



UNIVERSITÀ DEGLI STUDI DI MILANO – BICOCCA

Dipartimento di Psicologia

Dottorato in Psicologia Sperimentale, Linguistica e Neuroscienze cognitive

XXII Ciclo

Arabic Handwriting: Cinematic and Geometric descriptors

Supervisore: Prof. Natale Stucchi

Dottoranda: Sana Bouamama

Matricola 062462

ANNO ACCADEMICO 2009-2010

DEDICATION

To my sister, my best friend

For all the times you started, but you was never able to complete your PhD

Aknowledgments

After two degrees, at two universities, in two different countries, I have learned one thing – I could never have done any of this, particularly the research and writing that went into the dissertation, without the support and encouragement of a lot of people.

First, I would like to thank my advisor, Professor Natale Stucchi. I owe you so much. You have given so much of yourself to help me succeed. You provided me with invaluable advice and comments on both my research and my future research career plans. Whatever path I do take, I will be prepared because of you.

I've been very lucky throughout most of my life in Phd graduate school, in that I've been able to collaborate with Prof. Pascal Zesiger (Univ. Geneva) and also Prof Edouard Gentaz (Univ. Grenoble) who gave me the chance to work in his laboratory with his team. I have learned so much from all of you.

Special thanks for Prof. Bouzaouèche (Univ. Tunis) with whom I also collaborate. You was my professor and I will never stop learning from you. Thank you for your generous help and interest.

The experimental research could never be done without the help and participation of teachers, parents, children, and students. Thank you. Especially, Chaouachi Dir of Melassine School (Tunis).

I have been also fortunate to have a great group of friends and colleagues too numerous to name. This is the key to getting through Ph.D program-having good friends to have fun with and to complain to. Thank you Mme Fausta, you have been more than a friend. Special thanks to Chiara Cantiani, Gelsomina Perrone, Irene Senna, and Matteo Forgiarini with whom I shared the best and the worst of my Ph.D

I would like to thank Dr Linton and Dave. Thank you for helping me and being my English reviewer for the dissertation.

Finally, I would like to dedicate this work to my family: Ali, Naziha, Amor, Kadhem, Kaouthar and my lovely nephews: Elyes, Wael, and Anas. Also, a special person: Lilianna. Without your unending support and love from childhood to now, I never have made it through this process any of the tough times in my life. Thank you for existing.

TABLE OF CONTENTS

DEDICATION.....	p2
AKNOWLEDGMENTS.....	p3
TABLE O CONTENTS.....	p5
Introduction and Motivation.....	p9
Chapter 1: Theoretical section Arabic Writing and Methods for the Measurement of Handwriting Difficulties	P15
1. Writing system	
1.1 Arabic Handwriting System	P16
1.2 Features of Arabic handwriting	P17
1.3 Differences between the Arabic and English writing systems	P18
1.4 Arabic and Hebrew handwriting	P19
	P22
2. Handwriting Evaluation Scale	
2.1 The Test of Legible handwriting –TOLH.....	P23
2.2 The Concise Evaluation Scale for Children’s – BHK.....	P24
2.3 The Hebrew Handwriting Evaluation – HHE.....	P25
2.4 Merits and limitations of Handwriting Evaluations Scales.....	P25
2.4.1 <i>The evaluator</i>	P26
2.4.2 <i>The criteria</i>	P26
2.4.3 <i>The assignment</i>	P26
2.4.4 <i>The instructions</i>	P27
2.4.5 <i>Pen and paper</i>	P27
2.4.6 <i>Variability in personal writing style</i>	P28
2.4.7 <i>Writing speed measurement</i>	P28
2.4.8 <i>Applicability of the scales to different populations</i>	P28
3. The use of Computerized Temporal and Spatial Measurements in Evaluating Handwriting Performance	
3.1 Automation of stroke generation.....	P31
3.2 Speed.....	P32
3.3 Variability.....	P33
3.3.1 <i>Neuromotor Noise</i>	P33
3.3.2 <i>On air movements</i>	P33
3.4 Axial pressures.....	P34
	P35

4. Individual variability	P35
4.1 Pen Grip.....	
4.2 Handedness.....	P35
4.3 Gender.....	P36
4.4 Extrinsic factors affecting handwriting performance.....	p:36
4.5 Orthographic characteristics and writing.....	p.36
4.6 Graphophonological constraints	p 37
	p 37
5. Software packages for the study of handwriting production	
5.1 The most used.....	p 37
5.2 VB Digital Draw.....	p 38
6.Chapter 2: Experimental Section Arabic Handwriting Analyses	
Experiment 1: Description of Arabic Handwriting difficulties in Children	p 42
	p 42
6.1 Method.....	
6.1.1 <i>Participants and selection procedure</i>	p 42
6.1.2 <i>Evaluation session</i>	p 43
6.1.3 <i>Procedure</i>	p 43
6.2 Analysis and results.....	p 44
6.3 Discussion.....	p 47
6.4 Conclusion.....	p 47
	p 48
7. Experiment 2: Cinematic and Geometric Analyses of Arabic Handwriting	
	p 48
7.1 Method.....	
7.1.1 <i>Participants</i>	p 48
7.1.2 <i>Stimuli</i>	p 49
7.1.3 <i>Digitizing tablet and on line data collection</i>	p 49
7.1.4 <i>Procedure</i>	p 49
7.2 Data analysis.....	p 50
7.3 Results.....	p 50
7.3.1 <i>Stroke</i>	p 51
7.3.2 <i>Dysfluency</i>	p 52
7.3.3 <i>Time</i>	p 53
7.3.4 <i>Velocity</i>	p 54
7.3.5 <i>Length</i>	p 55
7.3.6 <i>Pressure</i>	p 56
7.4 Discussion.....	p 57
7.5 Conclusion.....	p 62

Chapter 3: Theoretical section	
8. Perception and Implicit Motor Knowledge	p 64
8.1 Detecting anticipatory events in handwriting.....	p 65
8.2 Perceptual asymmetry.....	p 57
8.3 Fixation in reading.....	p.68
8.4 Directional reading habits.....	p.71
8.5 Mirror handwriting.....	p.73
Chapter 4: Experimental section	
9. Experiment 3: The role of Reading and Writing habits in priming letter recognition	p.76
9.1 Method.....	p.74
9.1.1 Participants.....	p.74
9.1.2 Stimuli.....	p.75
9.2 Procedure.....	p.77
9.2.1 <i>The first absolute threshold assessment</i>	p.78
9.2.3 <i>The familiarization task</i>	p.78
9.2.3 <i>Reading and Space tasks</i>	p.78
9.2.4 <i>The second absolute threshold assessment</i>	p.79
9.3 The experimental task.....	p.79
9.4 Design.....	p.79
9.5 Analyses and Results.....	p.80
9.5.1 <i>Reaction Time</i>	p.80
9.5.1.1 Group and Task.....	p.80
9.5.1.2 Quadrant.....	p.81
9.5.1.3 Character.....	p.82
9.5.2 <i>Accuracy</i>	p.83
9.5.3 <i>Eye Landing Point</i>	p.83
9.5.3.1 Reaction Time.....	p.85
9.5.3.2 Accuracy.....	p.86
9.6 Discussion.....	p.87
9.7 Conclusion.....	p.84
9.8 Limitations and future investigations.....	p.94
	p.96
10. General Discussion	
	p.102
APPENDIX 1.....	
APPENDIX 2.....	p.109
APPENDIX 3.....	p.114
APPENDIX 4	
BIBLIOGRAPHY.....	p.119

*« Da grande voglio essere un cuoco
Perché vorrei tanto usare le mie mani a fare tutt'altro che.....
.....scrivere”
PW.*

Introduction and Motivation

We are aware of the appearance and the importance of our writing legibility, and anything that comes as abnormal is perceived as disturbing. At any moment over the years when I have presented my research question, there are members in the audience who stop writing, or make remarks expressing concern that their child's or friend's handwriting may not be normal. Professional observations and authentic informal interviews confirm anecdotal beliefs in the correct handwriting.

With the background of 8 years as a student in stage in the department of Pedopsychiatry of Tunis' Hospital, and before beginning my PhD, I pictured in my mind, how normal functioning hand would be writing, but it has completely changed afterward. When I started the experiments in the classrooms, I was confused as I observed pupils representing extremes in academic performance and handwriting, different gender and social ability. I was shocked when I knew that, those children "labelled as poor writers", could not have any structured rehabilitation intervention since no clinical tools exist for Dysgraphia or handwriting difficulties in Tunisia. The lack of such knowledge and material constituted, and still, the motivation of my researches. The question that I posed myself was and still is: what are the tools to measure the handwriting deficits for Arabic writers? Unfortunately, there are no clinical tools available. Hence there is a necessity for a 'method' that looks at individual needs of the pupils and helps them to sustain the skills they are learning by identifying the characteristics of their handwriting; this is the aim of the experiment I and II.

The first step was to understand the handwriting process (proper of a language), to identify its cognitive and motor requests, and secondly, to create psychometric "tools" that allow the measurement, description and quantification of the deficits in order to restore it.

Increasing awareness of the socioeconomic costs of learning disabilities has prompted developed and developing countries to engage in an ongoing interest in reading and writing disabilities. Research on developmental dyslexia has witnessed remarkable progress over the last twenty years in the Arabic speaking world and

cross-linguistic studies of dyslexia in other languages are becoming increasingly popular (Belajouza et al., 2005). However, studies on the occurrence of handwriting difficulties in Arabic have hitherto been rare and far between. This study attempted to investigate how such deficit manifests itself amongst Tunisian children by exploring the characteristics of their handwriting movements. However, methodological mistakes can be avoided when controlling the variability of the studies reviewed in the literature on writing. In fact, Rosenblum, Weiss & Parush (2003a) explained and argued the development of methods used to evaluate handwriting difficulties and concluded that a combined approach to handwriting evaluation, one that takes advantage of strengths of both human and digitizer-based evaluation procedures.

Handwriting is a fundamental skill that impacts various fields of one's everyday-life and professional performance. Despite of the widespread use of keyboard, handwriting is still an important means of communicating through space and time; especially, in childhood and in adolescence. It plays a crucial role due to its implications in motor and cognitive development children's performance in school as well as their self-esteem depends on their handwriting. Pupils spend 30 al 60% of their time in school on handwriting and fine motor tasks. Learning to produce a legible handwriting takes a lot of time and effort even for typically developing children (Smith-Engelsman, 1995).

Handwriting requires a high level of fine motor coordination and high/precision force regulation, and also perceptual, cognitive and language abilities (Van Galen, 1991). It is a complex interaction between motor and cognitive processes. Some components of the handwriting process are considered of 'low' level such as motor planning and execution. Other components are considered 'high' level as strategies for generating language at the sentence and text levels (linguistic and lexical), and reviewing and revising written text. Visual-motor integration, bilateral motor integration, motor planning, proprioception, visual perception and sustained attention are important components that attribute to complex fine motor skills like handwriting and drawing.

In addition, it has been established that writing movements can help subjects whose reading abilities are impaired: for instance, patients with pure alexia, who were no longer able to recognize letters visually, sometimes succeed in doing so when they were asked to trace the outline of the letters with their fingers (Bartolomeo et al.,

2002; Seki et al., 1995). There are evidences which strongly suggest that writing movements are involved in letter memorisation (Naka, 1998). Visual recognition was also studied by Hulm (1979) who compared children's learning of a series of abstract graphic forms, depending on whether they simply looked at the forms or looked at them as well as tracing the forms with their index finger. The tracing movements seemed to improve the children's memorisation of the graphic items; thus, it was suggested that the visual and motor information might undergo a common representation process.

Such evidence confirms my belief that writing and reading are intimately linked; I assume that the main process when reading is influenced by motor activity. Such process is also based on spatial competences. In fact, various studies discussed (Christman and Niebauer, 1997) the influence of scanning habits. This bias has an ecological origin, as the organism is supported to be engaged in visual search for objects that are relatively far away and hence in the upper VF. For this reason I proposed the experiment III.

The general purpose of the study was twofold. One aim was to contribute evidence on the literature that children with handwriting difficulties will demonstrate significant difference in the legibility and kinematics of their writing movement compared to proficient writers. The main goal of the study was to determine whether these difficulties are linked somehow to the characteristic of the Arabic writing system. The specific purpose of the thesis was to investigate whether the reading habits may influence the performance of Arabic and Italian adults in a character recognition task.

The structure of the thesis is as follow:

CHAPTER 1 Presents the characteristics of Arabic handwriting and the basic explanations of its writing system comparing to Roman and Hebrew. It also introduces the topic of the studies, reviewing the related researches on handwriting evaluations relevant for the experiment (I) and (II). More specifically I will focus on two types of methods for the measurement of handwriting difficulties: (1) scale of evaluations of handwriting and (2) the computerized methods. This includes an in depth-discussion of the existing methods and their application. Furthermore, it demonstrates why the existing work is essential.

CHAPTER 2 introduces two experiments, carried out with Tunisian children, and their respective results and discussions. The first experiment is a pilot study that aid to describe the common errors of Arabic handwriting in scholar. The description is based exclusively on the handwriting product. The second experiment aimed to investigate the kinematics of the handwriting and analyze it using a digitizer tablet. An important aim of this thesis is to develop a tool that permits to analyze handwriting produced from right to left and vice versa. To this end, a program was created: VB Digital Draw, which is experimental software expressly developed in our department for recording and analyzing the data of my dissertation (Toneatto et al., *in progress*).

CHAPTER 3 presents a theoretical background concerning five main topics that include: (1) detection of anticipatory events in handwriting, (2) perceptual asymmetry, (3) fixation in reading, (4) directional reading habits and (5) mirror handwriting. The aim of this introduction is to underline the intimate relationship between writing and reading; an important implication of this assumption is that there is a common medium for perception and action.

CHAPTER 4 introduces the third experiment and its respective results and discussion. The experiment III is based on a Character recognition task and aimed to

determine whether (1) two different types of recognition Tasks (Read and Space) could induce different competence of character recognition even if stimuli remain unchanged. (2) Secondly, it permitted to examine the performance of Italians and Tunisians observers (3) finally; this study informed us about the visual scanning preference adopted for each group and each task

Finally **CHAPTER 5** contains a general discussion and conclusion with suggestions for further researches. It also provides evidence on remediation instruments and activities to promote handwriting readiness. .

Chapter 1

Theoretical section

Arabic Writing and Methods for the Measurement of Handwriting

1. Writing system

There are approximately 6900 languages currently spoken around the world, the majority of which have only a small number of speakers. About 230 million are Native Arabic speakers (Sakkal, 2007).

Arabic belongs to the Afro-Asiatic (Semitic) family of languages along with Hebrew. These languages are characterized by the use of three-letter roots that are modified in many ways to form words. For example the word **k-t-b** connotes writing; **kitab** means book; **maktaba** means library and so on. The Arabic script evolved from the *Nabataen* Aramaic script. It has been used since the 4th century AD. The Aramaic language has fewer consonants than Arabic, so during the 7th century new Arabic letters were created by adding dots to existing letters in order to avoid ambiguities. Further diacritics indicating short vowels were introduced, but are only generally used to ensure the Qur'an was read aloud without mistakes.

There are two main types of written Arabic:

- **Classical Arabic:** the language of the Qur'an and classical literature. It differs from Modern Standard Arabic mainly in style and vocabulary, some of which is archaic. All Muslims are expected to recite the Qur'an in the original language, even though many rely on translations in order to understand the text.

- **Modern Standard Arabic (FusHa):** the universal language of the Arabic speaking world which is understood by all Arabic speakers. It is the language of the vast majority of written material and of formal TV show, lecture, etc.

However, it is important to notice that each Arabic speaking country or region also has its own variety of *colloquial spoken Arabic* (**Aamiyya**). These colloquial varieties of Arabic appear in written form in some poetry, cartoons and comics, plays and personal letters.

1.1 The Arabic writing system

Arabic is cursive. From its simple and primitive early example of the 5th and 6th century AD; The Arabic alphabet developed rapidly after the rise of Islam in the 7th century into a beautiful form of art. The main two families of calligraphic styles were the dry stiles, called generally the Kuffi, and Naskhi.

The city of Kufa, established in Iraq in the year 641 AD, flourished in a short time into an urban center with vital cultural activities. Among them the refinement of the Arabic script: Kufic style is an elegant and uniform script. It had a combination of square and angular lines. As Kufi reached perfection, it was used for copying Qur'an for the next three hundred years.

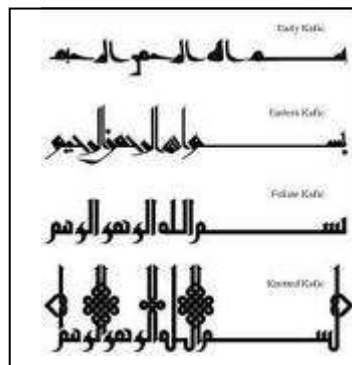


Figure. 2 Samples of the same Arabic sentence written with four Kufi styles.

Naskhi, which means "copying", is the soft cursive style of Arabic script. It was developed in the 10th century, and refined into a fine art form in Turkey in the 16th century. The early examples, however, lacked elegance and discipline and were used mainly for the secular and practical, rather than aesthetic, purposes (Sakkal, 2007). In spoken Arabic there are 29 consonants and 8 vowels (3 short vowels, 3 long vowels, and 2 diphthongs). Jensen (1970) provides a complete description of the writing system for Arabic. As one can see there the majority of Arabic letters differ in form depending on their position in a word, that is depending on whether they appear at the beginning, middle, or end of the word. However, Arabic script remains one of the most fashionable writings, as it is cursive (see figure 3).

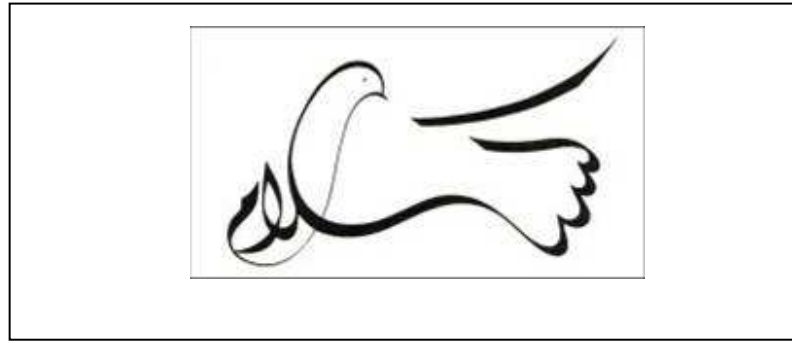


Figure. 3 The word “Salam” (peace) written in a fashionable and symbolic representation

1. 2 Features of Arabic Handwriting

Semitic writing systems such as that used to write Arabic are unique amongst alphabetic writing systems because Semitic systems short vowels are represented as diacritics on consonant letters, and not represented at all in text intended for skilled readers.

In the following section I will describe the notable features of Arabic writing system (in contrast of English writing system) such as direction, number of letters and their forms, diacritic system and orthography.

Isolate	End	Middle	Beginning
ه	ا	ح	ح
ع	ع	ا	ع

Figure 4. The four possible shape of the letters [ha] and [3a]

As it can also be seen there, the consonants are written as cursive characters whilst the vowels are written as diacritics attached to these cursive characters, above or below him.

The three short vowels are represented by diacritics, of which two stands above letters and one below them:

1- "Fatha" (َ): this sign, written above a consonant letter, means the vowel "a"

2- "Kasra" (ِ): this sign, written under a consonant letter, means the vowel "i"

3- "Dhamma" (ُ): this sign, written above a consonant letter, means the vowel "o"

In addition, there are the “double damme” (ً), and the “double kasra” (ٍ): these three signs are only used and pronounced at the end of nouns and adjectives that are not, grammatically, in the definite form.

Although the letter " alif", " waw" and "ja" represent consonants when written together with another consonant these three letters represent the three long vowels of Arabic.

In addition to the diacritics for the short vowels, the long vowels, and the diphthongs, there are four other reading signs:

- 1- “skoon” (ْ): this sign indicates that there is no short vowel to follow;
- 2- “shaddeh” (ّ): this sign is written above a consonant letter to indicate doubling of the letter;
- 3- “maddeh” (˘): this sign is written above the consonant letter alif to indicate doubling of this letter;
- 4- “hamzeh” (ء): this sign signifies a glottal stop

With the exception of “hamzeh”, these reading signs in themselves do not have phonetic value.

1. 3 Differences between the Arabic and English writing systems

The Arabic writing system cannot unambiguously be classified as either syllabic or alphabetic.

In its written form, the modern Arabic writing system, like the English writing system, is alphabetic (Azzam, 1993).

It is a system which allows reading (and writing) to occur at the level of the phoneme, since the individual characters of the Arabic writing system correspond to phonemes. However, if one considers the diacritics used for specifying vowels in vowelized Arabic as “part of” the consonant letters with which they correspond, and then it might be argued that the Arabic writing system is syllabic, unlike English.

A major difference is that English is written from left to right whereas Arabic is written from right to left. Also, in the modern Arabic script there are groups of different Arabic consonant letters that are strikingly similar in shape, only distinguishable by the number and position of diacritics dots (see figure 5).

ت - ث - ب	ع - غ
ح - خ - ج	ط - ظ

Figure. 5 Arabic letters differentiated only by the number and placement of dots.

Furthermore, as already noted, the form for the majority of Arabic letters varies according to their position in a word. The difference between the final forms of a word and the corresponding non-final forms is much greater than the differences between many contrasting pairs of Arabic letters (Sakkal, 2007). Vowelized Arabic orthography is transparent or “shallow”, since letter sound correspondences are simple and invariant, and the deduction of phonological information straightforward. In contrast, the unvowelized script as used in the adult reading, where the vowel diacritics are normally absent and where alternative meanings and pronunciations are possible for a given word (or letter sequence), is opaque or deep. Usually the context, the grammatical construction and/or prior knowledge will be the key factors for deducing vowel phonemes and deciding which meaning and pronunciation are intended.

Therefore, an essential difference between Arabic and English orthography is that a high proportion of the vocabulary of a Semitic language such as Arabic consists of words derived from roots (usually comprising three consonants, having a verbal or adjectival meaning).

Here is the example of the word **k-t-b** (connotes writing) written with different combinations of diacritics. Each word has a single meaning but belongs to the same lexical field.

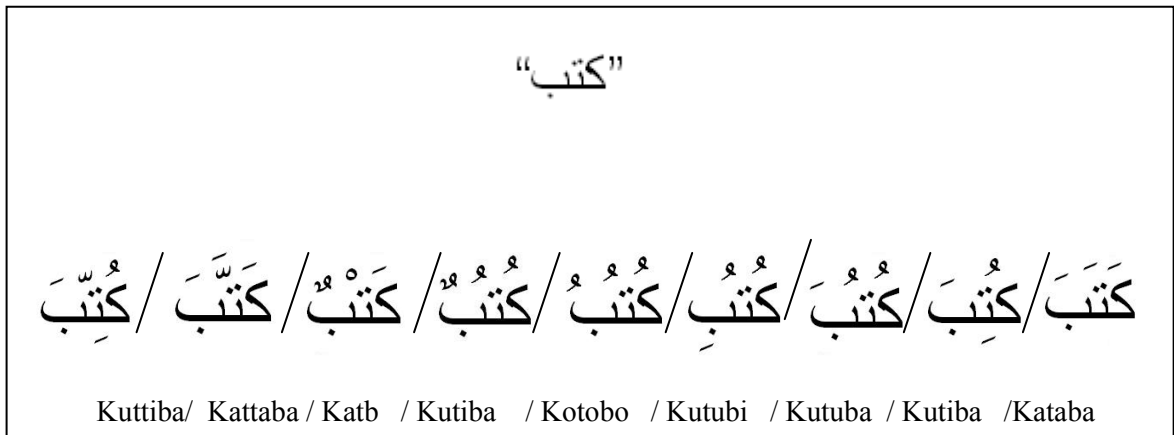


Figure. 6 An example of nine words derived from the same root k-t-b using different diacritics

Another major difference between the Arabic and English writing system is that the letter-sound or grapheme-phoneme correspondence in the (vowelled) Arabic Script is very predictable and regular, whereas there are many irregular or exception words (approximately 25%) in English – words such as “colonel” or “steak”, that disobey standard grapheme-phoneme rules. Moreover, many graphemes in English are multiletter graphemes (such as the “th” and the “igh” in “thigh”) whereas all graphemes in Arabic are single letter graphemes except in the case of long vowels, which are represented by two letter graphemes consisting of a vowel letter plus a diacritic vowel-sign. Thus, the mapping of letters to phonemes in Arabic is largely but not entirely one-to one.

In addition, Arabic (unlike English) does not possess any heterotrophic homophones, that is, words identical in pronunciation but different in spelling – only one grapheme can ever correspond to any particular phoneme. Hence in Arabic, if two words have the same pronunciation they must also have the same spelling. In English, on the other hand, sets of words that are identical in pronunciation but different in spelling and meaning are quite common- for example, “sail” and “sale”.

Yet another difference between Arabic and English is that the Arabic language is dichotomised into a formal or classical form (FusHa) and colloquial dialect (Aamiyya). Both forms are spoken but only the formal one is seen in printed materials. Overall, the two forms are quite different in their vocabulary (Azzam,

1993; Sampson, 1985). FusHa is the Classical form of Arabic to communicate through the media (spoken) and printed material (books, news paper, and signals) and permitted to all Arabic speakers over the world to communicate even if they are native from different countries, speaking different dialects.

These features of written Arabic make the study of learning to read and to write in this language of particular interest.

1. 4 Arabic and Hebrew handwriting

The following paragraph is a very brief introduction to the Hebrew language. Since we based our research on reviewing the existing literature, especially, the studies carried on Hebrew handwriters (Rosenblum, 2000).

Hebrew as Arabic is a Semitic language. It dates back to biblical time. It remained relatively unchanged for about 2000 years until the end of the nineteenth century, when the birth of the Modern Hebrew took place.

Hebrew alphabet uses 27 characters to represent 22 consonants. This is because five consonant have different shapes when they appear at the end of the word. Vowels are represented in two ways: diacritic marks and specific consonants. Diacritic marks, called short vowels, may be used above, below or inside characters. However, the diacritic marks are not shown; the vowel sounds are inferred from the context. Besides, some consonants also serve as vowels (long).

Written Hebrew, as Arabic, has no equivalent to capital letters and it is written from right to left.

Unlike Arabic, Hebrew letters do not take on different shapes depending on the surrounding letters. The five final shape letters are considered additional, separate letters of the alphabet. Furthermore, it does not have a cursive script and the letters are not connected.

2. Handwriting Evaluation Scales

This section highlights the importance of handwriting evaluation to discriminate between proficient and dysgraphic writers and reviews the development

of methods used to evaluate handwriting difficulties. It, also, included a discussion of methodological aspects of current conventional handwriting evaluations, a presentation of kinematic and geometric descriptors, and the use of a computerized system that may be helpful in better understanding the handwriting process of poor writers.

Handwriting and drawing are complex motor behavior in which linguistic, psychomotor, and biomechanical processes closely interact with maturational, developmental, and learning processes

Over the years, many methods have been developed for the evaluation of handwriting. Traditional handwriting research has focused on analyzing the product of handwriting activity and its speed. These evaluations helped the investigation of the developmental sequence of writing and the clinical identification of children with handwriting difficulties. The handwriting quality of children with difficulties has been described in studies as “poor” and can be characterized by inappropriate spacing between letters or words, incorrect or inconsistent shaping of letters, poorly graded pencil pressure, letter inversions, and mixing of different letter form (Rosenblum et al., 2003).

The process of describing the features that characterize the written output of children with handwriting difficulties has formed the basis for the development of scales for handwriting evaluation.

In fact, descriptive research in the field of handwriting, by using Scales, has helped to gain insight into several aspects of poor handwriting performance., including letter formation quality, size and slant control, and pen-holding postures (Hamstra-Bletz, De Bie & Den Brinker, 1987). Also developmental changes related to writing speed and the form features of script have been well documented. (Blöte & Hamstra-Bletz, 1991; Mojet, 1991)

Two factors are considered in the literature while describing handwriting performance: legibility and speed. Difficulties with letter formation, spacing, size, slant and/ or alignment may affect handwriting legibility. However, Amundson and Weil (1996) maintain that below-standard performance in letter formation, and size in particular can greatly reduce handwriting “readability”. A handwriting sample may be readable even though poor alignment interferes with its appearance. Speed is also an

important aspect of handwriting ability if a child has to cope with a classroom demand, and speed is a variable depending on context, instruction given, and whether the child is copying, taking dictation, or free writing. It is therefore, important to consider these factors when comparing children's handwriting speeds.

For instance, descriptive, product-oriented approaches have made clear which criteria must be met for script to be legible (De Ajuriaguerra & Auzias, 1975), what kind of malformations in letter forms are found, which letters are most important for legibility (Freeman, 1954), and how distance between letters and words affects legibility (Alston, 1983). However, the purpose of the researchers who created the various handwriting evaluation scales was to create standardized evaluations that give a quantitative scoring for handwriting quality. Their dilemma was how to define the "quality of handwriting" or "readability" (Ayres, 1912 cited by Rosenblum, 2004). Many evaluations scales were developed through the last 25 years.

The following section is devoted to a brief description of three evaluation scales: TOLH, BHK (both for Latin Handwriting), and HHE (Hebrew Handwriting).

2.1 The Test of Legible handwriting -TOLH

The Test of Legible handwriting –TOLH (Larsen and Hammill, 1989) is aimed to evaluate readability of manuscript (print) and cursive writing of children from the 2nd to 12th grade. The authors of the TOLH constructed a scale of writing samples consisted of written stories based upon pictures or passages written by the students during school.

The samples were made up by three writing types: print: (i.e., manuscript), script writing (i.e., cursive) that was tilted vertically or to the right, and script writing tilted to the left.

The objective of the evaluator is to match the written passage, as closely as possible, to one of the given samples. Standard and percentile scores are given to the written product's readability, and an informal protocol is prepared to summarize the analysis of the child's mistakes. This scale is considered unique in its capacity to evaluate three types of handwriting, and easy to perform. In fact, in a study carried by Graham et al., 2001, the TOLH was used by classroom teachers to select experimental groups of poor and proficient handwriters for research.

2.2 The Concise Evaluation Scale for Children's - BHK

The Concise Evaluation Scale for Children's Handwriting - BHK (translation from German) (Hamstra-Bletz et al. 1987), is a tool designed for the screening of poor handwriting quality on the basis of a completed piece of writing at elementary school (3-8). It has been shown that the BHK is suitable for describing changes in the handwriting characteristics of students from 2nd grade through 6th grade (Blöte & Hamstra-Bletz, 1991). It is also distinguishable by the amount of research devoted to investigate its psychometric properties by its use among children in various populations.

The writing task consists of copying a standard text in five minutes or at least five lines if the child is a very slow writer. The text is copied on un-ruled paper.

The test evaluates both quality and speed of handwriting. Quality is evaluated by assessing 13 characteristics¹ of the script as for example the writing is too large and the widening of left-hand margin.

A total score is calculated to determine writing quality which is subsequently used to categorize the child as a poor or proficient writer. Writing speed is calculated according to the number of letter written in 5mn.

Longitudinal studies conducted in Germany with 127 children from the second to seventh grade found that the test is sensitive to developmental changes during the elementary school years (Blöte & Hamstra-Bletz, 1991). The BHK scale has also been found to discriminate between children with and without dysgraphia (Hamstra-Bletz & Blöte, 1993). As a result, its authors suggest that the BHK can be used in the early identification of children with handwriting difficulties.

¹ The BHK evaluator includes: (1) the writing is too large; (2) widening of left-hand margin; (3) bad letter or word alignment; (4) insufficient word spacing, (5) acute turns in connecting joins to letters, (6) irregularities in joins and or absence of joins; (7) collisions of letters; (8) inconsistent letter size; (9) incorrect relative high of the various kinds of letters; (10) letter distortion; (11) ambiguous letter forms; (12) correction of letter forms and ; (13) unsteady writing trace.

2.3 The Hebrew Handwriting Evaluation – HHE

The HHE (Erez et al., 1996, 1999) was developed to assess the handwriting of children suspected of having writing difficulty in Hebrew. Children are asked to perform three assessments:

1. copying the letters of the Hebrew alphabet (in atypical order to avoid a possible influence of the familiar order on the copying).
2. copying a short story (of 30 words) onto a lined paper.
3. writing a short story from dictation (also containing 30 words) onto lined paper.

The tool enables the assessment of four factors: writing speed, quality, mistakes, and ergonomic factors. writing speed: measured by the number of letters written in one minute.

1. writing quality: tested along two dimensions, letter shaping and spatial organization. Scored according to a liked scale 1-4.
2. ergonomic factors (pressure, pencil grasp, grip consistency, body posture, paper position and stabilisation): scored according to defined criteria on a scale of 1-4
3. writing mistakes: counted in each of the passage written by the child.

Construct validity was indicated by the significant differences found to exist between children who write well and those who have difficulties (Dvash et al., 1995; Lifshietz and Parush, 1996) also regard to ergonomic factors measured (Parush et al., 1998).

2. 4 Merits and limitations of Handwriting Evaluations Scales

The common opinion among handwriting evaluation developers is that “readability” is an important factor in judging the quality of the written product. However, handwriting scales may differ as to their psychometric properties and the applicability of the scales to different populations. Precisely, there are many methodological variations among the scales in terms of “factors” that may affect student’s outcome scores. These factors include the nature of the handwriting

assignment, instruction given to the examinees, writing accessories, specific assessment criteria, and methods for quantifying writing errors (Rosenblum et al., 2003).

2.4.1. The evaluator:

Generally the assessments do not indicate who is allowed to administer the evaluation scales, whether it is a teacher, a therapist, or a student's self-assessment. In addition, they do not specify what preparation is required before performing the evaluation. The combination of a lack of precise instructions together with a lack of practice in using the tool raises doubts regarding the reliability of evaluators who are not part of the research team (Graham et al., 1998).

2.4.2 The criteria:

There is a great variability in the definition of "readability". Most researchers accept the criteria of size (high, width), slant, spacing (space between letters/words), the degree of line straightness, shape (letter form and shape), and the general merit of the writing (Bruinsma and Nieuwenhuis, 1991; Mojet, 1989). However, the grading scales for each criterion are different from one assessment to another. Yet, different scales evaluate the criteria differently. In the BHK scale, the evaluator needs only to check "yes" or "no" in response to questions relating to general letter forms. In the HHE scale letter formation is judged on a 1-4 rating scale.

2.4.3 The assignment:

Tasks complexity varies among the various evaluations scales. Some tools give a variety of assignments, such as copying shapes, letters, and words (Ziviani and Elkins, 1984). Others ask the child to copy paragraph (Erez et al., 1999; Hamstra-Bletz et al., 1987), to write a paragraph under dictation, or to write letter/ and numbers for memory (Amundson, 1995; Erez et al., 1999). Variability also, regards the time (from 5 to 20mn) and words number.

Researchers have found that people write differently when asked to copy than when asked to write creatively (Lewis, 1964). Moreover, writing can be affected by

the individual meaning that the assignment holds for the writer (Graham, 1986). Task parameters are important in clinical and educational settings where children observed to succeed in short-writing assignment (word, sentences) fail to complete longer assignments (paragraphs) or succeed in copying tasks but not in dictation tasks (Levine, 1993).

2.4.4 The instructions:

There exist different types of instructions for completing the writing assignments. A child may perform differently when asked to “to write as quick as possible without stopping for corrections” (Ziviani, 1984), “write as you usually do when you try to write well” (Riesman, 1993), or “write as you are used to” (Erez et al., 1999). It is possible that the way the writer perceive the instructions affect an individual’s handwriting performance.

2.4.5 Pen and paper:

From the review presented earlier, it is important to notice that: First, different handwriting scales do not specify the writing tool (pen or pencil; the one the writer is used to or another one) while performing the handwriting assignment. Second, in some assessments, the child is asked to write on unlined paper, and in others, on lined paper (Erez et al., 1999).

Previous studies had demonstrated that younger children write more legibly on a page with no lines (Hackney et al., 1973; Lindsay and McLennan, 1983). In contrast, Brunhill et al (1983) and Krzesni (1971) showed that the quality of writing on unlined paper was inferior to that done on lined paper. Moreover, young schoolchildren are used to writing on lined paper. Trap-Porter et al (1983) investigated whether writing on different types of paper effects handwriting quality. In fact, these researchers demonstrated that not only the presence or absence of lines affect the handwriting quality but the width of the line affects the quality as well. They found that letters written with a wider line (1,11cm) were more accurate than those written on paper with ordinary line width (0,5cm).

It is possible that the different findings regarding paper format are the result of the children's age or specific assignments given to them. Regardless of the reason, most of the assessments lack a description of the rationale for giving a page with or without lines, and no consideration is given to the way in which the child is accustomed to writing at school.

2.4.6 Variability in personal writing style:

A person's handwriting may change from one day to the next or even within the same written passage (Herrick, 1960). Assessment scales that are not sensitive enough to personal or developmental changes in the individual's handwriting may result in children being falsely judged as having handwriting difficulties.

2.4.7 Writing speed measurement:

Evaluation scales aim to assess the readability of the handwriting but also its velocity.

However, different writing tools vary in how they measure writing speed.

On one hand, speed is calculated by recording the time needed to write a specific text or the amount of text reproduced within a specific time period. On the other hand, some evaluations tests speed on the basis of the number of letters written in a limited time: one, two or five minutes. So what was the rationale of the various test developers for making their choice of assignment task?

2.4.8 Applicability of the scales to different populations:

A review of the literature demonstrates that a number of handwriting scales were developed but not further researched in terms of applicability (e.g. Alston, 1983; Helwing et al., 1976; Phelps et al., 1985; Rubin and Henderson, 1982; Stott et al., 1984; Ziviani and Elkins 1984). The two scales receiving the most thorough investigation are the TOLH (Larsen and Hammill, 1982) and the BHK (Hamstra-Bletz et al., 1987). Somehow, all above-mentioned assessments were developed for languages using a Latin-based character set. The HHE is the only standardized scale

for Hebrew writing, which is a language that contains unique features, making it impossible to evaluate Arabic with this evaluation tool.

In fact, even if Arabic and Hebrew texts are written from right to left, in Hebrew spaces occur not only between word and letters but within the letters themselves. In Hebrew, written letters are not connected (a fact that results in many breaks while writing) and furthermore, some letters change their form when they terminate a word (Modlinger, 1983), while in Arabic writing, letters are connected, and change shape depending on their position in the word (see p.7 and 8).

Abizeid, Albaret and Bouamama (In progress) are proceeding in the standardization of the Arabic version of BHK. The Arabic-BHK aims to evaluate the readability of the handwriting of Lebanese children aged from 6 to 12 year-old. The writing task consists of copying a standard Arabic text in five minutes or at least five lines if the child is a very slow writer. The text is copied on un-ruled paper. The test evaluates both quality and speed of handwriting.

3. The use of Computerized Temporal and Spatial Measurements in Evaluating Handwriting Performance

Several studies on dysgraphia have been conducted from a descriptive approach focused on the analysis of the product of handwriting activity. The application of the result of handwriting evaluation, notably in educational settings, is often based on the *static* final product without reference of the underlying source of difficulty. The rising of computerized technology over the last 25 years had permitted to researchers to examine the “input” of handwriting. This switch in orientation is appropriate because handwriting is a highly *dynamic* process (Longstaff and Heath, 1997).

Applications of technologically driven research into handwriting began with Freeman’s study (1914) who aimed to quantify cinematic aspects of handwriting in Children. A kymograph was used for recording the movement variability of the pen. While a sensitive plat form was used to register pressure variation. On the basis of the comparison of adult’s and Children’s handwriting speed (length/ duration), Freeman

demonstrated that adults were faster than children. He argued that children's writing was irregular, less automatic than adult's handwriting (Zesiger, 1995).

Teulings and Thomassen's study outlining advanced techniques for recording handwriting (Teulings and Thomassen, 1979). Research has emphasized the handwriting process of adults (e.g. Alimi and Plamondon, 1996; Rogers and Found, 1996; Teulings, 2001; Van Galen et al., 2001). However, less studies exists regard to the handwriting process of children in general and of children with difficulties in particular (Wann and Kadiramanathan, 1991).

Analysis of the handwriting process is accomplished through the use of a digitizing tablet, an electronic surface which, when used in tandem with a special pen and a computer, allows for the recording of the "x" and "y" coordinates of the specialized pen and, its position and pressure on the paper are determined on the digitizer with a high spatial and temporal resolution. These data are then saved on a PC and post-processed program using computational algorithms to determine a broad variety of kinematic parameters into that reflects different aspects of movement.



Figura.7 Wacom Intuos 3 A4 digitizer tablet²

² **Technical Specifications** • Physical size (W×D×H): 440 × 340 × 14 mm • Active area (W×D): 305 × 231 mm • Pressure sensitivity: 1,024 levels • Resolution: 5,080 lpi • Pen Accuracy: ±0.25 mm • Mouse Accuracy: ±0.5 mm • Tilt: ±60 degrees • Maximum reading height with Pen: 6 mm • Maximum report rate: 200 points per second • Connection: USB • Cable length: 2.5 m • Weight: 1,800 grams

A reduced number of variables are necessary for the practical analysis of movement data. It is suggested the categorization of the kinematic parameters into four subgroups that include automation of stroke generation, speed, variability (dysfluency) and axial pressure. Such recordings reveal the spatial and temporal features of handwriting in real time.

3.1 Automation of stroke generation:

When a healthy human participant produces a rapid stroke with his dominant hand from a restful posture on a digitizer, the pen tip trajectory is characterized by several properties similar to those normally encountered in the production of rapid movements (e.g. Gielen, Van den Oosten, & Van den Pullter, 1985; Latash, 1998; Morasso, 1981; Plamondon, 2003; Zatsiorsky, 1998). Handwriting strokes have been used and studied in many field of research and for many reasons.

First, in pattern recognition, many algorithms have been created to recognize handwriting based on the properties of the elementary strokes or primitives that have been used to generate a character or a letter (Plamondon & Srihari, 2000; Plamondon, Lopresti, Schomaker, & Srihari, 1999). Second, in motor control, the production of strokes studied from different points of view (speed-accuracy tradeoffs, optimization principles, fine motor control strategies, developmental coordination, etc) helped to gain better understanding of the underlying cognitive and neuromuscular processes involved in their production (Meulenbroek & Van Gemmert, 2003; Van Galen & Morasso, 1998; Van Gemmert & Teuling, 2004). Third, in neuroscience, strokes are analyzed to characterize neurodegenerative processes like Parkinson's and Alzheimer's disease (Schröter et al., 2003; Teuling & Stelmach, 1991) and afterward used as key patterns to evaluate the recovery processes in the rehabilitation of patients with cerebrovascular accidents (Van Galen, 1990)

So researchers concentrate on various aspects of handwriting strokes, depending on their research goals. Some of them are more interested in their global properties (number, length, curvature, duration, etc), while other analyze local details like velocity or acceleration peak, for example.

Still other are more concerned with the residual handwritten trajectory left on a piece of paper, a digitizer or a tablet computer, or with the kinematics or kinetic properties of the strokes.

3.2 *Speed:*

Since handwriting is the product of a dynamic process, it is reasonable and informative to look at the consistency of the dynamic characteristics of pen movement such as velocity and acceleration profiles (Zesiger, 1995). While variability in movement dynamic is undoubtedly not the only cause of reduced legibility it is likely to be an important contributing factor. The information gained from analyzing the dynamics of the process generating the handwriting will also leads to a better insight into mechanisms underlying lack of motor control during the execution of handwriting movements. The dynamics of mature handwriting, as exhibited in adults, involves an automated sequence of motor actions, the entire sequence of actions being made with minimal conscious control. Using a well developed dynamic motor memory; the cognitive system can perform accurate movements with little sensory feedback.

It is generally agreed (Longstaff, & Heath, 1997) that the movements performed in writing letters arise from the coupling of two velocity (or force) generating oscillators. The first is in the horizontal (x) direction and the second is in the vertical (y) direction (Hollerbach, 1981). While Dysfluency is the natural logarithm of the number of inversion of the velocity profile)

The x and y oscillations are mainly produced by modulating the force amplitude and duration generated from muscles in the hand by modulating the force amplitude and duration generated from muscles in the hand and wrist, with some contribution from the rest of the arm (Van Galen, 1991).

Several authors have demonstrated that good handwriting is characterized by smooth velocity profiles, while the velocity profiles for poor handwriting are disturbed by many inversions due to acceleration and deceleration of the pen movement (Van Galen et al., 1993; Wann, 1987; Wann & Jones, 1986). For example Van Galen et al. (1993) applied Power Spectral Density Analysis (PSDA), a technique which is sensitive to rhythm oscillations, to the velocity profiles generated by 24 good and 24 poor handwriters aged between 7 and 12 years. The results showed that the velocity profiles of poor handwriters were much more variable than those of good handwriters (discussed in the following section).

3.3 *Variability:*

3.3.1 *Neuromotor noise*

Van Galen et al. (1993) investigated the immature movement control in poor writers, expressed as “movement noise” or “neuromotor noise” in referring to the children’s lack of movement precision and consistency. These researchers suggested that this called neuromotor noise is a dynamic influence on the spatial variability of movement (Smits-Engelsman et al., 1998). Results showed that poor writers go higher absolute scores of “neuromotor noise” than did atypical writers (Van Galen, 1993). Spatial inaccuracy is caused essentially by the variability of the motor output system. In addition, the neuromotor noise is considered to be a dynamic influence on the spatial endpoint variability of the movement (Van Galen, 1993).

Power Density Analysis is a method to estimate the relative contribution of noise to the total energy in a recorded movement signal. Precisely (PSDA) is a mathematical method in which Fast Fourier analysis is used to decompose the energy in a time function of recorded movement signal into its frequency components. For application of the method, it is assumed that observed variation of movement velocity is a periodic signal which basically is the summed outcome of various periodic source of variation. Each source has its own typical frequency. As less than optimal implementation of an adequate motor program, due to poor biomechanical filtering, will produce greater space-time variability.

3.3.2 *On air movements*

Rosenblum et al. (2003) used information on pen pressure to analyze a series of kinematic variables at play when the student has his/her hand in the air while writing. This kind of data reveals information on what the participant does with his/her hand when she/he is not writing but planning or preparing the next movement sequence. The authors showed that the “on air” time for poor writers is significantly longer than for proficient writers. This finding, which they called the “in air phenomenon”, is extremely useful for detecting children with handwriting problem.

3.4 *Axial pressures:*

Writing pressure is a less well studied parameter of script. Until now there is no generally accepted theory on the relation between writing pressure and psychological task factors. The writing pressure is the component of the force exerted on a writing surface, measured in the direction of the pen's axis (Zesiger, 1995). Pressure is usually defined in terms of movement in the downward (z) direction with changes in the magnitude of the applied pressure modulating the frictional forces acting on the stylus (Wann & Nimmo-Smith, 1991). It is the complex dynamic interaction between these velocity generating oscillators which results in handwriting.

Regardless to the underlying cause of pressure variability, numerous researchers consider that the factors that may influence pressure include: stress, age, the velocity of motor execution, size, complexity and length of the script. In a graphic task, increased level of limb stiffness will be manifested by a higher level of axial pen pressure. This leads to the general prediction that mental load and physical stress both produce increased level of axial pen pressure (Van Gemmert & Van Galen, 1998).

Kao (1983) and Shomaker & Plamondon (1990) investigated the progressive pressure increase towards the end of words (maximum pressure while writing 90% of the word), and the relation between axial pen force and pen point kinematics. Furthermore, some developmental studies on writing pressure have been performed by Mojet (1989) showing progressive pressure decrease with increase of age. In addition, it was demonstrated that progressive pressure increase with increase of word length (Maarse, Schomaker, & Thomassen, 1986) and with letter complexity (defined by the number of direction changes) (Kao et al. 1986).

Furthermore, Wann & Nimmo-Smith (1991) have demonstrated that pressure amplitude is influenced by two supplementary factors: the size of the production and the execution velocity. So when participants wrote twice bigger than the spontaneous size, their pen pressure increased approximately to 12%. As well, when they wrote faster, their pen pressure increased approximately to 13%. Consequently, these authors concluded that the pressure modulation aim to maintain the straight relationship between the lateral forces applied to the stylus and its movement (displacement). By the fact that writing pressure is contaminated with friction

(between the planar surface and the writing instrument) the interpretation of such results is complicated (Wann & Nimmo-Smith, 1991).

4. Individual variability

Until now, the attention was given to the general variability of characteristics of handwriting. What about the individual variability?

4.1. Pen Grip

There are only few studies related to the role of pen grip, but also for this task aspect the scarce evidence seems to support the idea of motor equivalence. Sassoon et al. (1986) found that, although there is a great anatomical variety in pen grip, writing proficiency is not strongly related to specific grips.

4.2 Handedness

Handedness does not seem to have a significant influence on the efficiency of writing. Meulenbroek and Van Galen (1989) studied spatial dynamic characteristics of handwriting in right-handers and left-handers, with an inverted (hooked) pen grip, and non-inverted, with male and female subjects in all groups. Small spatial variations in letter slant and size were observed in lefthanders, apparently to be explained as ergonomic adaptations to the specific position of the hand. Similarly to findings by Peters and MacGrory (1987), no differences in writing efficiency, in terms of speed and fluency, were recorded.

4.3 Gender

Gender had a significant impact on writings speed and pressure, both being higher for man (Meulenbroek and Van Galen, 1989). In addition, descriptive studies demonstrated that writing inclination and style (cursive/ script) in addition to spatial parameters (circles) had permitted to distinguish between men and women's handwriting (Maarse, Schomaker, & Teulings 1986).

4.4 Extrinsic factors affecting handwriting performance

Factors that may affect handwriting performance in children and adults may be intrinsic, stemming from the writer's actual performance capabilities or extrinsic relating to environment/biomechanical issues. Extrinsic factors include sitting position, chair/desk height, writing instrument, type of paper used and its placement on the desk, environmental lighting and noise, blackboard distance when copying, and volume of handwriting that the writer is expected to complete.

4.5 Orthographic characteristics and writing Spelling

Spelling requires strong attentional and mnemonic competence, especially on young children, that affect other aspects of the writing process (Graham et al. 2002). The analytical study of handwritten production revealed, for instance, how the information encoded by the orthographic representation of spelling level regulates motor outputs in children (Kandel, Soler, Valdois, & Gros, 2006; Kandel, & Valdois, 2006a; 2006b) and adults (Kandel, Alvarez, & Vallée, 2006; 2008). The authors demonstrated that sublexical units regulate motor programming in handwriting, thereby producing significant movement duration and/or dysfluency increases at specific locations within a word. These increases appear at syllabic boundaries- for example, between *o* and *m* in the word *fromage* (“cheese”)-as well as at morpheme boundaries – in the word *montagne* (“putting up”), for instance, between the root *mont* and the suffix *age* (Guinet, & Kandel, 2010). The temporal increases are due to the simultaneous processing of the syllabic and/or morphological components of the word and local parameters, such as rotation direction, letter size, and force, necessary to execute the current movement sequence (Van Galen, 1991).

4.6 Graphophonological constraints

When a child has to write the word *chanson* ([Sãsõ]; “song”), for example, he/she segments the initial syllable into graphemes. He/she segments the initial syllable into grapheme *an* [ã] in parallel with local parameters (direction, size, and force), and finally *son* [sõ] as a whole syllable unit.

To sum up, numerous studies using online measures of the handwriting movement demonstrate that the orthographic representations used in writing production present a linguistic format. Letter, graphemes, syllables, and morphemes

modulate the processes involved in the production of handwriting movements. The way these linguistic units interact during the writing process depends on the orthographic characteristics of each language (Kandel, & Valdois, 2006a)

5. Software packages for the study of handwriting production

5.1 The most used

Various software packages that optimize the acquisition and the analysis of handwriting have been created. Most are commercial products, which may limit their use for some researchers. They are not adapted for Arabic Handwriting.

The software developed by Mai & Marquardt (1992) is particularly efficient for the automatic segmentation of strokes (i.e., movement sequence executed between two absolute velocity minima), but requires other tools, developed in Matlab. *OASIS* (De Jong et al., 1996) and *ComPET* (the evolution of *POET*, Rosenblum, Parush, & Weiss, 2003a) require further programming (in Matlab) for complete efficiency. *Spell-Write* is a free software package in which online processes can be studied, but the number of measures it allows the experimenter to implement is rather limited (see Alvarez, Cottrell, & Afonso, 2009, for an example of the kind of information it can provide).

Ductus is a free software designed to analyze and help understanding of the processes underlying handwriting production. It is an excellent tool that experimenters, psychologists and therapists can easily manage. It can be suitably used with children and patients presenting handwriting pathologies. It is a digitizer-based device that works on a Windows platform with Wacom digitizers. This software is composed of two distinct modules. The first module concerns stimulus presentation, and the second module is devoted to data analysis. Apart from the geometrical aspects of handwriting, such as trajectory formation, *Ductus* provides a wide range of kinematic information, such as velocity, duration, fluency, and pauses, linked to the mastery of the movement itself. *Ductus* is programmed to analyze scripts written from left to right.

An important aim of this thesis is to develop a tool that permits to analyze handwriting produced from right to left and vice versa. VB Digital Draw is experimental software expressly developed in our department for recording and analyzing the data of my dissertation (Toneatto et al., in progress). It seems to be a good alternative, because it is ready to use in its present state, it can perform a wide range of measurements, adapted to Arabic and Latin handwriting. Access to it is free with a simple request to the authors.

5.2 VB Digital Draw

VB Digital Draw aims to analyze and helps understanding of the processes underlying handwriting production. It is a digitizer-based device that provides information on the handwriting process. As Ductus, it consists of two distinct modules that operate independently. (1) The first module concerns stimulus presentation. (2) The second module is devoted to data analysis.

VB Digital Draw integrates the dynamic presentation of the script production and movement analysis into one package. Data acquisition is conducted with a module that acquired data on the handwriting movement from a digitizer. It was designed to adapt to different experimental possibilities and acquire data in a very “ecological” fashion. It can be used for studying adults’ and children’s handwriting production. Thus, when using VB Digital Draw, the children can have the feeling of writing as they usually do in their school task. A great number of measurements can be made automatically. Both the data acquisition and kinematic analysis “modules” are simple to use, so they can be used by non motor control researchers.

The two modules function on Windows platform XP with Wacom digitizers. VB Digital Draw is edited in Italian and will be translated in Arabic and French. A laptop and a digitizer are required to record the handwriting movement. While writing, the user can see the dynamic presentation of the script in real time on the computer screen. If the writer made a mistake there is no way to cancel it since the recording is automatically going on time. Further correction can be made manually, directly on the output data.



Figure. 8 The output data (txt file)

The handwriting data are recorded at a sampling frequency of 200Hz. The sampling frequency depends on the digitizer's capacities and not on the data acquisition module. The recorded information is the following:

1. *Pen position* on the digitizer surface (x, y raw coordinates) – that is, when the pen is in contrast with the paper. It is also possible to record the pen position on the digitizer area even if there is no contact between the pen and the digitizer – that is when the pen is in the air. The availability of these data depends on the digitizer's capacities. For a Wacom Intuos 3 A4 format, the pen is detected up to 250 mm above the digitizer's surface. Accuracy pen: $\pm 0.25\text{mm}$
2. *Pen pressure* refers to the pressure of the pen on the digitizer's surface. It is received in an arbitrary unit rather than in grams per area. For a Wacom Intuos 3 A4 format, Levels of pressure sensitivity on the pen (1,024 levels), which can be transformed in Newton..
3. *Azimuth*: angle of the pen with the horizontal line (in radians).
4. *Data Count*: automatic counting since the instant at which the pen touches the surface of the digitizer. There is no latency; The Digitizer driver automatically generates the signal.

The stimulus presentation module records all this information in a txt file in addition to a bitmap image of the production. The data analysis scripts generated in Matlab reads and performs calculation on this data (See Appendix 1 for “The user guide of VB Digital Draw” p.102).

Chapter 2

Experimental Section

Arabic Handwriting Analyses

So far, the abovementioned studies and measurement techniques of movement characteristics seem to be especially relevant in the search for causes of poor handwriting. They suggest it may be advantageous to combine both handwriting scales and computerized technology for the evaluation of writing difficulties. However, these tools regard exclusively the Latin and/or Hebrew handwriting. For this reason, two complementary studies were designed: the first experiment aims to give a general description of Arabic handwriting product while the second one is based on kinematic and geometric analysis of handwriting.

Both experiments were authorized by the Tunisian Ministry of Education and carried out in collaboration with The Institute of Human and Social Sciences of Tunis. These authorities indicated the school that participated to the experiment. The children participated in the experiment with the consent of their parents.

6. Experiment 1: Description of Arabic Handwriting difficulties in Children

The purpose of Experiment 1 was to describe and compare the handwriting product of Tunisian proficient and poor writers attending the same school. A secondary goal of the experiment was whether or not the origin of the writing difficulties of poor writers is influenced by the characteristics of the Arabic writing system.

6.1 Method

6.1.1 Participants and selection procedure

Study participants included thirty children (12 female and 18 male; 28 right handers and 2 left-handers) attending schools for regular education who were identified by their teachers as having significant handwriting difficulties. On the basis of teachers subjective evaluation regarding the legibility of their handwriting, children were assigned either to the Poor Writers Group (n=15) or to the Good Writers group (n=15); with equal number of male and female participants. All participants were tested individually in a quiet classroom, well illuminated, in their school out of course time.

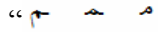
6.1.2 Evaluation session

The evaluation session includes the screening of the following abilities: selective Attention, memory, verbal abilities (semantic, phonological e metaphonological exercises), non verbal intelligence, reading ability, copying (words, sentences and isolated letters using a digitizer pen and tablet), executive functions, test of Visual, spatial integration and graphomotor capacities (standardized TOPIG)

None of the abovementioned tests is standardized. In fact, these tests, except the TOPIG, are part of the standardisation programme of the Arabic version of WISC and Raven PM47 through the Tunisian territory (throughout the Tunisian country) and for all school grades. The project is still in progress. In consequence, data are not completely collected nor officially standardized. So we do not use the scores for the statistical analysis. Nevertheless, the administration of these tests allowed us to verify the level of the children enrolled in our experiment. In general, the participants had no eminent difficulties in performing these tests.

6.1.3 Procedure

An Inking Pen and Digitizer tablet Wacom Intuos A4 were used to record the handwriting and the drawing shapes. A white unlined A4 paper was attached on the graphic tablet. Children had to perform two tasks:

(1) *Handwriting task*: in which participants were asked to copy, in their normal way of writing, a list of printed words, sentences and letters presented one at a time on 3 different papers in front of them (see appendix 2 p.109). Pupils were asked to read the list before writing it. There was no countdown because the graphic tablet recorded the time. This list contained by itself all the possible positions of the Arabic letters in a text (Initial, middle, end of the word but also isolated (e.g. “”, [m])). Participants used the same paper, in order to see how they used the space of the paper to organise their script. (2) *Drawing task*: in which, they were asked to draw 27 pictures (3 shapes on each paper) of the TOPIG-Test (Test de l’Organisation Perceptive et de l’Intégration Graphomotrice) inspired from the Bender-Gestalt test (See Appendix 3 p.114).

6.2 Analysis and results

The time used to complete the task is the first global descriptor of the writing performance. At any rate no statistical difference emerged between the two groups (802.7 ± 69.3 vs 786.7 ± 62.0 mean of PW and GW respectively, ns), which is in agreement with the absence of any detectable motor trouble in our sample, as resulted from a contextual clinical evaluation. At a preliminary qualitative inspection PW Group was characterized by some typical “errors” (see Fig. 2 and 3) which could be summarized in the following five types: (1) Deviation of a sentence from the horizontal, (2) misalignment of a word inside a sentence, (3) misalignment of a letter inside a word, (4) omission of dots, and (5) incongruent direction of writing movement (for instance a clock wise rotation where a counter clock wise rotation is required).

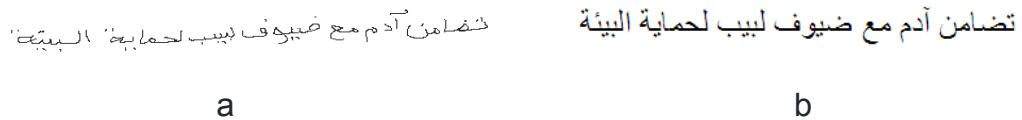


Figure. 9. A handwriting sample of a proficient child (a) and the sentence template to be copied (b)

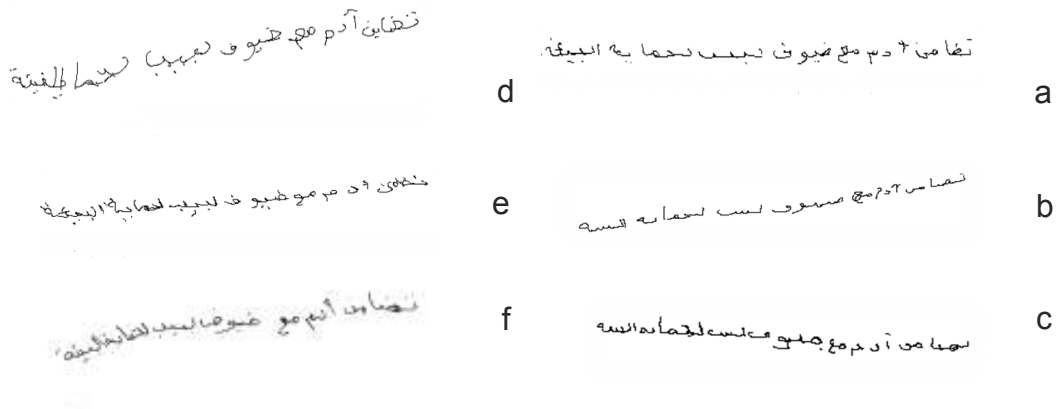


Figure.10 A handwriting sample of a proficient child (a) and the sentence template to be copied (b) Sample writings of six poor writers

To give a quantitative assessment of these typical “errors” the sentence in figure 9b was analyzed. The deviation from the horizontal alignment was measured as the slope (expressed in degrees) of the line interpolating the whole written sentence

(see figure 11a). A difference was found between the two groups (10.01 ± 1.50 vs 4.37 ± 1.67 deg, $F(1, 25) = 6.24$, $p < 0.05$).

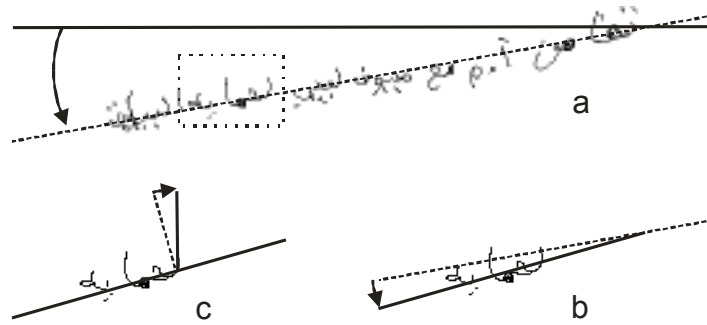


Figure. 11 The different type of misalignments taken into account for describing handwriting: Sentence misalignment (a), word-sentence misalignment (b), and letter-word misalignment (c).

To measure the bad alignment of words inside the sentence, the word “لحمية” was chosen as a representative example. The word-sentence misalignment was defined as the angle expressed in degrees between the lines interpolating respectively the whole sentence and the word (see figure 11b). Although in some rare cases quite important misalignments were found (till to -6.9 deg), no difference between the two group was discovered (-0.38 ± 0.49 vs 0.38 ± 0.54 , ns).

The letter-word misalignment was expressed as the deviation of the sample letter “ل” from the perpendicular to the line interpolating the word “لحمية” (see figure 11c). As well as for the word-sentence misalignment, quite important letter-word misalignments were measured here (till -26.1 deg), but no statistically significant difference came out (1.95 ± 2.94 vs 2.75 ± 3.29 , ns).

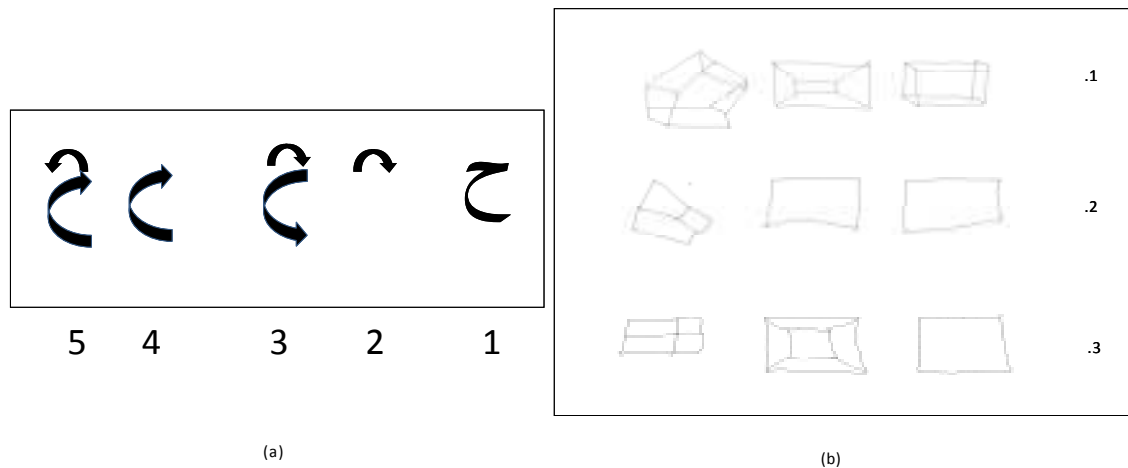


Figure. 12 (a) opposite motor execution for writing the letter “ح” [ha]: (2-3) conventional and (4-5) PW’s motor executions. (b) Sample of Cube Drawings of proficient (1) and PW (2-3)

Besides, PW tended to omit dots. The sentence we analyzed contained 21 dots, and the average number of dots was different in the two groups without reaching statistical significance (15.7 ± 1.75 vs 18.8 ± 1.96).

During their development, children alternate between a preference for clockwise and anticlockwise patterns (Thomassen and Teulings, 1979). If poor writing would be related to a developmental delay; one would expect to find that poor writers and good writers as differentially affected by the rotational direction of the writing. PW started writing the following letters: “ح, م, ظ, ع, ك” with a direction of movement incompatible with the continuity of handwriting movement which is strictly required in Arabic. The analysis of the dynamic writing of the first six words of the template list, (أرض- أغطية- بيئة- مذيع- صباح- بساط), showed a significant difference in errors of direction between poor and good hand writers (5.9 ± 0.13 vs 1.1 ± 0.15 , $F(1,25)=573,4$, $p < .0001$). Actually poor hand writers began producing the stroke at the conventional “ending” point of the letter. In this way, writing became hard even if they made a clockwise writing movement for the letters “ع” and “ح”.

6.3 Discussion

From this descriptive study emerges clearly that sentence misalignment and inappropriate movement direction appear to be the salient handwriting descriptors able to discriminate between PW and GW production. The score of spatial organization obtained from the TOPIG test reinforced this result. Actually, the two groups resulted to be statistically distinguishable in their score expressed as perceptual age: 9.1 ± 0.5 vs 10.2 ± 0.5 mean age of poor and good hand writers respectively ($F(1,25) = 5.42$, $p < 0.05$). No difference emerged for the graphomotor integration (TOPIG test 8.1 ± 0.5 vs 8.8 ± 0.5 mean age, ns); considering it as a drawing task, this result is in line with literature that limit the correlation between drawing and writing (Goyen & Duff, 2005); Vlachos & Karapetsas, 2003). Furthermore, this pilot study pointed out that Arabic handwriting is a visuo-spatial demanding task. As Eviatar and Ibarhim (2007) demonstrated that for Arabic and Hebrew, both hemispheres are implicated in processing writing morphology, and in this case, operate through a symmetric information transfer between both hemispheres. This leads to the suggestion that one important step when evaluating an Arabic writer's script is to evaluate his/her visuo-spatial competences.

6.4 Conclusion

These preliminary data stressed that the structural complexity of visual stimuli and its effect upon all aspects of encoding and processing of sensory input is an important factor to be dealt with in an attempt to understand the lag between perception and motor execution. Especially, it provides us with important information about the rehabilitation of such deficits. In fact, the particularities of these "problematic letters" ("ع", "ك", "ح", "ظ") is the need to perform mental orientation when the letter change position in the word. In this case it could be very interesting to extend this study to a "training" based on the implicit strategy to write these letters. These results, even if interesting, cannot be generalized to all the letters of the Arabic alphabet.

7. Experiment 2: Cinematic and Geometric Analyses of Arabic Handwriting

The second experiment focuses on investigating the kinematic and geometric characteristics of Arabic Handwriting. To this end, findings reported in the literature on Latin and Hebrew scripts will be necessary to gain insight into the comprehension and the discussion of the process underlying Arabic handwriting.

The main question of this study is whether Poor and Good Arabic writers differ on the amount of cinematic and geometric factors of their handwriting movement. As a secondary issue, an attempt was made to find evidence whether the production of Poor and Good Writers is differentially affected by specific, psychometric task demands (size and velocity). More precisely, the question is to search for evidence about any particular component of the handwriting process that may be involved more than others in the origin of poor Arabic script.

7.1 Method

7.1.1 Participants

Twenty pupils of a Tunisian elementary school were selected on the basis of their handwriting proficiency from a larger sample of 48 children (5 classes of the third grade). They were 3rd graded and attend to the same public school in Tunis. They were all right handed (Edinburgh Handedness Inventory) and their age ranged between 9 and 9,8 (mean age 9,3) All children were free from organic pathologies and from cognitive and psychopathological impairments.

On the basis of the teachers subjective evaluation of their handwriting legibility, children were assigned either to the Poor Writers Group (n=10) or to the Good Writers group (n=10); with equal number of male and female participants. For each PW, a peer belonging to the GW Group was matched on age, grade, class, gender and general school achievement.

7.1.2 Stimuli

In order to avoid in air movements while writing, the word “سلم” [sulam] was chosen as a target for the experiment. It is completely cursive and written neither with points nor diacritics. The word Sullam, printed on a paper (size police 18), was placed in front of the participant.

7.1.3 Digitizing tablet and on line data collection

The participant performed the experimental task (writing) on an unlined A4 paper that was fixed to the surface of the tablet (Wacom, Intuos3 A4 – see figure7 p.30) using a wireless electronic inking pen (Wacom). The position of the pen tip and the force exerted along the pen’s axis were recorded online using the dedicated VB Digital Draw software connected to a Dell Latitude laptop computer. Data analysis was performed off line. Before starting the experiment, students were offered a few practice trials to familiarize themselves with writing on the digitizing tablet. The experimental variables of interest are: *size* (big and small) and *velocity* (fast and slow).

7.1.4 Procedure

Participants were tested individually in a well illuminated and quiet room of their school. They were asked to firmly grasp a Wacom stylus in their dominant hand and to write the Arabic word “سلم” [sulam] on the digitizer, 6 times under 6 conditions. Participants were asked to write horizontally, from right to left as they usually did. During the experiment, the experimenter made sure that: first, the participant was seated comfortably and read correctly the target word, second, the student’s posture and grip of the digitizer pen were correct, third, no punctuation marks separated words (“dot”, “slash”, “dash”, “comma”,) and finally, words were written 6 times for each condition.

The experimental task was divided into two sessions: in the first one, students were asked to write the word [sulam] 6 times spontaneously (S1), then as fast as possible (Fast) while keeping the word legible, and finally very slow (Slow). In the second session, participants were asked to write 6 times spontaneously (S2), then

twice bigger (Big) than in the spontaneous handwriting, and finally as small as possible (Small). Both, conditions and experimental sessions order were randomized across participants. Each experimental session lasted approximately 30 minutes.

7.2 Data analysis

Using the VB Digital Draw software, first, the starting and ending point (pressure $\neq 0$) of each word was manually selected; second, labelled by condition and replication. (e.g. Sullam.1.S1 means Sullam first replication in spontaneous condition), and finally, saved as a TXT file ready to be processed by Matlab.

A Matlab program was used for the conversion of the txt data file into excel and for the calculation of the geometric and cinematic variables. The following variables were analyzed: (1) trajectory length (distance in mm covered by the pen tip), (2) velocity (average absolute velocity of the pen-down movements in mm/s), (3) pressure (the average axial pen pressure in Newton), (4) dysfluency (variability of the difference between maxima and minima of the velocity profile), (5) strokes segmentation, and (6) writing time (total time in seconds taken to complete the word Sullam).

7.3 Results

Statistical testing was performed with STATISTICA. The experiment consisted of a design with a between-subjects factor Group (2 levels: PW and GW) and two within-subjects factors Condition (6 levels: S1, S2, Fast, Slow, Big and Small) and 6 Replication (6 levels). ANOVA was used to analyse the kinematic variables (velocity, trajectory length, dysfluency, pressure, strokes, and time) one by one.

7.3.1 Stroke

The figure 13 displays the interaction of Stroke by Condition. Indeed, PW produced more strokes than GW.

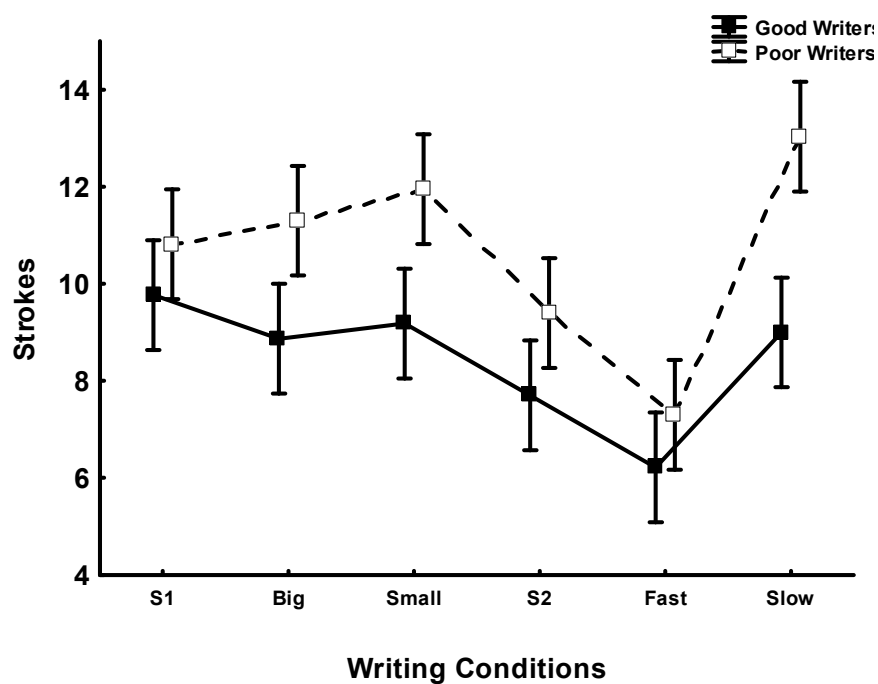


Figure. 13 Stroke number performed by each group in all writing conditions: S1, S2: Spontaneous1, Big, Small, Fast, and Slow

There is a significant interaction of Stroke by Condition ($F(5, 90) = 10.7$; $MS = 307.5$; $p < .001$) which does not affect the interpretation of the main factors. PW and GW differed significantly from each other on stroke number ($F(1, 18) = 5.1$; $MS = 853.6$; $p < .05$). More precisely, PW made more strokes than GW while performing spontaneously ($10.8 > 8.45$) as well as in all writing condition ($10.95 > 8$). Moreover, as it is apparent from the figure, also the factor Condition is significant ($F(5, 90) = 10.7$; $MS = 307.5$; $p < .001$) indicating that the stroke number varies among conditions.

7.3.2 Dysfluency

The figure 14 shows the interaction Condition by Group. This interaction fails to reach significance.

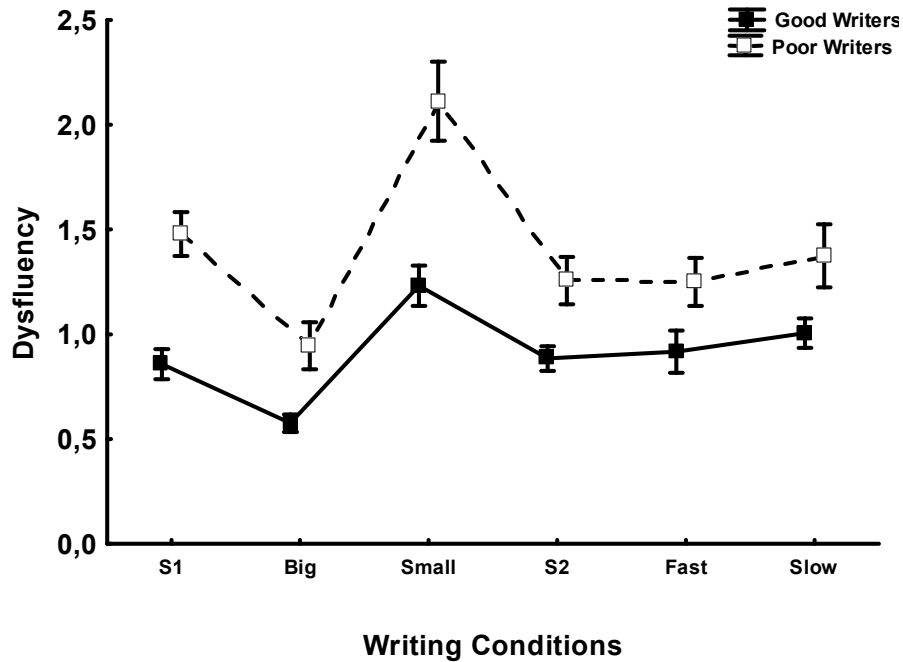


Figure. 14. Dysfluency variation among writing conditions for both groups

From the figure 14 it comes out a clear difference between the groups (GW are systematically more fluid than PW, $F(1, 18) = 12.80$, $MS = 43, 29$, $p < .01$) and a modulation of the performance as function of the different experimental conditions ($F(5, 90) = 35.47$; $MS = 10, 47$, $p < .001$). In particular, small writing entails the greater dysfluency. Surprisingly no difference appears between the fast and slow conditions. PW presents a more variable and less fluent profile than GW. The effect of the main factor Condition is expected to be reflected also by Time analysis.

7.3.3 Time

The figure 15 displays the interaction Condition by Groups. The interaction turns out to be significant ($F(5, 90) = 2.5$; $MS = 1268.5$, $p < .05$)

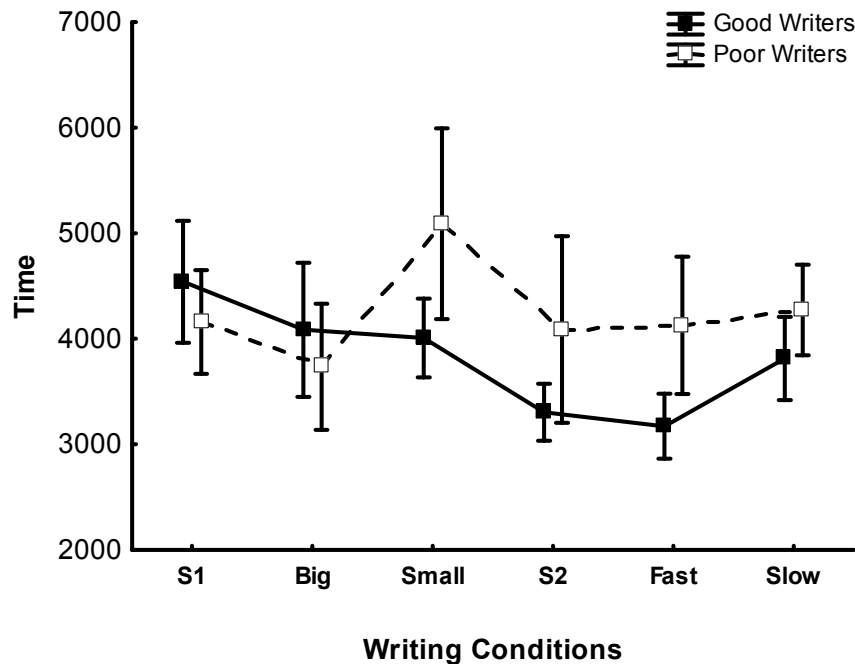


Figure.15 Time variation among writing conditions for two Groups

From the figure 15 emerges that PW were slower than GW ($F(5,648) = 2,5461$; $M = 1,2$; $p < .05$). However, the profile is inverted from the “Small” condition. Indeed, the maximum time for writing is reached in this condition for PW; while it is quite the same for the S1, S2, “Fast”, and “Slow” conditions. In contrast, GW demonstrated a decrease of Time (approximately 10ms) from “S1” to “S2” probably due to a familiarization of the task. In the following conditions they demonstrated a regular Time profile matched with the task demands (“t-Big” > “t-Small” and “t-Slow” > “t-Fast”). PW were significantly slower than GW in all writing conditions except for the “S1” and “Big” condition where no significant difference is met between groups. Time and Dysfluency profiles are similar for PW.

7.3.4 Velocity

The figure 16 shows the interaction Group by Condition which fails to reach significance.

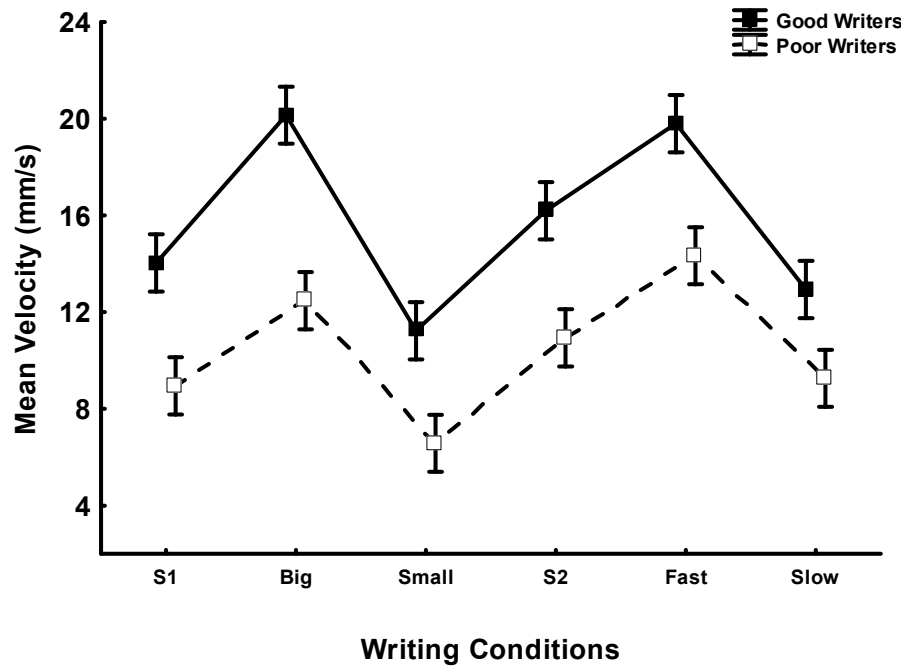


Figure. 16 Mean velocity profile of both groups in all writing conditions

The modulation of the mean velocity is coherent with the experimental conditions and indicates that participants fulfill the experimental task. Actually, as expected Small and Slow conditions were systematically smaller than “Fast” and “Big”. Curiously the spontaneous conditions share the same mean velocity of the “Slow” conditions. PW are significantly slower than GW in all conditions ($F(1, 18)=13,80$, $MS=5061,8$ $p<.001$). Furthermore, the mean velocity changed significantly among writing conditions ($F(1, 90)=37$; $MS=1212, 2$; $p<.001$).

7.3.5. Length

The figure 17 displays the interaction of Conditions by Group which turns out to be significant ($F(5, 90) = 2.9$; $MS = 3677$; $p < .05$).

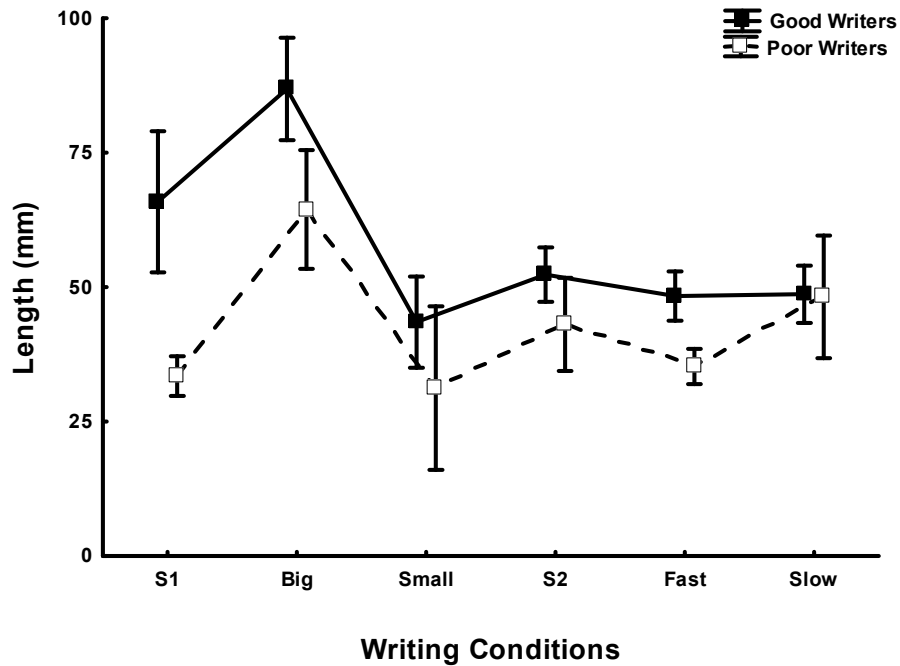


Figure. 17. Length trajectory of written words in all writing conditions for both groups.

The factor Group is not far to be significant ($F(1, 18) = 3.7$, $MS = 40440$, $p = .06$). The figure 17 shows that PW wrote smaller than GW, but the post-hoc comparisons show that the length difference between groups is significant only in the spontaneous and big conditions. Maximum and Minimum length for written word by PW and GW are respectively (114, 7-14mm) vs (148, 3-25mm). GW maintains the same Length trajectory in S2 and in the two kinematic conditions, indicating that the velocity variation did not influence on the length trajectory. Conversely, PW showed a fairly variation in the same conditions. The length trajectory decreases from S2 to S2 in both groups; this might indicate an habituation to the task.

7.3.6 Pressure

The figure 18 displays the interaction Condition and by Group. This interaction is not significant.

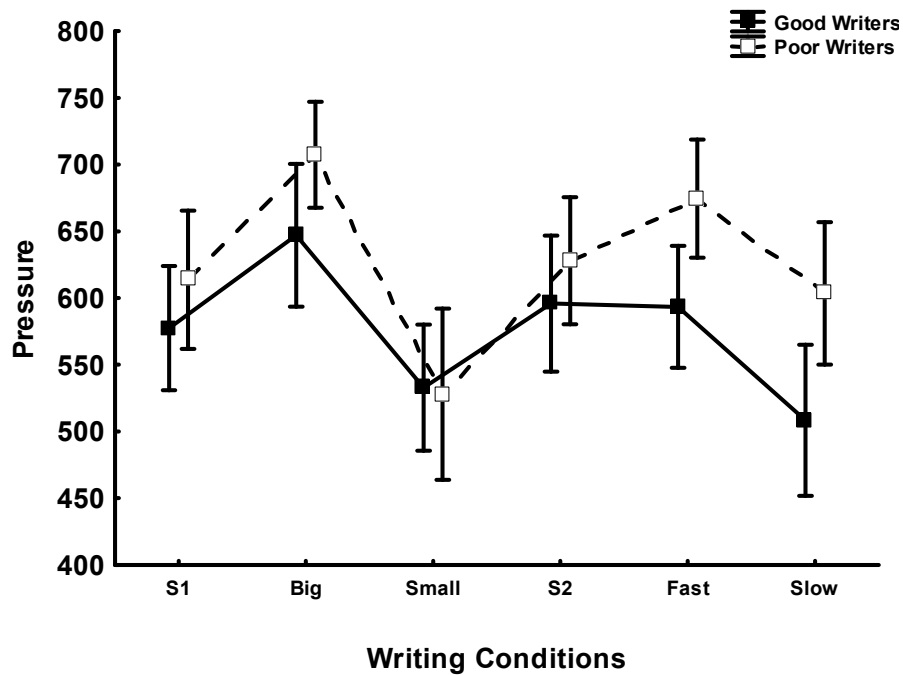


Figure. 18 Pressure profile among the writing condition and between Groups

There was no significant difference between groups ($F(1, 18) = 0.4$, $MS=44923$, $p = .063$). Actually PW seems to be more sensitive to the Kinematics condition (fast and slow) since the group difference reach its largest difference in those conditions as confirmed by post-hoc. Conversely, PW and GW demonstrate to have fairly the same pressure when writing spontaneously (S1, S2) and small. Pressure was significantly variable among writing conditions ($F(5, 90) = 7.52$, $MS=33093$, $p < .001$). The figure 18 shows that the pressure was systematically higher in the big and fast conditions and lower in the Small and Slow condition for both groups as confirmed by post-hoc comparisons.

7.4. Discussion

The aim of this experiment was to analyze the questions whether poor and good Arabic handwriters exhibit different patterns of movement proficiency. The analyses focused specifically on identifying the type of failure of the psychomotor system that could inhibit the poor writer's ability to keep the natural uniformity of their writing. Such effect is modified by specific task demand during the experiment.

For this reason, a digitizer was used for analyzing the geometric and cinematic characteristics of the handwriting of Tunisian young children with and without writing problems, providing static and dynamic analyses of Handwriting.

As expected, PW and GW presented contrasting profiles in all measured descriptors. In fact, PW and GW differ significantly on movement velocities, dysfluency, duration, and stroke production. Comparing to GW, PW's handwriting was smaller, slower, less fluent and discontinuous (high stroke production). These evidences are in agreement with the literature that identify the defining features of poor writing as disproportions, letter distortions, inconsistency in letter and word size more spatial errors and inaccuracies (Smits-Engelsman & Van Galen, 1997), difficulties related to the consistency of letter formation (Rosenblum et al., 2006), and the irregularity of size and slant (Mojet, 1991; Wann & Jones, 1986).

The main evidence of this study was the significant influence of Conditions on participants' performance. Such conditions were meant to stress on the participants and stand out their movement adjustments. Actually, participants had to adapt their movements either for Cinematic (velocity) or Geometric (size) demands of the task. Precisely, PW contrasted GW performance selectively among conditions. Geometric conditions showed their effect on Stroke, dysfluency, and length, while Kinematic condition did on Pressure.

That finding does not merely reflect the biomechanical conditions of a given trajectory since movement time, writing size, writing fluency and other parameters have been shown to vary also as a function of cognitive and motor demands of the task. This has been shown also for word length and serial position of letters within words (Van Galen et al, 1986), stroke and letter repetition (Van Galen et al.1989), the phonological structure of words (Van Galen, 1990), and spatial demands related to the performance of between-word spaces.

Trajectory length effect in Fast and Slow conditions respectively for GW and PW (48, 3 vs 48, 6) demonstrates that GW were able to speed up writing maintaining exactly the same size. Furthermore stroke number (6.3 vs 9) increased when they slow down. However, PW increased length trajectory (35, 2 vs 48, 1) and stroke number when they slow down (7, 4 vs 13, 1).

In the Geometric condition, GW and PW had to write either twice bigger than in the spontaneous condition or as small as possible. What happens is that they move proportionally from Big and Small condition. So, from “Small” to “Big” condition, Length trajectory and mean Velocity increase by about 170%, reaching nearly a double value for both groups (Length 20, 1 vs 11, 2; 12, 1 vs 6, 9). There are no plain reasons to expect a systematic change in the stroke number in the geometric condition. In fact, GW produce the same number of strokes (9 vs 9, 3) while PW surprisingly produced a slightly increased number of strokes when writing smaller (11, 4; 12, 1).

This difference indicates that size variation influences somehow the motor adjustment. Most of the cited studies interpret an increase of movement time and trajectory length as reflecting the sharing of processing resources between real-time stroke production processes and concurrent preparatory processes concerning forthcoming task segments. But alternative explanations related to movement strategies should be considered as well.

In particular, one strategy, described by Viviani and Terzuolo (1989), and by Lacquanti et al. (1983), is to hold the angular velocity of writing movements constant. A more detailed account of time and space invariance's at word, letter and stroke level in handwriting has been presented by Thomassen and Teulings (1985). In some studies (Van Galen, 1990; Van der Plaats and Van Galen 1990) it has been found that subjects tend to use specific strategies with respect to the distribution of space and time across consecutive words in the same task. When longer and shorter words have to be written within one single session, longer words tend to be speeded up and their letter size tends to be decreased.

It was proposed that this strategy was a manifestation of motor constancy, now defined as the tendency to use equal time and space in varying task conditions. Pressure did not discriminate between PW and GW even if it significantly varies among conditions; this results was unexpected. However, the difference between the two groups was largest in the Kinematic condition, which might indicate a possible

implication of this factor (velocity) in the handwriting difficulties. In contrast, Denier Van Der Gon & Thuring (1965) postulated the implication of size variation on pressure value. These researchers demonstrated that lateral pressure exerted by fingers on the writing tool can be modified as function of the word length: pressure grows with the word's length. However, Kao et al., (1986) demonstrated that pressure reach its maximum value when letters (or geometric shapes) get smaller.

In the Cinematic condition, Length trajectory reached its minimum value while Pressure reached its maximum value. The pressure of PW was significantly higher than the one of GW in the Cinematics condition.

A third important finding is the significant difference of Dysfluency and Velocity between groups. They showed the largest group difference; more precisely. The contrast was slightly higher in the writing "Small" condition (twice that of the GW) but, irrespective of condition, it was higher for PW. Furthermore, Dysfluency and Velocity are extremely connected to the length trajectory, pressure, and stroke production, indicating somehow an irregular motor processing. Such interaction will be described as follow. (1) As I already described, PW wrote smaller than GW in all conditions.

These results contrast with the findings in literature which affirm that PW typically wrote much slower than GW. In fact, Rosenblum et al. (2006) suggested that PW's larger script may be due to the fact that it may help them achieve greater legibility and Mojet (1991) proposed that it might simply make it easier for them to obtain an acceptable writing result because it requires less precise letter formation.

(2) From a cinematic point of view the low pressure of the PW seem to indicate a hesitation while they are writing, which is in agreement with their high dysfluency. This demonstrates that PW also could be characterized by their less efficient management of the physical costs of movements in terms of impulse and force. (3) Compared to the performance of their matched peers, the performance of PW was characterized by numerous deviations from GW in Dysfluency and Stroke.

4. Finally, PW showed an irregular writing (not fluent) since dysfluency and strokes are higher in all condition especially in the "Slow" one. In according with Wann (1987) a mature and effective movement strategy is characterized by smooth velocity profiles, i.e. by profiles which are minimally disturbed by inversions of the current direction of acceleration or deceleration.

These results are in line with geometrical descriptions of poor script postulated by Mojet (1991) who stressed the irregularity of size and slant. Also, Wann (1987) has demonstrated that poor writers use less mature movement patterns that allow greater visual control during execution.

It is worth explaining some methodological choices of the experiment. First of all the use of the replications; Words were written six times (for each condition) in order to avoid any phonological effect, familiarize the participant to the task, and minimize bias. It is well known that an effect was found when individual writing times for identical letters at varying letter position were analyzed (Zesiger, 1995). The same letter was written more slowly when it occurred at a more initial position in the task word. It was concluded that, after the installation of a phonological code and a speed setting process at word level, a letter by letter grapheme selection process was responsible for the lexical and motor processing at letter level. The increase of writing speed towards the end of a word was attributed to the shrinking content of the phonological buffer which caused a decreasing retrieval load for letters at later positions

Van Galen (1990) studied the combined effects of the phonological structure of a word and the motor complexity of separate letters. By an analysis of movement time data this study showed that, at word level, a global, slowing down of the writing movements was found as a function of the phonological similarity of consecutive syllables of task words, but this effect was independent of a local effect at letter level of a repetitive stroking structure (as in the letter *m*). Second, the stimulus selected as target, i.e. the word “Sullam”, has: (1) a repetitive stroking structure (“س” that is the first letter), (2) than followed by an upstroke, (3) a downstroke, (4) a circle, (5) and at the end a downstroke. To write this word it is necessary to link the letters with a horizontal stroke. It is possible to write it down without on air movements, since it is free from dots. Sullam is considered a simple word that does not require demanding morpho-syntactic or graphomotor processing. It has a disyllabic structure and frequently used in the scholar books. Keeping in mind the abovementioned criteria, we consider that we used an easy word enough sensitive to detect any irregularity.

Besides, it may be said that strokes with a left to write orientation and horizontal relocations of the hand along the line of writing are produced through abductions of the wrist, whereas vertical strokes and trajectories with a high degree of curvature are more strongly dependent upon the involvement of finger flexions and

extension. A greater anatomical complexity of finger system, as it requires the simultaneous control of a greater number of joints, has sometimes been invoked to explain the smaller efficiency in terms of movement time and fluency of vertical strokes (Meulenbroek and Van Galen, 1986).

To conclude, the general profile of PW that emerged in this study suggests a deficit at both motor programming and execution levels; since the irregularity of the handwriting raised in all kinematic variables.

In literature, a deficit at a motor programming level (Rosenblum, Parush, & Weiss, 2003; Wann & Jones, 1986; Zesiger, 2003) is characterized by a long production times, dysfluency in the velocity profile, slowness, pauses (which corresponds to the profile of PW in Small and Slow conditions). However, motor execution deficit (Smith-Engelsman & Van Galen, 1997; Van Galen Portier, Smits-Engelsman, & Schomaker, 1993) includes variability of handwriting that affects the spatial (stroke and form) and temporal (timing) dimensions of the child noisy handwriting (which corresponds to the profile of PW in Big and Fast). I did not consider that children who were identified as PW are dysgraphic but poor writers. We are confident that the deficit can be recoverable with a suitable and personalized therapy since the origin of the deficit has been extrapolated and identified

The analyses performed in this study combined descriptive and kinematics method that are complementary. Indeed, further statistical and kinematics analyses can be made as long as the VB Digital Draw will be in progress (e.g. for the calculation of the On Air Movements).

7.5 Conclusion

It is worth important to notice that, from a psychological point of view, this study represents a first descriptive approach to a long neglected field. The results of this research have two main future prospects.

On one hand, Arabic can offer some interesting possibilities to understand reading and handwriting processes, because, in contrast with Latin writing, it presents an unusual equilibrium between local (transparent) and global (ideographic) factors. On the other hand, Arabic handwriting troubles require the development of specific tools of measurements and diagnosis different from those developed for the Latin writing. It must be interesting to exploit such knowledge to study bilingual Arabic & Italian speakers and to progress with a longitudinal study.

Chapter 3

Theoretical Section

Perception and Implicit Motor

Knowledge

8. Perception and Implicit Motor Knowledge

In modern life people are bombarded with written messages from, for example, road signs, advertising, textbooks, and the internet. Might attention develop a bias that anticipates the occurrence of future information in a direction consistent with text reading?

The following introduction aims to give an overview with regard to the theoretical bases of letter recognition. In addition to their visual representation, letters are also coded under a sensorimotor form. Because of the close relation between the visual shape and the corresponding graphic movement, and because both reading and writing are learned simultaneously in the early school years, it may be assumed that the visual and sensorimotor representations are not functionally independent but closely associated, forming two components of a global network to process letters (Anderson et al., 1990; Longcamp et al., 2003).

The theoretical background of the following research is based from various experimental evidences reported in the literature that includes: (1) detection of anticipatory events in handwriting, (2) perceptual asymmetry, (3) fixation in reading, (4) directional reading habits and (5) mirror handwriting. Even if these findings give the impression of being unlinked, they are crucial to highlight the intimate relationship between writing and reading; an important implication of this assumption is that there is a common medium for perception and action.

It has been well documented that when an observer perceives events resulting from an action, corresponding motor codes are also activated. Thus, the perceived events are connected with the actions in the individual's repertoire (Rizzolati et al., 1996).

Knoblich et al., (2002) demonstrated that adults are able to generate accurate predictions for their own handwriting. In following research Knoblich & Repp (2004) demonstrated that pianists can reliably recognize their own performance of relatively unfamiliar musical excerpts after a delay of several months. These results supported the hypothesis that self-recognition in pianists' results from perception of action identity.

The hypothesis of the perception of action identity was also investigated in the domain of complex graphic behaviour as reported in the following section.

8.1 Detecting anticipatory events in handwriting

For a long time, it has been known that the selection and sequencing of movement trajectories in graphic and other space-oriented behaviour is under the influence of abstract rules as well. In recent years, also the more peripheral, kinematic aspects of joint movements have been unravelled with respect to their ruling principles.

Several studies from different domains suggest that the visual perception of graphic traces could be partly influenced by knowledge relative to the movements involved in handwriting production.

However, studies relating to word or letter identification have been widely influenced by feature analysis theories (Gibson and Levin 1975). According to these theories, recognition of a letter involves previous perception of its spatial component. For example: upper-case block letters are characterised by several distinctive features, orthogonal or oblique lines, symmetry axis, differences between open and closed curves- and character recognition would consist in detecting and analysing these different features. In fact, units of motor action being executed often carry the imprint of yet-to-be-executed units. These anticipatory adjustments, which are due to co-articulation, are well documented in movements such as speech, typing and handwriting.

Babcock and Freyd (1988) have shown that the shape of artificial handwriting characters is subject to specific spatial distortions related to the movement that produced them. These distortions provide information on stroke order and direction, and this information may be used by the visual system to recognise the characters. According to the authors, this ability to extract 'dynamic information' from the graphic traces does not involve a conscious knowledge of the production processes but seems rather to depend on an implicit knowledge of these processes. Similar results have been observed with meaningful characters.

In the Chinese logograms, for instance, the visual system is particularly sensitive to stroke order. The order of stroke writing is an essential component of the orthographic knowledge of a character and this cue is used in lexical retrieval. Furthermore, Wada et al (1995) have shown that the automatic recognition of a sequence of letters could be optimised by extracting some points of the trajectory considered as representative of the movement-pattern generation. Taken together, the data showed that 'dynamic information' contained in a static graphic trace could be extracted to identify a character. Kandel et al., (1994) and Orliaguet et al (1997) suggested that motor information could be used during visual processes to anticipate forthcoming motor sequences.

Their research aimed to show that the visual system could detect the spatial and kinematic differences observed in the production of the letter *l* written in three different contexts (*ll*, *le*, *ln*), and exploit them to predict the identity of the subsequent letter. Results showed that the percentages of correct responses were higher in the conditions where the stimulus provided kinematic information than in the condition in which only spatial information was available. Such findings confirmed that knowledge of anticipating motor rules allows the prediction of the forthcoming components of the motor sequence.

This assumption was necessary to carry on another important study which aimed to explore when visual processes detect anticipatory information during the presentation of dynamic handwriting movement. More precisely the goal was to determine the moment at which the subject can predict the following letter. Comparing to the first study, the size (*ll* vs *le*) and rotation (*le* vs *ll*) were changed in order to investigate their possible involvement. Results showed that with only the first 75% of the down stroke trajectory (or the first 60% of the down stroke time) subjects are already capable of predicting the identity of the letter following the *l* that is well before the end of the down stroke. Analysis also reveals that identification takes place after the presentation of the movement acceleration phase. The visual perception of motor anticipation seems to involve the detection of motor events.

To conclude, it seems likely that studies on the visual perception of static and dynamic graphic traces suggested the importance of motor knowledge in perceptual processes. In accordance to this assumption, recent fMRI research has demonstrated that neural activation patterns change after motor experience with objects. This has

been recently found to occur when we view letters as well (James & Gauthier, 2006), suggesting that our history of interacting with letters through writing is stored and perhaps re-activated upon visual presentation. This argument will be discussed in the following section.

8.2 Perceptual asymmetry

The relationship between perceptual asymmetries for the recognition of verbal stimuli and Left Hemisphere (LH) superiority has traditionally been interpreted in terms of a structural model of cerebral asymmetry. Kimura's (1967) absolute structural model assumes that the LH is solely responsible for verbal processing, with the Right Hemisphere (RH) playing little or no role. Perceptual asymmetries are thought to arise because the right visual field (RVF) has direct access to the language centers located within the LH.

Thus, information received by the LVF-RH must be transferred to the language processing centers in the LH via the corpus callosum. The transfer of information may prolong the time required to process the information and may also degrade the quality of the stimulus; resulting in slower overall reaction times and lower level of accuracy (Kimura, 1966). Visual half field studies have demonstrated that tachistoscopic presentation of stimuli in the left versus right visual field (RVF) results in performance asymmetries that are indicative for hemispheric specialization.

In terms of stimulus or task properties, the left hemisphere primarily mediates verbal processing, while the right hemisphere mediates non verbal, visuo-spatial processing. In terms of processing style, the left hemisphere is specialized in global (low spatial frequency) processing (Sergent, 1982). Cohen (1982) discussed two models that explain visual half-field asymmetries, (1) the *structural* model, and (2) the *attentional* model.

(1) The *structural* model explains visual half field asymmetries in terms of the efficiency of pathways between brain areas.

For instance, verbal stimuli are better recognized and processed if they are projected directly toward the left hemisphere compared to indirect connections via the right hemisphere and corpus callosum.

(2) The *attentional* model explains visual half-field asymmetries as a consequence of neuronal activation (Kinsbourne, 1970).

For instance, the presentation of verbal stimuli results in left-hemisphere activation, which triggers a rightward attentional bias and results in a right visual field advantage.

Cohen (1982) has adopted a combined structural-attentional model of hemisphere asymmetries. The combined model is compatible with clinical studies, which show both structural and attentional deficits in brain-damaged patients.

An increasing number of studies in vision research have demonstrated that even early levels in the visual pathway undergo experience-dependent changes throughout life. Under certain training conditions improvement in performance obtained by practicing a visual discrimination task is often restricted to the trained stimulus, including its orientation and location on the retina (Ahissar & Hochstein, 1997; Crist et al., 1997; Dill & Fahle, 1998; Nazir & O'Regan, 1990).

It is this lack of generalization of training to other stimuli and retinal locations that indicate that learning involve early cortical stages where attributes of a stimulus are represented with fine resolution (Gilbert et al., 2001). Given the systematic pattern in reading eye movement visual training that comes with reading should naturally provoke the development of perceptual learning at these lower processing stages.

One well known example of functional specialization is the neural response associated with single-letter (James et al., 2004) and word perception in the adult visual system (Cohen & Dehaene, 2004). That is, a region in the left fusiform gyrus has been found to respond more to individual letters than to letter strings, words, digits or Chinese characters (James et al., 2005). In contrast, a more posterior region in the left fusiform, often described as the visual word form area (VWFA), has been found to respond more to letter strings or words than to individual letters (Cohen & Dehaene, 2004; James et al., 2005).

The specialization found in the area also responds more to objects than to words in some cases (Price & Devlin, 2003; Moore & Price, 1999). Although, it is assumed that functional specialization for letters reflects our extensive experience with reading text, the specific type of experience that is necessary for the

development of this pattern of neural response is not known. The requirement for specialization to emerge for individual letters may be different from those for words. For example, letters are learned before words during development, and children learn to write individual letters before they learn to read words.

Furthermore, since functional specialization has often been characterized as a neural response pattern that is stimulus-specific, it may, in fact reflect the recruitment of a specialized type of processing that is required for efficient recognition of a particular stimulus category (Gauthier, 2000). For instance, the visual processing of face stimuli reveals functional specialization of the right fusiform gyrus (Kanwisher et al., 1997). This specialization could reflect category specificity, but it could also reflect a recruitment of a specialized holistic or configural process that is necessary for efficient recognition of stimuli from other, non-face categories (Gauthier et al., 2000). Functional specialization for perceiving letters may reflect category specificity of this brain region ("letter area"), but it may also reflect the recruitment of a feature based, analytic, or local analysis of a stimulus (Marsolek, 1999; James et al., 2006); that is. It may reflect a processing difference. Indeed, the visual processing of words, characters of objects is also linked to the eye landing point during fixation.

One question is whether or not variables other than spatial information can influence where the eyes initially fixate in a word in reading.

8.3 Fixation in reading

It has been well documented that the initial fixation position in a word influences both (1) reading behaviour and (2) how easy it is to recognise a word.

As noted by Farid and Grainger (1996), three hypotheses have been proposed to explain initial fixation location effects: (1) attention, (2) lateral-dominance, and (3) lexical constraint.

(1) According to the attention hypothesis, initial fixation location effects are due to the fact that in the left-to-right scripts the next eye movement (and the movement of attention) is generally to the right.

Furthermore, a number of studies have demonstrated that the perceptual span (or area of effective vision) in reading is asymmetric to the right of fixation in left-to-

right scripts (McConkie & Rayner, 1975; Rayner et al., 1980) as readers acquire more information to the right of fixation than to the left of fixation. The fact that the perceptual span extends further than to the right fixation than to the left is commonly attributed to attentional factors as attention is directed towards newly arriving information (Morison, 1984). According to this hypothesis, readers prefer to fixate on the first half of a word because it ensures that attention is directed to that area of the word in which most of the visual information that has not yet been identified is located.

(2) The lateral dominance hypothesis claims that initial fixation location effects are due to the lateral dominance of the left hemisphere of the brain in linguistic processing.

This suggestion is also consistent with studies in which a right visual field superiority has been observed in word identification tasks when words were tachistoscopically presented in the right or the left visual field. However, whereas the right visual field superiority has been consistently found for scripts printed from left-to-right (Barry, 1981; Bryden et al., 1990; Melamed & Zaidal, 1993), conflicting results have been found for the right-to-left scripts (Babkoff & Ben-Uria, 1983; Babkoff & Faust, 1988; Carmon et al., 1976; Faust, Kravetz, & Babkoff, 1993; Koriat, 1985; Silverberg et al., 1979).

This hypothesis is also weakened somewhat by the fact that Pollatsek et al., (1981) found that the perceptual span of Israeli readers is asymmetric to the left fixation; such a finding is perfectly consistent with attention hypothesis, but inconsistent with the lateral dominance hypothesis.

Nevertheless, the latter hypothesis is still considered by some as viable explanation of initial fixation location effects (Farid & Grainger, 1996).

(3) The linguistic information that is specific to word structure is an important contributor to initial fixation location effects.

Further factors may influence word fixation. They include: orthographic cuing, word morphology, frequency of the initial morpheme, location of the root, and word length.

(4) Orthographic cuing. It was demonstrated that right visual field superiority was observed regardless of the locus of informative orthographic cues (Bryden, 1986; Bryden et al., 1990).

Conversely, other studies have demonstrated that orthographic properties of words influence the initial landing position. That is an orthographically irregular letter cluster at the beginning of a word results in the readers' initial eye landing position deviating towards the beginning of the word (Beauvillain & Dore, 1998; Beauvillain, 1996; Dore & Beauvillain, 1997; Hyona, 1995).

Beauvillain and Dore (1998) found that the orthographic regularity of the initial bigram influenced the initial landing position, but the regularity of the second bigram did not. In addition, Pynte (1996) reported that when the initial fixation location was controlled, refixations were directed towards letters which contain critical orthographic information for distinguishing a word from another similar.

(5) Word morphology is another lexical factor which has been claimed to interact with the initial landing position relates to word morphology.

Beauvillain (1996) used prefixed and suffixed French words that were around 10 letters long and found little effect morphology on initial landing position. The initial landing position was closer to the centre of the word for compound words than for suffixed or mono-morphemic words.

(6) Frequency of the initial morpheme. Hyona and Pollatsek (1998) varied the length and then the frequency of the initial morpheme. They obtain a small difference such that the initial landing position was further into a word for more frequent morphemes.

(7) Location of the root. For example, Farid and Grainger (1996) manipulated the location of the root morpheme in Arabic, and in contrast to previous findings, in which an asymmetric distribution with a right visual field superiority was usually observed for left-to-right scripts, a symmetric distribution was found for Arabic.

However, by separately analysing prefixed and suffixed words, it was observed that asymmetric distributions with a left visual field superiority existed for suffixed words, while the reverse trend was found for prefixed words.

8.4 Directional reading habits

Pollatsek et al., (1981) found that the shape of visual attentional field deployed by participants was dependent on the language that they were reading in the test. If they were reading in English then the field was asymmetrically expanded to the right. Conversely, if they were reading Hebrew, the field was expanded to the left.

In addition, participants typically draw human figure (Dennis & Raskin, 1960) and the subject of subject-verb-object relationship (Maass & Russo, 2003) on the side of the page where text writing and reading would originate in their culture.

Vaid & Singh (1989) found that the judgement of what affect was depicted in a chimeric face was facilitated when the informative part of the face was on the side where text would originate.

Finally, Harsel & Wales (1987) observed improved performance on an inductive reasoning test when the stimuli were arranged in a way consistent with the direction that members of the culture read and printed text. Thus, there is mounting evidence that improved performance is observed on a range of tasks when attention starts on the side of the display where text would originate and moves in a direction consistent with text reading and writing.

These results suggest that the asymmetry is due not to some innate bias arising from some kind of hemispheric specialization in the attentional system, but rather to a bias that develops as a result of the direction of text reading.

8.5 Mirror handwriting

The term "mirror writing" was introduced by Buchwall to describe "that variety of script which runs in an opposite direction to the normal, the individual letters being also reversed" (Critchley, 1928).

Various theories to account for mirror handwriting have been proposed, they include:

(1) The motor centre hypothesis (Rodriguez, 1991; Rodriguez et al., 1989), in which it is postulated that there are motor programs in the brain, with the programs represented bilaterally but in mirror form in the 2 hemispheres. When the left hand

carries out handwriting movement normally carried out by the right hand, it has been suggested that in mirror writing there is a failure to inhibit the natural left-handed tendency to write leftward and in mirror form.

(2) The visual hypothesis (Davidson, 1935), in which it is similarly envisaged that there are bilateral visual memory traces (engrams) in the brain, the non dominant (usually right) hemisphere engrams being mirrored form and again normally suppressed (Orton, 1928). Thus, when suppression is impaired or incomplete, mirror writing with the left hand would result. Conflict between abnormal motor pathway subserving mirror writing and normal visual monitoring system has also been suggested.

(3) The spatial-orientation hypothesis (Buxbaum et al., 1993), in which it is suggested that there is confusion in respect of direction and orientation of reading and writing, sometimes associated with spatial confusion. These phenomena may emerge with other related phenomena, including difficulties in overcoming the left-to-right directional bias of normal writing, right-to-left perceptual difficulties, different, different processing of writing in right and left hemisphere, and access to mirrored graphemes when mirror writing is part of more complex mirror and perceptual phenomena.

(4) The involvement of thalamo-cortical circuitry (Chan, 1988). Rarely, mirror writing may be seen in essential tremor, Parkinson disease, and spinocerebellar disorders. It has been postulated that disruption of thalamo-cortical pathways may be the common underlying factor in these conditions.

(5) Bimanual mirror movements of the upper limbs (Schott, 1977), which is rarely manifested. In this case, patient simultaneously acquired mirror writing together with bimanual mirror movements.

Thus, there are many circumstances in which mirror writing occurs and numerous theories invoked to explain the phenomenon, but the unifying features are two. On one hand, the fact that mirror writing is nearly always carried out with the left hand. Furthermore, left-handers often find mirror writing particularly easy. On the other hand, mirror writers exhibit a competence for mirror reading too.

Chapter 4

Experimental Section

The role of Reading and Writing habits in priming letter recognition

9 Experiment 3: The role of Reading and Writing habits in priming letter recognition

The advantage for word recognition in the right visual field and in some case in the upper right visual field has been shown by Darler et al. (2004) and Hagenbeek et al. (2002).

The interpretation of these visual field asymmetries is in terms of directional scanning tendencies arising from reading habits. Nevertheless, in a previous experiment we showed that the recognition of a printed letter is primed by the coincidence between fixation point and handwriting starting point (Bouamama et al., 2009). Thus, visual field asymmetries seem to reflect both reading and writing habits. To further explore this hypothesis we carried out an experiment on Arabic and Italian students who are characterized by opposite script and reading directions.

We investigated whether short presentations of four rotations of the character presented in upper right, upper left, lower left, and lower right visual fields provide additional information about the influence of reading and writing habits on character recognition.

9.1 Method

9.1.1 Participants

Two groups each one composed of 30 Italian (18 girls, 12 boys) and 30 Tunisian (20 girls, 10 boys) students participated to the experiment. The student's age ranged from 19 to 27 (mean age 23, 3) for the Italian group, and from 21 to 30 in the Tunisian group (mean age 26, 1). Depending on the instructions of the experiment, each group was divided into two under groups: reading task group "Read" and non reading task group "Space". Four subgroups composed by 12 students each made part of the experiment.

Italian students were recruited from the University of Bicocca in Milan (Università degli studi Milano Bicocca) while the Tunisian students were recruited from the Institute of Social and Human Sciences in Tunis (Institut des Sciences Humaines et Sociales de Tunis). All participants were attending the psychology course; all were in good health, with normal or corrected to normal vision and did not

present any neurological, muscular or cognitive disorder. The experiments were carried out in agreement with legal requirements and international norms (Declaration of Helsinki, 1964).

9.1.2 Stimuli

To design the experimental task, it was necessary to create a font *ad hoc* for the characters presentation. We used three pilots (see figure 19) in order to select the adequate contrast between the font and the letter colour just a little over threshold.

Standardized printed C, U and their respective mirror transformed (reflection) were chosen as stimuli for the experiment. Every character was always presented next to the fixation point. Participants were asked to maintain their fixation on the fixation point marked by a “+” during all the session. Stimuli and fixation was presented in a slightly different location on the screen, which randomly varied within a circular area (5cm in diameter) at the centre of the screen.

Each letter was presented 10 times in each quadrant of the Cartesian plane, and was followed by a mask (14.12x18.36 cm) for 17 ms (See Figure 20).

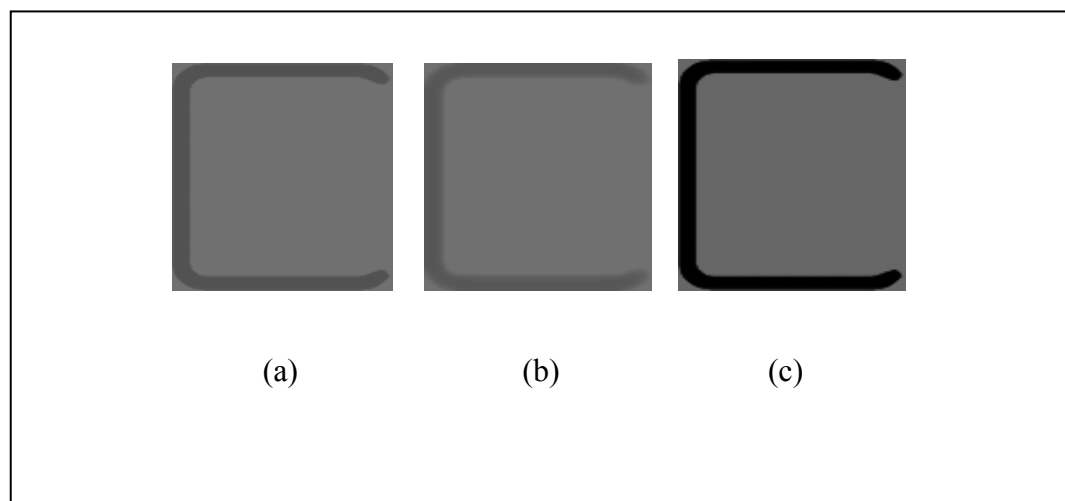


Figure. 19 (a) example of the C used as stimulus during the experiment with an adequate contrast (b) example of the C not used for the experiment because it is under the threshold perception (difficulty bias).(c) example of the C unused for the experiment because it is well over the threshold perception (facilitating bias).

The duration of the character presentation corresponded to the absolute threshold measured for each participant at the beginning of the experiment.

Each stimulus was followed by a 100ms mask which was built with two structures (see figure 20). The first one is composed of two dimensional uniform random distributions of small grey and white discs, with randomly variable luminance and diameters ranging between 0,5 and 3cm. the mask covered a circular area of about 12cm in diameter. The second structure is composed by squares; each of them fits the dimensions of the stimuli.

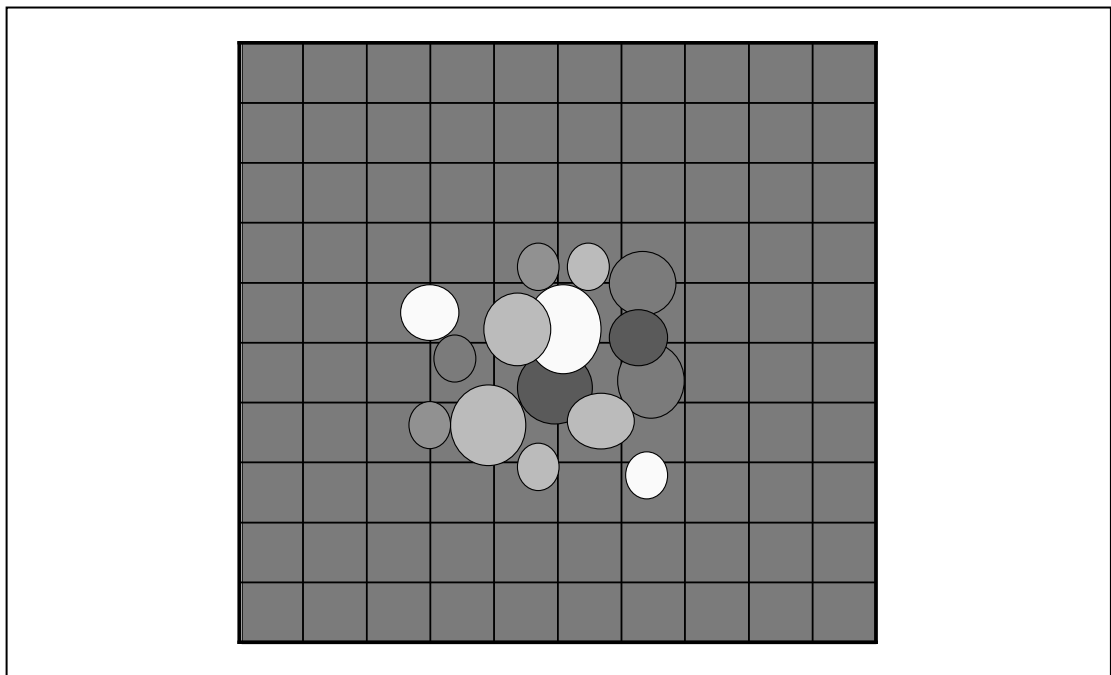


Figure. 20 The mask used for the familiarization and experimental tasks

Corel draw and Photoshop were used to draw the letters. It was necessary to use the same dimensions in order to include the shape (letter) into the same space of a square. The characters were each printed in a bordered square measuring 2.86 x 2.86cm (screen resolution 600x800). The C was used as a font to design all the characters, as they are a rotation of it. (180° mirrored C; 90° U- mirrored; -90° U), All the lines shared the same thickness and colour.

9.2 Procedure

Each subject was assigned to one of the two versions (Read or Space) of the experiment.

Before starting the experiment, participants had to read the experimental instructions carefully. The experiment supervisor ensured that the participants understood the task. Participants were informed that the central fixation was important, and a chinrest was used to ensure stable head position at a distance of 50cm from screen center. The experiment proceeded in a non illuminated room. Light was turned on only during the rest time after each session.

9.2.1 *The first absolute threshold assessment:*

Contrast threshold was measured using the method of limits to assess the duration of the stimulus presentation corresponding to each participant's absolute threshold. The four possible rotations of the character C were randomly presented on the computer screen. Participants pressed one of the two arrow keys (left or right) to indicate if they see (\rightarrow) or do not see (\leftarrow) the stimuli. (See figure 21). An automatic calculation through a Matlab program provides an estimation of the individual threshold at the end of the session.

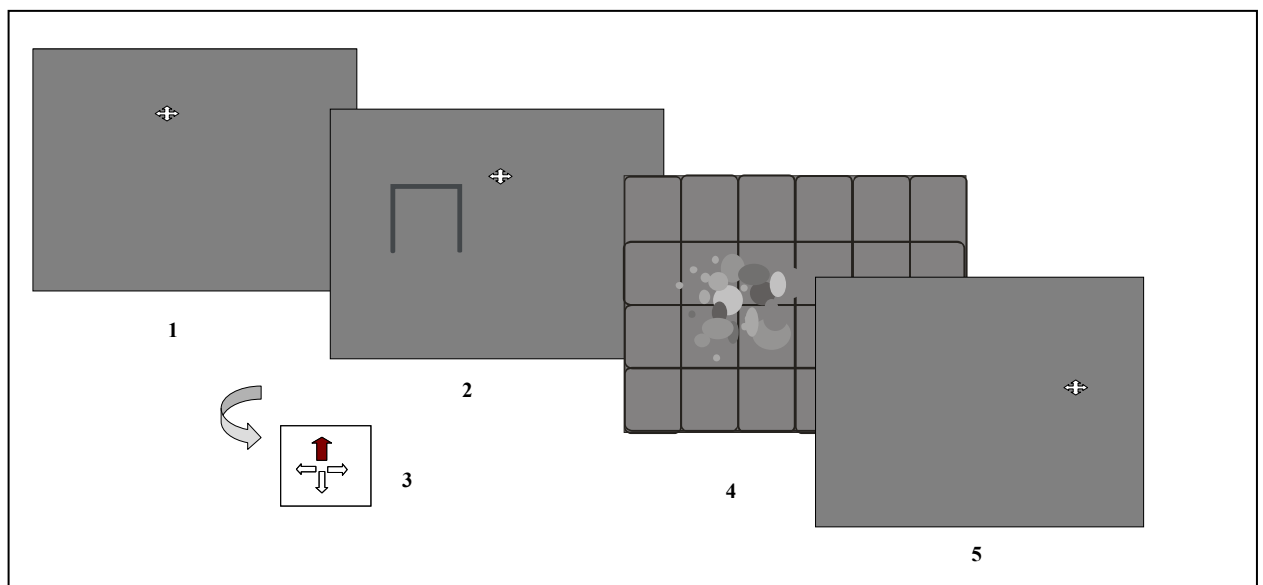


Figure. 21 The chronological steps of the experiment: (1) Fixation point, (2) Character (3) Response (4) Masking (5) Next trial.

9.2.2 *The familiarization task:*

80 trials were used (4 characters by 4 quadrants by 5 replications) in the experiment. The duration of the presentation varied according to each participant's absolute threshold (calculated earlier).

9.2.3 *Reading and space tasks*

Participants who belong to the "Read" group were asked to recognise the letters: "u", "c", "mirror u" (n), or "mirror c" (ɔ) as quick as they can. Characters are considered letters.

Participants belonging to the group "Space" were required to interpret the rotated character as a symbol indicating a specific direction ("n" as up, "u" as "down", "ɔ" as "right" and "c" as left. Characters were not considered nor named as letters.

All Participants gave their response by using the 4 directional arrow keys of the keyboard which corresponds to the stimuli: C (←); C- mirrored (→); U (↓) and U-mirrored (↑)

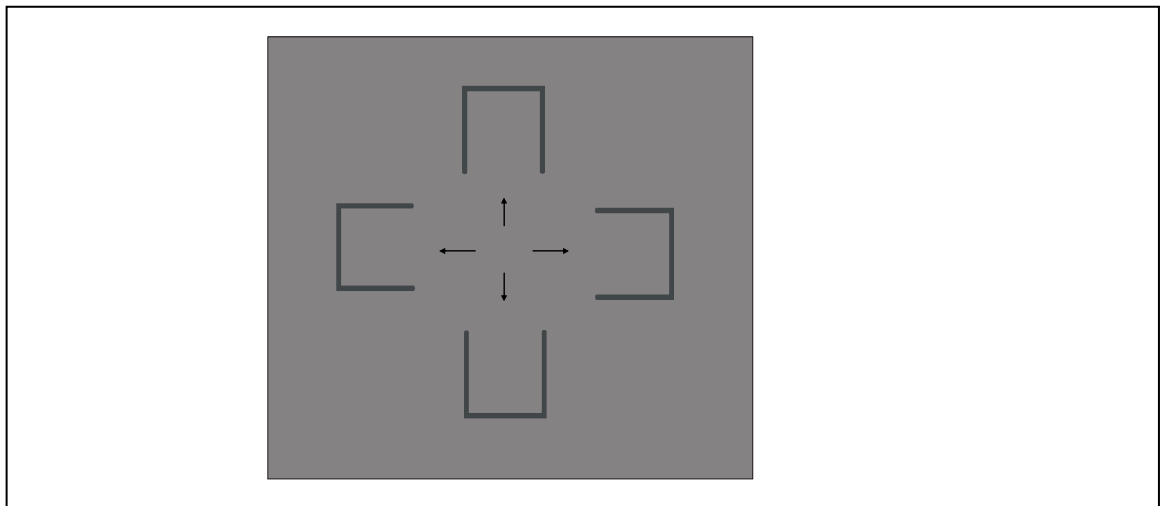


Figure. 22 The four rotations of the character C displayed in the four possible quadrants used in the experiment with the corresponding keys used to enter the response (down, left, up and right).

9.2.4 *The second absolute threshold assessment*

A second threshold measurement was performed; as it was known that generally the threshold value may decrease after the familiarization with the stimuli.

9.3 The experimental task :

The participants of both groups were asked to recognize as quick and accurately as possible 160 stimuli (4 stimuli by four quadrants by random 10 replications). The first 80 trials were followed by a brief rest period. Each trial began with a cross appearing at the center of the screen for (100ms), which disappeared when the stimulus was presented. Stimuli were briefly presented (using the second threshold) at a displacement of 2.5° from the fixation point to the center of character shape.

9.4 Design

The experimental design consists of two between factors and four within factors. Between-subjects factors were: Group (2 levels: Italian and Tunisian) and Gender (2 levels: male and female); while the within-subjects factors were: Task (read and space), Characters (C, U, C-mirrored, and U-mirrored), the Quadrant (4 levels: 1-up-right, 2-up-left, 3-down-left, and 4-down-right), and Eye landing points (4 levels: 1-starting writing point of the character; 2-the first angle; 3- the second angle; and the ending point of writing the character). Response Time (RT) of correct responses was measured as dependent variables. RT was defined as the time between the appearance of the stimulus and the participant's response. Accuracy is defined as the number of correct responses out of the replications (10 in average) planned for each condition.

9.5 Analysis and results

9.5.1 Reaction Time (RT)

9.5.1.1 Group and Task

A general ANOVA on RTs was performed. Let us begin with the interaction of Group by Task illustrated in Figure 23. It can see the Italian and Tunisian participants do not differ in the two experimental tasks.

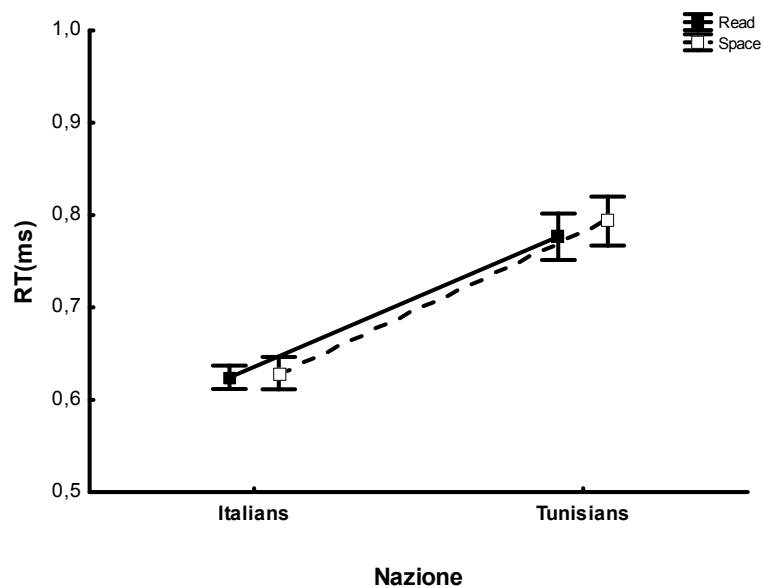


Figure 13 The RTs interaction of Group by Experimental Tasks (Read and Space)

Actually, there is no significant interaction ($F(1, 52) = .97$; $MS=0.909$ $p < .33$) showing that experimental tasks were not performed in a different manner between groups. Instead, there is a main effect of the factor Group ($F(1, 9472) = 181, 9$, $p < .001$) indicating that Italian were faster to perform both Read and Space task comparing to the Tunisian group. There is no main effect of Task.

9.5.1.2 Quadrant

The figure 24 shows the performance of participants as function of quadrants and letters.

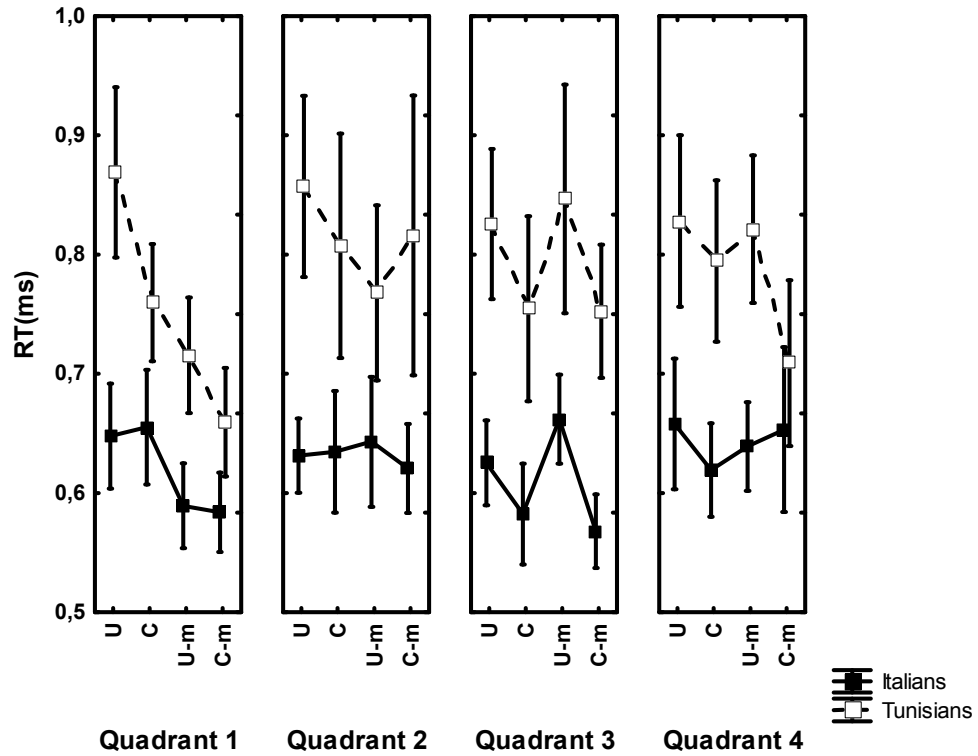


Figure 24 The RTs interaction of Group by Characters (U, C, U-Mirrored, and C-Mirrored), and by Quadrants (I, II, III, and IV)

Qualitatively, the figure 24 shows that Italian participants adopt a homogeneous strategy for recognizing characters among quadrants while Tunisian participants demonstrated more variability among quadrants in recognizing stimuli. Nevertheless the Analysis showed no significant effect of any interactions where the factor Quadrant was involved, but the interaction Quadrant by Character ($F(9, 504) = 2.24$; $MS = .053$, $p = .02$). Post-hoc comparisons showed a significant trend for the Tunisians in the first quadrant. The main effect of quadrant is not far to meet the criterion of significance ($F(3, 156) = 2.54$, $MS = .627$, $p = .058$).

9.5.1.3 Character

Figure 25 displays the interaction of Group by Task by Character.

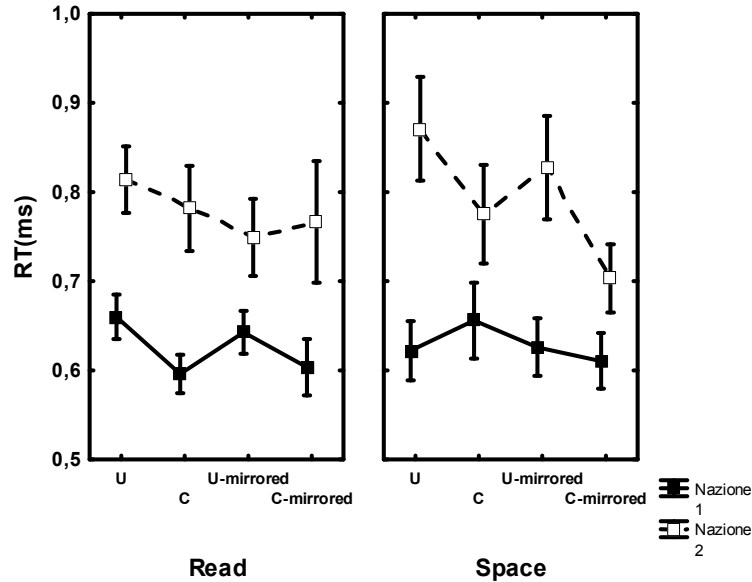


Figure. 25 The RTs interaction of Group by Experimental Tasks (Read and Space) and by Characters (U, C, U-Mirrored, and C-Mirrored)

Among the interactions where the factor Character was involved the interaction Quadrant by Character was significant ($F(9, 504) = 2.24$; $MS = .053$, $p = .02$) as already mentioned. This is mainly due to the variation of the Tunisians' means. Italians showed no RTs difference among characters in both tasks, except may be for the C that is faster than U in the Read Task whereas it is slower in the Space task as it comes out from the significant interaction Group by Task by Character ($F(3, 168) = 2.70$; $MS = .098$, $p = .047$) and pot-hoc comparisons. Conversely, Tunisians demonstrate significant RTs differences among characters in the Space task as confirmed by post-hoc comparisons. This result is interesting if we consider that, in both tasks, stimuli are the same. However, this interaction does not affect the interpretation of the main effect of the factor Character which turns out to be statistically significant ($F(3, 156) = 4.90$, $MS = .182$, $p < .001$)

9.5.2 Accuracy

The mean error rate was of 20% (± 0.12). A general ANOVA on Accuracy did not show any statistical effect.

9.5.3 Eye Landing Point

The above presented data demonstrated significant differences between Italians and Tunisians performance. On the one hand, it demonstrated that each group used a different strategy to process stimuli: Letters as well as Characters. On the other hand, participants seem to manage their space using different approaches to achieve their goal. Such differences may probably be due to an attentional bias rising from the reading and writing habits; since the two groups belong to distinct cultures. This bias may be reinforced by linguistic knowledge and by motor training.

Evidence from RTs interaction of Group by Quadrant by Character (figure 24) demonstrates an uniform scheme in recognizing characters in space. The approach adopted was specific for each group and each task. The stimuli's characteristics or their location in the space, or both, help the observer in programming the saccade to fall on an optimal viewing position in the stimuli.

Further analysis was performed in order to investigate whether there is an attention cue to indicate the optimal landing point of the eye.

I consider four possible landing points for each character: the writing starting point (1), (2) the first angle, (3) the second, and (4) the ending point as illustrated in the figure 26 below.

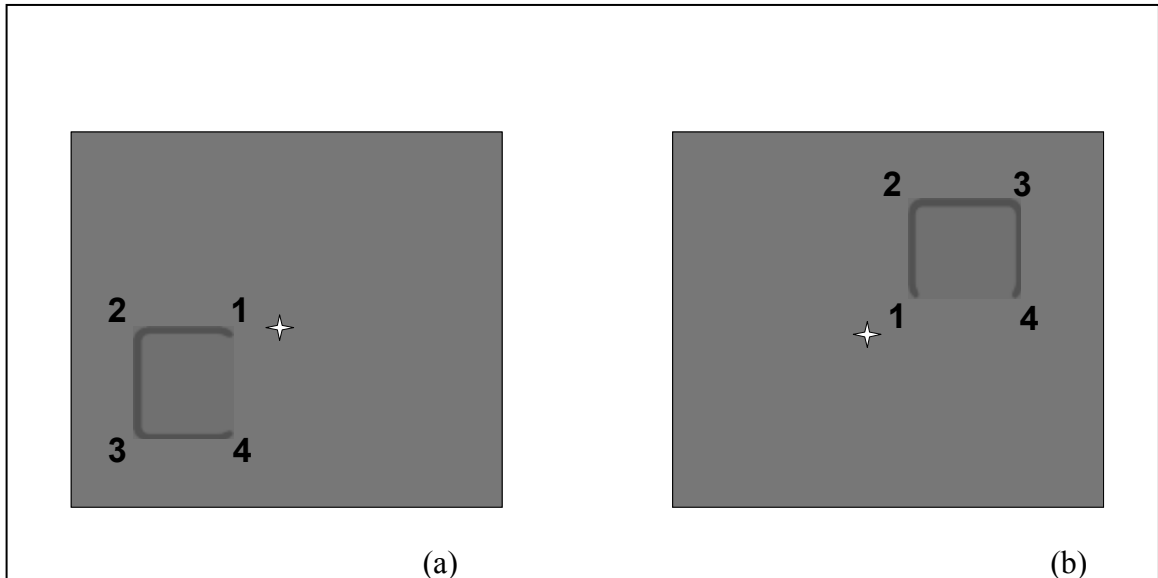


Figure 26. Examples of eye landing points for the C (a), and for the (b).

The calculation of these “eye landing points” (ELP) was obtained by matching the four possible fixation points (described earlier) and the four possible locations of the character in the quadrant (right, left, up and down). So I obtained a new classification of the data in a within subject factor which I will call Fixation with four levels: fixation next to 1) the writing starting point, 2) the first angle, 3) the second angle, and 4) the last writing point of the Character.

Using this method, the hypothesis investigated was, whether there is a “cuing” based on an implicit motor knowledge that facilitates letter recognition. In other words, a character is better recognized if its starting (writing) point corresponds to the fixation point.

9.5.3.1 Reaction Time (RT)

An ANOVA was performed with two between subject factors (namely Group and Task) and a within subject factor (Fixation with four levels). No interaction turned out to be significant. Instead, both Group ($F(1,56)=6.37$, $MS=1.57$, $p<.01$) and Fixation ($F(3,168)=3.30$, $MS=.020$, $p=.02$) reached a statistical significance. The figure 27 illustrates these effects.

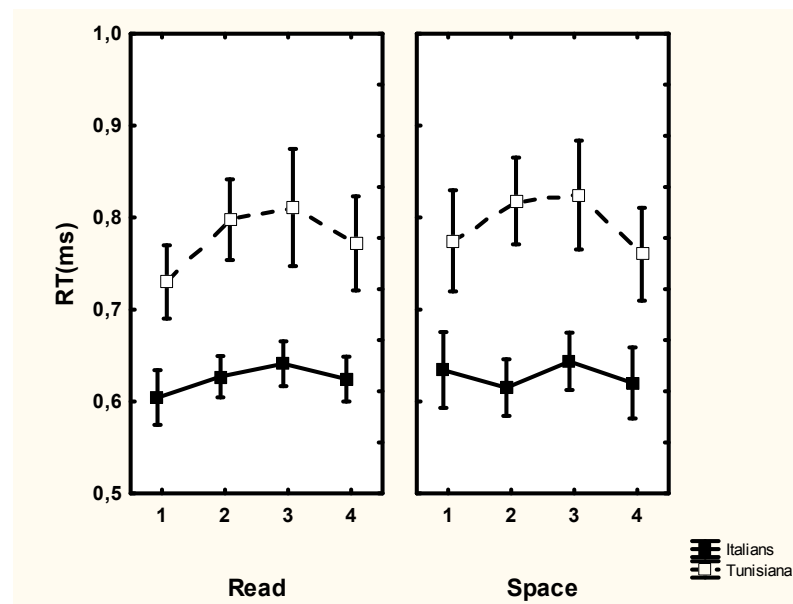


Figure. 27 The RTs interaction of Group by Experimental Tasks (Read and Space), and by ELP

Italians manifest preference in the first ELP in the Read tasks, as Tunisians clearly do in both tasks. This visual fact is also confirmed by post-hoc comparisons. Such effect indicates that participants recognize the characters faster when the ELP corresponds to the starting point of handwriting. However, as far as Tunisians are concerned, this facilitation is not limited to the 1st ELP but also to the 4th ELP; In addition, this trend is systematically present in both experimental tasks, suggesting an identical strategy in processing characters. Conversely, Italian manifested this facilitation only in the read task.

9.5.3.2 Accuracy

An ANOVA with the same previous design was performed on accuracy. Neither interactions nor main factors met the statistical criterion of significance.

To sum up, from the above mentioned results emerges a strong facilitating effect of the 1st ELP in both groups for the reading task. Such effect confirms the hypothesis about a facilitation of character recognition when the fixation point corresponds to the starting handwriting point of the character.

9.6 Discussion

The aim of this study was to determine whether (1) two different types of recognition Tasks (Read and Space) could induce different competence of character recognition even if stimuli remain unchanged. (2) Secondly, it permitted comparison of the performance of Italian and Tunisian observers in the experimental Tasks. (3) Third, it permitted investigation of whether there is a facilitation in recognizing the character when the ELP of the writing starting point corresponds to the fixation point (4) finally, this study has provided information about the visual scanning preference adopted for each group and task. The statistical results have offered some thinking points that are not easy to interpret, because of the lack of such studies on Arabic participants. Furthermore, in literature, studies on word fixation are numerous while those on letter recognition are few.

The main interesting result of this experiment is the evidence that the starting point of handwriting of the character (U, C, U-mirrored and/or C-mirrored) is the facilitated eye landing point when recognizing it. Such effect confirms the hypothesis that claims a facilitation of character recognition when the fixation point corresponds to its starting handwriting point. Furthermore, both groups had this facilitation in reading task even if a difference comes out between them in Space task. This result likely indicates the use of different approaches in performing the task. Tunisians are more facilitated when ELP corresponds to the starting and ending writing points of the characters. Moreover, such a strategy is generalised to Read and Space tasks. Conversely, Italians attest such facilitation only in the read task while in the space task they appear to have no preference.

To place this result in perspective with respect to previous demonstrations of perceptual anticipation, consider the condition that makes such anticipation possible. The hypothesis, of which, a motor facilitation to recognise the letters we have considered the fact that the subjects had used an implicit motor knowledge a priori existent. Such an interpretation is consistent with findings proposed by Wada that the automatic recognition of a sequence of letters could be optimised by extracting some points of the trajectory considered as representative of the movement-pattern generation.

Most notably, Kandel & al., (1997, 200) has built a consistent argument for the role of the motor information, which could be used to anticipate forthcoming motor sequence.

The authors demonstrated in several studies that the visual system could detect spatial and cinematic differences in handwriting. Their subjects were able to exploit such observed differences to predict the subsequent letter as a forthcoming component of the motor sequence.

In order to account for the level of perceptual anticipation demonstrated by these results, an alternative motor hypothesis can be suggested, based on the core assumption underlying neuroimaging findings. A recent fMRI study (Longcamp et al., 2003) addressed the question as to whether motor perceptual interactions might be involved in reading. They investigated whether simply viewing a letter suffices to activate the corresponding motor representation. Their results indicated that the writing motor processes are implicitly evoked when passively observing letters. This finding shows the existence of a close functional relation between reading and writing processes and suggests that our reading abilities might be somehow dependent on the way we write.

In this research, the stimuli were created following precise criteria that may have presented some limitations. In fact the most difficult character for letter (capital symmetric letters with mirrored versions) presentation was used in order to verify our hypothesis in the worst condition. Fortunately, significant results were found: my hope is that this, along with further experimental and correlation evidence, will contribute to a more explicit and complete demonstration of motor facilitation in letter recognition. Hence, the interaction of reading and writing is corroborated by these results.

Consistent with past visual half-field research (e.g., Ellis et al., 1988; Young & Ellis, 1985), the results of the present experiment indicated a strong upper right visual field advantage for character recognition, illustrated in faster RTs in response to the Right Visual Field (RVF) trials. Furthermore, evidence from the data underlines a difference between groups, but more importantly, the data demonstrated a differential effect of Read and Space Tasks among quadrants and groups even if the stimuli remain unchanged. In order to deal with this attentional bias I suggested engaging an implicit task. It is well known that linguistic processing can be highly automatic and implicit, and studies have reported that the mere presence of words

automatically drive language-related brain area even when the participants are not required to explicitly “read” the words, such as in non linguistic feature detection tasks (Brunswick et al., 1999; Price et al., 1996; Turkeltaub et al., 2003) or subliminal masking priming task (Dehaene et al, 2004; Delvin et al., 2004).

For this reason, only the experimental instructions were different (Read and Non read), in order to considerably minimize the influence of the semantic and phonological processing of the letters (C and U) relative to the explicit task (Read), in investigating the scanning strategy in the space. Moreover, it should be kept in mind that the experiment undertaken did not simulate a reading situation but a letter recognition task.

The scanning direction might influence the perception on how one approaches objects in the space, on whether one starts the perceptual exploration. If the visual scanning while reading is from the left-to right or on the contrary, if it is from right-to-left. This research is a pilot study to determine the directionality of the perceptual exploration between Italian and Tunisian. Because of the left-to-right orientation of Roman writing, directionality is a serious factor to consider in this study. Reverse visualisation is a common phenomenon among the people whose native language follows the right-to-left writing system such as Arabic and Hebrew. Such competence permits to Arabic and Hebrew readers to easily manage both directions of reading (left-to-right as well as right-to-left).

Firstly, the difference between Italian and Tunisian was expected because as shown in the literature the role of attentional reading habits influences the way we perceive object and text. However, this difference was expected more in the Space task than in the Read task because Tunisian participants are perfectly bilinguals: L1 Arabic and L2 French., while Italians are monolinguals: L1 Italian. Sarig (1987) and Anderson (1991) rightly pointed out that reading is a highly individual activity. Nevertheless, there are some general factors that influence reading speed and accuracy.

One of such factors is the reader’s mother tongue. As Cook (1992) points out, we cannot switch off our native language resources when we read in a second language. It is unrealistic to treat a second language in isolation from the first language. Our native language is all the time in our minds. It is readily and constantly available to us. Its knowledge is connected in all sorts of ways with the second

language. As Selinker (1992) remarks, native language has “a principle role” in a second language acquisition.

This role of the first language has become a central issue in second language acquisition thinking. So, these affirmations may explain the “constant” performance of Italians when performing the Read task in contrast with Tunisians that manifest great variability. In fact, Tunisians were slower and this may indicate (1) a non automatic approach to perform the task or (2) a negotiation between the L1 and the L2 (inhibiting a predominant linguistic knowledge), or (3) both interactions.

As Cook (1992) argues, “the L2 user does not switch-off the L1 while processing the L2, but has it constantly available”. The two languages interact with each other in all sorts of ways. In addition, reading by a monolingual reader is different from reading by a “bi-literate reader” (Singhal, 1998). Reading in a second language is a bilingual process, not a monolingual event (Upton, 1997). Bilingual readers have two languages available simultaneously. They consciously or subconsciously process the second language with reference to their first language. However, whether these two competences are dissociated or not it is still discussed.

In the literature, there are number of views mentioned, often contradictory concerning how two languages are represented in the human brain. The main issue relevant here is the cerebral organization of language in bilinguals. Various influential studies along with more up-to-date information obtained with technology such as neuroimaging techniques also appear to support this concept of double-dissociation (Caramazza & Zurif, 1976; Moreover et al., 1999).

In a case study, Ibrahim (2008) reported the performance of MM, an Arabic-Hebrew bilingual man who had a focal left brain damage, evinced more deficits in his L1 (Arabic) perception and production than in his L2 (Hebrew). The case report provided dissociation between processing L1 and L2; the data supports the position that distinct brain regions are involved in the representation of multiple languages of a bilingual speaker. This supports the conclusion that a patient with a more prominent L1 impairment usually has a lesion centered on the left hemisphere areas.

Secondly, I stressed the fact that attentional habits acquired through reading practice can indeed generalize to other visual processes. In some visual perceptual tasks such as the evaluation of facial affect of chimeric faces (Eviatar, 1997; Vaid & Singh, 1989) or the directionality of apparent motion perception (Morikawa &

McBeath, 1992) a significant correlation had been reported between perceptual judgment and the directionality of reading.

Another explanation concerns more the integrated system of visual cognitive motor activity of handwriting. Kao et al., (2003) mentioned that there are certain communal geometric properties which appear in both English and Chinese scripts, even in any other writing system, such as holes, symmetry, linearity, parallelism, closure, connectivity, shape, form, etc. No matter which writing system one chooses to write in, the basic visual motor exercise of those geometric properties is equal for alphabetic letters and Chinese ideograms.

However, if we compare the performance of Tunisians in both tasks we find that they were faster in Space task rather than in Read Tasks. In between these two profiles, an intermediate view proposes that a stimulus first involves a non conscious analysis associated with the lower levels of processing based on automatic activation, and then a second conscious stage associated with higher levels of representations associated with strategic processes under volitional control. According to this view, non conscious processes of reading exist but are limited between groups.

A third important finding is that experimental tasks were sensitive to the location of the stimuli in the Cartesian quadrants. Firstly, for the Read task, an advantage for the lower left and upper right diagonal was found, an outcome consistent with Christman and Niebauer's (1997) conclusion of a systematic link between lower and left visual field processing and between upper and right visual field processing. Secondly, attentional factors may contribute to upper right VF advantage for character recognition in the Space task. Christman and Niebauer's (1997) discussed the influence of scanning habits. This bias has an ecological origin, as the organism is supported to be engaged in visual search for objects that are relatively far away and hence in the upper VF.

The upper VF attentional bias may be intrinsically related to structural mechanisms and hence attentional habits need to be investigated with further experimental tasks.

Despite the group differences that have emerged from the study, both groups had an upper right visual field facilitation. Similar to our results Heron observed a right visual field advantage when quadruplets shapes (arranged in squares or in horizontal strings) were presented in either of the two half fields, but a left visual field advantage when one quadruplet was displayed in each half field simultaneously. For a

given quadruplet subjects tended, to report letter from (upper) left to (lower) right, with decreasing accuracy.

Lubow et al., 1994, reported similar results and indicated that readers of Hebrew showed the opposite report bias. Furthermore, when stimuli were displayed in one visual field only, pre-cueing the side in which the stimuli would be displayed improved performance in the left but not in the right visual field. Given these results Heron proposed that factors related to the way we allocate attention during reading explain visual field effects in the perception of orthographic material. He postulated that reading induces a general (but weak) stimulus-dependent tendency to attend the side in the direction of reading, and a dominant stimulus-dependent tendency to scan letters from left to right (for scripts that are read from left-to-right).

In the study by Morikawa and McBeath (1992), for instance, native readers of scripts that are read from left-to right showed a robust bias to perceive (apparent) leftward motions while bilinguals who also read a right-to-left script did not show any lateral bias. It should therefore be emphasized from the above discussion that the specificity of visual field effects to the probed character was expected. So, these effects may reflect the involvement of motor pattern memories as well as visuospatial competence.

Fourth, I am questioning the possibility that characters projected directly to the dominant/facilitated quadrant (VF) can profit from more efficient processing than those projected to the other quadrants. The experimental results indicated that additional factors are needed to explain visual field dependent variations in the perception of Characters. However, it is interesting to note that despite the fact that participants had no previous training to mirror reading, they succeed recognizing the mirrored characters. Mirror image generalization might be a property of reading acquisition.

Infero-temporal neurons frequently respond identically to mirror-image pairs of objects, even if they have been trained with only one view. A principle of mirror generalization seems to have been deeply entrenched by evolution into our visual system, presumably because the identity of most objects in the natural world remains the same under a mirror-image transformation. After exposure to a single image in a fixed orientation, human and many animals spontaneously treat the mirror-symmetrical version as identical to the original (Biederman & Cooper, 1991; Logothetis & Pauls, 1995). The experimental results found in preparing this thesis are

in line with these explanations. Mirrored C and U were processed by Groups in the same way compared to the C and U which were the best performed in the reading task. In contrast, Mirrored Characters were better processed than U and C in the Space task for both groups.

The experimental data deserves further investigation because of the possible applications in understanding and treating pathologies as Dyslexia (reading difficulty) or Dysgraphia (writing difficulty), which implicate both motor and perceptual processing. As demonstrated, reading is not reducible to a purely visual process but it implicates a complex integration with the motor system. To go further, it might be hypothesised that in the future Dyslexia will be examined not only through reading tests but also through “motor” investigation. This proposal, whether strange, may change the way of considering some clinical pathology.

To sum up, the present study shows that (1) Italians were faster than Tunisians, (2) Read and Space tasks were operated with two different approaches only for Tunisians. (3) This study brings out the fact that Character’s location in the workspace is facilitated in the first quadrant which is in line with an upper right visual filed preference. Such effect is explained by a left-to-right scanning habit for Roman writing. An opposite results was not expected for Arabic because they are bilinguals and the stimuli are Roman Characters. (4) Finally, the novel result in this study is that the fixation of the starting point of handwriting facilitates letter recognition.

9.7 Conclusion

The idea that our movement organizes our perceptions and contributes to setting up our spatial representations is not new and has by now become widely recognized (Viviani, 2002). Reading is not a purely visual process, and writing is not a purely motor process. The cerebral representation of letters might not be strictly visual but might be based on a complex neural network including sensory-motor component acquired while learning concomitantly to read and write.

Through writing and reading training (experience) we learn to associate actions with their correlated perceptions in order to build up unified, coherent representations of words, letters and characters in the workspace. Such representations fit the characteristics of the writing and reading system (e.g., ideogram, alphabet) and their directions.

The existence of these motor-perceptual interactions underlines a specified neural network. Although alphabetic characters are not graspable objects, motor perceptual links presumably contribute to their representation, since they associated with highly specific writing movements.

9.8 Limitation and further investigations

What was critical with respect to the study is the selection of the Group, Stimuli, and Fixation. To optimise the investigation of the reading scan habits on character recognition it will be interesting to have an Arabic monolingual population. Such request is impossible in Tunisia; French courses are introduced at the third grade of public school and in the first grade in private schools. Tunisian monolingual are rare and can not match with socio-cultural criteria of the experimental group. This situation is not limited to Tunisia but all the Arabic countries. The most frequent L2 are French (North Africa) and English (Middle East and Asia).

The following alternative solutions are suggested by this author: (1) First, create a recognition task for children using Roman letters, pseudo letters and abstract characters. (2) Second, replicate the experiment with Arabic characters for example using the letter “ﺃ”. (3) Third, training Italian adults to write and read Arabic letters and/or word and replicate the experiment (it will be easier to perform this experiment with students that are studying oriental languages). (4) Fourth, perform a forced

choice task with Arabic and Roman characters, with Arabic and Italian readers. In this case stimuli will be presented simultaneously in both visual fields. (5) Finally, the eye tracker measurement is necessary to investigate whether there is facilitation when the Eye Landing Point (ELP) corresponds to the starting point of handwriting, and to examine the strategy used in each experimental task (Read and Space).

A further study would be necessary to complement these experiment findings. It would be interesting, in light of these initial findings, to consider the role of implicit motor knowledge in reading using cursive handwriting as stimuli.

The research presented in this Thesis is a pilot study that can ramify into the above described “control studies”.

General Discussion

This thesis dissertation has presented the requirements for an implementation of Arabic handwriting exploration and analyses. This method allowed also the review of interesting research areas within various fields despite the lack of research on Arabic handwriting.

Some researchers have begun to describe handwriting “product” through scales (De Ajuriaguerra et al., 1975) others explored the use of technology in assessing the “process” of handwriting in poor writers (Rosenblum et al., 2003). Both methods are exclusively applied on Roman or Hebrew writing systems, and none on the Arabic one. An intermediate preliminary method to investigate Arabic Handwriting (AH) was the combination of both methods. To this end I carried out the first and second experiments presented in this Thesis. Those studies aimed to investigate Arabic handwriting difficulties in proficient and poor handwriters using two complementary methods: descriptive and analytic ones. (1) I have demonstrated that; also AH can be described qualitatively and quantitatively with respect to its characteristics. Besides the descriptive analysis of the Arabic handwriting product in the first experiment 1, complementary kinematics and geometric analyses were carried out on the handwriting movement. Hence, this method yields a complete screening of handwriting that highlights the underlying process.

The results of the first experiment offer an opportunity to advise us, and whom it may concern, to take into consideration the cognitive complexity factors of Arabic writing when investigating dysgraphia or writing difficulties. It was salient that Arabic writing requires high visuo-perceptual competence beside motor and psycho-affective needs. Furthermore, the second experiment shows that it is possible to extrapolate a handwriter profile on the basis of kinematics and geometric analyses of the handwriting movement. Thus, the analyses have demonstrated that geometric (Size: big and small) and Cinematic (Velocity: fast and slow) variations are discriminating features in poor writers. In fact, the movement of poor writers was substantially more dysfluent, discontinuous, smaller and slower than proficient writers. A transient psychomotor delay may be a plausible explanation of these

difficulties, since PW presented also a delay in visuo-spatial competence (TOPIG-Test). In this case, a rehabilitation program can be proposed.

The same technology, used for the diagnosis could be used in intervention from a self-regulated learning perspective. In using a digitiser tablet, children could receive ongoing feedback about their letter formation and how much pressure they are applying through the writing implement. The technology may offer intrinsic task value in that it would be novel to the students and would add variety to their experiences. With this approach, researchers would be able to glean more information about the process of handwriting in struggling writers, which would be helpful in designing effective interventions for these children. I can cite as example, my personal experience in this application during my PhD stage in Grenoble with Professor Gentaz (2010)³. Two groups of 1st graded children (n=100) participated to the experiment, they were divided into: (1) experimental group (trained) and (2) control (none trained) group. Digitized Wacom Intuos A4 tablets were used to collect handwriting products (alphabet and syllables) before and after the daily training. The training was performed on a Wacom Cintiq on which individual exercises were proposed (Gentaz, 2009). The experiment covered the academic year (September-June). The analysis demonstrated those trained group improved significantly handwriting comparing to the control group. The main limitation of this method is the economical cost of the Wacom digitizers (Intuos and Cintiq) and their respective laptops.

Despite this limitation, there are several practical implications for these findings, particularly for Tunisian as well as Italian occupational therapists, spatial educators, teachers, and psychologists. I am confident that it will be a great benefit of an intervention related to the extra practice of (guided) handwriting. This intervention should be based on a three main activities in which the therapist helps the writer to (1) abandon the wrong motor program and execution in order to (2) restore a new one. In addition, (3) perform activities based on visual training that improve the perception of children through games and exercises. However, further practical applications rose from evidence yield in the experiment 3.

³ The project was accepted by the CNRS and the French Ministry and generalized to the city of Lyon and includes 90 schools (about 2000 pupils), this project is focused on reading screening more than writing. The experiment is called "Expérimentation Lecture Lyon" and I was one of the two managers of the project.

In fact, I have confirmed through the experiment 3 that reading and writing are intimately related and demonstrating that (1) the Eye Landing Point (ELP) is important to recognize the letter; more precisely, character recognition is facilitated when the ELP of the starting writing point of the letter corresponds to the fixation point. (2) The main result was the significant difference between Italian and Tunisian to perform both experimental tasks, and (3) finally, the significant difference of characters and quadrant processing (Task and quadrants). I found an Upper Right Visual Field facilitation for both group, even if, according to the attentional (right-to-left) reading habit bias and the hemispheric specialization hypotheses, Tunisians and Italian had to have opposite spatial facilitation. Conversely, it wasn't; probably because Tunisians are perfectly bilinguals, and they are trained to manage easily both hemifields. Italians demonstrate a fairly homogeneous behaviour in both Tasks while Tunisians were slower, and they performed the Read and Space Tasks with two different approaches, demonstrating that they handle more visuo-spatial information.

In fact, the ELP for Tunisians was identical for all Tasks: they used systematically the starting and ending writing points of the character as a cue to recognize it, while Italian was facilitated only for the starting writing point in the read task. From my point of view, this study provides preliminary evidence that could be useful to investigate “dyslexic-dysgraphic” children, since the time and accuracy of scanning direction are investigated in dyslexic children (Ruff et al., 1986). Furthermore, visuospatial attention has been investigated in children with and without dyslexia (Ho-Chuan Huang & Tsui/Ying Wang, 2009).

In summary, findings from these combined studies (experiments: 1, 2 and 3) are surprising, very interesting and at the same time difficult to interpret. Again, the motor and perceptive competences emerged as a superior need for handwriting, consolidating the intimate relationship of reading and writing which are, however, based on different underlying processes.

I've demonstrated that the use of technological measurements and Scales for the screening of handwriting difficulties is the best combination; it permits to study both; static product and its underlying process. My experience in the Italian Schools is short, however, I suggest the use of the digitizer with the clinical tools available for the screening of both Reading (e.g. Batteria per la valutazione della dislessia e della Disortografia Evolutiva (Sartori et al., 1995); Prove di Lettura MT per le scuole

Elementare (Cornoldi, 1998)), and writing(e.g. Batteria per la valutazione della scrittura e della competenza ortografica nella scuola dell'obbligo (Trissoldi et al., 1991) difficulties.

To conclude on a more general note, I want to point out that our data also highlights the dangers of generalizing scientific knowledge beyond the cultural context in which it is generated (Nisbett et al., 2001). The fact that the vast majority of (neuro) psychological researches are carried out in the culturally homogeneous context of America, North Africa, Asia and Europe may bias theorizing in unknown fashion. In the absence of cross-cultural comparisons, one may easily overestimate the power of (intuitively appealing) biological causes. Unfortunately, in a world of increasing globalization and rapidly reduced cultural variability, researchers may find it increasingly difficult to uncover cultural influences, especially with bilinguals.

This study provides preliminary evidence that further research is required to replicate and contribute to these findings, particularly by improving the cognitive intervention proposed before, by adding more components of self-regulated learning into the treatment protocols.

APPENDIX 1

Data analyses and recording using VB Digital Draw

1. Data recording

When starting VB Digital Draw it is better to close any other applications and control the calibration of both, digitizer and its pen on the computer as shown below. Points 1 and 2, refers to the angles of the digitizer, while the point 3 refers to its centre. While moving the digitizer pen on the working space, the cursor moves on the computer screen; the selected area/ points indicated on the computer must match with the one indicated by the pen.

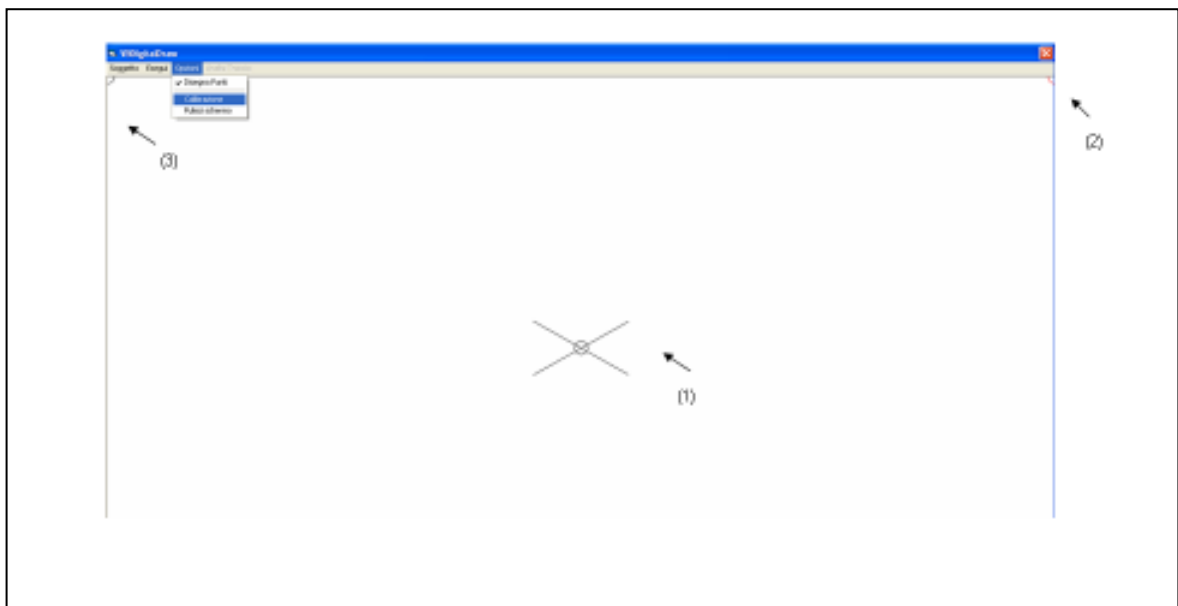


Figure 1

- Prepare the stimuli text file: enter a filename for the results file
- Click on “Nuova Acquisizione” (new recording) to start the registration
- Click on “bare space” to end the registration

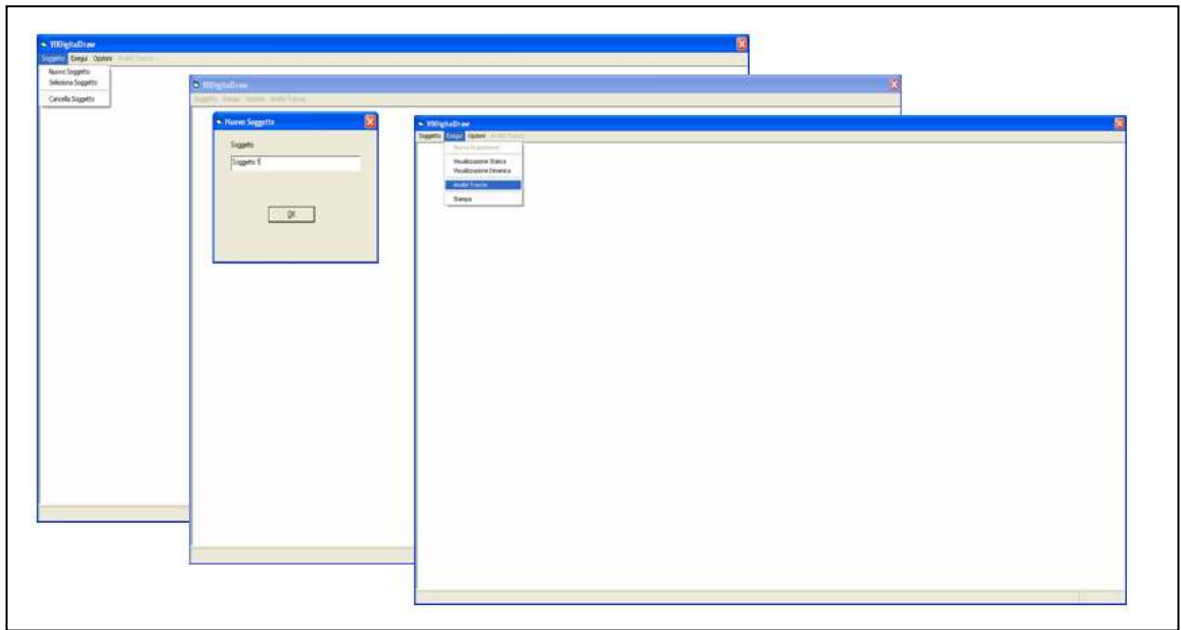


Figure 2

2. Data Analysis

The trajectory raw data (xy) are converted to centimeter and suited to the real dimensions of the digitizer. VB Digital Draw calculated the kinematics and geometrical parameters of the handwriting movement: horizontal, vertical, and absolute velocities of the pen tip (expressed in cm/sec).

VB Digital Draw's graphic interface presents the results of these calculations. These data are used for the elaboration of the movement parameters such as duration, mean velocity, and the like. The stimulus presentation module records all this information in a txt file (see figure 3).

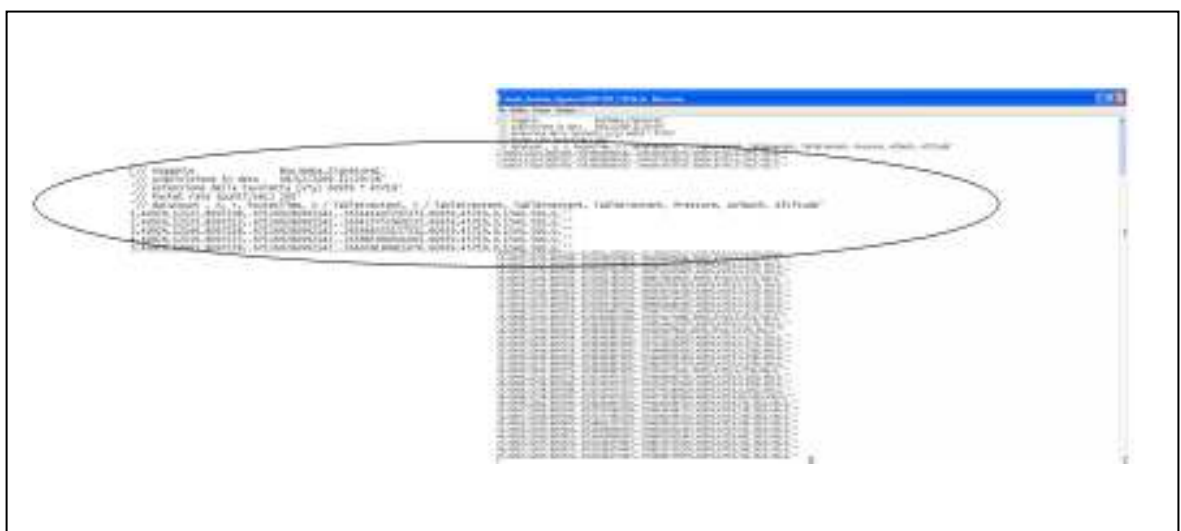


Figure 3

Visualization and navigation interface

- The writing production can be visualized in *dynamic* or *static* way (see figure 4)

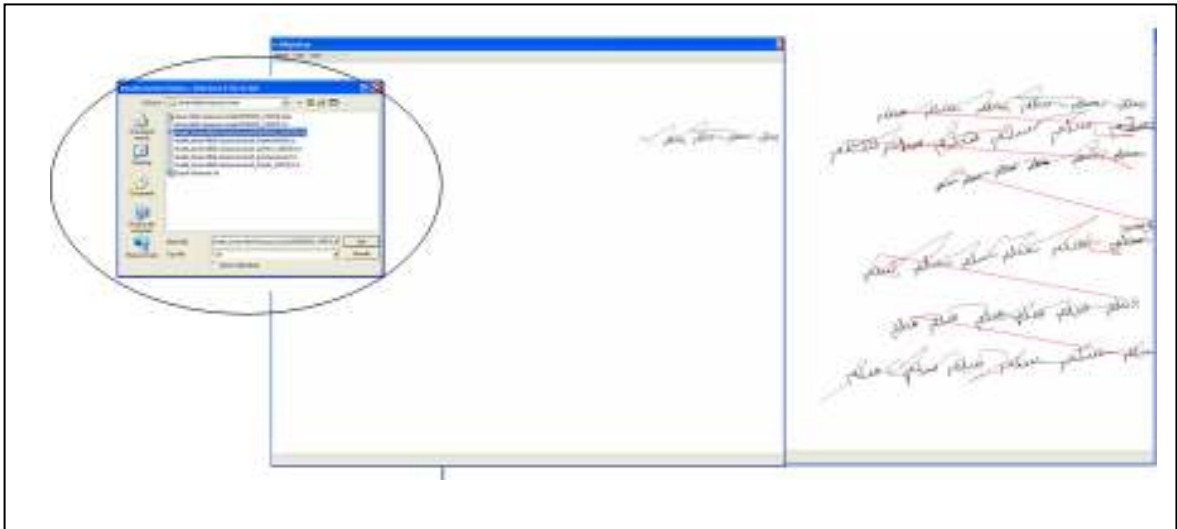


Figure 4

- Open the filename to analyze
- Click on “Analizza Traccia” (Analysis)
- A window shows the whole script (static).



Figure 5

Figure 5 shows the script trajectory. The black color indicates the part of the writing movement that is produced with pressure > 0 , while the yellow lines show the air movements made when the pen does not touch the digitizer's surface; that is, the movement that the digitizer detected where made with pressure 0. There is an automatic zoom that facilitates the visualization of the segment of the trajectory the user is focusing on; the width of this data window can be modified in the Option Panel (Ampiezza Movimento Window) as shown in the figure 8. This is the trajectory of the pen tip that touched the digitizer and that can be seen on the paper if the experiment was conducted with an ink pen.

These are the functions that offer the program as shown in the figure 6:

- F1 go back
- F2 go ahead
- Fast scroll (Spostamenti Veloce): Shift+F1 or Shift +F2
- F3 Mark begin (Marca inizio)
- F4 Mark end (Marca fine)
- F5 Previous Track (Traccia Precedente)
- F6 Next Track (Traccia Successiva)
- F7 Label the Track (Etichetta Traccia)
- F9 New Track (Nuova Traccia)
- F12 Cancel Track (Elimina Traccia)
- Reload last saved (Ricarica ultimo salvataggio)
- Save (Salva)
- Exit (esci)

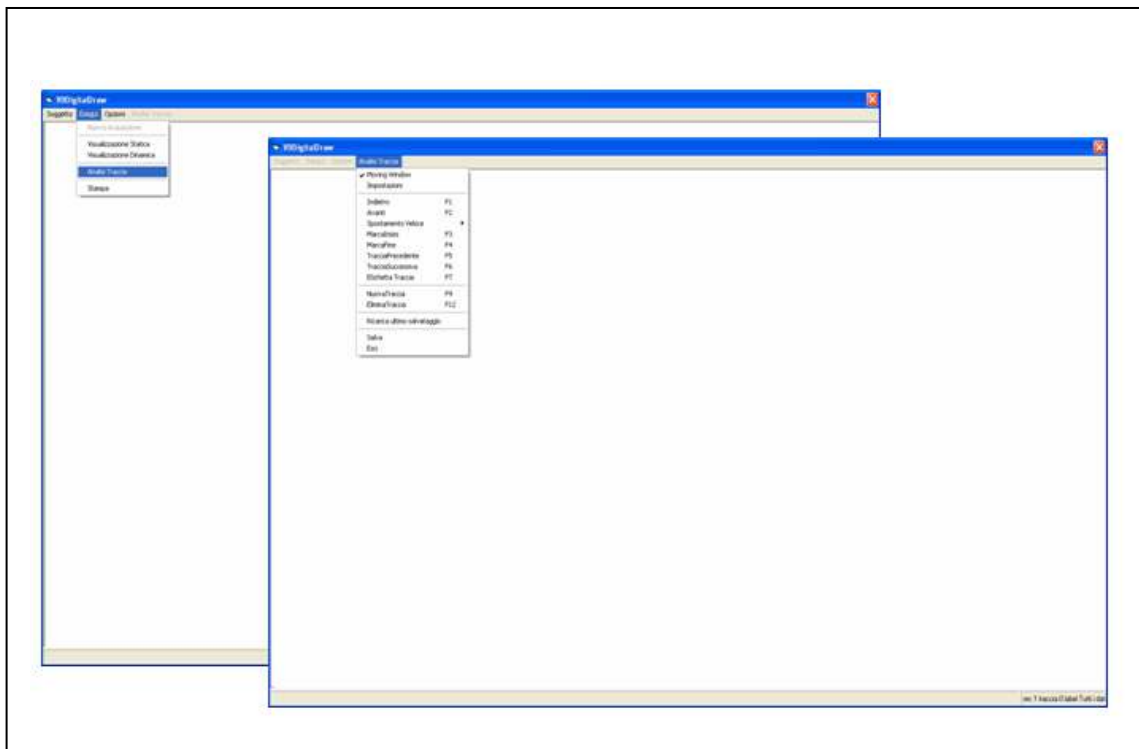


Figure 6

Handwriting is usually a continuous trajectory, and to gain understanding of handwriting production, researchers need to segment this trajectory into smaller units such as letters or syllables.

VB Digital Draw is designed to select segments and perform calculation on them.

The user determines the size of the segment. The selected segment can be organized in hierarchical fashion. Here is an example of words segmentation in figure 7.



Figure 7

Figure 7 shows the movement trajectory. The red circle, as a cursor, is moved by the user along the line that indicates the recorded movement even if it the movement was produced with pressure ≥ 0 .

The user move the cursor using the functions described previously.

The selected segment turns automatically to red when the user marks its end. Then, it turns to green when the user moves to the next segment.

It is just a control- feedback to mark the starting and the ending points of segments.

When all segments are analyzed the user must label and save them. If not the data get lost when the user exit the program of move to another application.

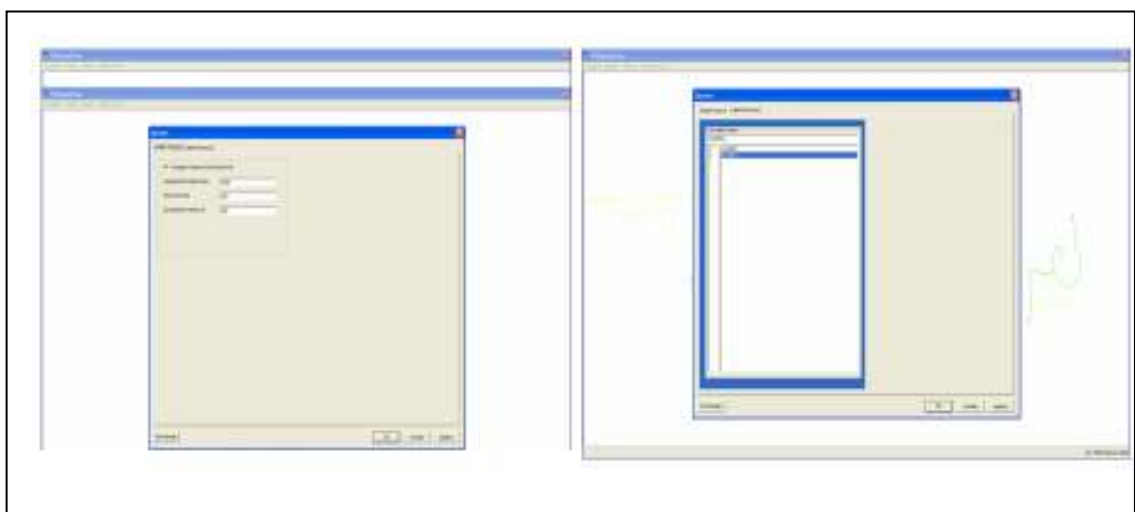


Figure 8

VB Digital Draw requires further programming in Matlab to analyze Velocity, Stroke segmentation and Dysfluency.

APPENDIX 2

Lists of Stimuli used in the experiments 1 and 2

List of words

أرض

أعطية

بيئـة

بساط

صباح

سماء

شـتاء

سحاب

ثـقب

تضامن

وقت

رفاهة

كرة

محراث

مجازات

خزان

دجاجة

مذيع

جامع

صيد

شمس

ظلام

ضيوف

نهار

أبيب

أسلاك

سطل

أدم

List of isolated letters

ح

ج

د

ذ

ر

س

ش

ظ

ص

هـ

ق

ك

ك

ي

List of sentences

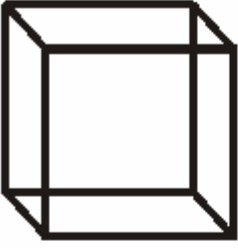
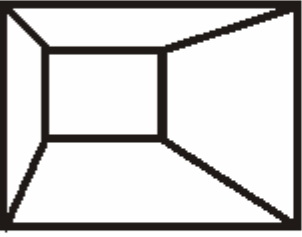
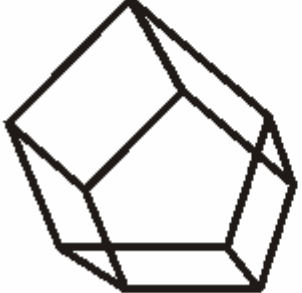
خلق الله السماء و الأرض.




تضامن آدم مع ضيوف لبيب لحماية البيئة.


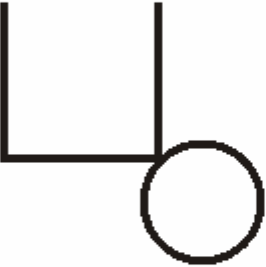

APPENDIX 3

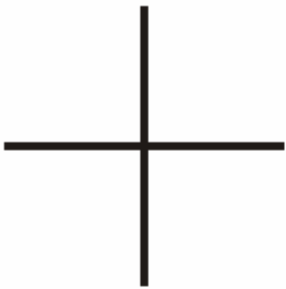
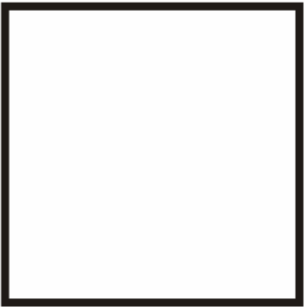

Samples of the TOPIG-Test

(Test de l'Organisation Perceptivo Spatiale et de l'Intégration Graphomotrice)

	<p>22</p>
	<p>23</p>
	<p>24</p>

 Two overlapping polygons, one slightly larger and shifted to the right of the other, creating a central intersection.	19
 A simple diamond shape (rhombus) oriented horizontally.	20
 Three interlocking rings arranged in a triangular pattern, each ring overlapping the other two.	21

	10
	11
	12

	4
	5
	6

HVG Page 2

	Group		Condition						Anova			Factors				
	GW	PW	SI/S2	SD	Big	SD	Small	SD	Fast	SD	Slow	SD	Condition	Group	C*Group	Replication
Kinematics	GW	PW	59	31,6	86,8	26	43,4	18,1	48,3	14,2	48,6	17,6	**		*	
			38	9,5	64,4	30,9	31,2	26,9	35,2	9,8	48,1	26				
Velocity	GW	PW	15	2,9	20,1	5,5	11,2	2,6	19,8	5,7	12,9	3,4	**	**		**
			10,4	3,3	12,1	3,6	6,9	2,9	14,3	5,1	9,2	3,3				
Stroke	GW	PW	8,8	3	9	2,6	9,3	2	6,3	1	9,1	2,9	**	*		
			10,9	3,5	11,4	2,4	12,1	3,8	7,4	2,2	13,1	5,4				
Dysfluency	GW	PW	0,8	0,2	0,5	0,12	1,23	0,28	0,9	0,38	1	0,23	**	**	**	
			1,3	0,36	0,9	0,40	2,1	0,68	1,2	0,43	1,3	0,44				
Pressure	GW	PW	586,6	178	647	208	532,8	181,7	593,3	173,2	508,4	221,8	**			**
			620,7	192	707,3	139	527,8	240	674,4	169,6	603,4	204,3				
Writing time	GW	PW	23,7	10,1	21,4	12,8	23,9	5,3	19	5	23,3	6,1		*		*
			24,7	7,4	22,4	12,4	30,5	13,2	24,7	10,5	25,6	7,6				

* p<.05

** p<.01

Table1. Means of the six kinematic variables in each of the six writing conditions for the good (GW) and the poor (PW) writers, and the F value for Condition , Condition*Group (C*Gr), Replication , and Group (** means p<.01, and * p<.05).

BIBLIOGRAPHY

- Ahissar, M., & Hochstein, S. (1997). Task difficulty and the specificity of perceptual learning. *Nature*, 22 (387), 401-406.
- Alimi, A. M., & Plamondon, R. (1996). A comparative study of speed–accuracy tradeoff formulations. The case of spatially constrained movements where both distance and spatial precision are specified. In: Simner, N. L., Leedham, C. G., and Thomassen, W. M. (eds.), *Handwriting and Drawing Research*, IOS Press, Burke, pp. 127–142.
- Alston, J. (1983). A legibility index: Can handwriting be measured? *Educ. Rev.* 35: 237–242. American Psychiatric Association (1994). *Diagnostic and Statistical Manual of Mental Disorders (4th Ed.)*, American Psychiatric Association, Washington, DC.
- Álvarez, C.J., Cottrell, D., & Afonso-Hernández, O. (2009). Writing dictated words and picture names: Syllabic boundaries affect execution in Spanish. *Applied Psycholinguistics*, 30, 205-223.
- Amundson, S. J. (1995). *Evaluation Tool of Children’s Handwriting (ETCH) Examiner’s Manual*.
- Amundson, S.J., & Weil, M. (1996). Prewriting and handwriting skills. In: J. Case-Smith., A.S. Allen, & P. Nuse Pratt (Eds.), *Occupational therapy for children*. St Louis: C.V. Mosby.524-541.
- Anderson, S.W., Damasio, A.R., & Damasio, H. (1990). Troubled letters but not numbers. Domain specific cognitive impairments following focal damage in frontal cortex. *Brain*, 113, 749–766.
- Anderson, N. J. (1991). Individual differences in strategy use in second language reading and testing. *Modern Language Journal*, 75, 460-472.
- Ayres, L. (1912). *A Scale for Measuring the Quality of Handwriting of School Children*, Russel Sage Foundation, New York.
- Azzam, R. (1993). The nature of Arabic reading and spelling errors of young children: A descriptive study. *Reading and Writing*, 5(4): 355-385.
- Babcock, M.K., & Freyd, J. J. (1988). The perception of dynamic information in static handwritten forms. *American Journal of Psychology*, 101, 111-130.

- Babkoff, H., & Ben-Uriah, Y. (1983). Lexical decision time as a function of visual field and stimulus probability. *Cortex*, 19, 13-30.
- Babkoff, H., & Faust, M. (1988). Lexical decision and visual hemifield: An Examination of the RT accuracy relationship. *Neuropsychologica*, 26, 711-725.
- Barry, C. (1981). Hemispheric asymmetry in lexical access and phonological encoding. *Neuropsychologica*, 19, 473-478.
- Bartolomeo; P., Bachoud-Lévi; A.C., Chokron; S., & Degos; J.D. (2002). Visually- and motor-based knowledge of letters: evidence from a pure alexic patient. *Neuropsychologia*, 40(8) : 1363-1371.
- Beauvillain, C. (1996). The integration of morphological and whole-word forming formation during eye fixations on prefixed and suffixed words. *Journal of Memory and Language*, 35, 801-820.
- Beauvillain, C., & Doré, K. (1998). Orthographic codes are used in integrating information from the parafovea by the saccadic computation system, *Vision Research*, 38, 115–123.
- Bellajouza, M., Kostas, S., Ben Cheikh, T., (2005). Situation de la lecture en sixième année de l'enseignement primaire tunisien. Une approche de problèmes du livre et de la lecture. Institut national des sciences de l'éducation, 37(08.2/10).
- Biederman, I., & Cooper, E.E, (1991). Evidence for complete translational and reflectional invariance in visual object priming. *Perception*, 20, 585 - 593.
- Blote, A., & Hamstra-Bletz, L. (1991). A longitudinal study on the structure of handwriting. *Perception Motion Skills*, 72: 983–994.
- Bouamama, S., Bouzaouache, I., Zesiger, P., Stucchi, N. (2009). Reading/Writing habits prime letter recognition?. 32nd European Conference on Visual Perception. Regensburg.
- Bruinsma, C., & Nieuwenhuis, C. (1991). A new method for the evaluation of handwriting material. In: Wann, J., Wing, A. M., and Sovik, N. (eds.), *Development of Graphic Skills*, Academic Press, New York, pp. 41–51.
- Brunswick, N., McCrory, E., Price, C.J., Frith, C.D., & Frith, U. (1999). Explicit and implicit processing of words and pseudowords by adult developmental dyslexics: a search for Wernicke's Wortschatz?, *Brain*, 122, 1901–1917.
- Bryden, M.P. (1986). On the possible dangers of using horizontal words displays in visual fields studies. *Brain and Cognition*, 5, 362-368.
- Bryden, M.P., Mondor, T.A., Loken, M., Ingleton, M.A., & Bergstron, K. (1990). Locus of information in words and the right visual field effect. *Brain & Cognition*, 14, 44-58.

- Burnhill, P., Hartly, J., & Lindsay, D. (1983). Line paper illegibility and creativity. In: Hartley, J. (ed.); *The Psychology of Written Communication*, Kogan, London, England, pp. 82–91.
- Buxbaum, L.J., Coslett, B. Schall, R. McNally, B., & Goldberg, G. (1993). Hemispatial factors in mirror writing.
- Caramazza, A., & Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension. *Brain & Language*, 3, 572-582.
- Chan, J. J., & Ross, M. (1988). Left handed mirror writing following right anterior cerebral artery infarction. *Neurology*, 38, 59-63.
- Chatterjee, A., Southwood, M.H., & Basilico, D. (1999). Verb, events and spatial representations. *Neuropsychologia*, 37, 395-402.
- Christman, S.D., & Niebauer, C.L. (1997). Chapter 9: The relation between left-right and upper-lower visual field asymmetries: or: What goes up goes right, while what's left lays low. *Advances in Psychology*, 123, 263-296.
- Cohen, G. (1982). Theoretical interpretation of lateral asymmetries. In: J.G. Beaumont (eds.), *Divided visual field studies of cerebral organization*. London: Academic.
- Cohen, G., & Dehaene, S. (2004). Specialization within the ventral stream: The case for the visual word form area. *NeuroImage*, 22, 466-476.
- Cook, V. J. (1992). Evidence for multicompetence. *Language Learning*, 42, 557-591.
- Crist, R.E., Kapadia, M.K., Westheimer, G., & Gilbert, C.D. (1997). Perceptual learning of spatial localization: Specificity for orientation position and context. *Journal of Neurophysiology*, 78, 2889-2894.
- Critchley, M. (1928). *Mirror-writing*. London: Kegan, Paul.
- Darker, I.T., & Jordan, T.R., (2004). Perception of words and nonwords in the upper and lower visual fields. *Brain and Language*, 89, 593–600.
- Davidson, H. P. (1935). A study of the confusing letters b, d, p, and q. *Journal of Genetic Psychology*, 47, 458-468.
- De Ajuriaguerra, J., & Auzias, M. (1975). Preconditions for the development of writing in the child. In E. Lenneberg & E. Lenneberg (Eds.), *Foundations of language development (Vol.2)*. New York: Academic Press.
- Dehaene, S., Molko, N., Cohen, L., & Wilson, A.J. (2004). Arithmetic and the brain. *Current Opinion in Neurobiology*, 14 (2), 218-224.

- De Jong, W.P., Hulstijn, W., Kosterman, B.J.M., & Smits-Engelsman, B.C.M. (1996). OASIS software and its application in experimental handwriting research. In: M.L. Simner, C.G. Leedham, A.J.W.M. Thomassen (Eds). *Handwriting and Drawing Research: Basic and Applied Issues*. Amsterdam: IOS.
- Denier Van Der Gon, J.J., & Thuring, J.P.H. (1965). The guiding of human writing movements. *Kybernetik*, 2, 145-148.
- Dill, M., & Fahle, M. (1998). Limited translation invariance of human visual pattern recognition. *Perception & Psychophysics*, 60, 65-81.
- Dore, K., & Beauvillain, C. (1997). Latency dependence of word-initial letter integration by the saccadic system. *Perception & Psychophysics*, 59, 523-533.
- Dvash, L. E., Levi, M., Traub, R., & Shapiro, M. (1995). Reliability and Validity of the Hebrew Handwriting Evaluation, Unpublished manuscript, Faculty of Medicine, School of Occupational Therapy, Hebrew University, Jerusalem, Israel.
- Ellis, A. W. (1988). Normal writing processes and peripheral acquired dysgraphias. *Languages and cognitive Processes*, 3 (2), 99-127.
- Erez, N., Yochman, A., & Parush, S. (1996). The Hebrew Handwriting Evaluation, Faculty of Medicine, School of Occupational Therapy, Hebrew University of Jerusalem, Israel.
- Erez, N., Yochman, A., & Parush, S. (1999). The Hebrew Handwriting Evaluation (2nd Ed.), Faculty of Medicine, School of Occupational Therapy, Hebrew University of Jerusalem, Israel.
- Eviatar, Z. (2000). Culture and brain organisation. *Brain & Cognition*, 42, 50-52.
- Eviatar, Z., & Ibrahim, R. (2007). Morphological structure and hemispheric functioning: The contribution of the right hemisphere to reading in different languages. *Neuropsychology*, 21, 470-84.
- Farid, M., & Grainger, J. (1996). How initial fixation position influences visual word recognition: A Comparison of French and Arabic. *Brain and Language*, 53, 351-368.
- Faust, M., Kravetz, S., & Babkoff, H. (1993). Hemispheric specialization or reading habits: Evidence from lexical decision research with Hebrew words and sentences. *Brain and Language*, 44, 254-263.
- Freeman, F. N. (1954). *Teaching handwriting-What research says to the teacher* (4th ed.). Washington: Association of Classroom Teachers of the National Education Association.

- Gauthier, I. (2000). What constraints the organization of the ventral temporal cortex? *Trend in Cognitive Sciences*, 4, 1-2.
- Gauthier, I., & Logothetis, N. (2000). Is face recognition not so unique after all? *Cognitive Neuropsychology*, 17, 125-142.
- Gentaz, E. (2009). *La main, le cerveau, et le toucher : approche neurocognitive*. Dunod (1st ed).
- Gibson, E.J., & Levin, H. (1975). *The psychology of reading*. Cambridge, Mass: MIT Press.
- Gielen, C.C, Van den Oosten, K, & Pull ter Gunne, F. (1985). Relation between EMG activation patterns and kinematic properties of aimed arm movements. *Journal Motor Behaviour*, 17(4),421-42.
- Gilbert, C. D., Sigman, M., & Crist, R. E. (2001). The neural basis of perceptual learning. *Neurone*, 13, 681-697.
- Goyen, T. A., & Duff, S. (2005). Discriminant validity of the developmental test of visual-motor integration in relation to children with handwriting dysfunction. *Australian Occupational Therapy Journal*, 52, 1098-1115.
- Graham, S. (1986a). A review of handwriting scales and factors that contribute to variability in handwriting scores. *Journal. Science. Psychology*. 24, 63–72.
- Graham, S. (1986b). The reliability, validity, and utility of three handwriting measurement procedures. *Journal. Education. Research*. 79, 373–380.
- Graham, S., Berninger, V.W., & Weintraub, N. (1998). The relationship between handwriting style and speed and legibility. *Journal. of Educational. Research*, 5, 290–296.
- Graham, S., Weintraub, N., & Berninger, V. (2001). Which manuscript letters do primary grade children write legibly. *Journal of Educational. Psychology*. 3, 488–497.
- Graham, S., Harris, K. R., & Chorzempa, B. F. (2002). Contribution of spelling instruction to the spelling, writing, and reading of poor spellers. *Journal of Educational Psychology*, 94(4), 669-686.
- Guinet, E. & Kandel, S. (2010). Ductus: A software package for the study of handwriting production. *Behavior Research Methods*, 42, 326-332.
- Hackney, C. S., Myers, E. M., & Zaner-Bloser, P. (1973). "Sound of!" Teacher's Edition. *Expressional Growth Through Handwriting*, Zaner-Bloser, Ohio.
- Hamstra-Bletz, J. de Bie & B. den Brinker, (1987) *Concise evaluation scale for children's handwriting*, Lisse, Swets & Zeitlinger.

- Hamstra-Bletz, L., & Blöte, A. W. (1993). A longitudinal study on dysgraphic handwriting in primary school. *Journal of Learning Disabilities*, 26(10), 689-699.
- Harsel, Y., & Wales, R. (1987). Directional preference in problem solving. *International Journal of Psychology*, 22, 195–206.
- Helwing, J. J., Johns, J. C., Norman, J. E., & Cooper, J. O. (1976). The measurement of manuscript letter strokes. *Journal of Applied Behaviour Analysis*, 9, 231–236.
- Herrick, V. E. (1960). Handwriting and children's writing. *Elementary English*, 37: 248–258.
- Ho-Chuan, H., & Tsui-Ying, W. (2009). Stimulus effects on cancellation task performance in children with and without dyslexia. *Behaviour Research Methods*, 41 (2), 539-545.
- Hollerbach, J. M. (1981) An oscillation theory of handwriting. *Biol. Cybern.* 39, 139-156.
- Hulme, C. (1979). The interaction of visual and motor memory for graphic forms following tracing. *Quarterly Journal of Psychology*. 31, 249-261.
- Hyona, J. (1995a). Do irregular letter combinations attract readers' attention? Evidence from fixation locations in words. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 68- 81.
- Hyona, I. (1995b). An eye movement analysis of topic-shift effect during repeated reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21, 1365-1373
- Hyona, J., & Pollarek, A. (1998). Reading Finnish compound words. Eye fixations are affected by component morphemes. *Journal of Experimental Psychology: Human Perception and Performance*.
- Ibrahim, R., Eviatar, Z., & Aharon-Peretz, J. (2002). The characteristics of Arabic orthography slow its processing, *Neuropsychology*, 16, 322–326.
- James, K.H. & Gauthier, I. (2005). Neural spe.
- James, K.H., & Gauthier, I. (2006). Letter processing automatically recruits a sensory–motor brain network, *Neuropsychologia*, 44, 2937–2949.
- Jensen, H. (1970). *Sign, symbol and script* (George Unwin, Trans.). London: George Allen & Unwin.
- Kandel, S., Orliaguet, J-P., & Boë, L-J. (1994). Visual perception of motor anticipation in the time course of handwriting. In *Advances in handwriting and Drawing: Multidisciplinary Approach*. Eds C., Faure, P., Keuss, G., Lorette, A., Vinter. (Paris Europa) . pp379-388.

- Kandel, S., Orliaguet, J-P., & Boë, L-J. (1997). Visual perception of motor anticipation in cursive handwriting: Influence of spatial and movement information on the prediction of forthcoming letters. *Perception*, 26, 905-912.
- Kandel, S. Orliaguet, J-P., & Boë, L-J. (2000). Detecting anticipatory events in handwriting movement. *Perception*, 29, 953-964.
- Kandel, S. Orliaguet, J-P., & Viviani, P. (2000). Perceptual anticipation in handwriting: The role of implicit motor competence. *Perception & Psychophysics*, 62(4), 706-716.
- Kandel, S., Soler, O., Valdois, S., & Gros C. (2006). Graphemes as motor units in the acquisition of writing skills. *Reading & Writing: An Interdisciplinary Journal*, 19(3), 313-337.
- Kandel, S., & Valdois, S. (2006). French and Spanish-speaking children use different visual and motor units during spelling acquisition. *Language and Cognitive Processes*, 21(5), 531-561
- Kandel, S., & Valdois, S. (2006). Syllables as functional units in a copying task. *Language and Cognitive Processes*, 21(4), 432-452
- Kandel, S., Alvarez C., & Vallée, N. (2006). Syllables as processing units in handwriting production. *Journal of Experimental Psychology: Human Perception and Performance*, 32(1), 18-31.
- Kandel, S., Alvarez C., & Vallée, N. (2008). Morphemes also serve as processing units in handwriting production. In M. Baciú (ed.), *Neuropsychology and Cognition of language Behavioral, Neuropsychological and Neuroimaging Studies of Spoken and Written Language* pp. 87-100. Kerala, India: Research Signpost.
- Kanwisher, N., McDermott, J., & Chun, M.M. (1997). The fusiform face area: a module in human extrastriate cortex specialized for face perception. *Journal Neuroscience*, 17, 4302-11.
- Kao, H.S.R. (1983). Progressive motion variability in handwriting tasks. *Acta Psychologica*, 54, 149-159.
- Kao, H.S.R., Van Galen G.P., & Hoosain, R. (1986). *Contemporary research in handwriting*, North-Holland, Amsterdam.
- Kao, H.S.R., Mak, P.H., & Lam, P.W. (1986). Handwriting pressure: Effects of task complexity, control mode and orthographic difference. In: H.S.R. Kao, G.P. Van Galen and R. Hoosain, Editors, *Graphonomics: Contemporary research in handwriting*, North-Holland, Amsterdam.
- Kimura, D. (1966). Dual functional asymmetry of the brain in visual perception. *Neuropsychologia*, 4(3), 275-285

- Kimura, D. (1967). Functional asymmetry in the brain in dichotic listening. *Cortex*, 163-168.
- Kinsbourne, M. (1970). The cerebral basis of lateral asymmetries in attention. *Acta Psychologica*, 33,193-201.
- Knoblich, G., & Flach, R., Seigerschmidt, E., & Prinz, W. (2002). Authorship effects in the prediction of handwriting strokes: Evidence for action simulation during action perception. *The quarterly Journal of Experimental Psychology*, 55A(3), 1027-1046.
- Knoblich, G., & Repp, B. H. (2004). Perceiving Action Identity. *American Journal of Psychology*, 15, 604-609.
- Koriat, A. (1985). Lexical access for low and high frequency words in Hebrew. *Memory & Cognition*, 13, 37-44.
- Kimura, D. (1966). Dual functional asymmetry of the brain in visual perception. *Neuropsychologia*, 4, 275-85.
- Kimura, D. (1967). Spatial Localization In Left and right Visual fields. *Canadian Journal of Psychology*, 23(6).
- Krzesni, J. S. (1971). Effect of different writing tools and paper on performance of the third grader. *Element English*, 48, 821–824.
- Lacquanti, F., Terzuolo, C. & Viviani, P. (1983). The law relating the kinematics and figural aspects of drawing movements. *Acta Psychologica*, 54, 115-130.
- Larsen, S. C., Parker & Hammill, D. P. (1982). Effectiveness of psycholinguistic training: A response of Kavale. *Exceptional Children*.49, 60-66.
- Larsen, S. C., & Hammill, D. P. (1989). *Test of Legible Handwriting*, Pro-Ed., Austin, TX.
- Latash, M.L. (1998) Virtual reality: A fascinating tool for motor rehabilitation. (To be used with caution). *Disability and Rehabilitation*, 20, 104-105.
- Lewis, E. (1964). *An Analysis of Children's Manuscript Handwriting*. Unpublished doctoral dissertation, University of California, Berkeley.
- Lifshietz, N., & Parush, S. (1996). *Screening Assessment for Children with Handwriting Deficits*, Unpublished manuscript, Jerusalem: School of Occupational Therapy, The Hebrew University.
- Lindsay, G. A., & McLennan, D. (1983). Lined paper; It's effects on the legibility and creativity of young children's writing. *British Journal of Educational Psychology*. 53, 364–368.

- Longcamp, M., Anton, J-L., Roth, M., & Velay, J-L. (2003). Visual presentation of single letters activates a premotor area involved in writing. *NeuroImage*, 19, 1492-1500.
- Logothetis, N. K., Pauls, J., & Poggio, T., (1995) .Shape representation in the inferior temporal cortex of monkeys'. *Current Biology*, 5, 552-563
- Longstaff, M.G., & Heath, R. A. (1997). Space–time invariance in adult handwriting. *Acta Psychologica*. 97, 201–214.
- Lubow, R. E., Tsai, Y., Mirkin, A., & Mazliah, G. (1994). English and Hebrew letter reports by English and Hebrew reading subject: Evidence for stimulus control, not hemispheric asymmetry. *Brain and Cognition*, 25, 34-51.
- Maass, A., & Rosso, A. (2003). Directional bias in the mental representation of spatial events: Nature or Culture?. *Psychological Science*,14, 4.
- Maarse, F.J. Schomaker, L.R.B. & Thomassen, A.J.W.M. (1986). The influence of changes in the effector coordinate system on handwriting movements. In: H.S.R. Kao, G.P. van Galen and R. Hoosain, Editors, *Contemporary research in handwriting*, North-Holland, Amsterdam
- Mai, N., & Marquardt, C. (1992). CS-Computer-assisted movement analysis in handwriting: Operational manual. Munich, Germany: MedCom Verlag.
- McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation inreading. *Perception and Psychophysics*, 17, 578-586.
- Marsolek, C, J. (1999). Dissociable neural subsystems underlie abstract and specific object recognition. *Psychological Science*, 10, 111-118.
- McCusker, L.X., Hillinger, M.L. & Bias, R.G. (1981). Phonological recoding and reading. *Psychological Review*, 89, 217–245.
- Melamed, F., & Zaidel, E. (1993).Language and task effects on lateralized word recognition. *Brain and Language*, 45, 70-85.
- Meulenbroek, R.G.J. & Van Galen, G.P. (1986). Movement analysis of repetitive writing behaviour of first, second and third grade primary school children. In: H.S.R. Kao, G.P. Van Galen and R. Hoosain, Editors, *Contemporary research in handwriting*, North-Holland, Amsterdam.
- Meulenbroek, R.G.J.,& Van Galen, G.P. (1989). Variations in cursive handwriting performance as a function of handedness, hand posture and gender. *Journal of Human Movement Studies*,16, 239–254.
- Meulenbroek, R.G.J. & Van Gemmert, A.W.A. (2003). Advances in the study of drawing and handwriting [Special issue], *Human Movement Science*, 22, 131–220.

- Modlinger, I. (1983). *Disorders of Written Language: Diagnosis and Remedial Teaching*, Sifriyat Hapoalim, Tel Aviv, Israel.
- Mojet, J. W. (1989). *Kemmerken van schrijfvaardigheid: Praesaspecten van het schrijven bij twaalfjarigen* (Characteristics of the handwriting skill: Process aspects in 6–12 year olds), Academisch Boeken Centrum, De Lier: Academic Boeken.
- Mojet, J.W. (1991). Characteristics of the developing handwriting skill in elementary education. In: Wann, J., Wing, A. M., and Sovik, N. (eds.), *Development of Graphic Skills*, Academic Press, London, England, pp. 53–74.
- Moore, C.J., & Price, C.J. (1999). Three distinct ventral occipitotemporal regions for reading and object naming, *NeuroImage*, 10, 181–192.
- Morasso, P. (1981). Spatial control of arm movements. *Experimental Brain Research*, 42, 223-227.
- Morikawa, K., & McBeath, M. K. (1992). Lateral motion bias associated with reading direction. *Vision Research*, 32, 1137- 1141.
- Morrison, R.E. (1984). Manipulation of stimulus onset delay in reading: evidence for parallel programming of saccades, *Journal of Experimental Psychology Human Perception*. 10, 667–682
- Naka, M. (1998). Repeated writing facilitates children's memory for pseudocharacters and foreign letters. *Memory and Cognition*, 26, 804-809
- Nazir, T. A. & O'regan, J. K. (1990). Some results on translation invariance in the human visual system. *Spatial Vision*, 5, 81-100.
- Nisbett, R. E., Peng, K, Choi, I., & Norenzayman, A (2001). Culture and systems of thought: Holistic versus analytic cognition. *Psychological Review*, 108, 209-301.
- Orliaguet, J.-P., Kandel, S., & Boë, L.-J. (1997). Visual perception of cursive handwriting: Influence of spatial and kinematic information on the anticipation of forthcoming letters. *Perception*, 26, 905-912.
- Orton, S. T. (1928a). Specific reading disability – strephosymbolia. *Journal of the American Medical Association*, 90, 1095-1099.
- Orton, S. T. (1928b). A physiological theory of reading disability and stuttering in children. *New England Journal of Medicine*, 29, 1046-1052.
- Peters, M. & McGrory, J. (1987). The writing performance of inverted and non inverted right- and lefthanders. *Canadian Journal of Psychology*, 41, 20–32
- Phelps, J., Stempel, L., & Speck, G. (1985). The children's handwriting scale: A new diagnostic tool. *Journal of Educational Resources*. 79: 46–50.

- Plamondon, R. (2003). A unified framework to study human movements under isotonic and isometric conditions. Neuroscience, New Orleans, USA.
- Plamondon, R. & Srihari, R. (2000). On-line and off-line handwriting recognition: A comprehensive survey, 20th Anniversary Special Issue, IEEE Transactions on Pattern Analysis and Machine Intelligence, 22, 63–84.
- Plamondon, R., Lopresti, D., Schomaker, L.R.B & Srihari, R. (1999). On-line handwriting recognition. In: J.G. Webster, Editor, Wiley encyclopedia of electrical and electronics engineering, 15, John Wiley & Sons, NY, 123–146.
- Pollatsek, A., Bolozky, S., Well, A.D., & Rayner, K. (1981). Asymmetric in the perceptual span for Israeli readers. *Brain and Language*, 14, 174-180
- Price, J., Wise, R.J.S., Warburton, E., Moore, C.J., Patterson, K., Howard, D. Patterson, K., Frackowiak, R.S & Friston, K.J. (1996). Hearing and saying: the functional neuroanatomy of auditory word processing, *Brain*, 119, 919–931
- Price, C.J., & Devlin, J.T., (2003). The myth of the visual word form area. *NeuroImage* 19, 473–481
- Pynte, J. (1996). Lexical control of within-word eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, 22, 958-969.
- Rayner, K., Well, A.D., & Pollatsek, A. (1980). Asymmetry of the effective visual field in reading, *Perception and Psychophysics*, 27,537–544
- Reisman, J. E. (1993). Development and reliability of the research version of the Minnesota Handwriting Test. *Physical Occupational Therapy in Pediatrics*,13, 41–55.
- Rizzolatti, G., & Craighero, L. (2004). The mirror-neurone system. *Ann. Rev. Neurosciences*, 27, 169-192.
- Rodriguez, R., Aguilar, M., & Gonzalez, G. (1989). Left non dominant hand. *Brain & Language*; 37, 122-44.
- Rodriguez, R. (1991). Hand motor pattern after the correction with hand mirror writing. *Neuropsychologica*, 29, 119-24.
- Rogers, D., & Found, B. (1996). The objective measurement of spatial invariance in handwriting. In: Simner, M. L., Leedham, C. G., and Thomassen, A. J. W. M. (eds.), *Handwriting and Drawing Research*, IOS Press, Amsterdam, pp. 3–13.
- Rosenblum, J. (2000). Design and development of online courses: Faculty working in collaboration. *Syllabus*, 3, 10-14.
- Rosenblum, S., Weiss, P. L., & Parush, S. (2003). Product and process evaluation of handwriting difficulties. *Educational Psychology Review*, 15, 41-81.

- Rosenblum, S., Parush, S., & Weiss, P. L. (2003a). Computerized temporal handwriting characteristics of proficient and poor handwriters. *American Journal of Occupational Therapy*, 57(2), 129–138.
- Rosenblum, S., Parush, S., & Weiss, P. L. (2003b). The in air phenomenon: temporal and spatial correlates of the handwriting process. *Perceptual and Motor Skills*, 96, 933-954.
- Rosenblum, S., Weiss, P.L., & Parush, S. (2004). Handwriting evaluation for developmental dysgraphia: Process versus product. *Reading and Writing*, 17, 433-458.
- Rosenblum, S., Dvorkin, A.Y., & Weiss, P. (2006). Automatic segmentation as a tool for examining the handwriting process of children with dysgraphic and proficient handwriting. *Human Movement Science*, 25, 608–621.
- Rubin, N., & Henderson, S. E. (1982). Two sides of the same coin: Variation in teaching methods and failure to learn to write. *Special Educational Forward Trends*, 9, 17–24.
- Ruff, R. M., Evans, R. W., & Light, R. H. (1986). Automatic detection vs controlled search: A paper-and-pencil approach. *Perceptual & Motor Skills*, 62, 407-416.
- Sampson, G. (1985). *Writing Systems*. Hutchinson, London
- Sassoon, R. (1997). Dealing with adult handwriting problems. *Handwriting Revue*, 11, 69–74.
- Ruff, R. M., Evans, R. W., & Light, R. H. (1986). Automatic detection vs controlled search: A paper-and-pencil approach. *Perceptual & Motor Skills*, 62, 407-416.
- Santori, G., Job, R & Tressoldi, P, E. (1995). *Batteria per la valutazione della dislessia e della disortografia*. Firenze, Giunti OS.
- Sassoon, R. (1997). Dealing with adult handwriting problems. *Handwriting Rev.* 11: 69–74.
- Sassoon, R., Nimmo-Smith, I., & Wing, A.M.(1986). An analysis of children's penholds. In: H.S.R. Kao, G.P. van Galen and R. Hoosain, Editors, *Graphonomics: Contemporary research in handwriting*, North-Holland, Amsterdam.
- Schomaker, L.R.B. & Plamondon, R. (1990), The relation between pen force and pen point kinema in handwriting. *Biological Cybernetics* , 63, 277–289.
- Schott, G.D. (1980). Mirror movements of the left arm following peripheral damage to the preferred right arm. *Journal of Neurology and Neurosurgery and Psychiatry*; 43, 768-73.

- Schröter, A., Mergl, R., Bürger, K., Hampel, H., Möller, H.-J. & Hegerl, U. (2003). Kinematic analysis of handwriting movements in patients with Alzheimer's disease, mild cognitive impairment, depression and healthy subjects, *Dementia and Geriatric Cognitive Disorders*, 15, 132–142
- Sergent, J. (1982). The cerebral balance of power: Confrontation of cooperation?. *Journal of Experimental Psychology: Human Perception & Performance*, 8, 253-272.
- Silverberg, R., Obler, L. K., & Gordon, H. W. (1979). Handedness in Israel. *Neuropsychologia*, 17, 83-87.
- Singhal, M. (1998). A comparison of L1 and L2 reading: Cultural differences and schema. *The Internet TESL Journal* 4(10). Retrieved January 10, 2010 from <http://iteslj.org/Articles/Singhal-ReadingL1L2.html>
- Smits-Engelsman, B. C. M., (1995). Theory based diagnosis of fine motor coordination development deficiencies using handwriting tasks. PhD. Thesis, University of Nijmegen.
- Smits-Engelsman, B. C. M., & Van Galen, G. P. (1997). Dysgraphia in children: Lasting psychomotordeficiency or transient developmental delay? *Journal of Experimental Child Psychology*, 67, 164–184.
- Smits-Engelsman, B. C. M., Van Galen, G. P., & Shoemaker, M. M. (1998). Theorybased diagnosis and subclassification in the developmental coordination disorder. In: Rispens, J., Van Yperen, T. A., and Yule, W. (eds.), *Perspective on the Classification of Specific Developmental Disorders*, Academic Publisher, London, England, pp. 245– 264.
- Seki, K., Yajima, M., & Sugishita, M. (1995). The efficacy of kinesthetic reading treatment for pure alexia. *Neuropsychologia*, 33(5), 595-597
- Selinker, L. (1992). *Rediscovering interlanguage*. London, Longman.
- Stott, D. H., Moyes, F. A., & Henderson, S. E. (1984). *Diagnosis and Remediation of Handwriting Problems*, Hayes Publishers, Burlington, ON.
- Teuling, H.L.T., & Stelmach, G.E. (1991) .Control of stroke size, peak acceleration and stroke duration in Parkinsonian handwriting, *Human Movement Science* 10, 315–333.
- Teulings, H.L. (2001). Optimatization of movements duration in accurate handwriting strokes in different directions in young, elderly, and Parkinsonian subjects. In: Meulenbroek, R. G. J., and Steenbergen, B. (eds.), *Proceedings of the Tenth Biennial Conference of the International Graphonomics Society*, University of Nijmegen, IGS, The Netherlands, pp. 40–45.
- Teulings, H. L., & Thomassen, A. J. W. M. (1979). Computer aided analysis of handwriting movements. *Visible. Language*, 13, 218–231.

- Thomassen, J.W.M., & Teulings, H.L., (1979). The development of directional preference in writing movements, *Visible Language*, 13, 299–313.
- Thomassen, A.J.W.M., & Teulings, H.L. (1985). Time, size, and shape in handwriting: Exploring spatio-temporal relationships at different levels. In J.A. Michon & J.B. Jackson (Eds.), *Time, mind, and behavior* (pp. 253-263). Heidelberg: Springer.
- Trap-porter, J., Gladden, M. A., Hill, D. S., & Cooper, J. O. (1983). Space size and accuracy of second and third grade students cursive handwriting. *Journal of Educational Research*, 76, 231–233.
- Turkeltaub, P.E., Eden, G.F., Jones, K.M, & Zeffiro, T.A (2002). Meta-analysis of the functional neuroanatomy of single-word reading: method and validation, *NeuroImage*, 16, 765–780
- Upton, T. A. (1997). First and second language use in reading comprehension strategies of Japanese ESL students. *Teaching English as a Second Language Electronic Journal* 3(1). Retrieved January 10, 2010 from <http://tesl-ej.org/ej09/a3.html>
- Vaid, J., & Singh, M. (1989). Asymmetries in the perception of facial affect: Is there an influence of reading habits? *Neuropsychologia*, 27, 1277–1287.
- Van der Plaats, R.E, & Van Galen G.P. (1990). Effects of spatial and motor demands in handwriting. *Journal of Motor Behaviour*. 22(3), 361-85
- Van Galen, G.P., Meulenbroek, R.G.J.& Hylkema, H., (1986). On the simultaneous processing of words, letters and strokes in handwriting: Evidence for a mixed linear and parallel model. In: Kao, H.S.R., van Galen, G.P. and Hoosain, R., Editors. *Graphonomics: Contemporary research in handwriting*, North-Holland, Amsterdam, pp. 5–20.
- Van Galen, G.P., Smith, M.M., Meulenbroek, R.G.J. & Hylkema, H., (1989). The role of short-term memory and the motor buffer in handwriting under visual and non-visual guidance. In: Plamondon, R., Suen, C.Y. and Simner, M.L., Editors, 1989. *Computer recognition and human production of handwriting*, World Scientific Publishing Co., Singapore, pp. 253–271.
- Van Galen, G.P. (1990). Phonological and motoric demands in handwriting: Evidence for discrete transmission of information. *Acta Psychologica*, 74, 259–275.
- Van Galen, G. P. (1991). Handwriting: Issues for a psychmotor theory. *Human Movement Science*, 10, 165–192.
- Van Galen, G. P., Portier, S. J., Smits-Engelsman, B. C. M., & Shomaker, I. R. B. (1993). Neuromotor noise and poor handwriting in children. *Acta Psychologica*, 82, 161-178.

- Van Galen G. P., & Morasso, P. (1998). Neuromotor control in handwriting and drawing [Special issue], *Acta Psychologica*, 100, 1–227.
- Van Gemmert, A. W. A., & Van Galen, G. P. (1998). Auditory stress effects on preparation and execution of graphical aiming: A test of the neuromotor noise concept. *Acta Psychologica*, 98, 81-101.
- Van Gemmert, A.W.A. & Teuling, H.L.T. (2004). Connecting sciences using graphonomics research [Special issue], *Motor Control*, 18, 367–566.
- Viviani, P. and Terzuolo, C., (1980). Space-time invariance in learned skills. In: Stelmach, G.E. and Requin, J., Editors, 1980. *Tutorials in motor behaviour*, North-Holland, Amsterdam, pp. 525–533.
- Viviani, P. (2002). Motor competence in the perception of dynamic events: A tutorial. In: W. Prinz and B. Hommel, Editors, *Common mechanisms in perception and action, attention and performance vol. XIX*, University Press, Oxford. Pp :406–442
- Vlachos, F., & Karapetsas, A. (2003). Visual memory deficit in children with dysgraphia. *Perceptual and Motor Skills*., 97, 1281-1288.
- Wada, Y., Koike, Y., Vatikiotis-Bateson, E., & Kawato, M. (1995). Acomputational theory for movement pattern recognition based on optimal movement pattern generation. *Biological Cybernetics*, 73, 15-25.
- Wann, J. P., & Jones, J. G. (1986). Space-time invariance in handwriting. *Human Movement Sciences*. 5,275–296.
- Wann, J. P. (1987). Trends in the refinement and optimization of fine-motor trajectories: Observations from an analysis of the handwriting of primary school children. *Journal of Motor Behaviour*. 19,13–37.
- Wann, J. P., & Kardirkamanathan, M. (1991). Variability in children’s handwriting: Computer diagnosis of writing difficulties. In J. Wann, A. Wing, & N. Sovik (Eds.), *Development of graphic skills*, (pp.223-236), London: Academic Press.
- Wann, J. & Nimmo-Smith, I. (1991) The control of pen pressure in handwriting: A subtle point. *Human Movement Science*, 10, 223-246.
- Wierzbicka, A. (1993). A conceptual basis for cultural psychology. *Ethos*, 21, 205-231.
- Young, A. W., & Ellis, A. W. (1985). Different methods of lexical access for words presented in the left and right visual hemifields. *Brain and Language*, 24, 326–358.
- Zatsiorsky, V.M. 1998. *Kinematics of human motion*, Human Kinetics, Champaign, IL.

- Zesiger, P. (2003). Acquisition et troubles de l'écriture [Handwriting acquisition and disorders]. *Enfance*, 55 (1), 56-64.
- Zesiger, P. (1995). *Ecrire: Approche cognitive, neuropsychologique et développementale* [Writing: A cognitive, neuropsychological and developmental approach]. Paris : Presses Universitaires de France.
- Ziviani, J., & Elkins, J. (1984). An evaluation of handwriting performance. *Educational. Revue*, 36, 249–261.