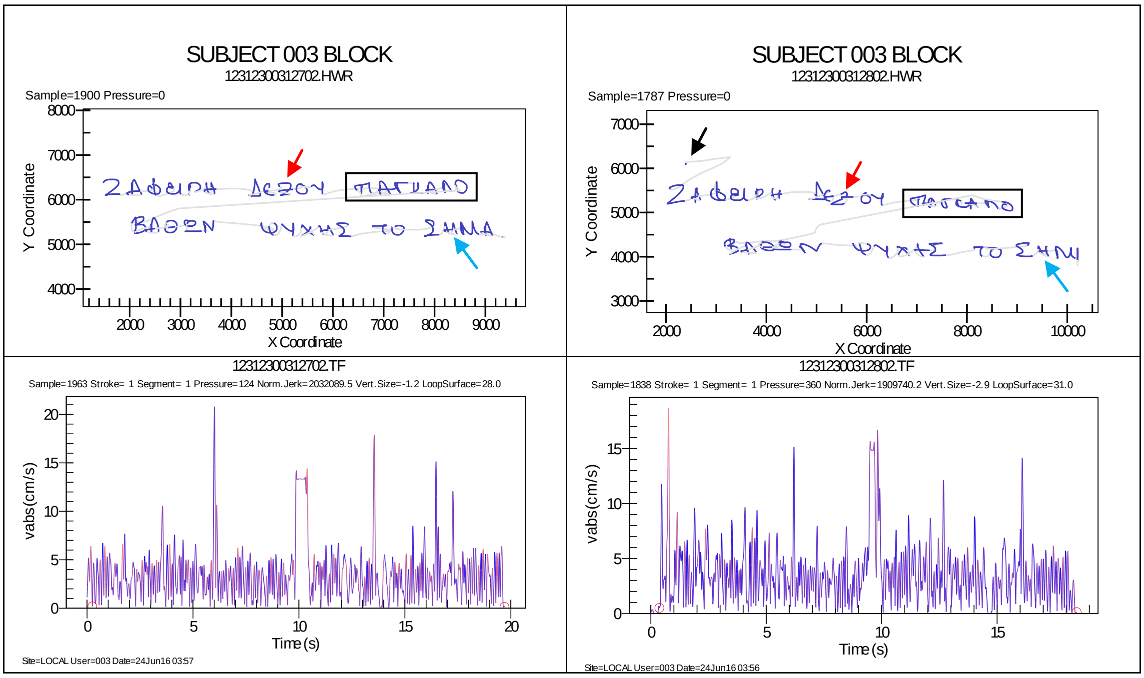


Figure 57. Decrease of line quality in the block sample in the condition of no visual feedback.

In Figure 58 the line quality in both conditions is mediocre – the letters are drawn hastily and not fully formed, the intra letter and intra word alignment is erratic and the base line wavy, but Condition 2 introduces the existence of the distorted drawn formation Λ (see red square).

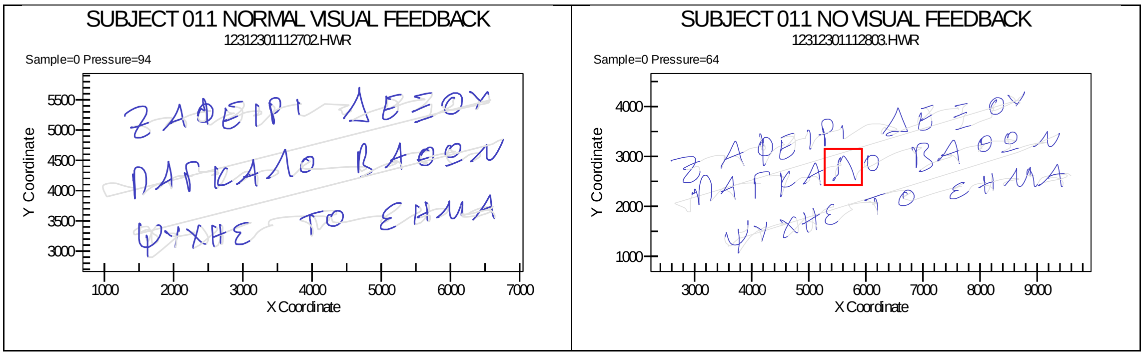


Figure 58. A distorted trajectory in the condition of no visual feedback.

4.2.2.15. Summary of Findings of the Forensic Comparison regarding Cursive and Block handwriting

Forensic comparison shows no significant differences between the subgroups of the handwriting (both cursive and block) executed under the two conditions.

However when an FDE comes across a number of the aforementioned flags –mostly connected to the loss of the writer's ability to successfully align the position of the executed trajectories in regards with already existing ones- they should bear in mind that a handwriting sample may be written under the condition of no or limited visual feedback. With the exception of the decrease of the level of Line Quality, any other differences found, and are linked with condition, 2 were seen only at the macro level of the handwriting sample. No indications of loss of visual feedback was found when examining an allograph by itself with the exception of possibly a decrease of Line Quality,

However the most interesting finding – as was implied in many instances above- is that the mechanisms that a person chooses in order to compensate for lack of visual feedback are not random, but are repeated and consistent. This occurs even in instances of complex compositions of slants, overwriting, non uniformity of margins and general design of the allographs, where this highly individualized combination is replicated in each trail. In Figure 59 the duplication of a complicated and individualized relation of slant, intra word alignment and letter positioning is shown:

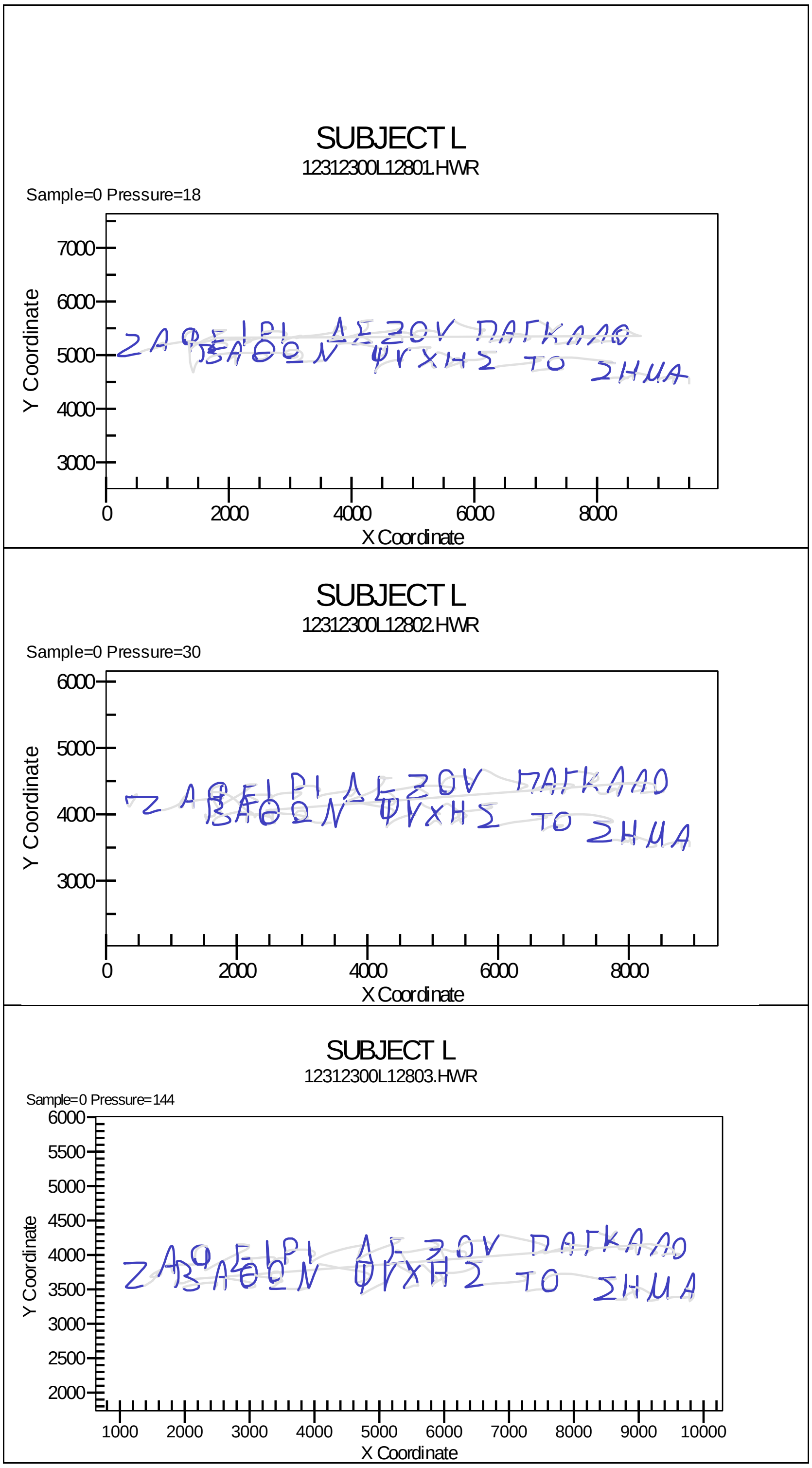


Figure 59. Duplication of a highly individualized relation of slant, intra word alignment and allograph positioning in three samples of block handwriting in the condition of no visual feedback.

In Figure 60 another example of replication of highly individualized changes in Condition 2 is presented. In both the block and cursive samples one could notice the elongated interlinear space between the first and second line, the transition of each line further to the right and the uniformity of slants.

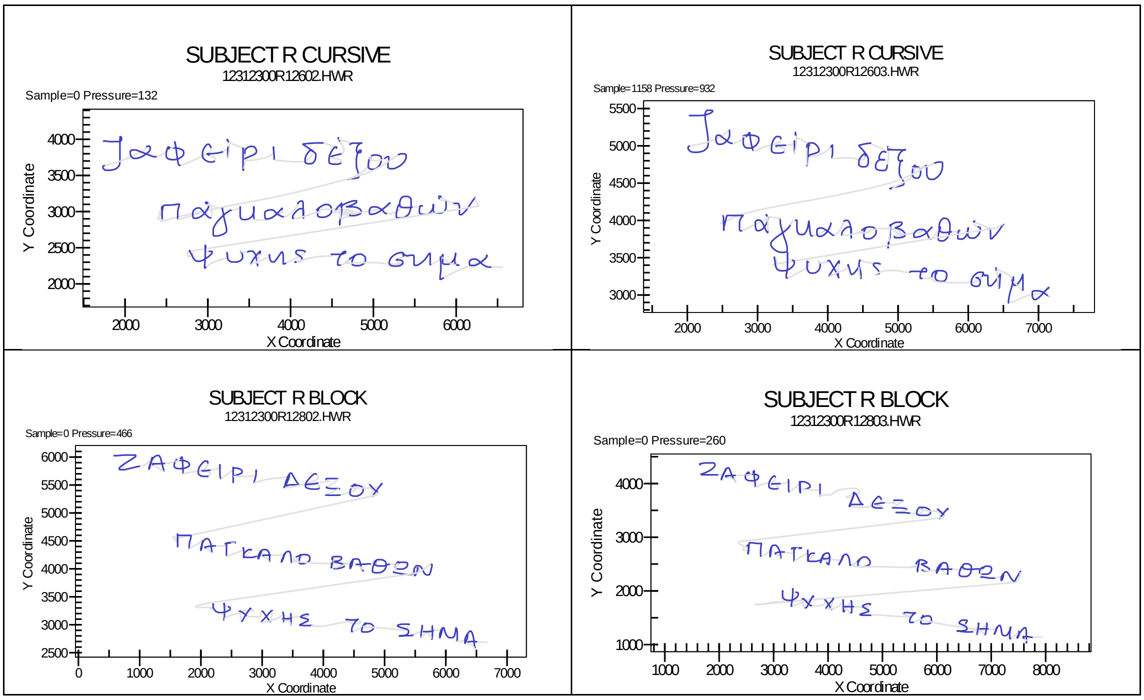


Figure 60. Duplication of highly individualized relations between the individual characteristics in samples of both cursive and block handwriting in the condition of no visual feedback.

As is further discussed in Chapter 5 the repeatability of such complex constructions is linked with a open loop motor program that is used to create signatures and handwriting and is not influenced at a trajectory level by the loss of visual feedback and thus it is able to produce repeatable and legible results.

In verification to the above findings the Second Examiner certified the lack of significant differences in both cursive and block handwriting and the existence of a group of highly individualized similarities. She furthermore found and commented on a number of differences ,e.g. regarding the size of the letters and the spacing between words and lines, that could be used as a sign of lack of feedback but could not differentiate the writer and thus could not be considered significant. Concluding she states that under proper evaluation of the facts a trained forensic document examiner should not reach an erroneous conclusion.

Once again the semantic meaning of the reviewer's quote "*Regarding the cursive writing the similarities found between the group with visual feedback and the one without visual feedback, were more than one would expect…. it was expected to find major differences between the two groups*.*"* is linked with the literature contradiction that was analyzed in par. 1.6.

4.3. Findings of the analysis through the use of software module.

As mentioned in par. 1.6.2., the data collected of duration (s), absolute, horizontal and vertical size (cm), average pressure (z), road length (cm), average absolute velocity (cm/s) and slant (rad) were statistically analyzed using the statistics analysis software SPSS (version 21). The results are presented in the next paragraphs and explore a) whether there is any significant difference between the two conditions of visual feedback for each one of the eight examined individual characteristics and b) in the cases of said differences, whether the gender, handedness and education level significantly influence them. This presentation will include signature, block and cursive handwriting.

4.3.1. Statistical analysis of the influence of visual feedback in the individual characteristics of signatures.

Table 2 shows the results of the influence of visual feedback in the individual characteristics of signatures for normally distributed data.

Individual Characteristics	Mean	S.D.	t-test	r	Comments
Duration 1 - s	2.08	1.17	<0.001	0.55	The absence of visual feedback influences significantly the duration of the execution of the signature, since the time of execution increases in Condition 2.
Duration 2 -s	2.27	1.27			
AvAbsVelocity 1 - cm/s	10.48	5.38	<0.001	0.56	The absence of visual feedback influences significantly the average absolute velocity of the execution of the signature, since the speed of execution in Condition 2.
AvAbsVelocity 2 – cm/s	9.55	4.67			
Vertical Size 1 - cm	-0.12	1.07	0.35	---	The absence of visual feedback does not significantly influence the vertical size of the

Vertical Size 2 - cm	-0.17	0.97			signature.
HorizontalSize1 - cm	1.76	1.50	0.164	---	The absence of visual feedback does not significantly influence the horizontal size of the signature.
HorizontalSize2 -cm	1.92	1.35			
Roadlength1 - cm	18.71	9.51	0.84	---	The absence of visual feedback does not significantly influence the roadlength of the signature.
Roadlength 2 - cm	18.64	9.04			
AvPenPressure1 - z	639.11	125.63	0.36	---	The absence of visual feedback does not significantly influence the average pen pressure of the signature.
AvPenPressure 2 - z	647.70	121.25			

Table 2. Presentation of the t-test results

Table 3 shows the results of the influence of visual feedback in the individual characteristics of signatures where the data distriburion was non-normal.

Individual Characteristics	Mean	S.D.	Wilcoxon signed-rank test	r	Comments
Slant 1 – rad	-0.164	0.97	0.46	---	The absence of visual feedback does not significantly influence the slant of the signature.
Slant 2 –rad	-0.152	0.65			
Absolute Size 1 - cm	2.27	1.28	0.53	---	The absence of visual feedback does not significantly influence the absolute size of the signature.
Absolute Size 2 - cm	2.31	1.34			

Table 3. Presentation of the Wilcoxon signed-rank test results

The above tables show that the absence of visual feedback significantly influences only the duration and the average absolute velocity of the signature. Therefore, there is no significant difference in any pictorial characteristic, while only the temporal characteristics are influenced with a medium effect size. The lack of any pictorial significant difference was already noticed by the forensic comparison, which did not pinpoint any such difference when the samples of the two different conditions were compared. Furthermore, as was noted in paragraph 4.2.1., contrary to both cursive and block handwriting, no flags of writing during the absence of visual feedback were found by the forensic comparison, which is verified also by the statistical analysis presented here. The temporal significant difference suggests that during the condition of no visual feedback the writer reduces the speed of execution which leads to an increase of the time of execution. Summarily, the above findings match with the depiction of the execution of signature as a highly automated action.

4.3.2. Statistical analysis of the influence of visual feedback in the individual characteristics of cursive handwriting.

Table 4 shows the results of the influence of visual feedback in the individual characteristics of cursive handwriting for normally distributed data.

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 Condition 2
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 Condition 2.
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 2
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 Condition 2
HorizontalSize 2 - cm	7.01	1.84			

Table 4. Presentation of the t-test results

Table 5 shows the results of the influence of visual feedback in the individual characteristics of cursive handwriting where the data distribution was non-normal.

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 Condition 2 .
AvPenPressure2 - z	151.83	33.54			

Table 5. Presentation of the Wilcoxon signed-rank test results

In the absence of visual feedback it is suggested that the average pen pressure is significantly increased as an attempt of the writer to reinforce the kinesthetic feedback received from the friction between the writing medium and the document. The absolute and the horizontal size are both increased significantly in the condition 2, while the vertical size is reduced. All these findings were already discussed in paragraphs 4.2.2., where the different strategies of writing in the second condition were presented. The quantification of the results illustrates the main strategy through which the writer tries to adapt to the lack of visual feedback: the overall handwriting is enlarged, showing larger intra- and inter-word spacing, while the vertical size of the text is reduced, sometimes to a degree where overlaps of the lines appear (see par. 4.2.2.9.). Slant is also significantly changed, as was suggested in the forensic comparison. Roadlength does not significantly change and this is expected since, as noted in the forensic comparison, the complexity of handwriting was not fundamentally changed between the two conditions, while the simplification of the letter design or the omission of letters is a rare occurrence. The insignificant influence on duration and average absolute velocity will be discussed in par. 4.3.4.

4.3.3. Statistical analysis of the influence of visual feedback in the individual characteristics of block handwriting.

Table 6 shows the results of the influence of visual feedback in the individual characteristics of block handwriting for normally 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 cursive handwriting sample, since it increases during Condition 2
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 cursive handwriting sample, since it decreases during Condition 2
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 cursive handwriting.
Roadlength 2 - cm	79.12	20.95			

Table 6.Presentation of the t-test results

Table 7 shows the results of the influence of visual feedback in the individual characteristics of block handwriting where the data distribution was non-normal.

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 slant of the block handwriting sample, since it increases during Condition 2 .
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 Condition 2 .
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 Condition 2 .
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 Condition 2 .
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 Condition 2 .
AvAbsVelocity 2 –cm/s	3.88	0.87			

Table 7. Presentation of the Wilcoxon signed-rank test results

The majority of the findings are similar to those of the cursive handwriting. Average pen pressure is significantly increased. The absolute and the horizontal size are both increased significantly in the condition 2, while the vertical size and slant are reduced, a cluster of findings which verify the forensic comparison. Duration is significantly increased while average absolute velocity is decreased, a finding which corresponds to the equivalent one regarding signatures.

4.3.4. Synthesis of the findings.

It is noticed that the significant changes do not appear randomly but follow certain patterns that will be analyzed in this section.

4.3.4.1. As already explained, the only significant changes in signature execution are temporal suggesting a large degree of automation in this action, to an extent that a whole signature could be regarded as one memory unit and thus executed as a one allograph. This is not the case in the cursive and block handwriting, where a large number of characteristics are significantly changed. Furthermore the absolute number of characteristics significantly altered can be considered as a manifestation of the degree of automation, in accordance to the forensic findings. Therefore cursive handwriting shows 5 out of the 8 characteristics changed, while block 7 out of 8, thus signifying that cursive retains a larger degree of automation than block handwriting. It is noted that the only characteristic not significantly influenced in all three different writing types is roadlength. Roadlength is linked to the complexity of the writing sample and as already noted no significant simplification of the allographs was noticed in condition 2 both in the case of cursive and block handwriting.

4.3.4.2. The group alteration of Slant, Horizontal, Vertical and Absolute Size in both the cursive and block samples during the two conditions is very enlightening. In both types of handwriting it is noticed that during Condition 2 Horizontal and Absolute Size are significantly enlarged, while Vertical Size and Slant are decreased, as is presented in Figure 61. This repetitive pattern is highly individualized and complex.

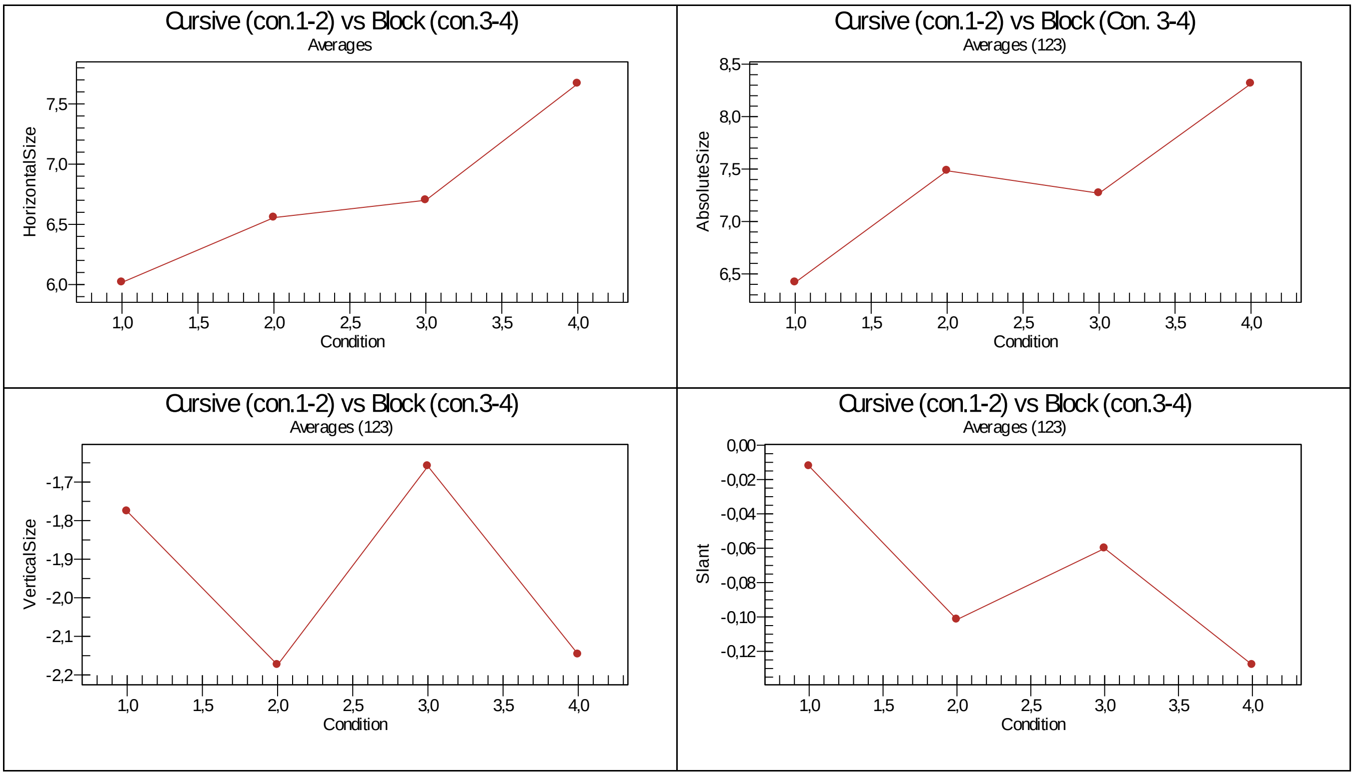


Figure 61. Legend: Condition 1 = cursive with visual feedback. Condition 2 = cursive without visual feedback. Condition 3 = block with visual feedback. Condition 4 = block without visual feedback. Horizontal, Absolute and Vertical Size are numbered in cm and Slant in radians. Vertical Size is a negative number because it measures the distance between the higher part of the allographs (point 0) and the lowest on.

4.3.4.3. The significant increase of average pen pressure in the cursive and block samples during the condition of no visual feedback is linked with the attempt of the writer to acquire a different type of feedback, i.e. trying to replace the visual to the kinesthetic feedback. Due to the high degree of automation this is not needed in the execution of signatures. Figure 62 illustrates the significant difference between the two conditions in both cursive and block handwriting.

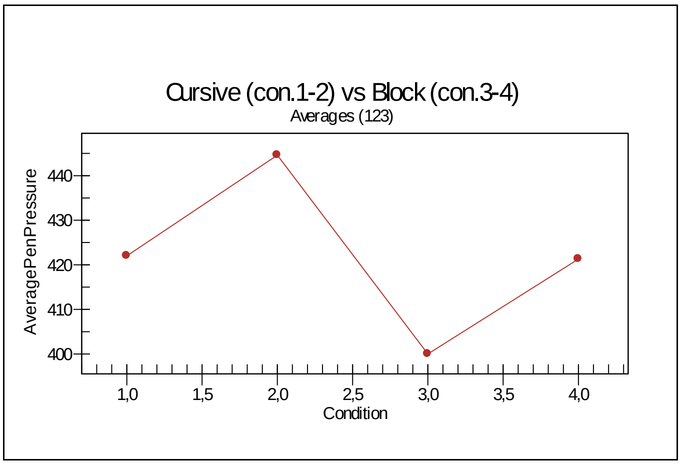


Figure 62. Legend: Condition 1 = cursive with visual feedback. Condition 2 = cursive without visual feedback. Condition 3 = block with visual feedback. Condition 4 = block without visual feedback. Average Pen Pressure is counted in raw digitizer pressure units (z).

4.3.4.4. A very interesting finding is that while the interaction between Duration and Average Absolute Velocity is significant in both signatures and block handwriting, it is not regarded as such in cursive handwriting, as is presented in Figure 63.

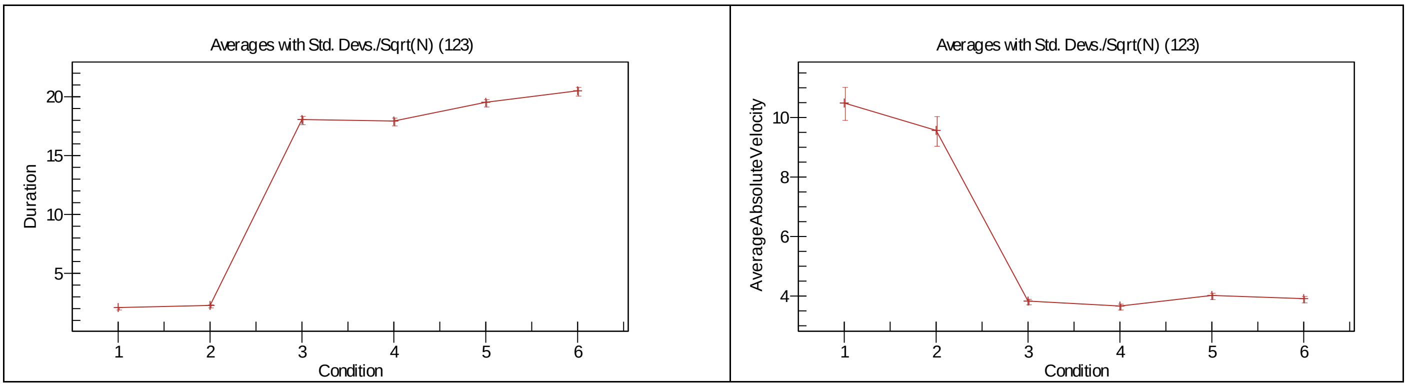


Figure 63. Legend: Condition 1= signature with visual feedback. Condition 2= signature without visual feedback. Condition 3 = cursive with visual feedback. Condition 4 = cursive without visual feedback. Condition 5 = block with visual feedback. Condition 6 = block without visual feedback. Duration is counted by seconds while Average Absolute Velocity by cm/s.

At this point the research cannot pinpoint the causes of this finding. The pertinent literature does not make a general differentiation between cursive and block handwriting and as presented in par. 1.6., there is a general discussion whether the lack of visual feedback slows the execution of writing samples. A working hypothesis, based on the cognitive theory of procedural memory [a type of implicit and long-term memory that is used by individual to perform complicated acts] (Ferma et al, 2009), suggests that since among the three types of writing cursive handwriting is the one more often used in non standard conditions, eg while standing, taking notes in a moving car, scribbling in hurry etc, this may lead to the notion of cursive being the most adaptive type of writing and as such the writer is conditioned by repetition to execute the writing sample without special delay even in extraordinary situations. Furthermore the fact that cursive handwriting is usually connected prohibits, to large degree, the pen stops and airlifts that appear in the handwriting and thus provide a steady kinesthetic feedback to the writer, without which the task of realigning the pen to the document will slow the handwriting execution.

4.3.4.5. There is a general similarity in the level of effect sizes in the individual characteristics significant differences in the two handwriting types (cursive and block) especially in the pictorial aspect, in which slant, vertical and horizontal size tend toward medium effect size (r=0.30-0.50), while absolute size towards large effect size (over 0.50). This homogeneity along with that of the previous findings suggest the unity of motor program (that is, there is one program that organizes the execution of signatures, cursive and block handwriting).

4.4. Comparative analysis of the statistically significant findings

The comparative analysis factored by Gender, Educational Level and Handedness was analyzed. Therefore, Mixed ANOVA tests were conducted to compare the effects of visual feedback and the absence of visual feedback and the interaction effect between Gender, Educational Level and Handedness in the individual characteristics whose changes were found significant in the above paragraphs. However due to the unequal size of compared samples (esp. in the case of educational level and handedness) a number of ANOVAs did not meet their initial assumptions and the following caveats should be taken into consideration:

- In the specific analysis of Horizontal Size of cursive handwriting factored by handedness, Levene's test of equality of error variances indicated that the variances of the variables were not homogeneous and the Shapiro WIlk test for normality of residual distribution showed a non normal distribution for at least one of the variables. Therefore, the analysis does not meet the basic parametric assumptions for mixed ANOVA. Logarithmic (Ln & Log10) and square root transformations of the relevant dependent variables were attempted but could not correct the parametric violations so it came to the conclusion that no ANOVA with dependable results could be calculated.

- In a number of ANOVAS the already discovered significant differences between the characteristic in the two conditions appeared as non significant. This is attributed to unequal size samples and the lack of normality as indicated by the Shapiro-Wilk normality test.

Therefore only the results of the robust ANOVAs will be described below.

Starting with the Comparative Analysis factored by Gender, Table 8 shows the results of the 2x2 mixed-design ANOVA with individual characteristic under investigation in the two conditions of visual feedback (duration under normal visual feedback, duration under absence of visual feedback) as a within-subjects factor and gender as a between-subjects factor.

Table 8. ANOVA results for the relationship between gender and individual characteristics

Individual Characteristics	Df	F	Sig.	Individual Characteristics	df	F	Sig.
Duration Signature - s	1	0.889	0.352	AvAbsVel Signature – cm/s	1	0.254	0.617
HorSizeCursive - cm	1	0.567	0.456	Slant Cursive - rad	1	1.113	0.298
AbSize Cursive – cm	1	1.263	0.268	AvPenPresCursive - z	1	0.704	0.407
Duration Block - sec	1	1.827	0.184	VerticalSize Block - cm	1	0.964	0.332
HorSize Block - cm	1	0.189	0.666	AbsoluteBlockSize - cm	1	0.970	0.331

The above results suggest that the individual characteristics are influenced by the loss of visual feedback the same way in both genders. Therefore the factor of gender creates an insignificant influence during the comparison of the two conditions of these characteristics. This finding adds support to the idea of one uniform motor program for handwriting execution that it is not influenced by other factors (open loop).

Table 9 shows the results of the 2x2 mixed-design ANOVA with individual characteristic under investigation in the two conditions of visual feedback (duration under normal visual feedback, duration under absence of visual feedback) as a within-subjects factor and educational level as a between-subjects factor.

Table 9. ANOVA results for the relationship between educational level and individual characteristics

Individual Characteristics	df	F	Sig.	Individual Characteristics	df	F	Sig.
Duration Signature - sec	1	10.082	0.003	AvAbsVel Signature – cm/s	1	0.869	0.357
HorSizeCursive – cm	1	1.265	0.268	Slant Cursive - rad	1	0.136	0.715
AbSize Cursive - cm	1	1.384	0.247	AvPenPresCursive - z	1	0.659	0.422
VerticalSizeCursive – cm	1	0.005	0.942	AbsoluteSizeBlock - cm	1	1.027	0.317
Duration Block - sec	1	0.281	0.599				

The above results suggest that the individual characteristics are influenced by the loss of visual feedback the same way in both educational levels. Therefore the factor of educational level creates an insignificant influence during the comparison of the two conditions of these characteristics since the subjects react the same manner to the loss of visual feedback regardless of their educational level. The only notable exception in this tendency is the Duration in Signatures, where the subjects react significantly differently to the loss of visual feedback, depending on their educational level: in both subgroups during no visual feedback, the execution takes more time but in the subgroup of subjects with a medium level of education the duration increases significantly. A suggested explanation is that a higher level of education is often connected with a more recurrent execution of signature. This repetition creates a higher degree of automation, which as already stated has the result that 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 doesn't, the signature of the first person will be divided into fewer memory units than the second person's and therefore the retrieval and storage in the buffer area until the "go" sign of the execution will be faster. Figure 64 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.

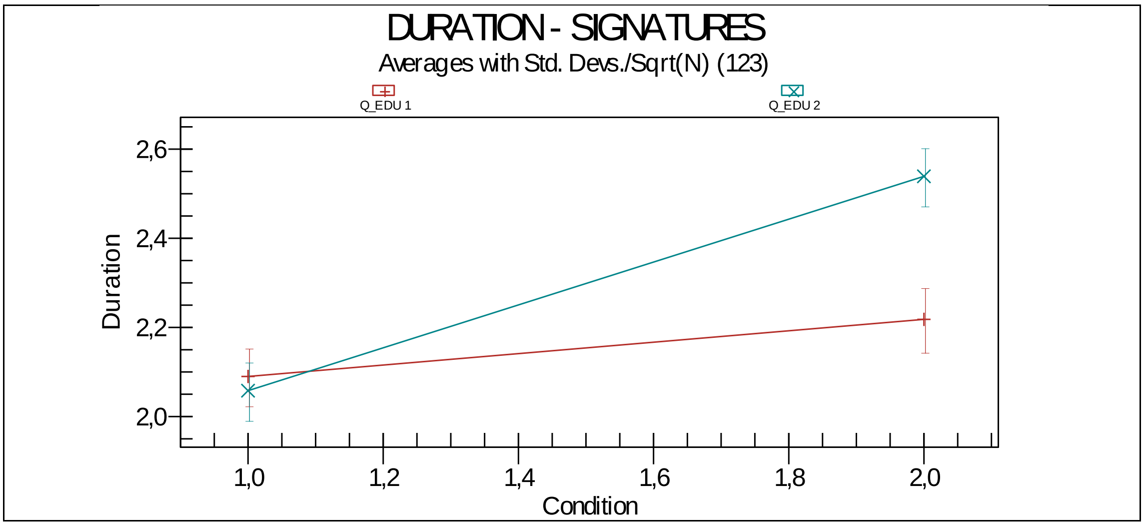


Figure 64. The subjects react significantly differently to the loss of visual feedback, depending on their educational level, in the Duration in Signatures.

However, as seen in Table 7 the interaction between average absolute velocity and educational level is not significant [p = 0.357]. This result initially contradicts the aforementioned significant interaction between duration and educational level. It is suggested that the significant difference in the interaction between the duration of the execution in the two conditions and the various educational levels is influenced to a degree not only by average absolute velocity, which was the leading assumption, but by the interference of another, unknown factor (eg initial delay at the starting time). Further analysis would add to this exciting discussion.

The results of the comparative work factored by handedness are limited by the lack of enough left-handed volunteers (only 3 out of 40) as is presented in Table 10. Once again the results suggest that the individual characteristics are influenced by the loss of visual feedback, the same way in both handednesses.

Table 10. ANOVA results for the relationship between handedness and individual characteristics

Individual Characteristics	df	F	Sig.
AvPenPresCursive - z	1	0.354	0.556
VerticalSizeCursive - sec	1	0.131	0.719
AbsoluteSizeBlock - cm	1	0.125	0.725
VerticalSizeBlock - cm	1	1.068	0.308

Summarizing the findings of the comparative analysis, the theory of the open loop handwriting motor control program is further strengthened. The investigated individual characteristics in this section react the same way to the lack of visual feedback, regardless of gender, educational level and handedness, with the the justifiable exception of duration in highly skilled signatures due to automation and its results in the memory retrieval program of the allographs.

Chapter 5 - Discussion

5.1. Introduction

The purpose of this chapter is to discuss the findings described in the previous chapter, to examine how these findings could help the FDEs with their case work, compare the results with the findings of other pertinent studies and to suggest how the methodology used in this research could be used as a springboard for further investigations. Finally a case report, regarding the influence of cataractus vision in the individual characteristics of handwriting will be presented, both as a further verification of the presented findings and as an example of follow-up research.

5.2. The major findings of the research

The major findings of this research are presented below:

- The peer-reviewed forensic comparison shows that the absence of visual feedback is not linked with the manifestation of fundamental differences in signature and handwriting samples written during the condition of normal visual feedback and the condition of lack of visual feedback. Therefore the sum of the individual characteristics of the writing samples of the two conditions belongs to the same group of natural variations.
- A comparison between a signature or handwriting sample written under normal visual feedback with another sample written under no visual feedback do not possess the methodological elements to justifiably lead a trained FDE to render an erroneous conclusion, that is to suggest that the two samples have different authorship. This is valid even if the FDE does not know that the two samples were written under different conditions. In this case, the FDE will acknowledge the differences found between the two samples but will not err by proclaiming different origin.
- Due to the large degree of automation, the influence of visual feedback on the signatures is minimized, to a degree that no evidence of limited visibility was found.

The highly individualized characteristics of general design of the allographs, line quality, direction of trajectories and intra-signature alignment manifest a group of similarities without the existence of fundamental differences. According to the above, the statistical analysis of the quantified data of the sample signatures imported to PC by the handwriting capture software Neuroscipt LLC's MovAlyzeR show that the only significant differences between the condition of visual feedback and that of no visual feedback lie in the kinetic characteristics of duration and average absolute velocity, since the signature is executed more slowly under no visual feedback.

- The forensic comparison of cursive and block handwriting shows that both react to the lack of visual feedback in a similar manner. General design of the allographs remains in the same variation group, while a number of flags appear through which an FDE could detect that the handwriting sample was written without visual feedback. As already stated, such flags do not appear in the signature execution. The most prominent of these flags are: the change of overall extension of the writing sample, the non uniformity of left margins, the change of overall slant, the avoidance of pen lifts, the inclusion of extra trajectories and the decrease of line quality. These flags, however, are mainly focused on the macromanaging level of the relationships between the executed allographs, are limited in quality and scope and do not constitute fundamental differences. Statistical analysis of the individual characteristics of cursive handwriting shows that with no visual feedback there is a significant increase in absolute, horizontal size as well as average pen pressure and a decrease in slant and vertical size. In block handwriting there is a significant increase in absolute, horizontal size, average pen pressure as well as duration and a decrease in slant, average absolute velocity and vertical size.

- In all three types of writing, the individual characteristic of roadlength does not show any significant change. The forensic analysis confirms this finding, since the complexity of handwriting was not fundamentally changed between the two conditions, while the simplification of the allograph design or the omission of letters was a rare occurrence.
- The comparative analysis suggests the factors of gender, educational level and handedness creates an insignificant influence during the comparison of the two conditions of the researched individual characteristics since the subjects react the same manner to the loss of visual feedback regardless of those factors. The only notable justifiable exception to that, lies in the relationship between signature duration and educational level due to automation and its results in the memory retrieval program of the allographs.
- The qualitative forensic findings show equivalent findings to the statistical quantitative findings regarding the pictorial individual characteristics. No discrepancy between the peer reviewed forensic and statistical results was found. <u>This finding shows that the methodology of forensic document examination is not subjective, but it is verifiable, has repeatable results and in fact represents the qualitative expression of quantitative findings.</u>

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 significantly in the procedure of allograph execution. On the contrary both forensic and statistical evidence suggest that visual feedback is mainly linked with the auxiliary order of macro-managing, inspection and possibly correction of the overall outcome of the combination of the above allographs. Since the lack of visual feedback decreases the inspection-correction loop as it is executed by the eye-mind-hand circuit and the auxiliary kinesthetic circuit does not provide the same amount of information, the final outcome can show a number of pictorial and kinetic distortions, but its degree is limited and its extent is localized and minimized so that it cannot influence the individual characteristics to a degree that can cause differences that will appear as fundamental. Therefore the handwriting samples from both conditions manifest a strong body of complex and individualized similarities with the simultaneous lack of significant differences and thus these samples belong to the same variation group. Furthermore the comparative analysis suggests that gender, educational level and handedness have an insignificant influence on the individual characteristics, strengthening the theory of an all inclusive open loop system not influenced by factors extraneous to it. The only factor that is suggested to influence this motor program is the degree of the automation of the execution of the allographs, especially in frequently executed and highly skilled signatures, since in such cases larger parts of the executed signature are regarded as one allograph and as such, are faster retrieved and executed.

5.3. The effect of these findings in the casework of an FDE

One main idea behind this research is to try to produce quantifiable, objective and verifiable results that can be used in the day to day casework of FDEs worldwide and proceed beyond qualitative analysis. An expert sooner or later may face handwriting samples allegedly written during a condition of no or of limited feedback, either as comparison or as questioned material. This condition could take many forms: from limited illumination, to medical reasons, to circumstances where the writer is blindfolded or cannot look at the document. This research provides another tool of discerning the nature of forensic differences, avoiding the rendering an erroneous conclusion. This erroneous conclusion could be doublefold:

- The expert may err by using the alleged absence of visual feedback to justify fundamental differences, which in reality are a result of different authorship.
- The expert may err by expecting differences between the writing samples of the two conditions and when they do not appear, a false conclusion about different authorship could be formed.

Taking into consideration the above mentioned findings, in such a case where the sample is cursive or block handwriting the FDE should expect the manifestation of a cluster of flags. The lack of such appearance should alert the FDE of a possible contamination of the sample with material either written in different circumstances or even written by another person. Furthermore, since this research suggests that the differences between samples written under these two conditions are not fundamental, the expert could use comparison material written under normal visual feedback to examine a sample allegedly written without or vice versa. While this is not optimum, a careful and trained expert should arrive at a safe conclusion: samples taken in those two different conditions can be compared without any hindrance, if the correct forensic methodology is used. Another important point is that the expert should not dismiss a writing sample allegedly written in a situation when visual feedback was compromised solely because it possesses higher line quality, complexity and stability than expected: a highly skillful writer will produce a signature with similar static and kinetic individual characteristics under both conditions, to a degree that the expert will not be able to discern which of them was written while there was normal visual feedback and which was not. Furthermore, the differences found in the comparison between the two conditions in a cursive or block handwriting sample should be always taken into account: these may constitute flags of limited visibility or at least of abnormal circumstances during execution but could and should not lead to an erroneous conclusion about differentiation of origin since the comparison of the samples of these two conditions will show a group of highly individualized and complex similarities with the simultaneous lack of any fundamentally significant differences.

Finally, these findings urge the experts to reexamine some well accepted beliefs regarding handwriting (Quoting the peer reviewer: "*The above comparisons had as a surprising result the absence of major differences between the signatures executed with visual feedback and the ones without visual feedback.")* and hopefully will act as an incentive for future research in a combined field of graphonomics and forensic document examination.

5.4. Comparison to other scientific works

In contrast to other physiological constrains (Harrison, 1958; Hilton, 1969) that may alter the handwriting to a degree that accurate comparison between the normal and the abnormal handwriting is impossible, this research shows that the loss of visual feedback does not significantly influence the individual characteristics of signature and handwriting. From a forensic aspect, there is an agreement between the findings of this research and the difficulty of maintaining a constant baseline and avoiding merging lines of writing as well as the increased avoidance of pen lifts (Dines, 1998; Lindblom, 1983; Walton, 1997; Plimmer et al, 2011), the occasional poor control of the number of stroke repetitions or letter repetitions (Lebrun & Rubio, 1972) and an influence on the connecting strokes (Meulenbroek & Van Galen, 1989). However a number of other effects (as mentioned by Huber and Headrick, 1999) were not present in this research: no square writing was found, the instances of retracing were minimal, the spacing between letters and words was not random but followed a constant pattern, the line quality, albeit reduced in some sample, was not significantly lower and no case was a significant increase in writing tremor in the condition of no visual feedback was monitored. In a sum, the expected "abnormal handwriting" was not found. Finally the presented findings are in agreement with the flags of limited visibility as shown by Morikiyo and Matsushima (1990), who stated that the most frequent kinds of error were the type of insertion of line elements or letter duplication and the fact that the size of written letters increased with lengthening delays of visual feedback, and by Lovelace and Aikens (1990), who suggested that with no visual feedback the volunteers have a tendency to increase the size of the letters.

The findings of this research are fully aligned with those that suggest that the handwriting motor system is an open loop system (Ellis, 1982; Keele and Summers, 1976; Glencross, 1977; Teulings, 1996) and *"…the performance of handwriting is largely independent upon internal and external feedback"* [both visual and proprioceptive feedback] (Teulings, 1988). Furthermore this research suggests that the open loop system is not influenced by gender and handedness, enlarging thus the scope of the independence of this system. Furthermore, in full agreement with Van Garner et al (1988) and Smyth and Silvers (1987) the findings suggest that visual feedback plays a monitoring role mainly in the multistroke level [monitoring the baseline and lineation levels (Schomaker, Thomassen,and Teulings 1989)], but less during the level of execution of a single stroke or in a noticeable manner (Van Doorn and Keuss, 1992). Therefore the findings of this research disagree with those of Benbow (1995), Arter et al (1996) and Camhill and Case-Smith (1996) who reinforce the importance of the visual feedback in the open loop system of handwriting.

5.5. Further implementations of the proposed methodology

One of the main goals of this research was to produce and test a sound methodology, heavily rooted in multiple circuits of verification and quantification. This two-pronged approach could be employed for investigating and measuring a number of factors that may influence the individual characteristics of handwriting with ease. By creating two or more conditions and taking handwriting samples during their period, which could be imported in a PC, the researcher could then employ the protocol presented in chapter 3. The first and obvious choice of implementation is the field of visual diseases, such as myopia, hyperopia, glaucoma, macular degeneration, retinal degeneration, cataracts etc. In these diseases the researcher should work in reverse: eg Condition 2 in cataract diseases is the pre-surgical period, where the vision is influenced by the opacification of the lens, while Condition 1 is the post-surgical period, where the opacification has been eradicated [for more details, see par. 5.5.1.]. However this methodology could be adapted easily to investigate factors regarding the graphic medium, the writing position, the influence of certain drugs and chemical and other controllable or not controllable factors, using the same protocol and the same software module with very few modification. Such an example of a possible use of this methodology will be elaborated in the next paragraph.

5.5.1. The influence of cataractus vision in the individual characteristics of handwriting and the implications in the work of an FDE.

5.5.1.1. **Introduction**

This subchapter examines the influence of cataractus vision in the individual characteristics of handwriting. It serves as a further verification of the overall findings and as an example of the use of that kind of research in the field work of an FDE. It is a priori expected that cataractus vision will not significantly influence the individual characteristics of handwriting and therefore will not produce discrepancies that would significantly differentiate cataractus handwriting from normal handwriting written by the same individual. As a result, according to the previous findings cataract disease should not lead a trained FDE to an erroneous conclusion.

The literature shows that there is no work in the field of forensic document examination and the graphonomics regarding the influence of cataractus vision in the individual characteristics of handwriting. This is something that could be perceived as peculiar due to how common this disease is, especially to the population group of older people, upon which the FDEs highly focus. Based on the above, the research of this section aims to a) show whether cataractus vision has no effect on the static individual characteristics of handwriting (null hypothesis) or that it changes it to a significant degree (alternate hypothesis), b) to pinpoint the individual characteristics that are affected by this disease and could be noted as signs of limited visual feedback and c) to investigate whether the absence of visual feedback could jeopardize the results of the comparison done by an FDE and lead to an erroneous conclusion.

5.5.1.2. The Nature of cataracts.

The healthy crystalline lens is a transparent, biconvex structure. Its primary function is to transmit the incident light and to focus it on the retina, providing the eye with a focusing refracting power of 20+ diopters [diopter is the unit of measurement of the optical power of a lens, that is of the degree to which a lens converges or diverges light] (Slamovits, 1993). This requires that the lens retains its transparency, a condition dependent on the structural organization between the constituent proteins and water. Figure 65 presents a pictorial description of the healthy crystalline lens in the human eye.

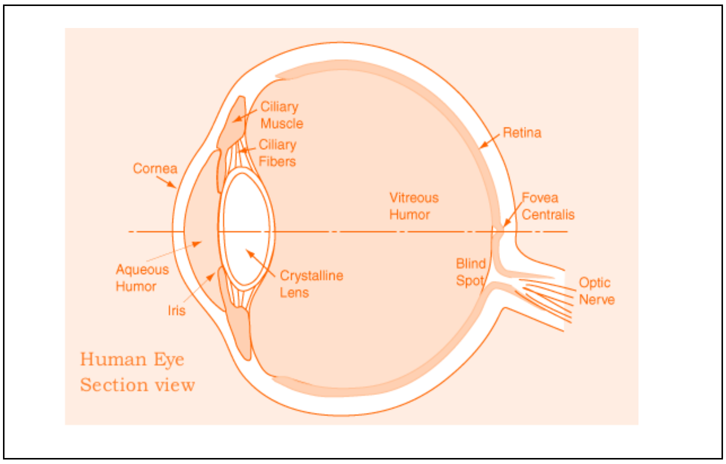


Figure 65. The position of the crystaline lens in the human eye.

Cataract is a common disease of the crystalline lens, a vision-impairing disease characterized by gradual, progressive thickening of the lens, creating a clouding effect varying in degree from slight to complete opacity, thus obstructing the passage of light (Ocampo, 2000). Cataracts occur when the lens loses its transparency by either scattering or absorbing light such that visual performance, (assessed through functional visual acuity recording), is compromised (Yamaguchi et al, 2011). In Figure 66 the magnified view of the cataract, under slit-lamp examination, is seen. The opaque lens is clearly seen at the centre of the eye.

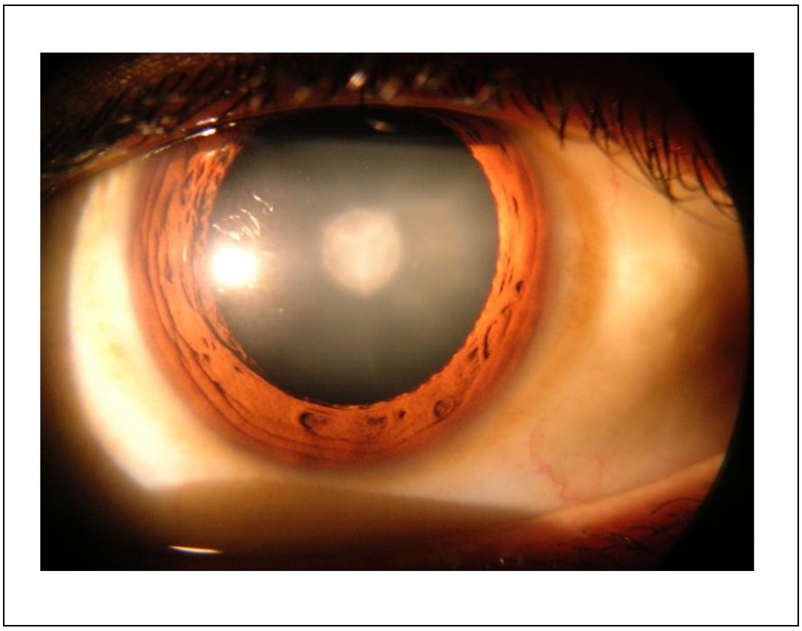


Figure 66. Opacification in the centre of crystalline lens caused by cataract

By far the most important risk factor in the development of cataracts is age- age related cataracts constitute the great majority of all cataracts (e.g. congenital and juvenile cataracts are relatively rare) and are a major public health problem in the world (Hodge et al, 1995). In developing countries, where the availability of surgical facilities is limited, age-related cataracts are the leading cause of blindness (Pavan-Langston,1990). In fact, age-related cataracts are responsible for 48% of world blindness (approximately 18 million people) (Livingston, Carson, Taylor, 1995).

Oxidative damage to lens constituents is believed to be a primary factor in the formation of age-related cataracts (Beebe et al, 2010). Studies show that oxidative stress can be cataractogenetic, since eye exposure to x-rays or to high levels of other types of radiation, including ultraviolet (UV), can cause the development of cataracts with definite oxidative effects in the lens (Duker et al, 2008). Further support for this hypothesis comes from epidemiological studies that have found an association between increased exposure to sunlight and aging-related cataract (Sliney, 1994).

As a result of the cataract, the quality of visual performance is compromised for both distance and near vision. The effect of cataract on functional impairment will vary depending on the type of cataract, its location and the degree of opacification. For example, since posterior subcapsular cataracts are usually located in the center of the lense, result in an increase of light scattering and of interference with the ability of the eye to focus an image on the retina, leading to significant subjective symptoms in its early stages. Based on the degree of visual impairment all types of cataracts are usually classified from Mild (Grade 1) to Severe (Grade 5) (Yanoff & Duker, 2008).

No pharmaceutical treatment which can inhibit, postpone or reverse a cataract has been found, leaving surgery as the only viable solution (Kador, 1983). Cataract surgery is one of the most commonly performed surgical procedures in Europe with extremely rare complications (Mojon-Azzi and Mojon, 2007). Until the early 1980s the preferred method of cataract surgery was intra-capsular extraction (ICE) (Meadow, 2005). At that point the most common surgical option is the removal of the opaque lens and its replacement by an artificial intra-ocular lens (IOL) (Slamovits, 1993). Complications after cataract surgery are relatively uncommon and variable and may appear during the surgery, the immediate or the later post-surgical phase (Jaffe, 1989). However, in the presence of residual post-operative refractive error, the use of spectacles correction for distance may be needed (Abdelghany & Alio, 2014). Residual refractive error may be due to planned or unexpected under-correction or over-correction by the IOL power and/or due to pre-existing corneal astigmatism or induced corneal astigmatism caused by saturation of the incision (Slamovits, 1993). The postoperative recovery period is usually short (*Cunningham & Riordan-Eva, 2011)*. Cataract surgery, even in cases when both eyes are similarly affected, is usually performed first on one eye and then on the other, in order to avoid any devastating complications, i.e. binocular postoperative endophthalmitis, but also other errors, for example post-operative refractive error due to inaccurate biometric assessment, however, simultaneous bilateral cataract surgery is gaining in popularity worldwide, since it has certain advantages, such as the reduction in medical visits (important in cases of older patients with other health problems), avoidance of inter-procedural anisometropia and decreased stereopsis, and very rapid rehabilitation making the surgery much easier on the patients and their families (Smith & Liu, 2001).

5.5.1.3. Methodology

Volunteers were recruited from patients attending for intraoccular cataract removal and lithotripsy at University Hospital of Heraklion, Crete, and screened to ensure conformity to the eligibility criteria. They provided samples of their handwriting and signature before surgery (Phase A) and 3 months after during routine post-operative visits to the hospital

(Phase B). The pre-surgical handwriting and signature samples of each patient were compared to the post-surgical samples of the same patient, as the vision is back to its pre-cataract healthy status at that time.

The group of the pre-surgical samples of a patient was examined and the extend of their natural variations was noted, accordingly to the methodology of forensic document examination. The same procedure took place in the post-operative samples of the same patient. These two groups were afterwards compared to each other, focusing mainly on the individual characteristics of general design, line quality, horizontal and vertical extensions, inter-allograph ration and spacing. The result of the comparison of each characteristic showed either (a) that the characteristic under inspection of the pre-surgical sample can be classified as a natural variation of the post-surgical sample and in this case the comparison results in a significant similarity or (b) that the characteristic under inspection cannot be classified as such and in this case the comparison results in a significant difference. At this stage, a significant difference shows that there is a disengagement of the pre and post-op samples, since their origin could not be attributed to the same writer.

5.5.1.4. Characteristics of the volunteers.

During this research six volunteers completed the post-surgical questionnaire. This number of questionnaires was extracted from a far larger pool from which the majority of volunteers were excluded by the research protocol, which is elaborated below.

Overall the patients exhibited the following characteristics:

- Out of the 6 volunteers used in the research, 3 were male and 3 female.
- All were right-handed writers (during the first part of the examination, no ambidextrous writers appeared).
- The average age of the males were 75.3 years old and of the females 74.3 years old.
- Five volunteers possessed a below medium educational level, while one possessed an above medium educational level.

The eligibility criteria required that volunteers were free from all not controllable factors that may influence either vision or handwriting ability. The criteria are summarised below and required that subjects:

- possessed normal and transparent cornea and anterior chamber.
- were free from any neurological and ophthalmological pathology (other than cataract) and normal binocular vision. Subjects with any prior intraocular surgical intervention were excluded.
- had lenticular cataracts grade 3 (pronounced) or 4 (severe).
- possess the below opthalmological data: Best-corrected distant decimal visual acuity of ≤ 0.6 in each eye, Spherical equivalent ≤ 6.00 D in each eye,Anisometropia < 2.00 D.

This inclusion protocol guaranteed that only cases of "pure cataract" were examined. Therefore these 6 volunteers did not exhibit any condition that may influence their handwriting, except of the condition of cataractus vision, and therefore any difference found between the pre- and post-surgical samples would be attributed only to this factor.

5.5.1.5. Findings

5.5.1.5.1. General Design: There is a notable similarity between the samples in how the overall shape, and the trajectories and loops which form it are drawn and thus the general design in the pre-op samples falls within the range of natural variation of the comparison material. The forensic comparison shows no significant difference between the two sample groups of each writer. In Figure 67 certain similarities in the general design of the allographs are presented.

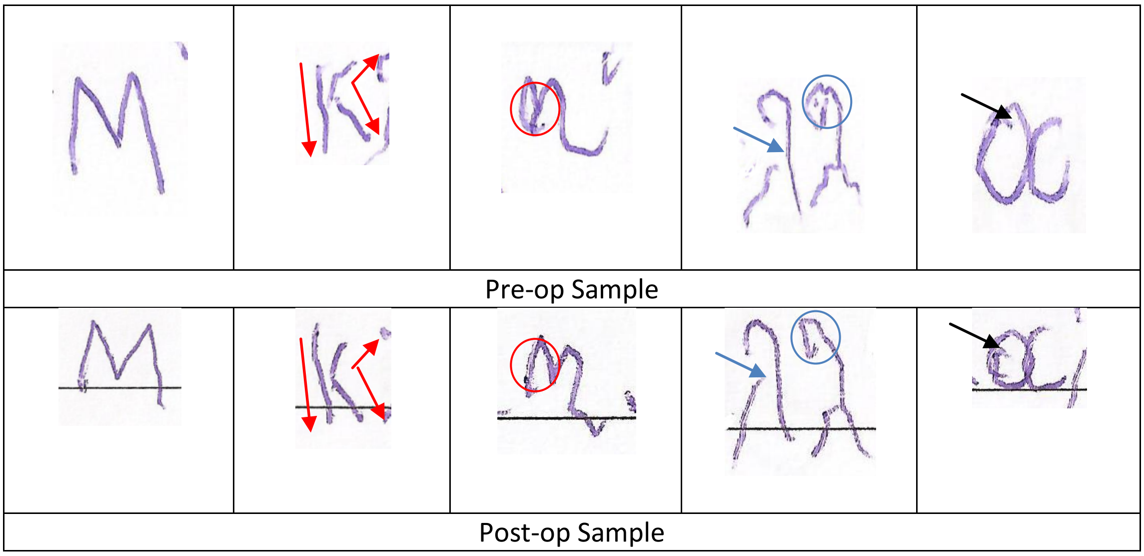


Figure 67. An example of pre-op and post-op writing samples from the same volunteer.

A number of significant similarities are presented in the above Figure: The red arrows show the manner of construction of the letter κ along with the pen lift at the center of its right part. The red circle shows the clockwise starting hook at the left part of the letter η. The blue arrow shows the pen lifts at the center of the letters λ, while the blue circle the hook at the top of the same letter: It is interesting to note that the two variations of this letter are present in both comparison groups. Lastly, the black arrow shows the starting point of the initial trajectory of the letter α. No significant differences were found.

5.5.1.5.2. Line Quality: The post-surgical samples show higher Line Quality based on less writing tremor, a higher degree of fluidity, lower pressure and higher speed of allograph creation. This is linked to the improvement in visual feedback during the writing process during the production of the post-operative samples. An example of this is shown in Figure 69 where the red arrows pinpoint areas of writing tremor in the pre-op sample, that is localized parts of the signature where the control of the writing medium is reduced. Such effect does not appear in the post-op sample. However the degree of the difference in the line quality is not significant (i.e. could not differentiate the origin of the two handwriting samples).

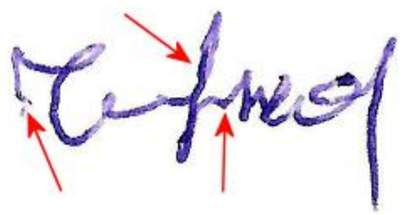
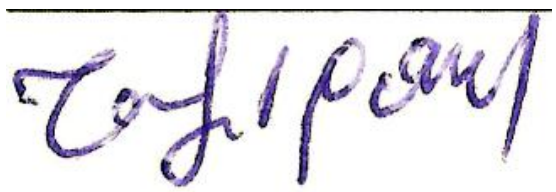
	
Pre-op Sample	Post-op Sample

Figure 68. An illustration of the different level of Line Quality between the pre-op and post-op samples of the same writer.

5.5.1.5.3. Vertical and Horizontal Size: The examination of size shows that this characteristic manifests a large mutability between the two conditions. Comparison shows that only a 16.6% of the samples retained the same horizontal size whilst changes in the Vertical Extensions were found at the 50% of the samples. Figure 69 shows such a change in both the horizontal and the vertical size in a comparison.

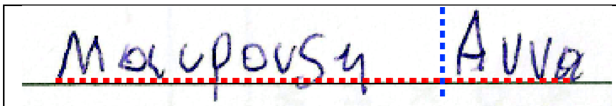
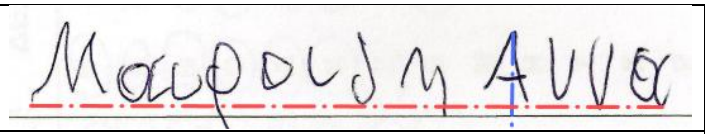
	
Pre-op Sample	Post-op Sample

Figure 69. Both horizontal (red line) and vertical (blue line) size are enlarged in the post-op (free of cataract) sample.

5.5.1.5.4. Inter-allograph ratio: The ratio of the size of each allograph to the other allographs inside the pre-op signature was measured and compared to the equivalent ratio of post-op signatures resulting in a score of significant similarity. Inter-allograph ratio scores a high percentage of similarity (83,3%) in the comparison. Figure 70 shows examples of significant similarities of this individual characteristic. Those similarities present a high level of automation and complexity.

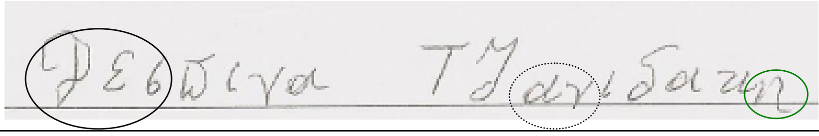
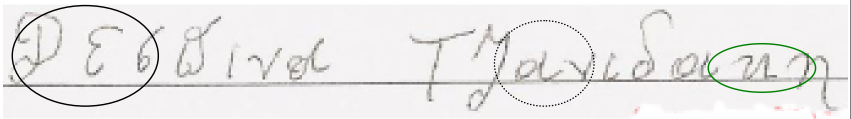
Significant Similarity in intra-allograph ratio.

Pre-op Sample

Post-op Sample

Figure 70. A comparison of pre-op and post-op inter allograph ratios from the same volunteer.

In the above figure the size of the allographs of “Δ”, “ε” and “σ” are compared in the black circular shape. The size of the allographs of “α” and “ν” are compared in the green circular shape. In the dotted black circular shape, the size of the allographs of “κ” and “η” are compared. The ratio of these comparisons belong in the same variation group before and after the cataract surgery.

5.5.1.5.5. Alignment: Alignment corresponds to the positioning of the specific allographs inside the signature. This characteristic exhibits a large degree of overall constancy (83.3%). Figure 71 shows an example of highly individualized similarity of alignment.

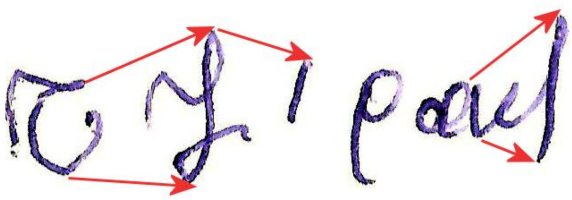
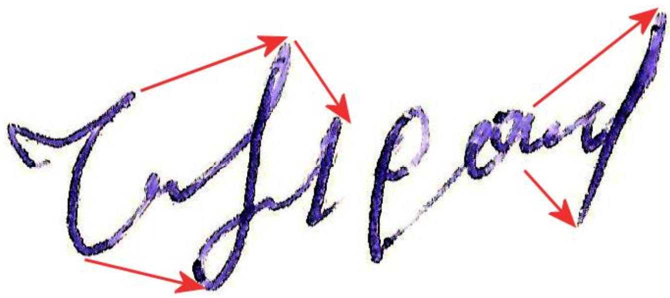
Significant Similarity in the sub-element of Alignment	
	
Pre-op Sample	Post-op Sample

Figure 71. The red arrows point at similarities in the positioning of the corresponding allographs in pre-op and post-op signatures.

5.5.1.5.6. Spacing: Spacing includes both intra-word and inter-word spacing - furthermore features like the mixed and uniform spacing are examined here. The overall comparison of the Spacing element shows a differentiation at the 67.7% of the samples. Figure 72 shows an example of dissimilarity between spacing in the pre and post-op signatures.

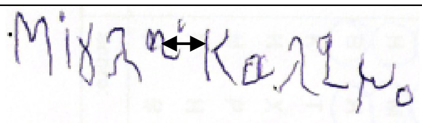
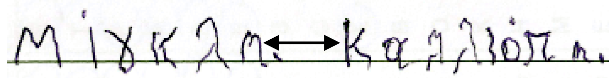
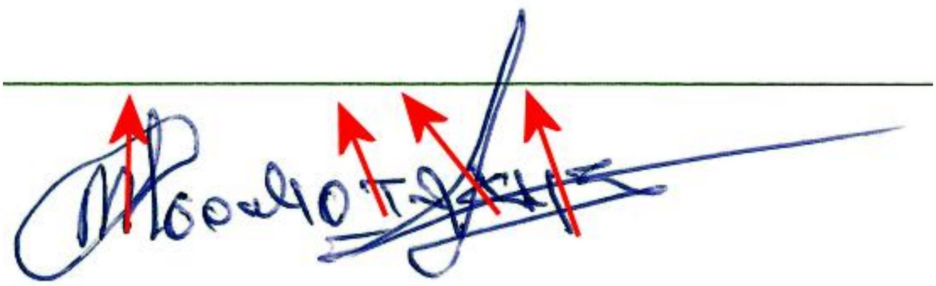
Significant dissimilarity in the characteristic of spacing	
	
Pre-op Sample	Post-op Sample

Figure 72. The black arrows show the difference of the interword spacing between the the samples.

This difference by itself would not lead to an erroneous conclusion (could not be regarded as significant difference) taking into consideration the amount of consistent significant similarities of the two samples in highly individualized characteristics, mainly intra allograph ratio, alignment and general design of the allographs).

5.5.1.5.7 Slant

Slant examines the inclination of allographs relative to the perpendicular to the baseline of the writing. The analysis shows that all allographs retained the same slant in both the pre and the post operation group. In Figure 73, one such comparison is presented.

Significant Similarity in the characteristic of Slant


Pre-op Sample

Post-op Sample

Figure 73. A comparison of the pre-op and post-op slant of the same volunteer.

In the above Figure the inclination of individual letters of the pre-op samples relative to the perpendicular to the baseline of the writing was measured and then compared with the inclination of the equivalent letters of the post-op samples. It must be noted that the pre-op signature shows a highly characteristic and variable group of slants, which all remain constant after the surgery.

5.5.1.5.8. Summary of the findings

In Table 11 the percentage manifestation of signs of limited visual feedback due to cataractus vision is shown.

Individual Characteristics	Appearance of signs of limited visual feedback in the comparison between pre and post op samples
General Design	0,00%
Line Quality	83,33%
Horizontal Extensions	83,33%
Vertical Extensions	50,00%
Inter Allograph Ratio	16,67%
Alignment	16,67%
Spacing	66,67%
Slant	0,00%

Table 11. The percentage of existence of signs of limited visibility in the cataractic samples.

5.5.1.6. Blind trial

The samples were summed in 6 groups – one per writer. Then each group was divided in two subgroups, one containing the pre-op samples (Subgroup A) and the second containing the post-op samples (Subgroup B). All the samples were sent to a trained FDE who was not informed that each paired group was produced by the same writer. Accordingly, the FDE was not given any detail of the nature of the research or of the medical status of the writers.

After examining the 6 groups, following the comparison methodology of the Forensic Document Examination, he correctly concluded that each subgroup A was written by the same writer who also wrote the equivalent subgroup B, while he made no erroneous judgment as to perceive the samples of the one subgroup as an imitation attempt of the second subgroup.

5.5.1.5.7.Discussion

The above findings clearly show that cataractus vision does not influence significantly the individual characteristics of handwriting to an extend that the pre-operational samples would appear to belong to a different variation group than that of the post-operational samples. Both the forensic comparison and the blind test furthermore suggest that the influence of cataractus vision is such that it would not lead an expert to an erroneous conclusion. These findings match exactly with the overall findings as presented in Chapter 5 of this thesis. In fact since in this research the examined cataracts which only reduce -due to opacification- and do not fully deny the vision of the writers, visual feedback is not removed but only decreased. Thus any difference found is evident to a lesser degree, than that of the main comparison between the groups of normal visual feedback and absence of visual feedback.

As expected the present findings of the comparison between the pre and post cataract surgery samples follow the same direction to those of the comparison between the samples written with visual feedback and without it: a striking example is that the general design of the allograph remains constant without any significant dissimilarities. Furthermore, as noted in chapter 4, certain findings of the comparison could be used as signs of limited visual feedback: in cataract research, it was noted that the line quality, the size and the spacing change during the pre-op samples (the samples written under the influence of cataract), while the slant of the allographs, the inter-allograph ratio and the alignment remain constant – findings that match those of the main research about visual feedback. Summarily, once again visual feedback is presented not so much as a factor that interacts with the creation of the allographs contained in the memory units, but mostly as a tool of macro-managing and inspecting the overall outcome of the combination of the above allographs. In the current example, the reduced visual feedback due to cataractus opacification presents the pictorial outcome with a limited pictorial distortion – as was witnessed by the decrease of line quality or the change of the size and spacing- but its degree and extent is so localized and minimal so that it cannot influence the individual characteristics to a degree that can create a differentiation between the two subgroups.

This research also pinpointed the difficulty of obtaining a large number of volunteers when the inclusion protocol is too specific. Especially in older ages, where the diseases and other factors that may influence handwriting appear mostly in clusters, the quest to obtain a large number of volunteers influenced solely by one factor only can be very demanding both in time and resources, especially if the special needs and the limited mobility of the old volunteers are taken into account.

The current research acts as a case report and illustrates the use of the findings of the research regarding the influence of visual feedback in the individual characteristics of handwriting. The blind trial strengthens further its arguments. It can therefore be naturally expected that any research regarding other visual diseases will move along the same route and present overall similar findings.

5.6. Suggested further investigation

During the present investigation, certain ideas for further research occurred , which will shed more light to complementary scientific questions and move the present research forward. The most interesting are the following:

- As was already discussed a trained FDE verified the researcher's results in the forensic analysis of the writing samples. Logistics forbade any major peer review process executed by a large number of FDEs. However, it would be interesting to commence such a peer review on a large scale or even a blind trial where the experts would be ask to differentiate between samples executed without visual feedback and forged ones. It is initially expected that the findings of a larger scale peer review will back up the existing findings. Such a large scale blind trial could be organized in an upcoming ENSFI [European Network of Scientific Forensic Institutes], since the preliminary findings of the present research were already presented in the ENFSI 2015 meeting in Zurich.
- The present research used Greek language which is written from left to right and from top to bottom. It would be worthwhile to organize experiments using other language families, that use different writing direction or different fonts, eg Arabic or Chinese, to investigate whether there are significant differences between the results. It is suggested that some of the flags of lack of visual feedback would be changed [eg in the Arabic branch of languages the horizontal overlap would be

mostly prevalent between the currently executed letter and its left one instead of its right]. Since the present findings –along with the presented graphonomic literature- suggest the existence of an open loop general handwriting motor program with minimized outside influence, the expected results should show that the change of the handwriting system should cause no significant difference.

- Another interesting addition to this research would be the compilation of an equal number of left handed writers (estimated number of 37 volunteers) for a stronger verification of the findings. The enrollment of such a number of Greek writers posses some logistical issues, however given a certain amount of time and expanding the recruitment, that number could be achieved.
- Contrary to signature and block handwriting, the absence of visual feedback does not significantly influence the temporal individual characteristics of cursive handwriting. Based on that, a working hypothesis has been formed and calls for further investigation. The first goal is to pinpoint the influence of automation in cursive handwriting. Therefore, an experiment could be created where the cursive sample of the pangram in the two conditions would be compared to a cursive sample with higher degree of automation also written in the two conditions. E.g. the participants could write their name in cursive handwriting and compare the degree of influence of the visual feedback with the degree of influence found when they write a cursive sample that they have not automated. The initial hypothesis is that the lack of visual feedback will influence less a highly automated action , and will present a less significant influence –exactly as happened with the signatures.
- Finally, the researcher has already started a long term research, where he continues collecting handwriting samples, using the same methodology that was presented in Chapter 3, and plans to seek subtler connections in the future.

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Appendix A - The Requested Material Form

Χώρος Εξέτασης	
Ημερομηνία Εξέτασης	
Κωδικός Εθελοντή	

Στοιχεία Εθελοντή

Όνομα		Επίθετο	
Ημερομηνία Γέννησης		Επίπεδο Μόρφωσης	
Επαγγελμα		Κατοικία	
Εθνικότητα		Άλλες γλώσσες	
Ασθένειες που επηρεάζουν τη γραφή			
Δεξιόχειρας		Αριστερόχειρας	
Το παρόν δείγμα θα χρησιμοποιηθεί ανώνυμα για τους σκοπούς εκπόνησης διδακτορικής διατριβής στο Πανεπιστήμιο του Staffordshire.			

Το παρόν δείγμα δίδεται οικιοθελώς:	
Ονοματεπώνυμο:	
Υπογραφή:	
Υπογραφή εξεταστή:	

ΔΕΙΓΜΑ ΜΙΚΡΟΓΡΑΦΗΣ ΜΕ ΟΠΤΙΚΗ ΑΝΑΔΡΑΣΗ

Ονομα: Υπογραφή: Κωδικός:	Ημερομηνία: Τόπος:

ΔΕΙΓΜΑ ΜΙΚΡΟΓΡΑΦΗΣ ΧΩΡΙΣ ΟΠΤΙΚΗ ΑΝΑΔΡΑΣΗ

Ονομα: Υπογραφή: Κωδικός:	Ημερομηνία: Τόπος:

ΔΕΙΓΜΑ ΥΠΟΓΡΑΦΗΣ ΜΕ ΟΠΤΙΚΗ ΑΝΑΔΡΑΣΗ

Ονομα: Υπογραφή: Κωδικός:	Ημερομηνία: Τόπος:

ΔΕΙΓΜΑ ΥΠΟΓΡΑΦΗΣ ΧΩΡΙΣ ΟΠΤΙΚΗ ΑΝΑΔΡΑΣΗ

Ονομα: Υπογραφή: Κωδικός:	Ημερομηνία: Τόπος:

ΔΕΙΓΜΑ ΚΕΦΑΛΑΙΟΓΡΑΦΗΣ ΜΕ ΟΠΤΙΚΗ ΑΝΑΔΡΑΣΗ

Ονομα: Υπογραφή: Κωδικός:	Ημερομηνία: Τόπος:

ΔΕΙΓΜΑ ΚΕΦΑΛΑΙΟΓΡΑΦΗΣ ΧΩΡΙΣ ΟΠΤΙΚΗ ΑΝΑΔΡΑΣΗ

Ονομα: Υπογραφή: Κωδικός:	Ημερομηνία: Τόπος:

Appendix B – 1. Peer Review regarding Forensic Comparison and 2. Peer Review regarding Cataract Findings

1.

QUESTIONNAIRE

Please submit this file to mpertsinakis@gmail.com until the 30th May 2016.

Before starting, read the whole questionnaire to get accustomed with its structure.

Important Note: During this questionnaire, the terms significant and fundamental difference and its opposite significant similarity are often used.

Using the accepted definition of the Science of Forensic Document Examination a significant and fundamental difference is a stable and reoccurring discrepancy focusing on structural and morphological characteristics, which leads to the creation of two distinctive and separate groups of variations , while a significant similarity is a total absence of significant and fundamental differences that leads to the creation of one group of variations.

QUESTION A – Proceed to compare the following pairs in the folder of each subject and notice the existence or not of significant differences.

- **Pair A:** Signatures executed under normal visual feedback vs Signatures executed during the condition of absence of visual feedback.
- **Pair B:** Cursive Handwriting executed under normal visual feedback vs Cursive Handwriting executed during the condition of absence of visual feedback.
- **Pair C:** Block Handwriting executed under normal visual feedback vs Block Handwriting executed during the condition of absence of visual feedback.

Signature	Name	Date
01/07/16 22:27	Eleni Christina Kastorini	28-6-2016

PAIR A COMPARISON

SUBJECTS	EXISTENCE OF SIGNIFICANT DIFFERENCES	NON EXISTENCE OF SIGNIFICANT DIFFERENCES
00A		-
00B		-
00C		-
00D		-
00E		-
00G		-
00H		-
00I		-
00J		-
00L		-
00M		-
00N		-
00O		-
00P		-
00Q		-
00R		-
00S		-
00T		-
00U		-
00V		-
00W		-
00X		-
00Y		-
00Z		-
002		-
003		-
004		-
005		-
006		-
007		-
008		-
009		-
010		-
011		-
012		-
013		-
014		-
015		-
016		-
018		-

Signature — Name: Eleni Christina Kastorini — Date: 28-6-2016

01/07/16 22:28

PAIR B COMPARISON

SUBJECTS	EXISTENCE OF SIGNIFICANT DIFFERENCES	NON EXISTENCE OF SIGNIFICANT DIFFERENCES
00A		-
00B		-
00C		Change of the letter “ξ”
00D		-
00E		-
00G		-
00H		-
00I		-
00J		-
00L		-
00M		-
00N		-
00O		-
00P		-
00Q		-
00R		-
00S		-
00T		-
00U		-
00V		-
00W		Change of letter “β”
00X		-
00Y		-
00Z		-
002		-
003		-
004		-
005		-
006		Change of letter “ζ”
007		-
008		-
009		-
010		-
011		-
012		-
013		-
014		-
015		-
016		-
018		-

Signature

Name
Eleni Christina Kastorini

Date
28-6-2016

PAIR C COMPARISON

SUBJECTS	EXISTENCE OF SIGNIFICANT DIFFERENCES	NON EXISTENCE OF SIGNIFICANT DIFFERENCES
00A		-
00B		-
00C		-
00D		-
00E		-
00G		-
00H		-
00I		-
00J		-
00L		-
00M		-
00N		-
00O		-
00P		-
00Q		-
00R		-
00S		-
00T		-
00U		-
00V		-
00W		-
00X		-
00Y		-
00Z		-
002		-
003		-
004		-
005		-
006		-
007		-
008		-
009		-
010		-
011		-
012		-
013		-
014		-
015		-
016		-
018		-

Signature	Name	Date
EKt 01/07/16 22:29	Eleni Christina Kastorini	28-6-2016

QUESTION B – Make a qualitative analysis of the major similarities found in the above comparisons. Analyze per pair. Do you consider these similarities significant?

Having in mind that the current research used signatures executed without visual feedback, the similarities found by the comparison with the ones executed with visual feedback are more than one would expect. In fact the similarities found in the above comparisons are numerous and fall in the category of "individual characteristics", such as the construction/design of certain letters or the way some of them are connected, the line quality and the speed of execution, the relative size of letters used, the positioning of one letter to another, the slant used during the execution of signatures and all the ornamentations one may use for his/her signature. All the above elements found in both groups of signatures (signatures executed with visual feedback and without visual feedback) are more than significant, are the proof that these signatures came from the some writer.

Regarding the cursive writing the similarities found between the group with visual feedback and the one without visual feedback, were more than one would expect. As it happened in the signature research above, the similarities were once again located in elements with high individuality such as the line quality, the speed of execution, the design/construction of each letter used or the connections between the letters, which means that the fundamental characteristics of one's writing remained unchanged despite the fact of the non visual feedback.

The same results were found also in the groups of block handwriting, locating the same principals.

Signature	Name	Date
01/07/16 22:29 Eleni Christina Kastorini	Eleni Christina Kastorini	28-6-2016

QUESTION C – Make a qualitative analysis of the major differences found in the above comparisons. Analyze per pair. Do you consider these differences significant?

The above comparisons had as a surprising result the absence of major differences between the signatures executed with visual feedback and the ones without visual feedback. In few cases there was a slightly noticeable change in the actual size of the signatures and also a difference in the internal spacing or ratio of signature's parts. But still the identifying elements of the writer were present and so these differences can't be considered as significant.

As far as it concerns the cursive writing it was expected to find major differences between the two groups. But surprisingly not all the samples had noticeable differences in fact some they had none, and the ones they had they were not as significant as one would expect. The most common difference was found at the general appearance of the writing and more specifically at the size of letters and at the spacing between words and lines, which is kind of normal considering the lack of visual feedback. These differences although they have some impact at the appearance of the writing cannot be evaluated as significant.

Regarding the block handwriting the results are the same as in the cursive handwriting analysis.

Signature	Name	Date
	Eleni Christina Kastorini	28-6-2016

01/07/16 22:30

QUESTION D – Would you regard the above differences as a potential factor for a possible erroneous conclusion of an accredited forensic document examiner?

As already have been said the differences between the two groups of signatures are located only in the slightly difference in the actual size of the signatures and in other cases there were a change in the internal spacing or the internal ratio of some componements of the signatures. An accredited forensic document examiner should take into consideration these differences and value their importance, but on the other hand the presence of individual characteristics and the importance we all know they have in the identification of a writer leave no space for erroneous conclusion.

Analyzing the differences found on the cursive writing with and without visual feedback a forensic document examiner is expected to take into consideration the differentiation on the relative size of a writing or the spacing between letters/words/lines but on the other hand one should always have in mind that this kind of differences are less important and significant when in the same writing one can find similarities in elements that are more individual (design of letters, connection between letters etc) and harder to copy. So under proper evaluation of the facts an accredited forensic document examiner should not reach an erroneous conclusion. The same results were found in the groups of block handwriting, so the above answer stands for the block handwriting as well.

Signature	Name	Date
	Eleni Christina Kastorini	28-6-2016

2.

BLIND TRIAL

To be used as part of the thesis "Effect of visual feedback upon static and kinetic individual characteristics of handwriting" written by Michael Pertsinakis.

Please examine the 6 folders names 1 to 6. Each folder has two subfolders, subfolder A and subfolder B. Proceed to compare the document in subfolder A ("Document A") with the document in subfolder B ("Document B") following the standard methodology of Forensic Document Examination.

Then answer the following:

- Document A and Document B possess a number of significant similarities along with no significant differences and therefore they are originated by the same individual or not?

The answer is scaled as such:

1. Strong evidence towards common origin (Scale 1)
2. Limited evidence towards common origin (Scale 2)
3. No Liquet (Scale 3)
4. Limited evidence towards differentiated origin (Scale 4)
5. Strong evidence towards differentiated origin (Scale 5)

COMPARISONS	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5
1	X				
2	X				
3	X				
4	X				
5	X				
6	X				

Name and Job title Dimitris-Leonidas Gidogiannos
Lawyer, Forensic Handwriting & Document Examiner
Address
3 Fraggon Str. Thessaloniki Greece
Date 2-8-2016

Signature

Appendix C - List of publications and presentations regarding the findings of this thesis

Publications:

- Pertsinakis, M. The influence of cataractus vision in the individual characteristics of handwriting and the implications in the work of forensic document examiner. Department of Forensic Sciences, Wroclaw University (under publication).
- Pertsinakis, M. Plainis, S. Limnopoulou A. Giannakopouloum T, Iliaki, O. Tsilibaris, M.K. , Pallikaris I.G., Jackson, A.W.R. and Platt, A.W.G. Evaluating the effect of cataractus vision on the general characteristics of handwriting: its forensic implications. Acta Ophthalmologica Special Issue: Abstracts from the 2010 European Association for Vision and Eye Research Conference, Vol. 88, Issue Supplement s246, September 2010.

Presentations:

- The effect of visual feedback in the individual characteristics of handwriting – 10th ENFHEX conference, Zurich 2015.
- Evaluating the effect of cataractus vision in the individual characteristics of handwriting – 16th Wroclaw Symposium of Questioned Document Examination, Wroclaw University 2014.
- Evaluating the effect of cataractus vision in the general characteristics of handwriting: its forensic implications - Forensic Science Society Conference (Poster Presentation) , Birmingham 2011.