Developmental aspects of handwriting acquisition

Michael John Allen

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Declarations

I declare that, while registered as a candidate for a Research Degree, I have not been a registered candidate or enrolled student for another award.

I declare that no material contained in the thesis has been used in any other submission for an academic award.

I confirm that the thesis submitted is the outcome of the work that I have undertaken during my programme of study and is all my own work.

MJ Allen

Abstract

This research set out to examine the changes in handwriting in children from the earliest learning experiences at about five years old through to the time that they leave education in late adolescence. The aims were to explore the changes that occur in handwriting, both of features used and their variability, to establish when they occur and to determine what the consequences are for the process of individualisation.

A coding scheme was devised that was used to establish detailed changes in feature use of particular letters in the handwriting of children. The scheme was tested and then revised to give a practical tool to use in the examination of large numbers of handwriting samples in cross-sectional and longitudinal studies that followed.

In the cross-sectional study three handwriting tasks (normal composition, neat copying and fast copying) were completed by 144 participants from six different age groups. Firstly, the results showed that, there are underlying higher order dimensions of handwriting that emerge from some of the individual features. Secondly, across all tasks, the variability of handwriting increased from the younger children and peaked at about 10-11 years old and then decreased. Within this general trend, there was also evidence that writing faster than normal led to increased variability in letter formation for younger children, but reduced variability for older children. Thirdly, some individualisation was present even in the youngest children, but the extent of this increased such that by late adolescence it was nearly almost complete.

In the longitudinal study handwriting samples from a smaller number of children were obtained over three years. The findings were similar to those obtained in the cross-sectional study.

The implications of this for handwriting acquisition in particular and skill acquisition in general are considered.

The research concludes that there is potential to extend the approach used in this research to clarify higher order dimensions of handwriting production, that the variability of handwriting is a good measure for determining handwriting development in children, that this variability increases up to the age of 10-11, and then declines, and that the handwriting of each child progressively develops its own style away from that of his or her peers.

Contents

List of Tables

List of Figures

Chapter 1 Preface

1.1 General introduction

The need to communicate in one form or another is central to the existence of all human beings. Often this involves recording the communication, a process that historically led to the development of handwriting.

For most people, the process that enabled them to acquire the skill of handwriting is largely forgotten once it has been acquired. In children, handwriting becomes an increasingly automated skill (Rueckriegel, et al. 2008), subservient to the higher thought processes that are to be recorded using it. This does not mean that handwriting is outside conscious control. If a high degree of automation does not happen, then the need to apply the mind to the act of handwriting is likely to be a barrier to the higher thought processes that are being communicated. For example, writing in unaccustomed circumstances requires different neuro-muscular input (Wing, 2000). But in the normal course of events, accomplished writers concentrate on what to write not how to write.

Handwriting is a skill the product of which is regarded as being unique to each individual (Ellen, 1993). This uniqueness is derived from two components of a person's handwriting. Firstly, the particular combination of forms of the letters used (style) to produce the handwriting will vary from person to person depending on a number of factors. These are considered in depth in Chapter 2. In this research, not only will letterforms be examined in isolation and in combination but they will also be analysed with a view to determining whether there are higher order dimensions of handwriting that some features share with one another.

Secondly, the variability of execution of the letterforms varies from one writer to another. This variability is usually called natural variation and is an intrinsic quality of handwriting. The origins of variability are often ignored in studies which aim to show what events occur during development and when they occur. However, in this research, variability will be at the heart of the analysis of handwriting development because the variations are a potential source for change in handwriting style within a given writer and hence the source of differences between writers.

Thus, for a given written character (such as the letter a), two writers might show variations some of which are shared by both writers and some of which are not. Multiplied by the various handwritten characters and the population of writers, there is scope for many dimensions of handwriting to be either similar or different both within the handwriting of a given writer and between the handwriting of different writers.

Indeed, the range of natural variation of a person's handwriting itself becomes a property of the handwriting that a handwriting expert can use when determining authorship. The range of variation incorporates dimensions of the extent of the variation and the nature of different handwriting features used. Taking into account natural variation is a central part of the identification process for the handwriting expert. The combination of features used and their variability are what produce the unique quality (style) of each person's handwriting (Ellen, 1993).

The author is a handwriting expert of more than twenty-five years of experience and therefore the origin of natural variation in handwriting is a matter that is of considerable interest.

Handwriting experts have accepted the fact of natural variation and used its significance in their work for many years. However, there has been virtually no attempt in the forensic literature (or elsewhere) to understand the origins of natural variation. Such an understanding is not only of academic interest; handwriting experts may be called upon to justify their assertion that each person's handwriting is unique and evidence for this could include a demonstration of the development of style differences between writers that occur during childhood and adolescence. It may also inform the handwriting expert when examining certain types of case material, such as when examining handwriting from young people whose handwriting is still developing.

The author's primary motivation for this research, therefore, was to gain an insight into the development of handwriting style in children and from this to understand the origins of individualisation of handwriting that are the foundation for the interpretation of the forensic document examiner in the identification of handwriting. This is related to, but not the same as, the development of writing in children which generally focuses on compositional processes and effectiveness of execution of handwriting, perhaps in terms of speed or legibility. Because handwriting is such a complex process, combining cognitive and motor components, it is inevitable that the factors that impact on composition and execution will affect the appearance of the handwriting (its style) but there will be other factors too such as how writing is taught, familial influences and the fine manual motor control of the writer.

This research, therefore, focussed on three aspects of handwriting development, looking at individual features and how they may be related to one another, the overall effect of variability of the features and how this translates into a process of individualisation. Changes in handwriting style that occur in children were explored, starting with those that are taking their first steps in learning to produce handwriting to those who are close to adulthood as they approach school leaving age. The foundations for this research therefore required reviews of a number of relevant topics.

Firstly, it was important to gain an understanding of general models of skill acquisition so that the development of the handwriting skill can be understood in the overall context of a child's wider developmental processes. This is because skills are not learned in a vacuum but rather are embedded in complex relationships with other skills. This is particularly true of handwriting production as it requires both high level language skills to generate text and fine motor control to execute the movements needed for effective handwriting production. Neither of these components is utilised only in handwriting production and hence their development in the contexts of other related skills, such as speech and reading or general manual dexterity will impact on the child's ability to produce handwriting. The developments of language and motor skills are huge topics in their own rights and will not be discussed in detail, but it is appropriate to consider some general models of skill acquisition so as to place the learning of handwriting in an appropriate context.

Secondly, in order to understand the processes involved in handwriting production, a review of models of writing production is appropriate. From this, the ways in which compositional elements are transformed into neuromuscular movements to move the writing implement will be considered and their potential for impacting on the style of handwriting highlighted.

Thirdly, a brief discussion of the developmental precursors to handwriting will provide an understanding of some issues of writing implement manipulation and movement. This will provide evidence as to the kinds of hand and finger movements that the youngest children find easiest to produce which would be expected to be constraints on the motor aspect of handwriting in the youngest writers.

Fourthly, an overview will be made of the multitude of external factors that impact on handwriting production throughout the school years since these will be sources for change in handwriting style. This will shed light on the reasons why style changes and the reasons for them, some of which the young writer may be unaware, such as a tendency to improve efficiency) but some of which may be more deliberate choices (such as adopting a generally 'pleasing' style the execution of which may be inconsistent with improved efficiency.

Finally, a general description of maturational processes in handwriting will be described, considering matters such as speed and legibility and more general changes from the child-like to the more adult appearance.

All of this background material will form the body of Chapter 2. Arising from the above reviews, it was possible to develop a strategy for measuring the development of handwriting style in children and, in particular, to measure changes in handwriting style as demonstrated by changes in its variability.

In Chapter 3, various ways of assessing and categorising handwriting will be discussed. Firstly, a review of how handwriting development is currently studied in children will describe the current approaches to handwriting development, how they are measured, and why they are measured since the purpose of the assessment of handwriting dictates what factors are to be measured. These generally are used in order to understand handwriting production in children with a particular emphasis on diagnosing and correcting problems with handwriting. They were contrasted with forensically focused schemes of handwriting classification which provide specific categorisation of detailed letterforms. Such categories of handwriting were needed to enable the detailed and fine-grained assessment of handwriting style and its variation that formed the cornerstone of this research.

Hence, the information in Chapter 3 informed the process of developing a detailed coding scheme that can be used to assess handwriting style. The scheme needed to be able to capture variability in handwriting style in children both between writers, within writers and also between writers at different developmental stages. The devising and testing of a scheme is described in Chapter 4 and an assessment of the coding scheme in the light of its use showed whether or not the coding scheme worked based on issues such as were the features proposed capable of being scored in samples of handwriting from different writers and did they show consistent patterns of use in samples of handwriting from the same person and between different writers? Use of the scheme enabled it to be refined in the light of the experience of its being applied, a factor that was particularly relevant since the intention was to use the coding scheme in two larger (and time consuming) studies.

The coding scheme was then be used in two larger studies that are described in Chapter 5 (a cross-sectional study) and Chapter 6 (a longitudinal study). These studies involved the analysis of letterforms, their overall variability and the individualisation of handwriting both between writers and within writers– the central aim of this research.

1.2 Preliminary considerations for the research

The variability of handwriting can be considered in a number of separate but related contexts. This research explored these and there is, therefore, a need to be clear about the distinctions between them.

The smallest amount of handwriting that will be considered is a piece of handwriting containing words written at essentially the same time. A piece of handwriting can be started and then interrupted on any timescale, ranging from a pause to think, to a break of minutes, hours, days or longer. However, within the school environment, in which this research takes place, a piece of handwriting can be taken to be an amount of handwriting produced on one occasion.

The multiple occurrences of the same letters within a piece of handwriting provide one measure of handwriting variability. In other words, the letter 'a', for example, will be written in a slightly different way each time that it occurs within a piece of handwriting by the same writer written on the same occasion. Such variation will be called *within-piece variation*. The average of this measure across different letters in a piece of text can be regarded as a measure of the overall variability of the handwriting.

The second kind of variation is that which occurs between two pieces of handwriting written on separate occasions by the same person. The time between two such pieces of writing can range from minutes to days, weeks or longer. In that sense, the distinction between the within piece variation described in the previous paragraph and the between piece variation described here is not necessarily clear-cut. However, pieces of writing prepared on different occasions may also involve changes to other factors, such as the physical conditions (for example, writing at a different desk or with a different implement), writing when taking more (or less) care, perhaps making notes rather than writing neatly and so on. As a result, it is likely that separate pieces of work will have been written at different times and these will be referred to this as *between piece variation*. This can be applied to either the individual features or to the overall handwriting variation.

The variation both within pieces of handwriting and between pieces of handwriting, written at about the same developmental stage, by a given writer, is combined into what I shall call *within writer variation*. This is in contrast to the range of *natural variation* to be found in adult handwriting which is stable over prolonged periods of time (Ellen, 1993).

Hence, within the handwriting of a given child, there is also the variation to be found over longer (developmentally relevant) periods of time that may be caused by one or more of various influences. These are likely to include the development of the writer's skill, especially in younger children, and input from third parties, such as teachers (Sassoon, 1990) and family members (Ellen, 1993). I will call this *developmental variation* being a form of within writer variation occurring over longer periods of time.

When a handwriting expert refers to the natural variation of a person's handwriting, all three kinds of variation just described may be involved, but the main focus would usually be on within piece and between piece variations (Ellen, 1993). Change over longer periods of time may be relevant in certain circumstances, such as when examining handwritings of young people or when pieces of handwriting written a long time apart are to be compared.

Adult handwriting production is stable over long periods of time (years) whereas in children handwriting can change much more rapidly (weeks and months). Therefore, time will be a factor when considering the relationships between within piece variation, between piece variation and developmental variation in younger and adult writers. In the latter, it is likely that all three variabilities will be similar, whereas in the child or young adult, whose handwriting has not yet stabilised, the types of variability may differ more markedly.

Finally, there are *between writer variations* attributable to the different ways in which individuals execute their handwriting (Ellen, 1993). In the context of the interactions of within piece, between piece and developmental variations, it is possible that these will be more or less marked between individuals at different times. For example, it might be expected that younger writers that were taught in the same school will have handwritings that are more similar to one another whereas handwriting samples from older children (also originally taught in the same school) will differ because their handwriting has developed over a number of years and will have deviated away from the taught style. In other words, the older children's handwriting will have developed and settled into a style of its own, based on a particular combination of features used. Alternatively, if the developmental processes are related simply to general maturational factors, children taught in the same way may tend to write alike one another as they get older too.

Unpicking the complex interaction of handwriting variabilities will require careful consideration in this research and, in order to explore this, a coding scheme will need to be developed which has the potential to measure variability in the various contexts.

However, before embarking on a detailed review of the literature in Chapters 2, 3 and 4, some further consideration will be given to the background of this research.

1.3 Background to handwriting production

It takes a number of years to acquire the skill of handwriting, involving as it does both high level cognitive elements associated with language production and the fine motor skills required for the rapid and effective manipulation of the writing implement (Graham & Weintraub, 1996). During this prolonged learning process, a number of influences will impinge upon it, and these are discussed in detail in Chapter 2.

In order to get a feel for the transformation that typically occurs in the acquisition stages of handwriting development, Figure 1.1 shows some typical examples of handwriting. They are from three children who are still learning to write (Figure 1.1a), have mastered the skill of writing but whose style is still recognisably child-like (Figure 1.1b) and have completed most of their school career (Figure 1.1c). In Figure 1.1a the production of each letter appears to be a difficult task, as if each letter is being created for the first time. In Figure 1.1b, the consistency of letter production is greater but the handwriting still shows modest skill. In Figure 1.1c, the skilfulness and consistency is vastly greater, with letters joining fluently. The letters in Figures 1.1a and 1.1b can be recognised individually whether or not read in the context of the other letters in the words. In contrast, many of the individual letters in Figure 1.1c would not be recognisable in the absence of the context of the other letters in the words, as if individual letters were no longer the units from which words are built but rather that certain letter groups are, where appropriate, used in combination to construct words. The more mature handwriting is likely be more consistent in execution (show less

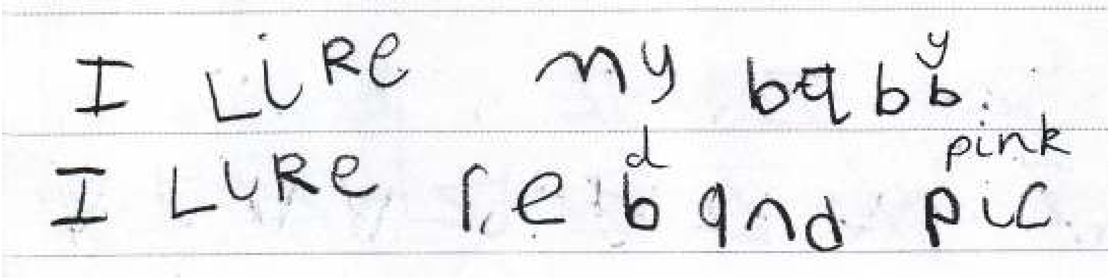


Figure 1.1a showing writing from a young child who is still learning to write

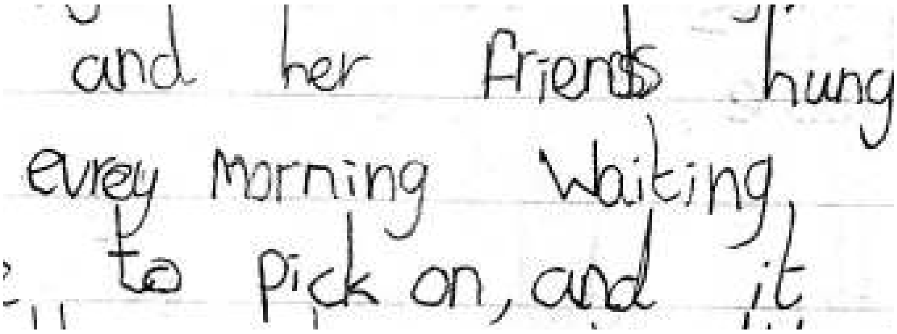


Figure 1.1b showing writing from a child showing mastery of the skill but whose handwriting still has a child-like appearance

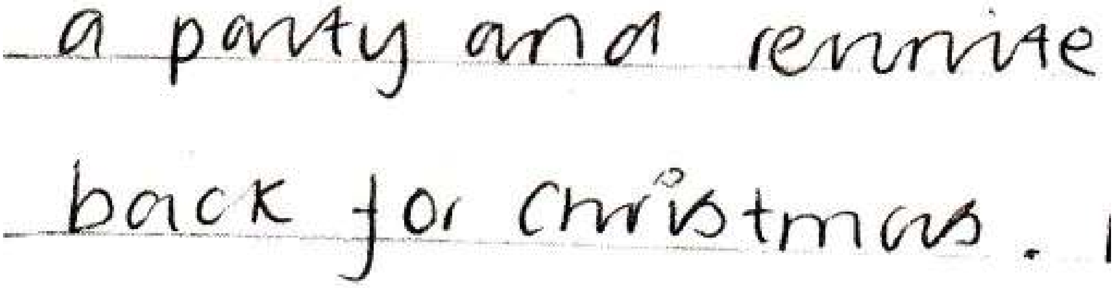


Figure 1.1c showing handwriting from a pupil in her mid-teenage years

within writer variability), having become highly automated and also to be more individualised compared to other writers (between writer variation). In contrast, the concentration and effort required to produce the (less automated) handwriting shown by Figure 1.1a might be reflected in greater within writer variability and, in the absence of major developmental changes, between writer variation is likely to be smaller. Given that handwriting production occurs in the context of acquiring other skills, the production of handwriting in the early stages of learning will be influenced by general cognitive and motor functions (Marr, Windsor, & Cermak, 2001).

The production of effective handwriting requires that both the cognitive and motor aspects are functioning. However, it may not be the case that the two develop in harmony; a child may know what they want to write, but not have the motor skills to move the pen over the paper well or vice versa.

The developmental changes in the linguistic capability of the child (including matters such as composition, grammar and spelling) might not therefore run in parallel with the improvements in the manipulation of the writing implement (involving letter formation leading to rapid, small movements of the musculo-skeletal system of the arm, wrist, hand and fingers). The cognitive and motor skills will not only be developing in the context of handwriting production, they will also be developing in other related contexts such as speaking and reading (Dunsmuir & Blatchford, 2004). These developmental processes may not be linear but rather may involve periods of practice and improvement (less stable) followed by a degree of competence (more stable), a sequence that could be repeated if new elements are learned. This could apply to both the cognitive and to the motor components. The process of skill acquisition is discussed in more detail in Chapter 2.

It is possible, therefore, that the cognitive and motor components of handwriting may show periods of stability and periods of change independently of one another and at different times. It is likely that this will be reflected in the skill and individuality of the handwriting of a writer at a given time in his or her development.

The cognitive and motor components of handwriting are those which impinge directly upon the handwritten product (Graham & Weintraub, 1996), and it is likely that there will be an interaction between them in all children, causing their handwriting to develop in particular directions such that it becomes unique to them. These influences could include specific matters such as suggested methods of writing from teacher or family, or more general influences such as a desire to write neatly or pleasingly. The nature of these influences and the potential for complex interaction within the individual will be explored in Chapter 2 in more detail.

The process of handwriting development is one with which we are all familiar from our own experiences of being taught to write as young children, through a protracted series of changes leading to a style which we use throughout adulthood. However, the nature of the changes, their relative timings in the development of individuals and the influences of external factors have not been brought together in a comprehensive context aimed at understanding the overall individualising process. This research aims to provide an understanding of these processes and to relate them to a theoretical psychological framework that describes the learning of complex skills. There are many skills that we acquire and the ways in which we incorporate them into our portfolio of skills is of interest, not least because it may help us to make the most of them and to understand them.

Chapter 2 Introduction

2.1 General introduction

Learning the ability to write is regarded as being one of the most important skills that a young child can acquire in the early school years. An understanding of the development that occurs during and following the acquisition phase is of considerable interest to diverse groups of professionals including developmental psychologists (Grossberg & Paine, 2000), teachers (Graham, Harris, & Fink, 2000) and forensic handwriting experts (Ellen, 1993).

The primary motivation for this research was to understand the origins of individuality of handwriting as this has fundamental relevance in a forensic context as has been highlighted in Chapter 1. By understanding the changes in handwriting style, especially during school years, it will be possible for handwriting experts to have an insight into the many different factors that impinge upon it in each individual and which then lead towards the proposition that the handwriting of individuals can be regarded as unique and therefore potentially identifiable. This will not only be reflected in the features that are used, but also in the variability of handwriting between writers, variability within writers at a given time and variability in those same writers over longer periods of time, as their handwriting develops.

Before moving on to consider theoretical and practical considerations that are involved in handwriting production, some of the factors that form precursors to handwriting will be reviewed.

2.2 Precursors of handwriting

Given the opportunity, young children like to make marks on paper with writing implements. The use of a writing/drawing implement begins in the young child when they can pick up and manipulate it in such a way as to make a mark on a substrate. The ability to make marks and their associated meanings, which in time come to be attributed to such marks, are the embryonic stages of drawing (Kellogg, 1969). Kellogg found that the early scribblings of young children can be de-constructed into a number of common elements which she calls The Basic Scribbles. They consist of various orientations of lines, circular movements, zigzags and other similar movements.

Vertical, horizontal, diagonal and circular pen movements that are found in handwriting are to be found in the drawing scribbles defined by Kellogg. It would seem likely that the capability to move the writing implement, learned in the domain of scribbling and later in drawing, can be transferred to the more controlled and prescribed requirements of letter construction at the time when handwriting is initially taught (Kellogg, 1969).

Brenneman, Massey, Machado, & Gelman, (1996) showed that children as young as three years old have separate notions about what constitutes a drawing and what is required for writing words. In a study of forty eight children, they found that drawings produced enclosed, non-linear notations whereas when 'writing' the notation took on a linear dimension usually in a left-to-right direction (although this is likely to reflect cultural differences in writing conventions) together with a fragmentation of characters suggestive of individual words. This effect was often present at three years of age and was almost universal by five years of age. The production of drawings and writing was videotaped and the explanations given by the children about their actions were recorded. From this, the authors found that children had much more to say about the appearance of their drawings than about the corresponding written 'words'. Even children that denied an ability to write and/or draw produced notational products that were different between writing and drawing. This suggests that the children have an implicit understanding of the difference between the two forms of notation, an early stage of development in terms of Karmiloff-Smith's theory of representational redescription (Karmiloff-Smith, 1992) (see section 2.3 below).

One thing that is striking about the process of learning to draw is the use of repeated sets of movements by the child to replicate in a formulaic manner frequently drawn images (Kellogg, 1969). Rather than re-invent a new series of pen strokes to draw a house or a face, the young child first learns a sequence of strokes needed to produce a satisfactory image and then uses the same set of movements each time they draw that item. As Hollis & Low, (2005) report, this rigid sequence is not readily modified by exposure to sequence changes in young (6 years old) children, but is in older children (9 years old). Of course, because of the inherent complexity of the motor and cognitive elements involved in drawing, no two drawings are identical; instead, they will show variation from one to another. Rueckriegel, et al. (2008) showed that the automaticity of both drawing and writing movements increased as children got older. Automaticity was measured by the number of changes of velocity in pen strokes as measured using a digitising tablet. Speed and writing pressure were also significantly correlated with age. This provides evidence for a maturational process in the motor components of both handwriting and drawing.

The idea that the ability to draw and the ability to write are connected has been widely investigated. Those who are proficient at drawing are also likely to be proficient at producing handwriting as found by Bonoti, Vlachos and Metallidou (2005) who showed a correlation between handwriting and drawing skills in 182 children aged 8-12 years old, scoring handwriting in terms of placement, conforming to taught styles and size and scoring drawings, such as a man or a house, to set descriptors of how they were drawn. Given the parallels between the cognitive components (deciding what to draw or deciding the form of letters to be handwritten) and the similarity of fine movements needed (involving the neuro-musculature of the arm, wrist, hand and fingers (Summers, 2001)), this relationship is not particularly surprising, although the idea formulation stage is obviously very different.

These earliest experiences with the manipulation of writing implements and their use to produce marks on paper eventually leads on to the more structured areas of handwriting production and drawing which combine in the study of graphonomics (Meulenbroek & Van Gemmert, 2003). Early attempts to produce functional drawing and handwriting may, to some extent, be influenced by early experiences in scribbling and the practice gained, but they are also likely to be determined by the intrinsic capabilities of the child to produce fine, coordinated movements (Sassoon, 1983). In other words, being an active scribbler does not necessarily lead on to being better able to produce handwriting in the controlled and conventional environment of letter production.

For many children, the first word with which they become familiar as a written word and which they may write is their own name. Much research has been done to show the significance of this in gaining an interest from young children as young as two or three years of age. For example, Levin, Both-De Vries, Aram, & Bus, (2005) showed that from two years old to at least five years old, children were more able to write their own names than other words. The "handwriting" was scored on a scale that considered how similar it was to conventional handwriting in terms of structure and appearance, ranging from formless scribble on the one hand to conventional handwriting on the other hand with various intermediates reflecting complexity and appropriate forms in between. The authors suggest that the special attention given to their own name by children may also be due to those caring for them focussing on the name as a starting point for writing instruction.

Arising from these precursor skills, teachers like to be able to assess the degree to which young children have sufficient competence to commence the formal teaching of handwriting. A variety of methods are used and have been summarised by various authors (for example (van Hartingsveldt, de Groot, Aarts, & Nijhuis-van der Sanden, 2011)) and the measures used are considered in more detail in Chapter 3 as some constitute methods of measuring handwriting.

It has been shown that a variety of factors impact on the pre-writing and first steps in acquiring the skill of handwriting. These early pre-handwriting experiences will now be put into the more general context of developmental models of skill acquisition in children which is considered in the next section.

2.3 Skill acquisition

The development of the mind is a major area of debate within cognitive psychology. An aspect of this that is of particular concern here is skill development and a number of theories have been put forward to explain how this occurs.

One theory that sets out to explain how development occurs is that of Fodor which makes particular reference to the neurological basis of skill acquisition (Fodor, 1983). This embraces the idea that specific areas of the mind are pre-destined by virtue of their neurological connections (receiving inputs and outputs in pre-determined ways) to carry out particular processing functions. For example, the domain of movement in the context of handwriting would have specific processing areas which would show up on brain scans (Siebner, Limmer, Peinemann, & Drzezga, 2001). According to Fodor, the more prescribed the connections, the greater the likelihood of automaticity being achieved because other potentially competing inputs are kept out. Automaticity is also helped if the processes are bottom up with little higher cognitive impact. In terms of handwriting production, this would make some sense inasmuch as the fluency of execution is reduced when, for example, someone attempts to wilfully change (disguise) their handwriting. This is because disguise of handwriting involves two elements namely an understanding and awareness of one’s own handwriting features and their (forensic) significance and secondly the ability to suppress these features and adopt another set of features (Ellen, 1993).

The models of handwriting production which describe the steps from idea creation to neuromuscular twitches moving the writing implement (which are considered in more detail in section 2.5 below), however, are top down models in which the passage of information cascades down from the high level cognitive to the peripheral motor levels of finger and wrist movement. The point in these models at which cognitive information is transferred to motor information is generally considered to be at the grapheme level which describes the letter shape about to be executed, taking account of whether it is upper case or lower case and the particular letterform that the writer uses at the time (Van Galen, 1991). Automaticity (as measured by the number of changes of velocity in pen strokes) increases significantly with age in children (Rueckriegel, et al. 2008). Greater automaticity will free up working memory (discussed below) for the cognitive components of handwriting production. From this, it could be inferred that this point of transfer is not yet so 'hard-wired' and that the greater levels of automaticity in older writers is indicative of greater hard-wiring. That is, a more dedicated (selected) series of neurological connections are used when triggered by appropriate cognitive outputs in more fluent writers.

A model that offers a general framework to explain how development occurs is put forward by Siegler (1989) who proposes that cognitive developmental mechanisms are available that enable a child to process information more efficiently. Siegler proposes that there is a suite of mechanisms that can be called upon to enable developmental processes to occur. Amongst these are neural mechanisms which are physiological in origin and can be considered as developments of the connectedness of the brain's circuitry with an initial over-connectedness and a subsequent pruning back of connections based upon experience and use. In other words, the initial neurological over-complexity of the brain circuitry is reduced to a more refined connectedness that is a reflection of those connections that have proved useful – retention of the most effective connections in neurological terms. This model supports the proposition that handwriting variability may initially increase and then, with experience, the variability reduces with the most effective, relevant and habitually used connections surviving, enabling handwriting production to be more automatic.

Such neurologically-based concepts are employed by connectionist models of development and they have been used, for example, by Grossberg & Paine (2000) in their work on connectionist models of handwriting generation. One of the aims of such models is to gain an understanding of the ways in which complex movements (be they tried as a result of imitation or novel movements generated by the writer) become smooth and automated as a result of predictive behaviour with finely integrated movements of the wrist, hand and fingers. Such models can relate their function to the relevant neurological structures of the brain such as the cerebellum (Grossberg & Paine, 2000) where the neural connectivity for retained movements will predominate.

In real world handwriting terms, such models make sense in that those movements that have the desired outcome would be retained and those that do not have desired outcome are lost (or if not 'lost' then at least demoted but perhaps still available). The implications for change of handwriting style are relevant in that the notion of desired outcome may itself change, either consciously or not, and this would become a force for change in the appearance of the handwriting. Some circuitry that used to work may need to be overwritten or replaced by new connections that give the new desired outcome, such as a change in shape of certain letters. From this it would be expected that the variability of handwriting would increase during such periods of neurological change (instability) and decrease again as the preferred (retained) connections became established and habituated.

A theory concerning the process of skill acquisition was put forward by Karmiloff-Smith (1992) but in this instance the focus is less on the neurological and more on a description of the cognitive processes that occur. It has at its core the ideas that information within the mind becomes available to the mind for further manipulation via a process of implicit to explicit representations in the child's mind. Initial attempts to acquire a skill involve repeated practice until the skill becomes more automated (as the brain acquires and interprets and reinterprets information). This process is described as representational redescription (RR) (Karmiloff-Smith, 1992). Increasing automaticity is equated with a reduced cognitive input and greater fluency of motor output, leading to a mastery of the skill that is reflected also in a diminution of the variability of the output. Mastery is not the endpoint of the development of that skill; rather it is the beginning of a new level of potential change in which the learned skill can be manipulated wilfully (hence the skill has become available to the mind). The progress of the skill to the higher level involving redescription is therefore based on a period of sustained positive feedback. In other words, if a procedure works and works again and is found to be satisfactory, then it is reinforced to the point where it becomes the norm and can then potentially be analysed as it becomes established.

Handwriting involves the execution of sequences of co-ordinated movements. How might these map onto the kinds of considerations put forward by Karmiloff-Smith? The analogy between learning handwriting and one of the examples that Karmiloff-Smith uses to describe her hypothesis (learning to play a particular tune on the piano) seems to be an apposite one inasmuch as the skills are composed of sub-routines. Individual strokes of letters might equate to notes, whole letters to chords, and words and sentences to tunes. Interestingly, Karmiloff-Smith then goes on to describe jazz-like improvisation in which the mastered musical skill becomes plastic, amenable to conscious change. An analogy with handwriting would suggest that it becomes available to subsequent manipulation by the writer once it has been (at least partially) learned. In reality, this would indicate a move away from the original learned style of handwriting towards some other form and this change would probably lead to an increase in the variability of output (just as jazz improvisations are likely to vary from one to another). The individualisation of handwriting might then be regarded as involving a similar process to that of improvisation in jazz, namely the learning of the 'base' skill and its subsequent wilful manipulation to yield a related, but nevertheless different, skill. Taking this one step further, it is generally considered that jazz performers have a style of playing (Rentfrow, Goldberg, & Levitin, 2011) and this may be equivalent, in a sense, to the writer adopting their own style of handwriting

Another element of RR is that practice leads to greater automaticity that then requires a reduced conscious input and as a result performers need to think less about how to perform the skill as they get more proficient, but will then also be able to consciously manipulate the skill. The impact of this on the output is difficult to predict as it depends on whether or not manipulation is occurring. If it is, then the likely result will be an increase in variability of the output. However, just because a skill has become highly learned and can be articulated does not mean that in reality output will thenceforth be ever-changing, especially if the skill is usually executed in a highly automated way, as handwriting is. On the contrary, the greater the degree of automaticity, the smaller the variability of output (Rueckriegel, et al. 2008). There is therefore a potential tension between greater automaticity giving reduced variability and greater explicit knowledge giving the possibility of increased (wilful) variability. This reflects the situation in handwriting production in which the production will usually be automatic but, when needed, handwriting production can come under wilful control, for example when attempting to disguise handwriting. In such circumstances, the disguised handwritten product will deviate from the norm (Ellen, 1993).

Skills are capable of being de-constructed into their component elements. This may involve a complex sequence of movements of the body, for example when executing a tennis serve. These individual elements may require practice on their own before they can be incorporated into the sequence, a process which itself may require further practice. Thus, Karmiloff-Smith's theory leads to the notion that the learning of a sequence of co-ordinated skills is processed as a series of segments during the phases before mastery which are integrated into a whole for the complete task to be carried out. In such a situation, it is difficult to start in the middle of the sequence of co-ordinated sub-routines successfully since the sequence is learned in the context of the routines which precede and follow it. By way of example, she describes the inability to commence a yet to be mastered piano tune at some midpoint. An analogy in handwriting might be the writing of a signature which is difficult to pick up part way through.

At a general level, the RR approach is potentially an interesting one to consider in relation to handwriting style development as it contains elements that can be mapped onto it. For example, the idea of the learning being initially very formal and prescribed would equate to the initial taught elements of letter formation. The value of practice in improving the skill, but not changing it until some sort of mastery is acquired, would be similar to the general improvement in handwriting skill in young children which is then followed by a period of change as the skill is adapted by the individual.

Evidence both for and against RR has been put forward in the literature. Karmiloff-Smith makes it clear that this developmental change is associated with emergent modularisation of function in the brain and that modularisation is a result of development. She states this is perhaps the most important idea in her theory (KarmiloffSmith, 1997). This emergent quality of modularisation is the focus for some criticism of her model based on the view that modules may precede experience (such as elements of language) (Bonatti, 1997). The functional modules do not necessarily equate to specific areas of the brain in her theory. Rather the plastic nature of brain interconnections is such that the functional modules cause the neurological modules to emerge. This fundamental debate as to the extent of structural and functional modularisation of the brain and the mechanisms by which it comes to exist, be it intrinsic to the brain architecture or whether it emerges over time and with experience, is a major issue in psychology. Whilst the debate is relevant to theories which describe skill learning, its relevance to this particular research, which is focussed on the practical question of handwriting acquisition and its variability over time, is more marginal.

Another aspect of the model is that in the early stages of learning formulaic procedures are inflexible and Karmiloff-Smith cites the rigid drawing patterns in young children in support of this (Karmiloff-Smith, 1992). However, her findings in this domain are contradicted by, amongst others, Spensley (1997) and Spensley & Taylor (1999) who found that firstly drawings of objects, such as a person, are neither rigidly composed of compiled sequences of sub-components (first head, then face, body, arms and so on) nor are they impervious to interruption – an 'accidental' break in concentration did not require a resumption of the drawing from the start. Both of these findings contradict Karmiloff-Smith's theory. However, Karmiloff-Smith took issue with some of the criticisms, pointing out some procedural experimental differences and that the general conclusions drawn by Spensley were more in keeping with a model based on short term memory use rather than representational redescription (Karmiloff-Smith, 1999).

Support for the concepts in Karmiloff-Smith's model of skill acquisition comes from a number of psychological learning domains. The most relevant to this research is the work of Hollis and Low (2005) who examined the drawing abilities of children of various ages. In particular, they studied the rigidity of the drawing sequence (of a person or a house) used by children when challenged to change the drawing (for example a different form of human). Younger children (6 years old) found it more difficult to incorporate nonstandard elements into their pictures than did older children (9 years old). Further, the experience of doing this was of short-lived value to the younger children who would rapidly revert to their fixed sequence of drawing elements whereas older children were more flexible in the use of their experience. In other words, one can show younger children that changes to the pattern of their execution are possible, but they do not incorporate such changes readily whereas older children do.

Pine & Messer (2003) take the RR model and add further sub-levels of development, based on a series of experiments in which children's understanding of balancing objects about a fulcrum are explored. Balancing is a useful concept to examine as children may be able to balance objects without being able to understand why they can do so. For Karmiloff-Smith, the child that is able to balance objects is in the early (implicit) stage of development which can, with positive feedback, become recognised and understood and made explicit. In their experiment, Pine and Messer explored the abilities of 25 children aged about 6 years old over just five days to make predictions about whether balancing would occur or not (using pictures) or to make beams with different asymmetries and symmetries balance and to articulate to the experimenter why they made their decisions. These explanations were categorised in terms of the levels used by Karmiloff-Smith (1992) ranging from implicit to explicit and with degrees of understanding. The authors found that there was little evidence of regression (once a higher level of understanding had been attained it was retained) and that there was little difference in the ability of children to balance objects between those showing only implicit understanding and those showing a more explicit understanding. The authors consider that their findings provide evidence in support of Karmiloff-Smith's redescription model.

Dixon & Kelley, 2007 carried out a review of the theory of RR in a number of areas of knowledge acquisition and concluded that the process of representational redescription enables learners to utilise previously learned information when confronted with a similar but new situation, building on retained, successful strategies. From this framework, the child proposes a likely relationship with the situation or objects and tests it against the expectations. Critten, Pine, & Steffler, (2007) used the model in the context of children learning to spell when identifying the strategies they used to deal with regularly and irregularly spelt words. They found that children did go through a number of developmental stages starting with alphabetic and phonological cues and advancing to more advanced strategies.

2.3.1 Implications for this research

Notwithstanding the arguments for and against RR, there are some points at which it would appear to map onto the development of handwriting style in children. In terms of this thesis, it is proposed that any learning process involves data acquisition by the child when first learning the task. In handwriting, this data consists of the cognitive components of the letters to be formed such as shape and structure and the necessary sequence of pen movements required and the motor components that execute the planned movements (Karlsdottir, 1996). The intended outcome as far as the child is concerned will coincide with their understanding of what the relevant letter forms should be which in turn will, in the earliest stages, be dictated largely by what they are being instructed to do and how they interpret those instructions. The ability of children to reproduce letterforms that are what they intend will be constrained by their manual dexterity. Hence two children exposed to the same teaching regime will produce handwriting of differing appearance based on their internalisation of what is required and their ability to reproduce their intentions on paper.

The prolonged time period during which handwriting develops (typically a decade or more) ensures that there is considerable opportunity for a variety of factors to impact upon the taught style of handwriting and these are discussed below in section 2.8.

The findings of Hollis & Low, (2005) suggest that in the domain of handwriting acquisition, even if young children are aware of alternative letterforms, they will not be able to incorporate them into their own handwriting until significant representational redescription has occurred which will then better enable them to manipulate their handwriting style. It is likely that drawing and handwriting capabilities are related (Bonoti et al., 2005), and the ages that Hollis and Low find associated with increased representational redescription (between 6 and 9 years old) might be expected to be similar to those that occur in handwriting acquisition.

The learning curve of a skill can be considered to be represented in the change in quality of the output measured over time. The improvement of a skill can be measured in various ways, depending on the skill being considered and the component of that skill that is the focus of interest. For handwriting, parameters such as speed of writing, size of letter forms, closeness to a baseline and so on can all potentially be used to measure the skilfulness of the writer. These parameters will be explored in more detail in Chapter 3 in which methods of assessing handwriting are described.

The learning curve for handwriting acquisition could simply be a linear one showing a gradual improvement in a skill over time although it would need to plateau eventually once the skill had been fully mastered to the point where further improvement was not occurring. A second possibility would be that the slope of the learning curve may vary as the rate of improvement changes over time. For example, the initial rate of change may be slow but this may accelerate on one or more occasions depending perhaps on transitions from one developmental stage to another.

The models which include the notion of an initial phase of learning followed by scope for change and then refinement to a preferred version would suggest that the learning curve would form an inverted-U shape and this is the shape of the learning curve suggested by Karmiloff-Smith (Karmiloff-Smith, 1992) with an upslope phase caused by any mismatch between internal (cognitive) and external (the handwritten product) representations and a down slope phase being attributable to the resolution of those conflicts leading to more automated handwriting requiring much less feedback to ensure its correct execution.

2.4 Models of writing

The production of writing and the integration of the components that it requires form the basis of an influential model by Flower and Hayes (Gregg, L.W. and Steinberg, E.R., 1980, Chapter 1). Hayes subsequently elaborated the model (Levy & Ransdell, 1996, Chapter 1). In the original model the writer's long term memory components (such as knowledge and general writing plans) were combined with the particular writing task to plan and organize the text. This was then transcribed into text which could be reviewed and edited. In the revised model, the focus shifts towards the external components of the task (such as the audience for whom the task is done and the physical environment in which the text is generated) and the individual writer with interactions of working memory, cognitive processes and motivational factors all of which are interacting with longer term memory elements. The inclusion of motivational factors in the revised model is of interest not only because it reflects on the amount of effort a writer will put into what is written, it is also reasonable to consider that it will impact on the appearance of what they produce, in other words the style of the handwriting.

This model of writing describes the process as it occurs in skilled, adult writers and not in children in the stages of acquiring the component skills. The process of writing in children, particularly in the context of schoolwork, may not need to be as sophisticated as that described by Hayes and Flower. For example, a number of authors have used the concept of knowledge telling as a description of what children are doing when relating information to their teacher in written work (McCutchen, 2000). This is seen as an adaptive response in children who have other processing demands centred on, for example, the production of handwriting itself and is further seen to be a relatively natural process in that it retells what is known without necessarily adding any cognitive insight. It is a contrast to more problematic writing which has been called knowledge transforming (Bereiter & Scardamalia, 1987) in which the writer adds layers of higher quality content adding value to the bare bones of the narrative.

The development of the knowledge telling to the knowledge transforming stages can be seen, therefore, to be of relevance to this research inasmuch as these cognitive elements impact upon the act of handwriting via the processing demands that are made by them. Further, the development of writing, linguistic and organisational skills may not necessarily occur in tandem one with another or with the motor skills needed for effective handwriting.

The resource within which these functions are carried out is working memory which is considered to be a mechanism for storing and processing information in the short term and thus provides an interface between incoming perceptual inputs, outgoing actions and longer term memory processes (Baddeley, 2003). In Baddeley's model of working memory, one element is what is called the phonological loop which is concerned with holding sounds in the working memory. A second component, which Baddeley calls the visual/spatial sketchpad, is available for visual and spatial information. In addition to being a store for information, working memory also has a processing capability and therefore there is an output from it. Whilst its anatomical correlates will vary depending on the modalities involved (sound and visual), the concept of working memory is one that implies a limitation as to what can be stored and processed successfully at any given time.

Kellogg in Levy & Ransdell's book, (1996, Chapter 3) uses Baddeley's model of working memory in his model of writing. This writing model has three stages, namely formulation, execution and monitoring, with the output from formulation (translating) being the input for the execution stage, and the output from the execution stage being monitored via reading and editing. Planning and translating consists of sub-processes such as goal setting, semantics, syntactic and phonological processes. The execution stage takes the output from the formulations stage and programmes it into a form that is available to output systems such as handwriting or typing. The monitoring stage uses sub-processes such as reading, comprehension, spelling and so on. All of these processes make demands upon the working memory and, depending on their extent at any time, will be constrained by the capacity of working memory. The less that the execution stage has to call on the working memory resource, the more it is free to take on tasks elsewhere in the creative process. The greater handwriting automaticity can be achieved, the more attention can be given to what is being written, and hence there is a premium on efficiently produced handwriting that requires minimal working memory capacity to execute.

The role of working memory in adult writing has been studied by a number of writers (for example, (Ericsson & Kintsch, 1995), (McCutchen, 2000) and (Olive, 2004)). Swanson & Berninger (1996) looked at this in children and found that working memory was a predictor of writing skill derived from results using a complex model into which various aspects related to writing, such as reading ability, are factored. The suggestion is that the more the planning stages tend to fill up the working memory capacity, the less scope there is for planning the necessary output functions such as handwriting. One explanation for their findings is that the capacity of working memory is not the only consideration, but it is also the way in which it is used. Hence, children may vary in the way that they utilise their working memory which in turn may reflect other skills such as reading ability, which can impact on the resource available for the transcription and handwriting processes.

The potential relevance of working memory considerations to this research is that variation in writing (as opposed to handwriting) in children is due to individual differences in working memory capacity and use and the related strategies that are available to use these resources. The impact of this on handwriting itself then depends on how much remaining memory capacity is available to effect execution of the handwriting. This would imply that different handwriting tasks (such as composing text versus copying text), requiring different demands on working memory, may cause the handwriting itself to vary in some way, particularly in the absence of automaticity. For example, the dynamics (such as speed and evenness) of the handwriting or in terms of letterforms used may vary depending on task.

The connections between general constraints, such as length of text, formal/informal context, awareness of audience needs and so on with more conventional linguistic constraints and the precise issues of spelling and word order are complex enough for experienced writers, but for young children the cognitive burden is not only great, but indeed many of the rules of text production may not be learned until some years after the skill of handwriting production has been learned (Bereiter & Scardamalia, 1987). Nonetheless, the cognitive strain on a young child to produce the high level material for text production will be added to by lower level matters such as spelling and grapheme production. In young children, handwriting production has both a phonological element (the sound of the words) and an orthographic element (the shapes of the language symbols – letters) (Stage & Wagner, 1992). Stage suggests that a young child's ability to spell may be constrained by both linguistic and working memory limitations based on the kinds of errors that such participants make in letter identification.

2.4.1 Implications for this research

The models of writing, with their emphasis on the role of working memory, show that the capacity of and the ability to utilise working memory can impact upon a child's capability to transcribe their thoughts into handwriting. The more that the working memory is loaded with higher level cognitive matters the less capacity there is to process this into an effective motor output and this in turn could potentially produce handwriting of a more unpredictable (more variable) appearance. However, children will be developing various strategies for efficiently using their limited working memory resources as they get older such that the transcription stage will ideally become more automated, freeing up capacity for the higher level processes. This will lead towards the ideal end point at which the mechanics of handwriting production require the minimum amount of attention resource. But the path to this end point may be far from smooth if the demands placed upon the high level cognitive elements become greater, for example due to use of more complex language, or if the motor element changes under pressure from various external factors which are considered in section 2.8 below.

As a result of these considerations, different types of handwriting task may impact on the working memory of the child leading to changes either in the letterforms themselves or to changes in the consistency with which they are written.

2.5 Models of handwriting

The process of handwriting production (as opposed to the developmental processes of acquiring the skill over a prolonged time period) is usually conceived of as a linear and modular process with high level ideas passed on down towards the peripheral motor output, with certain brain regions being responsible for the different components of the process (Van Galen, 1991). Supporting evidence for the modularisation of handwriting comes from the medical literature in which patients with localised brain lesions are reported to have selective loss of handwriting function or dysgraphias. Some of these cases also involve associated linguistic loss. For example, Kartsounis (1992) reports a case of a 67 year old man who, following an accident at work, presented with a loss of the ability to write in lower case letters but retained the ability to write using capital letters. Other dysfunctions at various levels of language and text generation are described by Ellis (1988) including letter substitutions (such as confusing a K with an H), mirror writing and micrographia (in Parkinsonian patients).

Various models of handwriting production have been developed along these lines (for example (Van Galen, 1991) and (Ellis, 1988)). Ellis describes a model that concentrates on the parts of the sequence that take the higher level conceptual information and from this initiates and effects the required movements. The transfer from the conceptual to the motor domain is considered to be at the point of the grapheme, the representation of the letter(s) that are the appropriate equivalent of their associated phoneme (a unit of sound which is a sub-component of the syllable/word) – given the spelling required for the word in question. The information from the grapheme level is passed on to the allograph level, at which the required shape of the letter is determined: for example, the choice of a letter of the appropriate upper case at the beginning of a sentence. Once the letter shape (or allograph) has been decided upon, the final step is to move the appropriate muscles and joints of the hand, wrist and fingers in a time-coordinated sequence to move the pen over the paper to produce the trace of that shape.

This process describing the production of handwriting points to the origins of its complexity. It is not surprising that the interaction between the internal representations of the allographs (and the linguistic content in which they are embedded) and the automation of the motor sequences needed to move the pen over the paper to execute the appropriate movements is complex. For this reason, mastery of the skill in the sense put forward by Karmiloff-Smith (Karmiloff-Smith, 1992) may be a relative term. In other words, some basic elements of handwriting can be learned, but the cognitive components (particularly at the grapheme level which determines letterform) can subsequently be modified either wilfully or because of other influences (such as writing quickly) leading to a requirement for further effort to perfect the modified skill (see also section 2.8 below).

Hence, one would not learn to write a letter k (in the sense of achieving some acceptable version of it) and then (and only then) modify it either wilfully or as a result of some external influence, such as writing more quickly. Rather, the basic form of the letter might be learned (if not necessarily 'perfected') and this might be subjected to any number of influences at various times during the ongoing development leading to changes of its form on any number of occasions. This would be demonstrable by changes in its variation over time.

The impact of this on the variability of the style of handwriting will be complex and will vary from child to child. According to Rueckriegel et al (2008), initial attempts to learn to write will be practised which will result in a kinematic improvement of the skill. Their research was carried out on 187 participants of various ages ranging from 6 to 18 and involved various parameters of stroke production, including velocity and pressure, measured using a digitising pad. The authors found a significant correlation between the age of the participants and four kinematic parameters of their handwriting – namely, speed of writing, automation, movement variability and pressure. Changes in the appearance of the handwriting cannot be inferred from these kinematic factors alone, but the findings do support the overall proposition that handwriting becomes more automated and that this is associated with an increase in speed of movement and a decrease in the variability of movement. The increase in speed is continuous and marked from the age of 6 to 16 and then slows whereas the automation markedly decreases with age. The variability of kinematic output gently decreases from 6 to about 14 years old. If the cognitive component is unchanged, then increased speed and decreased kinematic variability would be expected to lead to a decrease in the variability of the appearance of the handwriting. The effect of these kinematic changes in isolation on the style and its variability of handwriting is difficult to predict since speeding up could lead to either greater variability of appearance or it could be indicative of a tighter control of output (reduced variability of output).

The planning for the sequence of letter structures is based upon the generation of the correct letter order for a given word. This in turn is probably based on the recall of appropriate syllable structure for the word (within the constraints of a syllabic language such as English). Kandel, Álvarez, & Vallée, (2006) found that syllable structure constrained motor production in writing, with inter-syllable boundaries being associated with a slowing down of pen movement. This suggests that at this level, the syllable (a unit based on the sound of the word) may play a part in the ultimate dynamic of the writing process. If the syllable translates into a 'unit' of handwriting content, then the linguistic capabilities of children will impinge upon their handwriting ability as relationships are made between the creation of content for handwriting and the other linguistic modes of speech, listening and reading. In turn, the associated combinations of letters for syllables, particularly those that occur more frequently, might become learned as combinations of letters rather than as a sequence of individual letters, a suggestion that was made in Chapter 1 when comparing the handwriting from a young child and a skilful adolescent and considering the contextual aspect of letter formation and recognition. This would suggest that the variability of the output might be greater for less familiar syllables than for the more regularly encountered ones. The effect of this on this research is to ensure that any text that is to be written by the participants should consist of familiar words to ensure that the writers are not distracted by unfamiliar spellings and letter groups. The text used in copying tasks in the cross-sectional study in Chapter 5 complied with this, confirmed by experienced teaching staff.

Having considered models of handwriting production, the development of handwriting in children will now be considered.

2.6 The development of handwriting in children

A number of general aspects of development in younger children's handwriting have been studied including legibility, speed and size (Blote & Hamstra-Bletz, 1991; Graham, Weintraub, & Berninger, 1998; Rueckriegel et al. 2008). Handwriting speed and legibility in children aged 6 to 15 was studied and it was found to increase year on year although the rate of increase varied with, for example, those aged 6-10 improving more rapidly than those in the next few years (Graham, Weintraub, & Berninger, 1998). Graham also found that legibility generally improved with age but that again the rate of change was not even, with little improvement in the younger years and greater improvements in later years. Handwriting size tends to start larger in those learning to write, decreases in size over the next few years and thereafter some children start to write larger again (Blote & Hamstra-Bletz, 1991).

The various components of handwriting that the young child learns are, with practice over time and in the context of general developmental improvements, likely to change and become more efficient. In particular, the speed of handwriting, the size of the handwriting, the legibility of the handwriting and the associated construction of the writing may change over time. For example, as they get older, children tend to write faster. This has been substantiated in a number of studies. For example Blote & Hamstra-Bletz (1991) found that in normal writing conditions (with no instruction to attempt to write quickly) 7-8 year olds write about 24 letters per minute (lpm), 9-10 year olds write 46 lpm and 11-12 year olds write 66 lpm. Indeed, the findings of Chartrel & Vintner (2008) suggest that encouraging children to write more quickly and as accurately as possible may assist in the learning process as it pushes the child towards automaticity. Writing more quickly is likely to be one of the consequences of the increasing academic pressures that are placed upon children as they go through school life. It is likely that the increase in speed will lead to some changes in letter formation as accuracy and execution are compromised in the need for speed. This has the potential to cause between writer variation as the increase in speed is accommodated by writers differently and also may show developmental variation in the handwriting from individuals as they strive to write more quickly. The relevance to this research is that in the cross-sectional study reported in Chapter 5, participants are asked to write either neatly or quickly to execute copying tasks and the ability to write quickly and legibly are age-related. Hence, younger children might be expected to have greater difficulty in producing legible handwriting at speed which may lead to increased variability in its formation.

Developmental processes of handwriting change in older children attract relatively little attention in the literature (Weintraub, Drory-Asayag, Dekel, Jokobovits, & Parush, 2007). One of the reasons why handwriting attracts little attention in the later phases of development is that handwriting ability is no longer perceived as being a constraining factor on learning for most children and older children are thought to be less amenable to instruction in the case of any dysfunction. This may be a short-sighted view, however, as later academic performance may indeed be influenced by the ability to execute handwriting efficiently (Summers & Catarre, 2003).

Berninger, Mizokawa, & Bragg, (1991) suggest that the constraints on handwriting production change over time. In the youngest children, during the learning stages of handwriting acquisition, it is likely to be the immaturity of neurodevelopment that imposes the greater constraints. As the child gets older, the motor development will normally improve to the point where automaticity in handwriting production is usually achieved (or at least is achievable) but linguistic constraints (relating to word use, sentence structure and so on) then tend to become the greater issue and once these have been mastered, more general cognitive constraints (such as planning and revising) may interfere with handwriting production. This conceptualisation of handwriting production requiring a series of nested skills requiring mastery and it is used in further research reported by Berninger and helps to explain the complex modelling of handwriting production that is described (for example (Berninger et al., 2006)).

For the purposes of this research, the key point arising from this is that the motor maturation, linguistic and finally cognitive capabilities may impose restrictions on handwriting performance in children at different developmental stages. This is most usually considered in the context of handwriting performance rather than handwriting style. Unlike all other studies, the degree to which the formation of the handwriting (style) is constrained by motor, linguistic and cognitive constraints will be considered as a result of the findings in this research.

Graham and colleagues (Graham, Weintraub, Schafer, & Berninger, 1998) found that writers who rely solely on one writing format (joined up or script handwriting only) write less effectively (measured by speed and legibility) than do writers that adopt a mixed style. The degree to which such sub-strategies are adopted is likely to be developmentally relevant since they are more likely to occur in older, more skilful writers who are likely to have a greater capacity for using them. Greater flexibility of this kind will lead to greater variation in the handwriting (within writer and between writer) if the writer is finding sub-strategies for writing in different ways in slightly different contexts (such as dictated by letter order within a word (Van der Plaats & Van Galen, 1991).

General handwriting features affecting legibility, such as the smoothness of joins between letters, the evenness of the spacing between letters and words, consistency of size and evenness of alignment to the writing line all tend to improve with age (Hamstra-Bletz & Blote, 1990) and to that extent are likely to show less within writer variation. Such improvements are likely to be reflections of the general improvements in fine motor skills leading to greater automaticity of the writing process as children grow older. Since this research is focussed on the variability of letterforms and proportions in handwriting, the effect of greater consistency should be to reduce variability. However, this may be confounded if the writer's style of handwriting is changing as consistency would then decrease especially during any transitional phase between styles.

During the early stages of the acquisition process in particular, there is a tendency for some children to find learning some letter forms difficult. Graham, Berninger & Weintraub (2001) found that young children have more difficulty with a small group of letters in this respect with q and z being the worst. Whilst this may be related either to the infrequency with which these letters are written or to the writing movements involved, the effect is to create additional scope for within writer and between writer variations. For these reasons, the very infrequently encountered letters of the alphabet will not even be considered in this research.

Whilst the writing of an individual will be influenced by external factors and their own neurological capabilities, it is open to critical, reflective appraisal by the writer. This may be used as a means to help children improve their own writing (Jongmans, Linthorst-Bakker, Westenberg, & Smits-Engelsman, 2003). The authors proposed a method of self-instruction based on the reflection of writing performance after each writing exercise (considering factors such as sequence of pen moves and proportions), the purpose being to improve the planning element of the writing for the next exercise. They found that such methods did work, with self-instruction yielding improvements in handwriting quality in poor writers above that achieved by poor writers not receiving such instructions. This reflective capacity suggests that the handwriting skill is available to the mind of the individual for mental manipulation, as anticipated by the Karmiloff-Smith's theory of skill acquisition (Karmiloff-Smith, 1992). Individuals can reflect upon their handwriting and act upon those reflections leading to overall beneficial effects to the writer since they understand and internalise the lessons learned from those reflections. The nature of these reflections may be influenced by social aspects of the writers, such as their desire to please, to write neatly, or to write elegantly. Following these reflective processes, writers have the capacity to modify their handwriting to a certain degree to achieve particular aims (such as writing neatly or quickly). Such processes have the capacity to alter the appearance of a child's handwriting and these will be picked up by increasing variability in the handwriting during the periods in which they occur. They will also be constrained by the child's ability to control the fine movements of the fingers and hand and this aspect will be considered next.

2.7 Movement in handwriting

The models of handwriting production are thought to be reflections of the neurological processes that occur during handwriting production (Van Galen, 1991). The movements themselves when they occur are, in a skilled writer, rapid, complex and highly time-coordinated (Longstaff & Heath, 2003). The rapidity is such that it suggests that the movements are sequenced and held in readiness to be executed in a time-sequenced manner, with a series of overlapping discrete movements generating a smooth continual movement (Morasso, Ivaldi, & Ruggiero, 1983). The various pen strokes needed are written in a highly co-ordinated and rapid sequence. This is the situation in skilled writers. However, in children the dynamics of handwriting production are not so well established and go through a period of general improvement in most children (Rueckriegel, et al. 2008). Thus, a change to the pattern of movement brought about by a period of cognitive changes will tend to impede the overall trajectory of skill improvement and lead to greater within-writer variation in the handwriting during such periods.

Handwriting movements are constrained by the anatomy and neurological capability of the writer's arm, wrist, hand and finger movements as a result of which some pen movements are preferred to others as they are more readily executed (Meulenbroek & Thomassen, 1991). This finding will have implications for the way in which a child constructs letters because it would limit the scope for variation in the handwritten product with certain pen movements being preferred which in turn will affect letter shapes and possibly also proportions and structures.

Notwithstanding the constraints imposed by the anatomy of the writer, it is also possible that the cognitive components that younger children have for letter construction may be inappropriate causing them to make inefficient and even painful movements of their hand and fingers (Sassoon, 1990). This suggests that there is an interaction between ease of movement (tending to reduce between writer variation) and the use of various cognitive models of letter form (tending to increase between writer variation in letter form as a result of differing external influences).

Just as children use learned sequences of movement when drawing familiar objects such as a face or house (Cox, 1992), there may also be 'rules' that influence the production of biomechanically efficient writing (Thomassen, Meulenbroek, & Tibosch, 1991). For example, the letter K may be constructed in a number of ways (Eldridge, Nimmo-Smith, Wing, & Totty, 1984). Eldridge and colleagues describe variants of formation for the letter K (and indeed several other letters) in considerable detail. They found that certain forms were more frequently encountered than others. For example, 71% of the population wrote the letter using a single stroke and the remainder used two or more strokes. Whether this was because the more frequently occurring forms were biomechanically more efficient to produce or because they related to styles that are taught was not determined.

Van Sommers (Wann, Wing, & Sovik, 1991, Chapter 1) considers the implication of having a range of possible constructions available in terms of stroke planning in the context of stroke optimisation. In other words, given the desire to produce a letter K, is there a most efficient way of doing it? Even if there is, other factors can come into play, such as the desire to produce handwriting of a particular appearance, which may override the most efficient movements.

The use of appropriate skeleto-muscular movements is to some extent a response to the most distal aspects of the writing process, namely the interaction between the writing implement and the substrate (paper). The movements of the distal and proximal muscle sets involved in handwriting tend to become less variable as the efficiency of the handwriting process increases (Naider-Steinhart & Katz-Leurer, 2007). This supports the findings of Rueckriegel et al (2008) who found that a number of kinematic parameters, such as speed and automation, improved significantly with age. If the variability of the appearance of handwriting was determined purely from such motor considerations (and with no cognitive changes), then it should decrease in line with the decrease in kinematic variability.

There are considerations of force and friction and movement dynamics that dictate how the pen moves across the paper. Different pens may produce different forces; writing with a fountain pen may require the writer to adjust in comparison to how they write with a ballpoint pen (Wann, 1991). Wann found that all writers tested exert more pressure than is needed to create a visible trace on the paper. He found that exerted pen pressure tends to increase towards the end of a word and suggest that this is due to the writer's attention being drawn away from the writing process and towards a visual feedback check that the already written part of the word is acceptable. He found that tracing and copying produce increased pen pressure from the writer since again visual feedback plays an important role in these processes. In general, their findings suggest that the more the writer has to concentrate on the process of writing, the greater the pen pressure used. This is another, less obvious manifestation of the interaction between the cognitive and motor components of handwriting production. These observations are in keeping with the expectation that a handwriting expert would have, namely that when disguising one's own handwriting (a process that requires greater conscious thought), the pen pressure used will increase and variation in pen pressure will decrease due to more even pen velocity (Huber & Headrick, 1999, Chapter 11).

As has been noted, some pen movements are more readily made than others (Meulenbroek & Thomassen, 1991). However, similar movements may produce different outcomes, such as the letter pair e-l and the single letter d (A. M. Wing & Nimmo-Smith, 1987). The authors found that the context in which the movements were made affected the dynamics of the writing process. In other words, the kinetics of the pen movement when writing e-l are not the same as the dynamics when writing d, even though the pen path is similar in both instances. This suggests that there is an element of learned, anticipatory context-dependent production in the writing process, consistent with the syllabic element of word construction. Using the top down model for the generation of handwriting, if the cognitive part of the planning scheme differs (in this case the anticipation of writing the letter d or the letter pair el) this leads to differences in the motor planning and execution of the movements concerned. Hence, the learned movements for the pairing el (as part of one syllable) would be obviously different to that in a syllable containing the letter d.

The way in which the writing implement is held at the paper surface is the last link between the internal (biological) processes of handwriting production and its physical manifestation on the paper. Tseng (1998), for example, identifies over a dozen pencil grips in children in the 3-6 year old age range, although the number of grips used falls off with increased age as inappropriate grips are discarded by those who tried them. Nevertheless, some children will probably find particular grips more comfortable than others and this is likely to be in part determined by the suppleness of their finger and wrist joints (Summers, 2001). Other studies have shown that children select different grips for different tasks, for instance writing and block colouring (Schneck & Henderson, 1990). This suggests that there is a relation between grip and comfort to the writer and the grips that are more frequently encountered in older children (and which generally are used into adulthood) are preceded by other grips that young children use, perhaps experimentally, before they are rejected in favour of more practical, and in particular, more comfortable grips. Changes in pen grip are almost bound to lead to increased variation of the handwriting given the influence that changes on the fine motor movement this will have.

Aside from the way in which the writing implement is manipulated, the general body position and the ergonomic considerations of writing are relevant in that they may reflect both on the ease of writing and, in particular, on the comfort of writing for more prolonged periods. Rosenblum, Goldstand, & Parush (2006) found little evidence to link writing quality and legibility to body position or pen grip. These factors might be expected to impinge upon the motor aspects of handwriting. If a writer is writing in nonideal or non-familiar circumstances, there is also a likelihood that the need for increased cognitive input (to accommodate the factors concerned such as unfamiliar height of desk) could lead to greater variation in the handwriting produced, at least until such time as the writer becomes more accustomed to the changes. Learning to deal with such changes may itself be age-related in that finding coping strategies for change may lead to quicker and more effective ways of dealing with them.

The factors affecting movement in handwriting production can be linked to the models of skill acquisition that include the notion of emergent competence that varies both between people and that shows within writer variability too. Siegler's suggestion that there is a need to embrace variability in order to obtain an understanding of why differences occur (Siegler, 2002) is likely to lead to a richer understanding of developmental change, a view shared by Miller (2002) in a paper that reviews the potential gains to be had from studying the variability of cognitive processes. For example, Yan & Fischer (2002) suggest that careful, detailed examination of variation is not only desirable but crucial for illuminating the dynamic nature of learning and development. Their work, based in part on studying the learning of new computer routines, showed that performance did not show a simple ever-improving linearity, but rather got better and worse depending on various factors which may be a reflection of the task or the person or both – it showed variability both within and between participants.

A theory that is relevant to movement development is neuronal group selection theory which is based on the concept of initially complex neuronal structures being selectively kept and streamlined on the one hand or rejected (or at least not used if not forgotten) in the light of experience on the other hand. This theory has been used to understand the development of motor function where it is stated by some that typical motor development is characterised by variation (Hadders-Algra, 2010) and that this correlates with the neurological ontogeny of the brain. The detail of the latter processes is outside the scope of this research – suffice it to say that it involves various biochemical and neuro-anatomical changes and connections in the brain that occur under the influence of a multitude of different causes, involving both the creation and loss of connections.

Another theory of motor development is dynamic systems theory. Like neuronal selection, this theory is based in part on a non-linear development process, with periods of stability and transitional periods which may be caused by a variety of factors which can be external or internal to the child (Lockman & Thelen, 1993). Dynamic systems theory differs from neuronal selection largely in the relative contributions to motor development made by innate, pre-determined factors on the one hand and experience on the other (Hadders-Algra, 2010). Dynamic systems theory attempts to capture development not as a simplified linear process but rather tries to explain the complexity of development as caused by the range of variables and multiple levels of causation that impact upon it (Miller, 2002).

The relevance of these models to handwriting style is that they include notions of variability based on neuronal connectedness. Increased variability is brought about by explorative activity with the motor options being tried and tested. This is followed by a selection process in which motor patterns that do what is required are kept. Crucially, given the neuronal complexities involved, these exploratory and selective processes will be unique to each person (Hadders-Algra, 2010), albeit the notion of 'what is required' may itself change over time. The complexity of these neuronal processes allied with each person's unique experience shows that there is a great deal of scope for handwriting style to vary both within the handwriting of one person and between different people and that this understanding that variability will yield rich information about the handwriting process itself.

The description of the many internal factors that can impact on handwriting production and development given above and the prolonged period over which they influence handwriting gives considerable scope for external factors to also play their part in determining the appearance of the handwritten product and these external factors will be considered next.

2.8 External factors influencing handwriting production

Learning to write occurs in the complex day to day environment of the child and it would be surprising if some external factors did not impact on the learning process. Whilst the child's own intrinsic capabilities in terms of his control of fine movement of the hand, fingers and wrist together with his linguistic and cognitive capabilities will also play their parts, they can only do so under the influence of appropriate instruction and influence of others. Most children learn the majority of their handwriting skills in the classroom and this will be considered first. But also other social factors, such as the attitudes and encouragement to learn at home or from friends may also play a part and these will be considered too.

2.8.1 Influence of teaching

The teaching process is a complex one involving the interactions of individual teachers and children in the ever-changing dynamic of the classroom, working within the boundaries imposed by educational resources, local teaching policy and other regional and national polices (Sassoon, 1990). It is therefore difficult to describe in detail the teaching received by a particular child over the extended period of time during which he or she learns to write and virtually impossible to see the changes occurring and being incorporated into the developing handwriting style as they happen. There are general guidelines that form the basis for effective teaching of handwriting, although the existence of such guidelines does not, of course, imply their successful implementation in the case of a particular individual teacher or indeed pupil.

There are various approaches that can be made to the teaching of handwriting. These may revolve around the particular detailed letter formations advocated, the supporting materials and methods used and the general supporting environment (including family attitudes) in which the teaching occurs as it assists the motivational component of teaching (Sassoon, 1990). Sassoon places at least as much emphasis on the latter issues as on the particular detail of the letters being taught to the child, since a motivated learner is likely to be far more receptive than an unwilling one, no matter what they are taught to do.

Handwriting is considered first and foremost to be a movement-centred process and not a way to create images of letters (Inglis & Connell, 1964). If a child's skeleto-musculature of the hands, wrist and fingers are able to move appropriately and fluently and in a coordinated, rhythmic fashion, then effective handwriting should be relatively easy to teach. Handwriting should not be seen as an attempt to reproduce a static image; this could be done, in theory, by tracing a letter and reproducing an image but with no attempt to produce pen movements in the correct order, leading to completely incorrect construction of the letter (Sassoon, 1990).

The tempo of the learning process is also likely to be uneven as the abilities of the child tend to improve in spurts, interspersed with periods of practice and stabilisation (Inglis & Connell 1964). There may be associated changes in the variation of the handwriting during these periods of what is, in essence, part of the development of the handwriting of the individual. This suggests that the learning process for handwriting, being prolonged and complex, should not be regarded as a simple linear process in which a skill is taught, practiced and improved until optimally acquired. Rather, there is scope for continuous change, modification, periods of stability and periods of more rapid change depending on a whole variety of factors. This external view of the trajectory of learning resonates with the possibility of phases of stability interspersed with periods of change that were described in section 2.3 above when considering models of skill acquisition.

The teaching of handwriting has changed over time and it varies from place to place. This may lead to some general differences and also to some character-specific variations being found in the writings from those taught in different places and at different times. In many countries, the Roman script was traditionally taught in an elaborate version, such as copperplate. Whilst this may have been elegant and aesthetically appealing (to some at least), over time, simpler styles were considered more appropriate. These cultural influences will lead to an increase in variation between writers who are taught different copybook styles. It does not impinge on the individuality of each writer and hence the within writer variability is likely to be independent of such factors. In order to develop a scheme for measuring variability between writers and within writers (at a given time and over a period of developmentally relevant time), such cultural features should not be included in the coding scheme since cultural variability in handwriting is not the focus of this research.

Some differences are attributable to the prevailing method of teaching at a particular time in a particular country. As noted above, a number of systems are outlined in the book by Huber and Headrick (1999, Chapter 8) book for the teaching of writing in a number of countries. For example the following would be regarded as unusual by someone taught to write in the UK: the letter W constructed from four separate pen strokes – this is commonplace in many taught to write in West Africa; the use of the capital form of the letter R in lower case writing is a habit found commonly in the writing of those taught in Ireland; the numeral 7 written with a crossbar is widely regarded as a European affectation; the number 9 written with a markedly curved tail and often using two pen strokes is common in eastern Europe (Turnbull, Jones, & Allen, 2010).

Thus, some of the features of very specific forms are influenced by what is taught which in turn may vary by time and place although the derivation of particular traits is likely to be cultural. Such features are not necessarily universal, but they do tend to occur with greater frequency in some groups than others and they do provide another source for between writer variation in a multi-cultural society.

The multiplicity of these cultural influences is shown by the findings of Cheng et al (2005) when examining the writings of three culturally separate groups learning to write English as a second language, namely Chinese, Indian (writing Tamil) and Malay (writing Arabic) people in Singapore. These three handwriting systems (Chinese, Arabic and Tamil) have very different appearances and these were reflected in the romanised English written by individuals from these different backgrounds. For example, the stress on straight lines in Chinese, the formation of dots in Arabic and the curvature of the strokes in Tamil were reflected in the writing in English.

Different writers may absorb and adapt the influences to different levels not only in the general appearance of their handwriting but also in the detailed letter forms that they adopt. The dynamic of the interaction between such influences and the learned style may also lead to within writer variation especially in younger writers as they experiment with their writing.

2.8.2 Social factors

Since handwriting is a manifestation of its writer's handiwork, this might be reflected in general handwriting attributes such as neatness and aesthetic appearance under the wilful control of the writer. This might be particularly true in young children as their writings require a large degree of conscious input that will tend to fall away as the writing process becomes increasingly automatic. To the extent that letter shape is under conscious control, there are a number of factors that might affect the forms that are chosen, such as a desire to please, conforming to peer standards, and clarity of communication. The intellectual and cultural changes that children go through, into their adolescence and early adulthood, are far too complex and wide-reaching to be considered here, except to say that it is likely that some of these processes will have effects on handwriting inasmuch as it is a form of externalised expression. For these reasons, the cultural and intellectual capabilities of children were not used as selection criteria for participation in this research. (Instead, teachers were asked to select children whose style of handwriting varied from child to child, having no knowledge of the coding scheme – see Chapters 4-6).

2.9 The research questions

Following on from the discussions centred on skill acquisition in terms of both cognitive and motor components and the implications for the development of handwriting style in children in the preceding sections, it is now possible to frame the research questions that will form the basis of this thesis that will probe the aims set out in Chapter 1.

2.9.1 Feature use and higher order dimensions of handwriting

Do individual features show main effects of task or age and is there evidence of underlying commonality between any of the features?

The impact of change at the level of individual features used in particular letters was examined and these were further analysed with a view to finding higher order dimensions of the handwriting.

This had the potential to show that even at the level of individual letter construction, there might be changes that occur in children according to their age and the handwriting task, a finding that has not been reported in the literature at such a fine-grained level.

If features of certain letters do show commonality, then this may suggest that learning strategies are in part generalised, with letterforms being related to one another in some way, which would support such a finding in adult handwriting (Eldridge, Nimmo-Smith, Wing, & Totty, 1985).

2.9.2 Within-writer style variability

What is the extent of within writer variability (in relation to style) to be found in the handwriting of children and how does this change as they get older?

Efficient handwriting requires that cognitive and motor components interact effectively. As shown in the literature review, the acquisition of handwriting by children will be influenced by a number of factors, some affecting the cognitive component and some the motor component. The timing of these influences and their effect on a given child's handwriting will not follow some pre-determined pattern but rather will be dependent on the interaction of the internal and external factors that affect the handwriting, which will be reflected in the neuronal connections made and lost in the light of experience.

The extent of variability of handwriting style might be expected to be modest in the youngest children who are in the stages of learning to write, albeit their motor development will have an uneven and exploratory element to it which might be expected to increase the variability of the output. The cognitive element might be expected thereafter to vary as children become aware of different handwriting styles or change their style under pressure, for example needing to write more quickly, and these will need to acquire appropriate new or refined motor patterns to accommodate them. Ultimately, the skill of handwriting will be so automated that it will enable the child to concentrate on what they are writing, with the execution of the handwriting being a relatively minor, subservient output feature. This model of handwriting development would suggest an inverted U-shaped trajectory for the change in handwriting style variability in a given writer at least during this potentially prolonged phase of development. This trajectory of change of overall handwriting style is perhaps the most likely as it will tend to 'average out' any specific changes to how given letters are formed, taking a more general view across all features that contribute to handwriting style.

Another possibility is that the original learned style will become more and more efficiently executed leading to a reduction of variation as a consequence of the greater automaticity without necessarily involving a change of style. This could be a (fairly) linear process with a gradual improvement which eventually would plateau as the optimum handwriting is achieved for the writer. However, such a model would pose major difficulties for the notion of individuality. It would suggest that children being taught to write in essentially the same way (because they were in the same class, for example) would tend to have handwriting that starts similar and remains similar into adulthood, rendering the handwriting of such individuals less distinguishable from one another since between writer variation would be small. Hence, the model would be contrary to the commonplace observation that a child's handwriting does not just speed up as it gets older but its style also changes.

From a forensic perspective, evidence for increasing variability between writers as they get older is important since it would indicate a process that has the capacity to explain the individualisation of handwriting.

2.9.3 Between writer variability – the process of individualisation

What degree of individualisation (between-writer variation) occurs in the handwriting of children of different ages? Or, to what extent are samples of handwriting from young children similar to that from their peers and does this change as the children get older?

Between writer variation will almost certainly be affected by changes of within writer variation because as the handwriting of a given individual changes, it is likely that these changes will be manifested in different ways in different children. For example, in the context of the inverted U-shaped trajectory, individualisation would be caused by different changes in the variation within the handwriting of individuals over time. In other words, each child would be following his or her own 'personal' inverted U-shaped trajectory during the period of personal style development. Hence, it is hypothesized that younger children will tend to be writing more alike one another than is the case in their older peers.

If handwriting development occurs in a more linear fashion with the original skill becoming simply more efficiently executed, then such a model has less scope for individualisation even with periods of accelerated change.

The forensic relevance of this question is that it will show to what extent handwriting becomes individualised as the children develop their styles. Since handwriting style comprises many factors above and beyond those that will be used in this research, any such individualisation as measured by this research cannot reflect the full extent of individualisation possible if all dimensions of handwriting could be evaluated.

2.9.4 Imposing constraints on handwriting speed and appearance

How do children cope when constraints are put on their normal handwriting? For example, does writing more neatly or more quickly affect the variability of their handwriting style and, if it does, to what extent is the pattern of change similar across children of different ages?

One aspect of the change in handwriting in a child over time will be the general improvement in motor skill associated with increasing levels of automaticity, albeit against a backdrop of variously influenced cognitive changes. Children's handwriting speed improves over time (for example (Rueckriegel, et al. 2008) and it is to be expected that older children will be able to deal with changes in constraint of the handwriting task – such as writing more quickly or more neatly. This would, in general terms, be in keeping with Karmiloff-Smith's theory (Karmiloff-Smith, 1992) inasmuch as for older children, the degree of representational redescription will be greater (as the handwriting skill has matured and been more practised) and thus they should be able to respond to new constraints better than younger children can. It is likely that older children will have strategies for dealing with constraints placed upon the handwriting process from their experience in the classroom environment. Indeed, the possibility that the need to write more quickly is itself one of the drivers for change would suggest that children are able to adapt their handwriting when faced with such challenges, but with the ability to do so being greater in the older than in the younger children.

Karmiloff-Smith's model would suggest that younger children will find it difficult to respond to the challenge with the limitations of their working memory and the processes by which it operates, whereas older children will be able to rise to the challenges. What is not clear is the magnitude or direction of any changes. Will *any* change to the speed or appearance of handwriting have an effect? Or will writing quickly lead to more variability and writing neatly to less variability, for example? And will these effects be the same at all age groups or will they be more marked at some developmental times than others? This thesis aims to address these questions.

Whether changes in handwriting task are sufficiently marked so as to affect the individuality of the handwriting is of forensic interest because the circumstances in which a piece of handwriting was produced may be a significant factor in a handwriting comparison.

In order to address the research questions, there is an absolute requirement for a coding scheme that captures features of handwriting style in such a way that the variation in the use if the features can be determined objectively. Such a scheme will need to be devised so that it can generate numerical values that can be used to compare handwriting styles and to evaluate the variability of handwriting in children. In Chapter 3, methods of assessing handwriting variability will be discussed and these will inform the creation of an objective coding scheme that will be proposed and tested in Chapter 4.

Chapter 3 Assessing handwriting

At the end of Chapter 2, the need for a detailed coding scheme that could be used to address the research questions focussing on the development of handwriting style in children was outlined. Before proposing detailed features for such a scheme in Chapter 4, it is necessary to review the literature that has been published describing the ways in which handwriting can be assessed and categorised and that is the purpose of this chapter.

The two kinds of handwriting assessment and measuring schemes that will be reviewed are firstly those aimed at identifying good and poor handwriting in children and secondly schemes aimed at differentiating between adult writers in a forensic context.

The kinds of scoring criteria for the two kinds of scheme will differ greatly as they serve completely different purposes. The schemes aimed at assessing children's handwriting will inevitably focus on parameters that reflect the quality of the handwriting although there is scope for differing views as to what constitutes good and bad handwriting and how much emphasis should be put on the different parameters in their capacity of measuring handwriting quality. For example, is the evenness of the handwriting more important than its structure and is this in turn more important than the slope or spacing between letters and so on?

Forensic schemes are more concerned with letter structure and here the purpose is to find categories that can discriminate between the handwriting of different people based upon a combination of different letterforms. For example, the way in which the letter A is constructed, combined with the way the letter B is constructed and so on building up a profile of categories that makes it possible to determine, for instance, how many people write alike (at least, as measured by the letter categories).

3.1 Assessing developmental aspects relating to handwriting in children

In order to attain an understanding of handwriting in children, both functional and dysfunctional, there are various types of measure that are used. The type of test that is most relevant to research into handwriting style assesses the graphomotor capability in the context of producing handwriting itself. Other types of test measure general visuomotor capabilities which are considered to be skills related to that of handwriting. These tests can assess various elements of the execution stage required for handwriting such as the ability to maintain control of the writing implement and other aspects of finger movement (Berninger et al., 1991). A third kind of test measures children's relevant linguistic skills since cognitive readiness will probably have an effect on handwriting given the inter-connectedness of the two components of handwriting production. However, these latter two types of test will not be used in this research which, rather, will focus on the description and coding of the handwriting style rather than the speed or more general aspects relating to it.

A variety of tests aimed at assessing, describing or measuring handwriting have been proposed. The BHK (Beknopte beoordelingsmethode voor kinderhandschriften) test was devised as a means of assessing handwriting quality in dysgraphic children. The original paper is in Dutch, but the procedures are summarised elsewhere (for example, (Kaiser, Albaret, & Doudin, 2009)) and involve a handwriting task requiring the copying of a text in five minutes or the first five lines whichever is the greater amount, albeit only the first five lines scored in any event. The text becomes increasingly complex and at the same time each successive paragraph is reproduced in a smaller font. The child does this task without having had the opportunity to see the text and the handwriting is done on unlined paper. Scoring of the handwriting is based on a variety of features that assess deviations from the taught style according to thirteen criteria; letter size, left margin widening, poor word alignment, insufficient word spacing, acute turns in connecting letters or too long joining, irregularities in joining strokes, collision of letters, inconsistent letter size, incorrect relative height of letters, letter distortion, ambiguous letter forms, correction of letter forms, and unsteady writing trace. The assessment procedure is therefore involved but despite this it has a reported inter-rater reliability of 0.9.

The Test of Legible Handwriting (TOLH) is a set of graded handwriting samples that cover the spectrum from good to poor legibility which has been used by various researchers (for example (Graham, Struck, Santoro, & Berninger, 2006)) and which has a typical inter-rater reliability of 0.85. Samples of handwriting are compared visually against the graded samples with a view to matching the test sample to the best matching graded sample.

The Scale of Children's Readiness In PrinTing (SCRIPT) has been developed and used (for example (Marr et al., 2001)) and is based on the writing of target letters copied by the participants. Scoring is carried out by assessing the appropriateness of the letterform produced. In its original form, this test was not always found to be reliably scored so Marr and colleagues refined it by providing clearer, and in some instances quantitative, scoring criteria for features such as letter completeness, the appropriate presence of parallel strokes, curve shapes, angles and the an absence of irrelevant pen strokes. These closely defined criteria produced good inter-rater reliability of 0.95 which demonstrates that the more tightly the coding scheme is defined, the more objective it is (Marr et al., 2001).

Berninger et al. (1991) put forward a measure of handwriting fluency based on the number and accuracy of lower case alphabetic letters that can be written in order in one minute with a premium for those able to write it quickly. This was a skill that typically was mastered by most children by about Y2 and was found to correlate significantly with spelling capability. Whilst for most writers, attaining mastery of this task was complete at an early age, Berninger and colleagues found that many children that displayed handwriting problems and who had been referred for remedial help had not yet mastered this task, showing hesitancy and a re-touching of the handwriting indicative of an absence of automaticity.

The Evaluation Tool of Children's Handwriting (ETCH) was developed by Amundson and has been used by a number of authors (for example (Koziatek & Powell, 2002)). The test consists of a number of handwriting tasks including writing the alphabet from memory in cursive upper- and lower-case, writing numerals 1 to 20 from memory, near point copying (five words with the source adjacent to the writer), far point copying (seven words with the source at a distance from the writer) together with several other similar tasks. The assessment of the handwriting is then based primarily on legibility, focussing on letter formation, size, alignment and spacing, although observation of biomechanical factors is also included. The complexity of the scoring system and its subjective nature entail some operator training to ensure reasonable consistency of scoring.

Phelps, Stempel & Speck (1985) describe the Children's Handwriting Evaluation Scale (CHES) in which the handwriting quality of a piece of copied handwriting containing 197 letters is assessed against five parameters which are letterform, slant consistency, rhythm, spacing and general appearance with each category being scored as 0 or 1, hence giving a maximum quality score of 5. This binary approach on just five criteria would not be sufficiently discriminating to be of value in assessing style development as required by this research.

The handwriting problems that occur in children suffering from a number of conditions can be assessed by the Minnesota handwriting test which was designed specifically with such requirements in mind (Reisman, 1991). It is intended for use in young children aged about seven or eight and it is sensitive to small changes in handwriting performance. Participants are asked to copy a selection of words within a specified time. Handwriting samples are assessed for the legibility of each individual letter in terms of form together with spacing between letters (measured), alignment and appropriate letter form. The test has been used by a number of authors, for example to assess handwriting in those suffering from cerebral palsy (Bumin & Kavak, 2008). They found that in about 60 paired children there was a significant correlation between handwriting performance and sensory and cognitive function. Whilst this method of assessing handwriting is applicable in some instances, it is not relevant to the current research which is aimed at assessing the variation of letter form (style) in healthy children over a prolonged period of time capturing essentially all of their school years.

Stott and colleagues devised an assessment process known as the diagnosis and remediation of handwriting problems (Stott, 1977). The handwriting samples are produced by children prompted by pictorial cues. The assessment process considers a variety of factors including alignment and position of letters, consistency of letter size and pen control (tremor). Interestingly, this test also requires direct observation and assessment of the handwriting being executed with factors such as posture, pen grip and head position being recorded.

Karlsdottir (1996) describes a system of assessing handwriting that scores alignment, size, spacing and letter shape, for example, taking particular note of the internal consistency of the handwriting. Thus, if the baseline of the handwriting is even this is taken to indicate mastery of this dimension of handwriting production, but if there are instances where the baseline deviates markedly from the typical baseline of that same piece of handwriting then this is taken to indicate a lack of mastery. This test produced inter-rater reliability of 0.80.

The value of a tool that purports to assess handwriting quality can be measured along a number of dimensions. In particular, the test needs to be valid and it also needs to be reliable in its administration. In addition, where children are concerned, there are operational issues of timeliness and complexity that need to be borne in mind. Some writers have found tests of visuomotor capability to be helpful in the identification of functional and dysfunctional writers (Marr et al., 2001), whereas others have found it less useful (Doeringer, 1998; and Phelps et al., 1985). Karlsdottir (1996) instead suggests that there is, by contrast, a real benefit to the child to have a sound understanding of letterform (Graham & Weintraub, 1996); in other words, of the two components of the writing process, the cognitive component is of greater significance than the visuomotor component, albeit there is always likely to be some effect on handwriting in individuals that have poor motor control.

Once children get past the age at which the teaching of handwriting tends to decrease, the literature on dysfunctional writing also tends to fall off. However, both cognitive and motor constraints are likely to continue to play at least some part as handwriting develops in later years, determining handwriting ability and perhaps, in some individuals, affecting academic performance into secondary school and beyond (Longcamp, Anton, Roth, & Velay, 2003).

As noted previously, a variety of factors change in children's handwriting as they develop including size, speed and legibility. Graham et al., (2006) used the various kinds of measure employed by the various assessment schemes of young children's handwriting during the first two years in which it is taught, to try to dissect which elements were most related to legibility and quality in writing tasks that involved both copying and composing. Spacing between words, spacing between letters, alignment, letter height, letter slant, reversals (in which a letter is written as its mirror image), added strokes, missing strokes and missing letters were all scored. The authors found that, with the exception of slant, all other elements of the handwriting were correlated with good and poor handwriting. Letter placement and spacing was more variable in poor writers. In addition, performance was affected by task. In both good and poor writers, the quality of the handwriting as measured by these parameters was poorer when the handwriting task was a composition task rather than a copying task. This is consistent with the view that composition is more demanding than copying (due to the increased cognitive and linguistic demands of the former) and this is reflected in the production of letters (in terms of size and slant but not in terms of their letterforms - style) and the spacing of the handwriting. These findings impact on this research inasmuch as they suggest that the parameters measured to assess handwriting quality are more variable in poor writers than in their more skilful colleagues and that the appearance and consistency of handwriting will vary depending upon whether it is a copying or composing task.

This survey of testing procedures targeted at children's handwriting quality is not exhaustive but the kinds of category used in them keep recurring, focussing on descriptors of handwriting quality, such as appropriate form, size and consistency. Whilst the tests may be more or less useful in a variety of settings, particularly those requiring assessment for remediation purposes (Feder & Majnemer, 2003), none are concerned with the style of the handwriting in terms of its structure, proportions and symmetry and it is categories such as these that will be used in this research as described in Chapter 4. Nonetheless, the findings of Graham et al., (2006) show that in general poor writers may be less consistent in the general qualities of their handwriting and that different tasks impose different constraints on the handwriting process. These factors will be considered when the style of handwriting is assessed in the following chapters.

In order to measure handwriting style the dimensions of letter formation that can vary will be discussed next followed by a review of the forensic literature on handwriting classification.

3.2 Handwriting variation

Handwriting is a highly complex psychomotor activity; it is, indeed, one of the most complex skills that is routinely mastered by a large part of the population. From the mix of educational, social, neurological and biophysical factors that affect handwriting, it is not surprising that it is subject to variation both between individuals and within the writings of the same person. In some respects, perhaps, the single most striking feature of a person's handwriting is its overall, pictorial constancy mixed with a measure of variability of detail.

In writing using the Roman alphabet, all of the 26 letters can vary, both upper and lower case, as can numerals, other symbols such as the pound sign and ampersand and other marks such as even the simplest of all, the dot that is a full stop or i-dot. Variation can be considered to occur in a number of general ways.

The way in which handwritten characters are constructed varies (Ellen, 1993). There are only a few instances in which particular letter constructions are the subject of published literature (for example, (Eldridge et al., 1984)). As a consequence, the author of this thesis has drawn upon many years of experience as a handwriting expert for some of the follow descriptions. Construction is meant in this sense as the way in which multiple pen movements are put together to create the finished character. Examples might include the letter B written in one continuous movement or as two separate pen strokes (figure 3.1) or the letter E written as a semi-circle with a second, central horizontal stroke or written as an L-shape with two further strokes (figure 3.2).

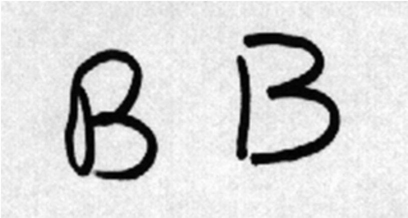


Figure 3.1

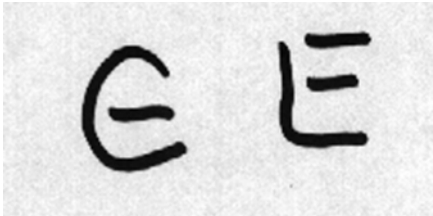


Figure 3.2

Characters of similar construction can themselves vary in the sequence of pen movements used to write them. Continuing with the letter E, the L-shape can be followed by the top stroke then finally the middle stroke or the middle stroke then the top stroke (figure 3.3). Similarly, the top stroke of the letter T may be written either before or after the downstroke (figure 3.4).

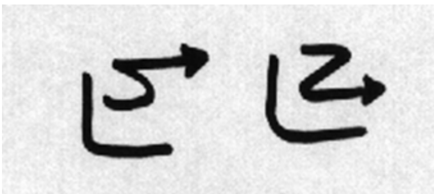


Figure 3.3

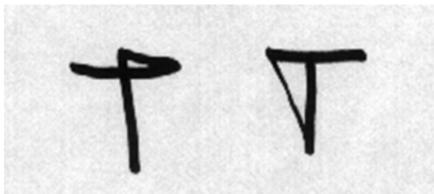


Figure 3.4

The direction of pen movement may vary. Some writers write their letter O in a clockwise direction (usually, but not always, left-handed writers), others write it anti-clockwise (most right-handed writers and also a significant proportion of left-handed writers) – see Figure 3.5. The direction of pen movement when writing the numeral 8 may vary together with the point of initiation. The most commonly occurring is to commence at the top right and move anti-clockwise, the pen finally returning to the top right from the bottom left. But some writers begin at top left and may head anti-clockwise or clockwise, and yet other writers start at bottom left (figure 3.6).

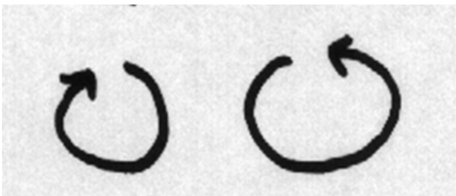


Figure 3.5 **Figure 3.6**

Most curved letters, such as the letters C and S, tend to be written starting at the top and finishing at the bottom. However, in a small minority of writers, the letter is begun at the bottom of the letter (figure 3.7).

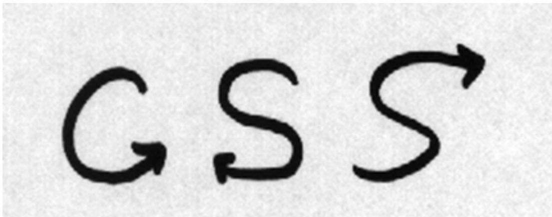
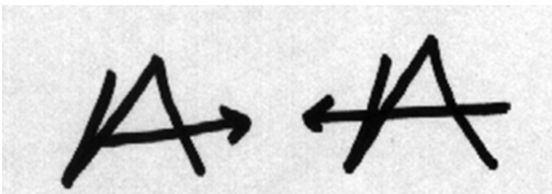


Figure 3.7

As well as variation in circular movements, writers vary in the horizontal and vertical directions too. For example, some writers write the A-crossbar from left to right and others in the reverse direction (figure 3.8). The initiation of many letters, such as M or N, with a downstroke is frequently encountered, but some writers omit the downstroke and therefore commence with an upstroke (figure 3.9).



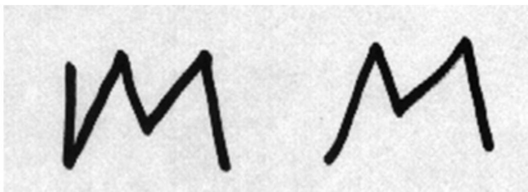


Figure 3.8 **Figure 3.9**

The proportions of written characters can vary both within themselves and also between various characters, although proportionality is usually fairly resistant to change (van Doorn & Keuss, 1993). They focussed on the repeated letter pair lele and found that there was a high level of spatial invariance when written under different circumstances (small, medium and large writing, with or without visual feedback).

Internal letter proportions are many and varied. For example, the letter O may be written as a tall, thin letter or as a squashed, flat letter (figure 3.10). This can be seen as a variation in proportion or as a variation in shape of letter. Another example of internal proportions would be the letter B with either both curved parts of roughly equal size or, as is seen in many writers, the upper curve smaller than the lower curve (figure 3.11).

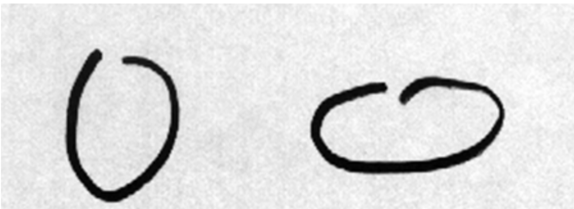


Figure 3.10

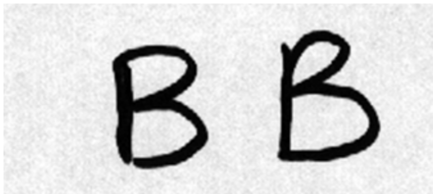


Figure 3.11

Some variations in proportion tend to be common in related groups of letters. For example, if a writer produces the letter y with a tail that is longer than the upper part of the letter, then it is likely that they will also produce the letters g and p in a similarly proportioned manner (figure 3.12) (Eldridge et al., 1985).

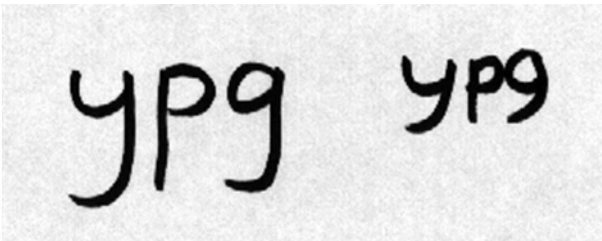
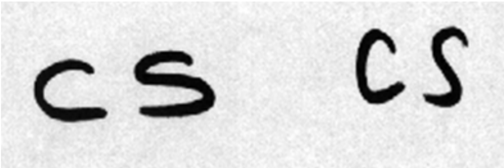


Figure 3.12

The shape of characters also may be connected; for example, a writer who produces a flattened, elongated form of the letter c may tend to produce a similarly flattened, elongated form of the letter s (figure 3.13), and quite possibly the bowl elements of the letters b and h (figure 3.14) and so on.



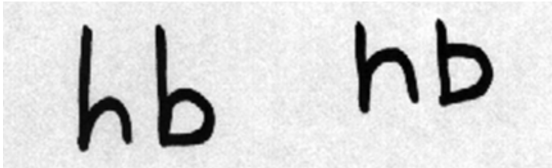


Figure 3.13 **Figure 3.14**

Thus, it can be seen that some features of writing tend to be somewhat generalised in the writing of a given person. This leads some to describe writing in very broad terms as, for example, rounded or spiky, general features that may be used to infer the gender of the writer (Burr, 2002).

Inter-character proportions vary too. A common letter pair in English is th. In many writers, the two letters are of about equal height, but in a number of writers the t is routinely smaller than the h (Muehlberger, Newman, Regent, & Wichmann, 1977). The relative heights of parts of letters may be related across characters. A writer who writes a tall ascending stroke and proportionately small hump in the letter h may construct the letters b and d in roughly similar proportions. These inter-character proportions may also be reflections of general writing styles such as rounded and spiky.

Not only can inter-letter proportions vary, so too can the way in which adjacent letters are joined. Most usually, this is in cursive writing. For instance, some writers join the letter t to the letter h via the tail of the t; others join to the letter h from the crossbar of the t (figure 3.15).

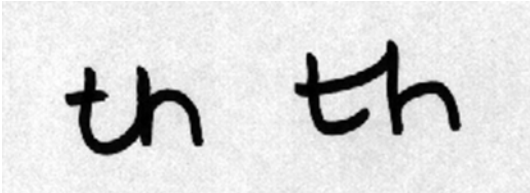


Figure 3.15

If capital letters are being hurriedly written, it is common for some letters to be joined. In this case, the joining often reflects the letter construction. So, for example, someone who writes the letter T top second will join to a subsequent letter from the end of the crossbar, whereas someone writing the downstroke second will join into the next letter from the bottom of the downstroke.

Some letters can be written in more than one form or allograph. For instance, the letter s may be written as one curve or two (figure 3.16). Some writers may use one form, others the alternative and some may use both forms, often in a context-dependent way. The need to facilitate the joining from a preceding letter or the need to ease the joining to a subsequent letter can determine the usage of a particular allograph (Van der Plaats & Van Galen, 1991).

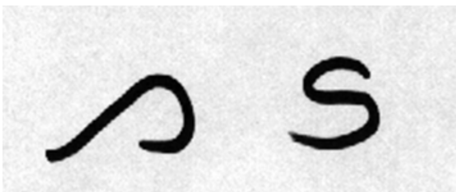


Figure 3.16

Other components of handwriting that can vary are the size and slope. In most cases, size is not particularly constrained, but when required to do so people can make their writing either larger or smaller. When writing on a blackboard, for example, the writing is not only larger but it also requires the writer to adjust to writing on a different surface and at a different geometrical orientation. Such changes do not significantly alter the appearance of the writing, however. Slope is fairly constant for some writers, but others may vary their slope markedly.

In summary, there are many different kinds of feature that can vary and all letters and numerals have several dimensions of such variation leading to many more sub-categories. Further, the handwriting of any one individual may show examples from more than one sub-category or even more than one major division of features. The degree of variation may itself vary from feature to feature and from writer to writer. In order for a coding scheme to be operable, it needs to be robust enough to cope with these degrees of variability and thus there is likely to be a premium on adopting a scheme that is relatively simple in the way in which it sub-divides the features that it attempts to distinguish between.

3.3 Forensic categorising of handwriting

Handwriting classification schemes have been devised for a variety of purposes. Some of them have been published in the forensic literature and are intended to be schemes that assist the handwriting expert in the assessment of evidence by giving some sort of indication of the frequency of occurrence of a given handwriting feature. Such schemes have a very strong tendency to use feature descriptors that are, as far as possible, mutually exclusive, typified by 'writer A uses form X' and 'writer B uses form Y' for a given letter form (for example, (Hardcastle, Thornton, & Totty, 1986)). However, between writer variability is noted but within writer variability is not quantified to give, for example, 'writer A uses form X 80% and form B 20% of the time' and 'writer B uses form X 30% of the time and form Y 70% of the time'.

Forensically driven handwriting classification schemes have the advantage that they need to be precise in terms of feature definitions, but as noted above they are not designed to capture variation in a person's handwriting but rather to differentiate between writers on the basis of differences in handwriting features used. This research requires a less sharply focussed tool that will firstly show differences in the degree of use of handwriting features and then have the potential to show changes in that degree of use of over time thereby providing a measure of change in handwriting style.

Many of the schemes in the literature have a forensic context. For example, Nicholson (1984) describes categories of block capital letters and their frequency of occurrence. The stated dual purpose of his scheme was to assist in the forensic linking of otherwise apparently unrelated matters but also to provide some statistical information upon which handwriting experts could draw when assessing various handwriting habits. Nicholson states that he originally started with a quite elaborate system but found that it did not function well because of ambiguities that tend to follow from complex descriptors with the associated problem of overlapping categories and individuals whose writing contain variants in multiple categories. It is a fairly complex scheme in that there are a number of categories into which a given letter can be placed. The kinds of discriminatory features used include the number of strokes, the order of strokes and the direction of pen movement and construction/shape of letter, with some letters having more than one of these kinds of discriminating features applied. Some examples are shown in Table 3.1.

Table 3.1 showing categories into which the letter A can be divided (Nicholson 1984)

Description	Example
Written in two strokes	
Written in three strokes	
Written in one stroke with single crossing	
Written in two strokes with two crossings	

As far as this research is concerned, the drawback with Nicholson's work is that it focuses on block capital handwriting, a style that is not so practised in younger children. However, his finding that elaborate coding schemes are difficult to apply is important since this research requires a coding scheme that can be applied as rapidly and unambiguously as possible to a large number of observed letters. Nicholson's work suggests that over complex coding schemes would not be consistent with this need.

When the specific purpose of a coding scheme is to split the population of handwriting up into more or less equal groups (as it may be in a forensic context such as Nicholson's), the descriptors have to be chosen in an attempt to produce this intended outcome. A scheme was developed for discriminating between samples of writing with the intention of obtaining near-even splits between categories (Hardcastle et al., 1986) – see Table 3.2.

Table 3.2 showing capital letter features used by Hardcastle et al (1986) to discriminate between adult writings

Feature	Type 1	Type 2	Type 3	Type 4
A	Initial downstroke	No initial downstroke	Other	Mix of types 1 and 2
B	One stroke	Other	-	-
C	No loop	Loop	-	-
D	One stroke, clockwise	Two strokes	Other	Mix of types 1 and 2
E	Bottom and upright joined	Bottom separate	'Greek' style	Mix of types 1 and 3
F	Separate top stroke	Connected top stroke	Other	Mix of types 1 and 2
G	Tail but no crossbar	Tail and crossbar	Crossbar but no tail	-
I	Single stroke, no dot	Other	-	-
K	Both diagonals meet upright	Other	-	-
M	Low centre	High centre	-	-
N	Last stroke upwards	Last stroke downwards	Other	Mix of types 1 and 2
O	Join at top or right	Join at bottom or left	-	-
P	One stroke	Two strokes	Other	Mix of types 1 and 2
R	One stroke	Other	-	-
T	Normal	Other	-	-
U	No tail	With tail	Other	Mix of types 1 and 2
W	High centre	Low centre	-	-
Y	Tail ends above line	Tail ends below line	Other	Mix of types 1 and 2
0 (zero)	Join at top or right	Join at bottom or left	-	-
1	Single stroke	Other	-	Mix of types 1 and 2
2	Z-shape	Retrace or loop at bottom	Other	Mix of types 1 and 2
3	Normal	Other	-	-
4	Open style	Closed style	-	-
5	Separate top stroke	Integral top stroke	-	-
7	Normal	With serif	Other	Mix of types 1 and 2
8	Join at top or right	Join at bottom or left	Other	Mix of types 1 and 2
9	Normal	Other	-	-
Ratio	First letter in word taller	First letter same size	-	-

The scheme was designed to function in such a way that handwriting samples (specifically on cheques) from the same person received on separate occasions could be linked, and writings from 'new' writers were not linked to existing groups. The scheme was used usually on relatively small amounts of adult handwriting and therefore had to focus on features that were likely to be reasonably invariant in a given person's handwriting. The features chosen for the scheme were therefore biased towards those that on the one hand were likely to be able to discriminate between writers and on the other hand were likely to be reasonably invariant in the handwriting of a particular person. This is an important test of the value of the features' ability to discriminate between writers. The converse of discriminating between writers is that samples from the same writer should be more similar to each other than to samples from other people, and this 'clustering' tendency is a good test for such a scheme and will be used as a measure of the success of the scheme proposed in Chapter 4.

The authors lay out a number of discriminatory features for some block capital letters and all of the numerals (except 6). They also code a general writing habit, namely that some writers tend to use a larger initial letter in a word when writing, whereas in other writers all of the letters in the word are of approximately similar height, which can be regarded as a general style feature.

The features listed in Table 3.2 are generally structural features. For example, the presence of a downstroke in the letter A or the strokes joining in the letter E are coded. Some features relate to the proportions of letters, such as the centre of the letters M and W. The numbers 0 and 8 are features for which the coding depends upon the starting position for writing the number. The features were all designed to be coded as unambiguously and quickly as possible in an operational setting in which many handwritings needed to be coded. It is for these reasons that the scheme was not over elaborate and relied to a large degree on binary splits – features were one of two types. Some three-way splits were used and some include a mix option where two forms are found to be frequently inter-changeable within the handwriting of a single person which itself then can become a feature of a person's handwriting. The choice of features was based on the extensive working knowledge of the kinds of feature variation to be found in the population that the authors had as forensic document examiners. Their paper does not give information about the frequency of occurrence of the individual feature types in the population, since it is the combination of features in a person's handwriting that 'identifies' it.

Such a classification scheme allows for the discrimination between writings of different people to a sufficient extent that a manageable number of subsequent, visual comparisons can be made by the handwriting expert. The purpose of the visual comparison is to confirm (or otherwise) whether samples held on record are a match with those of the 'new' piece of handwriting. Inasmuch as this was the stated purpose of the scheme, the authors say that after four years of applying it to the writings of over one thousand people, the scheme worked well, with the system finding correct matches in over 90% of instances (Hardcastle et al., 1986).

Experience showed that some of the original features considered were not, in fact, reliable (B, M, R and W) and they were eventually discarded. The authors indicate that classification schemes of this nature have an inbuilt capacity for error not only from the operating side but also from the intractable problem of producing schemes that divide continuous variables and the reliability of assigning examples that fall near to the dividing point into the correct category. Two types of error can occur when operating a scheme such as this: either a new sample can be erroneously 'matched' with other samples in the database (false positive) or a new sample cannot be 'matched', when it should have been to existing samples on the database (false negative). The visual comparison by an expert is intended to deal with the first type of error; a new sample may, when classified, match the *classifications* of several samples already on the database but the expert decides which, if any, the new sample in fact matches. These error types highlight the continuing need for the expert to make the assessment of handwriting evidence. The classification process can inform that assessment and, in particular, the weight given to the evidence in a given case, but for court purposes, the approach of handwriting classification as a replacement for the interpretation of the human expert is not reliable enough and therefore not appropriate.

In order to make the second type of error less likely, the authors used a data comparison procedure that allowed for up to two mismatched features between the test sample and the database. They, therefore, set out to achieve reliability in keeping with the intended purpose of the scheme; a figure of 90% was chosen, that is, nine out of ten submitted samples should be either correctly associated with previously held writings or identified as a new piece of handwriting. This target was achieved, having been monitored by various test procedures.

A follow-up paper (Hardcastle & Kemmenoe, 1990) describes a more limited scheme (again for handwriting specifically on cheques). This was based on a small number of lower case letter forms [d], [f], [i], [p], [t] and [u] together with the capital letters C (used in the frequently occurring word 'Cash') and F (used in the frequently occurring words 'Forty' and 'Fifty') from the earlier scheme together with the same numerals (the letters I and T and the number 3 also being dropped in the light of experience).

Table 3.3 showing lower case letter features used by Hardcastle & Kemmenoe (1990) to discriminate between adult writings

Feature	Type 1	Type 2	Type 3	Type 4
d	Normal	'Delta' style	Other	-
f	Tail turning to left	Tail straight, pen lift at base	Tail turning to right	Mix of styles 1 and 2
i	Dotted	Circle or no dot	-	-
p	One stroke	Two strokes	Open style (takes precedence)	Mix of styles 1 and 2
t-y join	Joins from base	Joins from crossbar	-	-
u	No tail	Other	-	-

The authors found previous work by Eldridge and colleagues, (Eldridge et al., 1984; Eldridge et al., 1985), to be too unwieldy to use for their purposes. The authors also said that a scheme for cursive writing is hampered because of the influence that letter position in the word has on letter construction. In this context, the authors were trying to avoid between-writer variation in the handwriting that was being coded since this might be considered to be hindering the process of discriminating simply based on feature use. By contrast, in my research the variation in letter forms that may result from letters being in different positions in words and joined or not is one of the very elements that is to be captured by the coding scheme described in the next chapter. In other words, the variability of handwriting that is such a problem for forensic schemes is at the very heart of the developmental scheme required by this research.

Ansell (1979) conducted a brief survey of classification schemes and their effectiveness but was only able to conclude that those that he studied were unable to provide much discrimination between writers and that further research was required. An unpublished study carried out by Ansell and Pritchard is described in outline only which used eighteen parameters of block capital lettering – but they are not described. One finding of interest is that most of the parameters were fairly resistant to change when written with pen-on-paper or written large with felt tip marker on a vertical surface. A purpose-built scheme for a particular forensic case is described by Harvey & Mitchell, (1973) but here the features of the scheme were dictated by the particular document, which being just a single cheque involved in a forensic investigation. The purpose of devising the scheme was to assist in the elimination of many hundreds of possible suspects by comparison with specimens of writing; using such a scheme would make it an auditable process and also non-experts could potentially use it. Taylor and Chandler (1987) describe a similar case-oriented system.

A scheme devised by Eldridge et al., (1984) has the stated aim of focussing on the variability of handwriting both between and within writers, although the methodology adopted (requested samples using similar materials) was aimed at minimising within writer variability as the authors acknowledge. Its underlying purpose was to inform handwriting experts about feature frequency. The study considers only the letters d, f, h, k, p and t and it examines these in the requested samples from 61 adults many of whom were from an educated background. It is a very complex scheme with often ten or more variants described for each letter. For example, the elements of the letter f are dissected by number of strokes (two categories), top of staff shape (three categories), top of staff direction (two categories), bottom of staff shape (three categories), bottom of staff direction (two categories), crossbar position (three categories) and crossbar curvature (three categories). There was, in fact, little attempt to measure within writer variability in normal handwriting samples and the developmental aspect of measuring variability in the handwriting of children was not considered. As a model for a scheme aimed at measuring handwriting, it is consistent with that used by others (for example (Hardcastle et al., 1986)), but the specific features used and the rationale for the scheme make the details less relevant to the current research.

Muehlberger et al. (1977) looked at the letter pair 'th', primarily because of its frequency of use in English. Their scheme also was complex and looked at the height ratio of the 'th' (four categories), the shape of the h loop (five categories), shape of the h arch (three categories), height of the t crossbar (four categories), baseline of the h (four categories) and shape of the t (five categories). The purpose of their study was to provide some statistical data on the features described and to point a way forward for similar research. The result of their study is therefore a series of features and the frequency with which they occur in their sample and some correlations between features. For example, 78% of writers made the t shorter than the h, 66% made the h with a pointed arch and 71.5% made the t crossbar in the upper half of the letter. The value of this research to the present study is similar to that for the Eldridge study mentioned above. As a model approach it is entirely in keeping with what is required in this research, but it is too unwieldy and lacks a consideration of developmental trends in the handwriting of children as measured by within writer variation. It is not coincidental that both the Eldridge study and the Muehlberger study are published in forensic journals.

Whilst schemes that are very intricate explore the fine differences between the use of letter forms, both Hardcastle & Kemmenoe, (1990) and Nicholson, (1984) found out their use can be cumbersome and lead to problems when interpreting subtle differences between categories. For this reason alone, an intricate coding scheme was not desirable for this research.

In the field of automated handwriting recognition, much work has been done to try to describe the written line as a mathematical function. Bridging the divide between this work and the classification of writing are studies such as that of Marquis, Schmittbuhl, Mazzella, & Taroni, (2005b) which used image manipulation techniques based on Fourier descriptors to show mathematically that the letters O from three writers were different. There was variation within the mathematical renditions and thus the possibility of 'misattributing' outliers, when looking at single examples, cannot be ruled out. Further work by Marquis and colleagues looked at similarly analysed transformations of the loops of the letters a, d, o and q in thirteen writers (Marquis, Taroni, Bozza, & Schmittbuhl, 2006). They found discrimination values of about 70-80% for the letters a, d, o and q. Different loops were found to have different values for discriminating between different pairs of writers, as would be expected from the complex nature of writing. For example, the shape of the loop of the letter o was less discriminating than the loop shape of the other three letters studied, whereas the shape of the loop of the letter d was the best at discriminating between writers.

In a similar vein, Ling, (2002) measured ten elements of cursive writing such as word spacing, the space between the ascenders of the letters t and h in the th letter pair, the space between the sides of the letter u and so on. Ling also found that no one feature was able to provide discrimination between the writings of the ten participants. Rather, he finds that a feature that discriminates between two given writers may not be so useful when discriminating between two other writers or even one of the original pair and a third writer.

The use of computer-assisted processes for analysing handwriting for forensic purposes has not taken so far been successful. A number of studies, such as that of Srihari, Cha, Arora, & Lee (2002) have shown that various algorithms can be used to examine handwriting samples offline (that is from the static image rather than the additional dynamic information that can be obtained using a digitising tablet). The purpose of his study was to test the hypothesis of handwriting individuality in adult handwriting, an hypothesis that has come under scrutiny following various legal challenges to expert evidence in handwriting in the US summarised in (Srihari et al., 2002). As Srihari recognises, the algorithms used may share some elements with those that forensic experts use, but they are not identical with them. Such studies have added support for the individualisation hypothesis, albeit the work of the handwriting expert requires an assessment not based on samples of handwriting obtained under experimental conditions, but rather the real world of case samples which may be short, disguised and far from ideal.

3.4 Summary

There are a number of studies in the literature that describe various ways in which the handwritten product can be assessed, measured and differentiated. In all instances, there has been a specific purpose, usually either remedial work for dysfunctional writing, usually in young children, or to assist in the determination of authorship. The former schemes use fairly general categories such as the slope, proportions and neatness of the handwriting and pay little attention to any feature specific categories (Rosenblum, Weiss, & Parush, 2003) except where letter appearance is appropriate (recognisable). In contrast, the latter schemes do focus on feature specific categories, such as the number of strokes to write the letter A or the ways of writing the letter pair th. The main use to which these schemes are put is in assisting the identification of handwriting, a process that relies heavily on the distinctiveness of the handwriting (Ellen, 1993). The classification schemes do not place much emphasis on within writer variation, because of their purpose to maximise between writer variation based, as far as possible, on mutually exclusive categories.

No scheme has been devised that fulfils the needs of the current research, namely those of measuring both between writer variation and within writer variation in the handwriting style of children across the whole age range from being taught to leaving school. The schemes that have been described in the literature in relation to the handwriting of children are too imprecise (using general descriptors such as legibility with the purpose of identifying remedial teaching needs). Schemes that describe adult handwriting are focussed on maximising between writer variations (particularly in the forensic literature).

Although the latter schemes help to inform the kinds of features that might be considered in the current research, no scheme is appropriate to the particular needs of this research.

In Chapter 4, a scheme will be described, the purpose of which is to address the research questions posed at the end of Chapter 2. This requires a scheme that captures and measures within writer and between writer variations in children and shows how these change over time as they develop their handwriting skill. From the models of handwriting production described in Chapter 2 and the kinds of handwriting feature that can vary that have been describe in this chapter, it is clear that an objective coding scheme should contain different kinds of features which have the potential to measure these variabilities of handwriting but for which categorisation can be established reliably. These kinds of features, in conjunction with the author's experience of examining handwriting for over twenty-five years, will inform the creation of the scheme that is now described in the next chapter.

Chapter 4 Coding scheme development

4.1 Introduction

The need for a coding scheme to measure both within writer and between writer variability in the handwriting of children has been identified in Chapter 2 as an essential prerequisite for researching into how handwriting varies and develops in children. No such scheme has been reported anywhere in the literature.

In this chapter, a coding scheme for handwriting will be proposed and this scheme will be tested and then refined so that it is suitable for the much larger studies that are to be the focus of this research which are reported in Chapters 5 and 6. Before proposing specific features for inclusion into the scheme, the categories of feature that could be incorporated into such a scheme will be considered. Since this is the first scheme of its kind, it will be wisest to include within it a range of different types of features to capture, for example, proportions, structural features, shapes and symmetry of letters. These categories will be informed by those used in the schemes published for use in other contexts which are summarised in Chapter 3, but it is intended that the particular features used and the combination of them will be effective in the exploration of handwriting development in children in general and to have the potential to answer the specific questions posed at the end of Chapter 2.

In this chapter, the new coding scheme will be applied to some samples of handwriting from a relatively small number of participants with the primary aim of determining whether or not separate pieces of handwriting from the same author are identified as more similar to each other than they are to pieces of handwriting from other writers. This is the question posed in section 2.8.1 and whilst it is posed as a question, it is the case that if handwriting is a random process with little commonality in the features used by a given person, then clearly demonstrating any sort of developmental changes will be impossible. In reality, it is expected that there will be some general constancy of feature use at a given time but that there will be variations within that and it is the capability to measure this variability using the coding scheme, within an overall constant framework for a given writer, that this the primary aim of this preliminary study.

There are two secondary aims of this initial study. The first is to assess the findings with a view to making the scheme as efficient as practicable by, where justified, discarding any features that are not particularly contributing to the primary aim referred to above and any revision of the scheme will reflect the need to use it for the larger cross-sectional and longitudinal studies that are described in Chapters 5 and 6. Within this context, the study reported in Chapter 5 will involve set handwriting tasks including writing at different speeds and thus at least some of the retained features should have the potential to show changes of handwriting variability when writing more quickly or more neatly. In this preliminary study, the handwriting samples will all be produced under fairly similar "classroom" circumstances. Hence, determining whether some features might reveal task-related effects will be based on imprecise information.

The other secondary aim is to determine whether there is a preliminary indication that the scheme does have the potential to distinguish between the handwriting of children of different ages. However, with the small number of participants in this preliminary study, any such findings will be indicative only and not capable of producing results of statistical validity.

4.2 The coding scheme

4.2.1 Criteria for developing a handwriting coding scheme to show development in children

Having considered various aspects of handwriting acquisition and development in the previous chapters, a new scheme needs to be devised that has the potential to show between writer and within writer variation in children's handwriting over the period of its development.

In Chapter 2 the ways in which handwriting can vary were described and the use of such variability in some published schemes considered in some detail in Chapter 3. Whilst these schemes may show between writer variability (and most of them are intended to do just that because of their forensic relevance), it is not necessarily the case that such features will show developmentally interesting trends of use, as reflected in their variability in children's handwriting over time. For this reason, it is sensible to choose features, based on the kinds of features used in other contexts and based on the author's experience as a handwriting expert, which might reasonably be expected to show trends in their use in children's handwriting.

4.2.2 General requirements for the coding scheme

The new coding scheme will need to be a practical tool that can be used efficiently and reliably. Its efficiency will be reflected in the number of features that are retained; the time-consuming process of scoring will lead to a need to compromise between the amount of time taken and the results obtained in terms of the primary aim of this evaluation.

The scheme needs to be applied in the same way across all participants, bearing in mind the wide age range (and ability range) involved. Thus, as far as possible, the features used should be reasonably uninfluenced by matters such as neatness or handedness of the writer.

For the purposes of this research it is necessary that the features chosen should, in principle, show some of the following characteristics in order that within-writer, between-writer and developmental variations can be assessed. Firstly, features should not vary randomly across the writings of participants across all age groups – if this were the case, then no meaningful information could be obtained to address variability and thus be able to distinguish between writers (Hardcastle et al., 1986; Hardcastle et al. 1990). This requires experience of studying the handwriting from many individuals, experience that the author possesses as a handwriting expert. That does not mean that some features cannot be random either in the handwritings of some individuals and/or in the handwritings of participants of certain age groups. Either of these latter possibilities could occur without contradicting the purpose of the scheme as feature use can be stable in some writers but not in others for that same feature as Muehlberger found when analysing forms of the letter pair t-h (Muehlberger et al., 1977).

Secondly, features should vary between writers and within writers to varying degrees across different age groups. This would allow for the possibility that developmental trends in different individuals can be shown to vary, providing evidence of a variety of departures from the taught style. There is no literature describing specific changes in letter forms during the development of handwriting. Rather, as has been noted in the previous chapter, developmental changes are described in more general terms such as appropriate letter forms (but not specifying shapes of individual letters), alignment and fluency.

Thirdly, the features should be *relatively* stable in the handwriting of a given individual at a given point in their development. If a feature shows a lot of variation in use from one occasion to another within a short space of time, then its use tends towards random and this is of less value than a feature that shows some stability of use. Others have found within writer feature variability to vary between writers (for example (Muehlberger et al., 1977)). In other words, for a given feature, it may be consistent in one writer but highly variable in another writer. Changes in within-writer variability over longer periods of time are of interest as they provide evidence of developmental change and individualisation of handwriting.

And finally, in the cross-sectional study to follow (Chapter 5), different tasks will be given to participants. With this in mind, some of the features chosen are ones that have the potential to show task-dependent variation (in particular, writing at different speeds) as discussed in general terms of legibility by Graham and colleagues (Graham, Weintraub, & Berninger, 1998).

Consideration had to be given to the sort of scoring to use. For example, each feature could be given a number of sub-categories, which in turn could be given sub-sub-categories and so on. Eldridge et al., (1984) subdivided the letter t into no fewer than twenty five sub-categories within nine categories relating to various features such as the number of strokes and the formation of the top and bottom of the upright.

However, a simpler, and hopefully therefore more robust, approach would be to use a binary scheme. That is, each feature can be designated as present or not present. This has the additional advantage that the time required to decide on each classification is reduced and the level of observer interpretation is kept to a minimum, thereby increasing the likelihood that independent observers will tend to score features similarly (see section 4.7 below). Binary schemes are only encountered in published handwriting assessment schemes in a small number of cases, for example in the Children's Handwriting Evaluation Scale, assessments of appropriate letter form, slant consistency, rhythm, spacing consistency and general appearance are either scored 1 or 0 (Phelps et al., 1985). Such categories are not adequate to track detailed and subtle letterform changes in handwriting style development as required by this research.

In order to create a scheme based on the general criteria outlined above, another issue was to decide on the style of handwriting to be studied, bearing in mind the participants are children, some still at the very earliest stages of learning to write. The options were lower case lettering or block capital lettering. The main reason why block lettering was not considered to be appropriate was that young children tend to be taught lower case lettering first and only move on to block capitals over time. As a result, the younger children could not be expected to produce reasonable sized samples written in a block handwriting style. Even if the children could produce a sample of such handwriting, it would probably not be as fluent and perhaps not as consistently written as a sample written in the more familiar and practised lower case lettering.

As mentioned above, the coding scheme needs to include a range of categories of feature type since at this stage it is not known what kinds of developmental changes different categories of feature will demonstrate. Feature types that might show within-writer, between-writer or developmental variability include allograph choice (the overall form of the letter, for example writing the letter e conventionally or as a Greek e) (Nicholson, 1984), letter shape (the detail of curve and stroke production, for example writing the letter o as a circle or as an ellipse), letter proportions (such as the symmetry of the crossbar in the letter t) (Muehlberger et al., 1977) and precision of placement (for example, starting the letter o to the right or left of its midpoint).

4.2.3 The coding scheme

With such classes of feature in mind, a number of particular features were put forward and are shown in Table 4.1. The features in the coding scheme were chosen on the basis that they (i) occurred frequently in English, (ii) showed one of the general handwriting feature criteria discussed at 4.1 above, such as symmetry, proportion or structure features (iii) could be clearly defined and then coded in a binary manner (feature present or absent) as unambiguously as possible. The particular letters and defined features used in the scheme used in this research are not intended to be the only possible combination of features that could be used. Rather, they are representative of a much larger population of possible features that could have been chosen and this aspect will be discussed in the context of further work in Chapter 7.

Perhaps the simplest type of feature is the choice of allograph. For example, feature a1 in Table 4.1 shows two alternatives of the form for the letter a. As a taught letter, the conventional form shown by a1 type 1 is by far the most widely encountered, and it is generally (from my own experience as a handwriting expert) in the years of adolescence that the adoption of alternative forms tends to occur. The expectation might be that any transition from one form to the other will take some time to become complete, and indeed may never become complete with two or even more variants being used interchangeably.

Letter shape is probably largely a reflection of the style of the handwriting although it may have a dynamic element to it which may therefore reflect motor control to a degree. An example of letter shape is the curved elements in letters, such as the tendency to write the letter o either as a circle or in a more elliptical form (feature o2), or the symmetry of the curved part of the letter n (feature n1), or the relationship of the changes of direction in the curve in the letter s (feature s2). These could all be worth monitoring as a writer develops a style that becomes either more angular or more rounded, for example, a change that is perhaps more likely to occur in later years (as opposed to changes of skill which may be more likely in the early years).

Table 4.1 The coding scheme*

Feature descriptor	Type 1	Type 2
a1 - standard allograph -	a	a
a2 - low tail retrace -	a	a
a3 - closed loop -	a	a
a4 - upward initial pen movement -	a	a
c1 - low point of curve -	c	c
d1 - proportionately tall loop -	d	d
d2 - flattened loop -	d	d
e1 - standard allograph -	e	ε
e2 - high curve bisection -	e	e
e3 - upward axis -	e	e
f1 - tail turns to right -	f	f
g1 - short tail -	g	g
i1 - i dot present -	i	ı
i2 - high dot -	i	i
i3 - dot to right -	i	i
k1 - one penstroke -	k	k
l1 - looped -	l	l
m1 - high centre -	m	m
m2 - pointed tops -	m	m
n1 - curve high to right -	n	n
n2 - initial downstroke -	n	n

o1 - starts to right -		
o2 - tall and narrow -		
p1 -curve high to right -		
r1 - open retrace -		
r2 - low retrace -		
s1 - script style -		
s2 - shallow centre axis -		
t1 - crossbar longer to right -		
t2 - high crossbar -		
th1 - t shorter than h -		
u1 - tail present -		
u2 - lowest point to right -		
w1 - left side wider -		

* These descriptors will be used throughout the thesis. A more detailed explanation of the features can be found in Appendix 2.

Letter proportion is likely to be of interest as shown by various studies. For example, the proportion of the letter g descender in relation to the rest of the letter (feature g1) or the height of the t crossbar on the upright (feature t2) (Muehlberger et al., 1977) are included. There are many other such features that could be defined. Also, there may be differences in left/right symmetry of certain letters or letter elements - for example the letter t crossbar (feature t1) or the symmetry of the letter w about its central upstroke (feature w1). There are many inter-letter relationships that could be explored, but by far the commonest pairing in the English language is the letter pair th. The relative heights of these two letters, when paired in that order, form a category (feature th1), although many other parameters can be derived from this letter pair (Eldridge et al., 1984; Muehlberger et al., 1977).

The precision of placement is likely to be a category reflecting, at least in part, the fine motor control of the writer and the related factor of handwriting speed, since it is likely that precision of execution will deteriorate with increasing writing speed. Features that may have placement components include the position of the i dot (features i2 and i3). This can be shown by the height of the dot above the main letter or the lateral position of the dot to the left or right of the main part of the letter which in turn might relate to the speed of the handwriting.

The coding scheme devised contains examples, therefore, of several different categories of feature that have the potential to show variability in the handwriting of individual children and within groups of children of different ages. The next step was to apply the coding scheme to pieces of handwriting from some children of different ages and to refine the scheme in the light of that experience before using it in the two larger studies which are aimed at providing answers to the questions posed at the end of Chapter 2.

4.3 Method

4.3.1 General

For the purposes of this preliminary study, it was decided to use schoolwork produced during normal classroom activities. Appropriate parent/guardian permission was obtained. Pieces of handwriting that had been produced in normal school work by the participants (who were unaware that they were to be the subjects of this study at the time) were used. This should ensure that the handwriting is naturally produced. Although the decision to use schoolwork was taken, one disadvantage is that pieces all have different texts and, for the less frequently occurring letters of the English language, it is unlikely that they will be present in sufficient numbers to assess their variability, even in quite a long piece of work. For this reason, the features of the initial scheme are focussed on the more frequently encountered letters. This may have an additional advantage in that these are the very letters that are more likely to have been well practised by the younger writers in particular.

The number of letter features analysed per piece of text will clearly have implications on the time taken to analyse it, although the examination of insufficient different letter features might prevent a reasonable overall description of the changes that occur. The optimal performance of the scheme can be set as a result of balancing various competing considerations. An elaborate, complex system requiring the classification of many examples would take too long and be too unwieldy. In contrast to this, the scheme does need to show some subtle differences of letter formation that may change during the development from taught to mature style, and by their very nature, subtle differences tend to be more difficult to define and measure. The scheme described in Table 4.1 above is intended to achieve the right balance of these needs.

The central focus of this research is the study of variability. As a result, it was necessary to examine sufficient instances of letter use so as to be able to establish the extent of that variation. For this reason, it was decided to examine the first twenty instances of each feature in a piece of handwriting or as many as were present if fewer than twenty.

Given the very large number of observations that are going to be made and the level of interpretation required by the observer, it is essential that the classifications are as unambiguous as possible and that they are robust in terms of rater reliability. It is important that the scheme is not too time consuming to use, with features being amenable to rapid discernment either with the unaided eye or with a modest amount of magnification and/or measurement (±0.5 mm achievable with a hand lens). The features in Table 4.1 are intended to fulfil these criteria too.

4.3.2 Design

In this study, three pieces of writing from fifteen participants from three different age groups (7/8, 11/12 and 15/16 year olds) were examined. These ages were chosen to reflect writers who had recently learned the basics of handwriting, those whose handwriting was close to maturity and an intermediate group whose handwriting might show elements of the transition from one phase to the other. The sample size was small since the purpose of this preliminary study was exploratory and given the large amount of data that would be collected even from this small number of participants (potentially 45x34x20 = 30,600 individual coded scores), this would be sufficient to determine whether or not the scheme had the potential to fulfil its purpose.

For each piece of handwriting, the 34 features described in Table 4.1 were scored for up to a maximum of twenty times.

4.3.3 Participants

Fifteen participants were chosen - five seven year olds (ranging from 7;6 to 7;11 - 2 girls, 3 boys), five eleven/twelve year olds (ranging from 11;7 to 12;5 - 3 girls, 2 boys) and five fifteen/sixteen year olds (ranging from 15;9 to 16;4 - 3 girls, 2 boys). The children within the same age group attended the same school, but each age group studied at a different school, all within a few miles of each other in central England. From this it is likely that the teaching regimes used would be generally similar from school to school although local variations (such as teacher preference and degree of tuition) are almost certain to occur. Nonetheless, it is unlikely that any differences would systematically affect significant numbers of the 34 features in the scheme which are themselves chosen to reflect a number of different categories of feature (such as symmetry and allograph choice) and which will, in later chapters, be used to study changing handwriting habits.

The selection of participants was done with the assistance of teaching staff at the schools each of whom had the general background and purpose of the study explained in summary form to them. Selection was based on a general subjective view of the handwriting of the participants with a mind to having an approximately even mix of boys and girls. The intention was to have a mix of samples reflecting characteristics such as neatness/scruffiness, skilful/less skilful, round/spiky and consistent/variable. Such samples provide a range that may test both interpretive skills of the observer and the robustness of the scheme. Criteria such as educational standard (unless markedly low), handedness and any other potential selection measures were not used. The reason for this was that the scheme is intended to reflect developmental changes over time irrespective of the starting point for each writer or group of writers, rather than identifying features associated with, say, handedness at a particular time.

4.3.4 Sampling procedure

Three samples of writing from each participant were selected with the assistance of teaching staff. The intention was that the teacher should select pieces of work as being typical of their pupils' everyday writing, the samples all having been written within a few weeks of each other with no knowledge on the part of the participants that their writing would be subjected to scrutiny. In addition, each piece of handwriting needed to be reasonably large to contain a fair number of letters that can be coded, albeit no precise cut off point was used since a pragmatic approach of using what was readily available and reasonably representative was used.

The samples of handwriting were collected from the schools after negotiation with teaching staff so that the work was not away from school at any important times (such as for assessment purposes). Typically, the handwriting samples were returned within about one month.

4.3.5 Scoring procedure

One piece of writing was scored at a time, starting with the feature a1 - standard allograph - and finishing with w1 - left side wider. In order to minimise confusion, one feature was scored at a time even when a letter had multiple features. For example, the feature a1 - standard allograph - was scored for the first twenty occurrences, then the feature a2 - low tail retrace - was scored and so on.

For some writers, particular features were scored readily just from unaided observation, but in many cases where the present/absent (Type 1/Type 2) boundary was approached for a feature, some magnification was required and this was supplied with a simple hand lens and graticule accurate to about 0.5mm. If a feature's presence could not be shown reliably using this, then it was treated as absent. Typically, the scoring of all 34 features in one piece of handwriting would take 2-3 hours.

The score for each feature was recorded as present or absent on a pre-printed grid, with all 34 features for a given piece of handwriting on the grid. The number of times that the feature was present as a proportion of the scored instances (up to a maximum of twenty) was recorded.

The scoring of the 45 pieces in this study was done in a cyclical sequence so that two pieces from the same writer were not scored consecutively. The reason for this was to avoid accidental memorising by the scorer of writing habits in the same writer.

An important aspect of a coding scheme is that it should be usable by others after any suitable instruction about its implementation. In this research, it was decided to test this aspect by using a second rater to score the features retained following an assessment of the initial coding scheme described in this chapter (see section 4.7 below). The second rater was not a handwriting expert but received sufficient instructions from the author to ensure that an understanding of the classifying process for each feature was understood using ten randomly chosen examples from within the many samples available.

4.4 Results

4.4.1 Descriptive statistics

The descriptive statistics from the coded scores for all 34 features from the 45 pieces of handwriting examined are summarised in Table 4.2.

Table 4.2 showing descriptive statistics of data in preliminary study of coding scheme (n=45 from 15 participants)

Feature	Mean (St.Dev)	Median (IQR)	Mean frequency of letter use	Discriminant function (see 4.6 below)
a1	0.99(0.06)	1.00(0.00)	19.3	0.025
a2	0.05(0.11)	0.00(0.05)	19.3	-0.031
a3	0.69(0.28)	0.70(0.42)	19.3	-0.092
a4	0.57(0.41)	0.65(0.90)	19.3	-0.265
c1	0.69(0.28)	0.75(0.53)	11.3	0.061
d1	0.49(0.43)	0.31(0.95)	14.8	-0.137
d2	0.50(0.35)	0.45(0.60)	14.8	-0.081
e1	1.00(0.01)	1.00(0.00)	19.8	0.027
e2	0.29(0.32)	0.15(0.50)	19.8	-0.059
e3	0.90(0.13)	0.90(0.15)	19.8	-0.003
f1	0.07(0.17)	0.00(0.00)	8.9	0.004
g1	0.25(0.28)	0.15(0.46)	11.0	0.013
i1	0.89(0.27)	1.00(0.06)	15.7	0.047
i2	0.55(0.34)	0.50(0.64)	15.7	0.051
i3	0.46(0.28)	0.50(0.43)	15.7	0.017
k1	0.42(0.47)	0.00(1.00)	6.8	0.056
l1	0.06(0.11)	0.00(0.08)	16.4	0.033
m1	0.06(0.17)	0.00(0.00)	11.0	0.023
m2	0.13(0.31)	0.00(0.00)	11.0	0.046
n1	0.46(0.29)	0.40(0.51)	18.0	0.013
n2	0.94(0.17)	1.00(0.00)	18.0	-0.025
o1	0.77(0.34)	0.95(0.32)	18.5	-0.085
o2	0.27(0.24)	0.21(0.39)	18.5	0.064
p1	0.45(0.36)	0.38(.65)	9.1	0.067
r1	0.11(0.17)	0.05(0.19)	16.0	0.058
r2	0.73(0.29)	0.88(0.52)	16.0	-0.063
s1	0.93(0.13)	1.00(0.10)	17.8	0.039
s2	0.72(0.28)	0.80(0.42)	17.8	-0.043
t1	0.78(0.24)	0.89(0.41)	18.8	-0.011
t2	0.66(0.25)	0.70(0.30)	18.8	-0.039
th1	0.38(0.32)	0.27(0.46)	11.9	0.000
u1	0.91(0.28)	1.00(0.00)	13.0	0.021
u2	0.11(0.15)	0.05(0.20)	13.0	-0.045
w1	0.37(0.28)	0.40(0.39)	11.9	-0.017

From Table 4.2 it can be seen that some features occur less frequently than others, as expected, and that some features have markedly skewed distributions. The frequency of letter use could have been predicted to some extent by referring to published tables showing frequencies of letter use. However, it was possible that school children, particularly younger ones, who have a more restricted vocabulary, may not show typical letter use. The possibility of excluding features on the basis of the frequency of letter use or on the basis of skewness was considered at this stage. However, an alternative approach was adopted, namely to use all of the data collected in a cluster analysis and to see which features showed the greater discriminant functions in that analysis and then, at that stage, to combine those findings with letter use frequencies to reduce the number of features to be carried forward into the larger studies in Chapters 5 and 6.

4.4.2 Handwriting individualisation

At the end of Chapter 2, the question was posed as to whether handwriting samples from an individual are more similar to one another than to samples from other writers. This was to be considered in a developmental context and one possibility would be that in younger children subjected to similar teaching regimes pieces of handwriting from different children could be similar one to another whereas in older children this might be less likely due to maturation of an individual style of handwriting. The primary aim of this preliminary study was to assess the extent of within writer similarity in the context of between writer similarities in participants in the three age groups. In order to do this, a method of analysis is required that can find patterns of similarity between different features used and the method of choice was cluster analysis. In the cross-sectional study reported in Chapter 5, the analysis of the much larger data set from 144 participants will follow a different approach and will consider trends in feature use and variability and will attempt to find common ground across features by using principal components analysis. The data from the small number of participants in this preliminary study are too limited to follow these approaches in order to attain meaningful results.

Cluster analysis is the method of choice when looking for patterns of association or disassociation in complex data and for that reason is essentially an exploratory process. It clusters together entities that are more similar to each other and dissimilar to those other entities that may form another cluster. Further, using the associated discriminant function analysis, the relative contributions of the scored features to the clustering patterns can be determined. Since one of the tests for the scheme is to show within writer similarity (which can be shown by clustering of pieces from the same writer) and at the same time a degree of within writer difference (but not so different that the writings stop clustering), this method is a good way of assessing the categories in combination.

There is a variety of ways in which clusters can be formed. One general way is to use agglomerative methods which essentially work from the bottom up, looking at the data relating to each individual example and finding which two examples are the most similar, combining those two into a single entity (cluster), and then repeating the process until all of the original individuals have been drawn into clusters.

There are a variety of clustering algorithms that view the data in different ways. Some use the nearest elements and some the furthest elements as the basis for clustering whereas others use the centroid values (determined as the average point in multi-dimensional space) as the basis of clustering. In order to compare the outcomes from a number of clustering algorithms, a measure is needed to compare the outputs. Two measures that could be used are (i) the capacity for the three pieces of handwriting from the same individual to be nearest neighbours in the resulting dendrogram of the cluster pattern (this would address a primary consideration of this preliminary study) and (ii) the extent to which participants from the same age group are adjacent to each other in the dendrograms, in other words the number of clusters formed by each age group (a secondary consideration of this preliminary study).

Given the many options for calculating cluster relationships, five were chosen which reflected a range of approaches to the clustering process. These were (i) between groups linkage, (ii) centroid linkage, (iii) simple linkage, (iv) complete linkage and (v) Ward's linkage. In each instance, the distances were based on the squared Euclidean distance. The dendrograms for the five methods of clustering are found in Figures 4. a-e. From these dendrograms it can be seen that the numbers of non-adjacent participants and the number of clusters for each age group are as shown in Table 4.3.

Figures 4.1a-4.1e showing dendrograms obtained using different clustering algorithms (4.1a using between groups linkage; 4.1b using centroid linkage; 4.1c using single linkage; 4.1d using complete linkage; 4.1e using Ward's linkage

Figure 4.1a

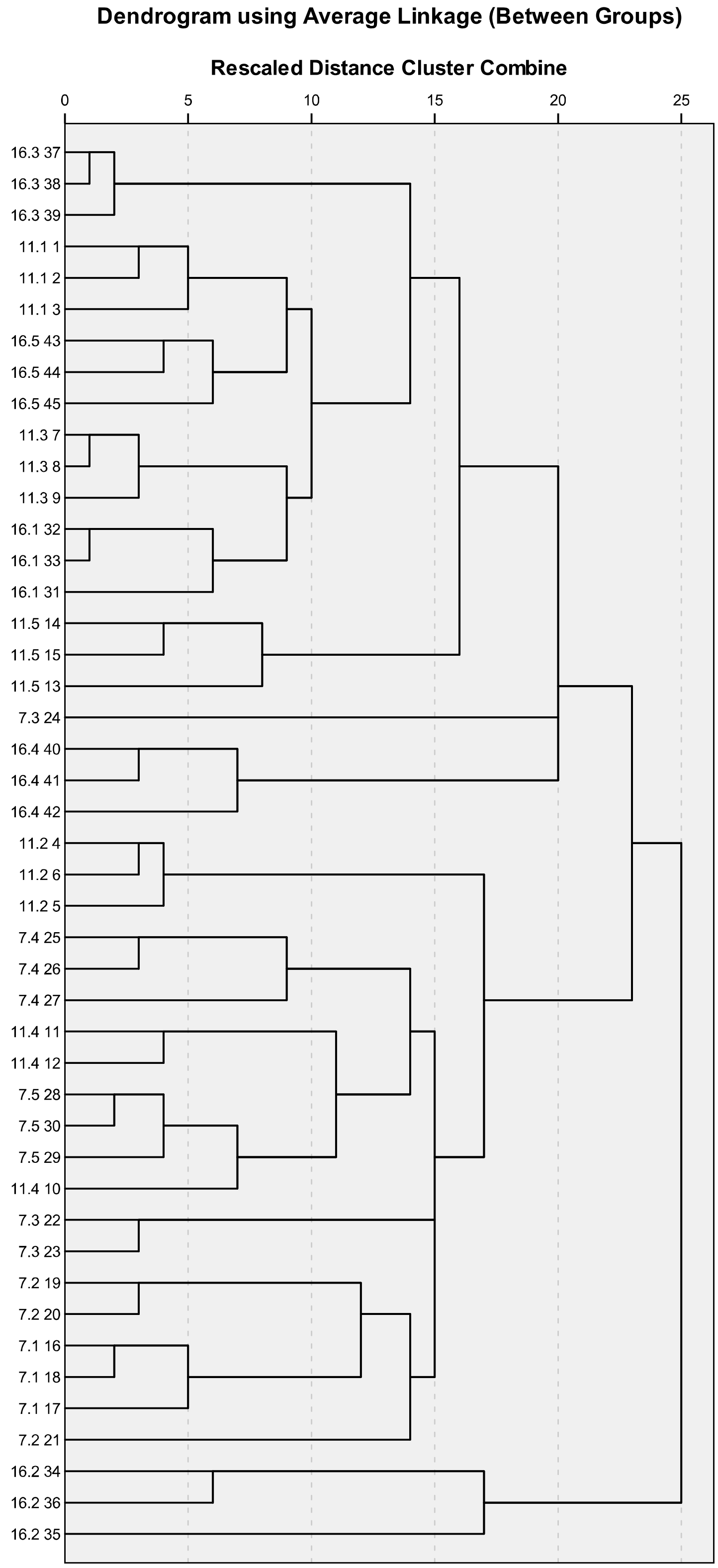
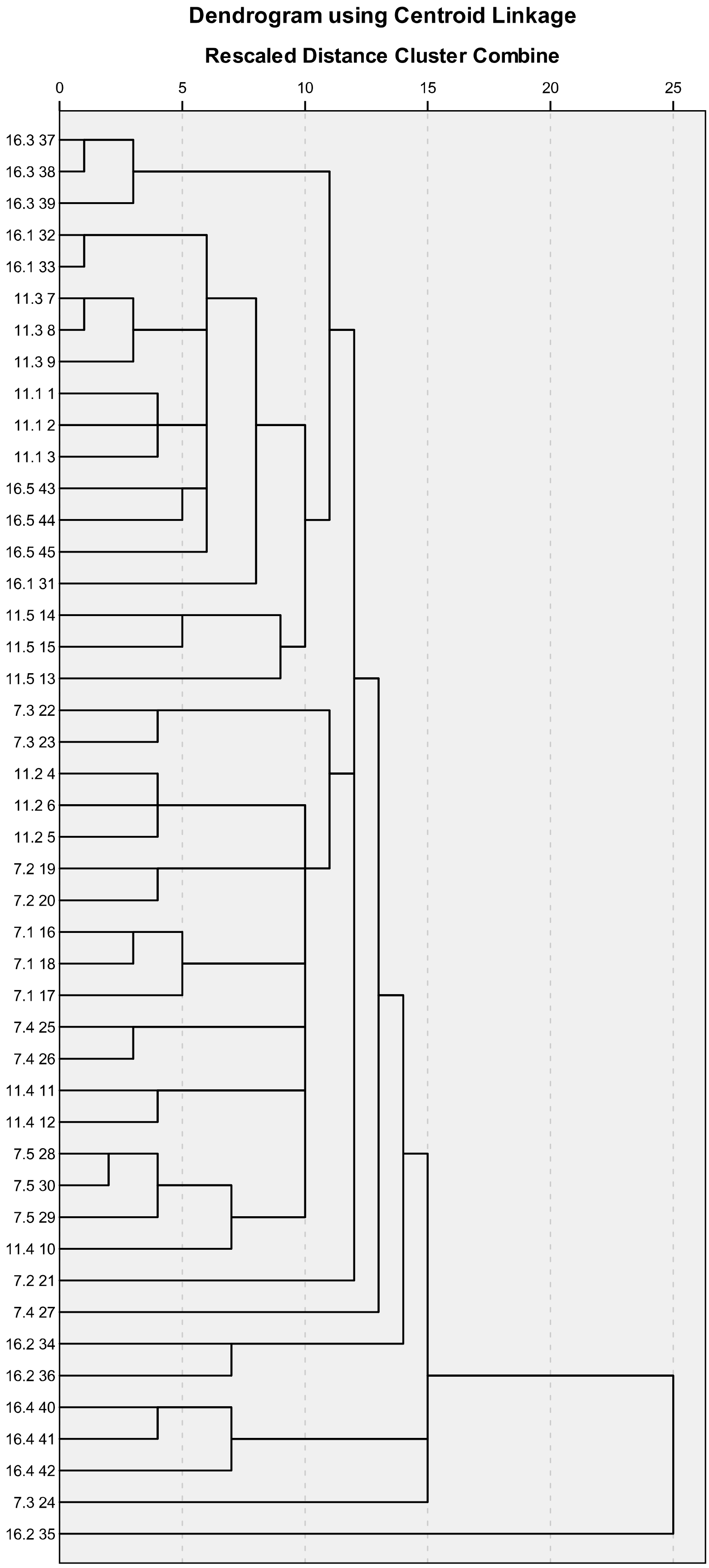


Figure 4.1b



Dendrogram using Centroid Linkage
Rescaled Distance Cluster Combine
0
5
10
15
20
25
16.3 37
16.3 38
16.3 39
16.1 32
16.1 33
11.3 7
11.3 8
11.3 9
11.1 1
11.1 2
11.1 3
16.5 43
16.5 44
16.5 45
16.1 31
11.5 14
11.5 15
11.5 13
7.3 22
7.3 23
11.2 4
11.2 6
11.2 5
7.2 19
7.2 20
7.1 16
7.1 18
7.1 17
7.4 25
7.4 26
11.4 11
11.4 12
7.5 28
7.5 30
7.5 29
11.4 10
7.2 21
7.4 27
16.2 34
16.2 36
16.4 40
16.4 41
16.4 42
7.3 24
16.2 35

Figure 4.1c

Dendrogram using Single Linkage

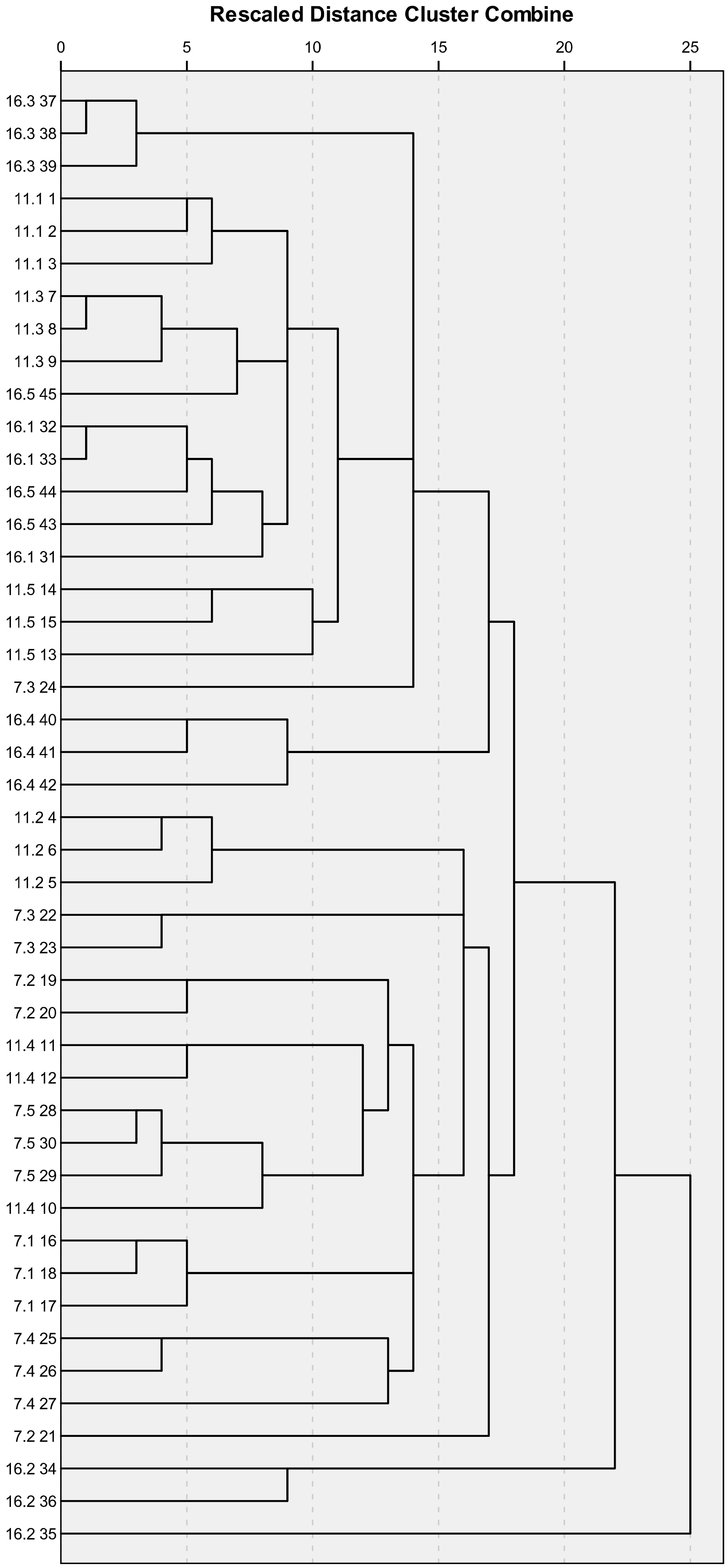


Figure 4.1d

Dendrogram using Complete Linkage

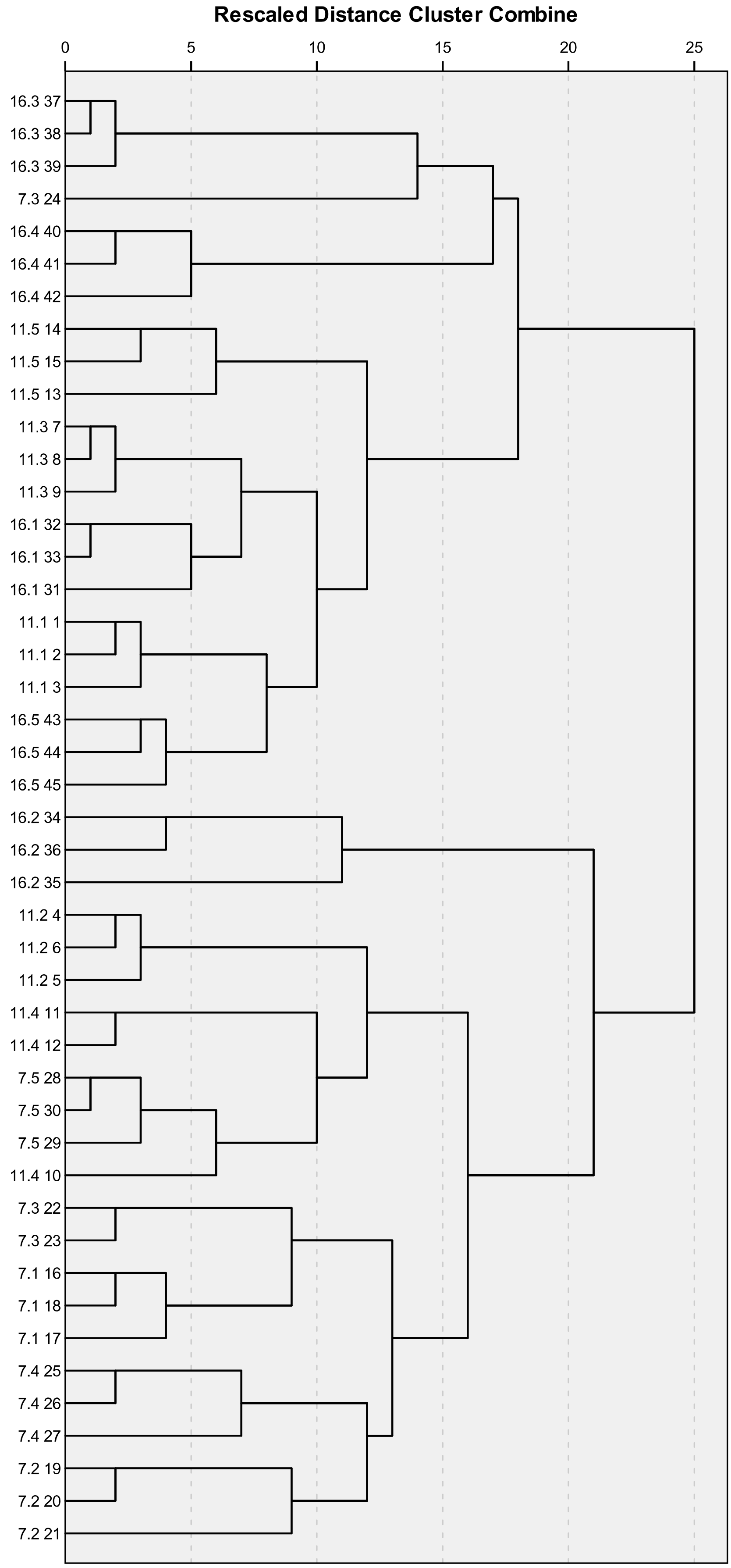


Figure 4.1e

Dendrogram using Ward Linkage

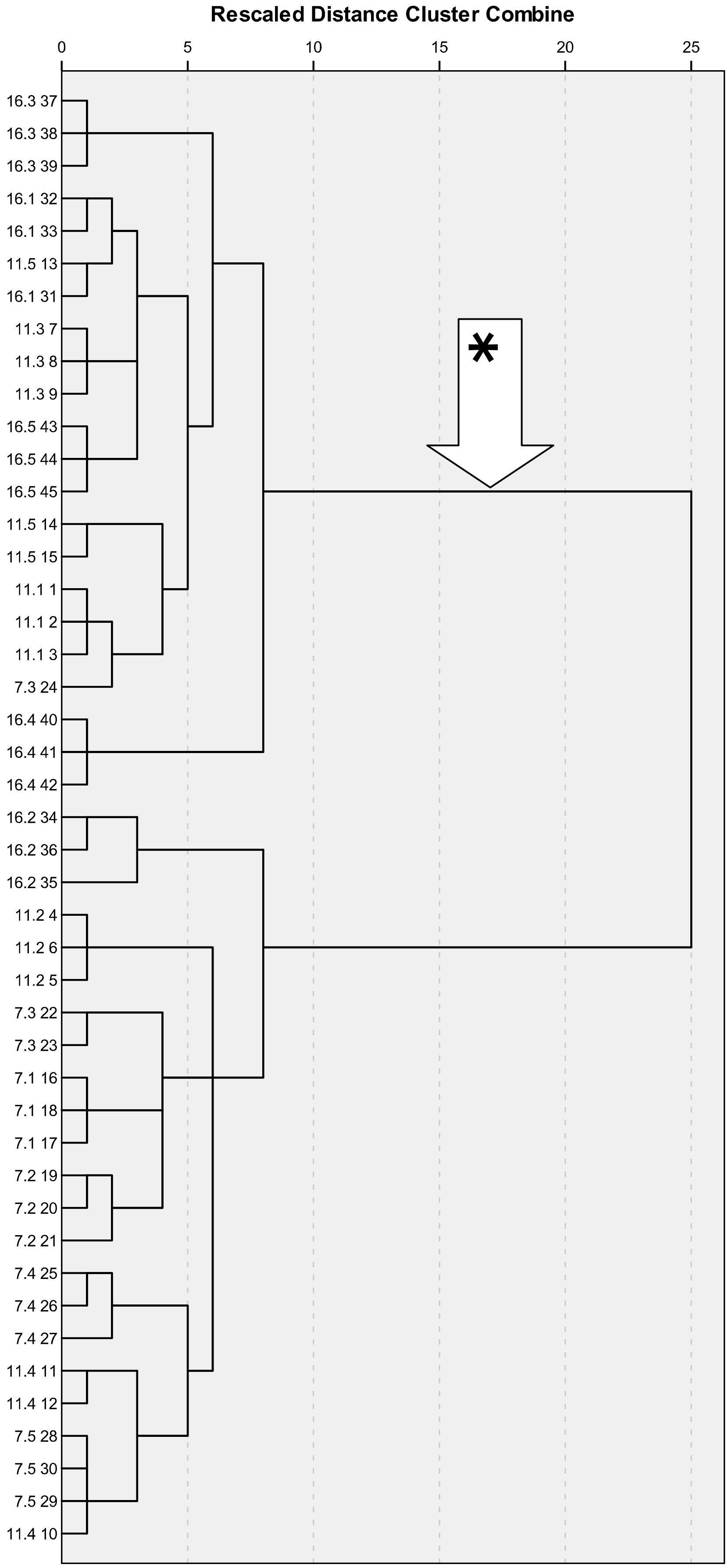


Table 4.3 showing participant clustering and age group clustering patterns

Cluster algorithm	Participant clustering[1]	Age group clustering[2]
Between groups	3	5.0
Centroid	6	4.67
Single linkage	5	4.33
Complete linkage	2	3.67
Ward's	3	4.0

[1] measured by number of instances in which a piece of handwriting from a participant is not adjacent to another from the same participant

[2] measured by the average number of clusters capturing all fifteen pieces of handwriting in each age group

The first comment to make about the findings in Table 4.3 is that even using a number of different methods for calculating cluster membership, the number of instances in which a piece of handwriting from a participant is not adjacent to one or other of the other two pieces of his or her handwriting is small. Related to this, there is a consistent tendency for the pieces of handwriting from each age group to cluster together. This underlying commonality of the results using different clustering algorithms, suggests that the coding scheme is producing patterns of data that are reasonably robust in that even when examined using different clustering methods, there is still a reasonable similarity of linkage found between the pieces of handwriting from the same individuals and from individuals of similar age.

The second comment is to determine which clustering algorithm is most appropriate to this research. On the face of it, of the five methods tried here, complete linkage gives the 'best' result with only two pieces of handwriting non-adjacent to other pieces from the same writer and with all fifteen pieces in each age group being, on average, captured in 3.67 clusters. The next best result was obtained using Ward's method and the worst being the centroid method. However, examination of the dendrograms themselves shows that the Ward's method produces a clearer pattern of triplication of pieces from the same writer and also the rescaled cluster distances are larger in Ward's method which is indicative of more profound differences between clusters. Whilst there is no clear cut reason to choose one algorithm over another in this instance, the clustering pattern obtained by using Ward's method gives cleaner triplicates from the same writer and since this is a primary objective of the coding scheme, Ward's method was chosen for the remainder of this thesis. Ward's method calculates the 'distance' between the multidimensional points of data using the squared Euclidean distance, evaluates the loss of information that results from each of the clustering steps and checks this loss for each possible clustering, only clustering in those instances which minimise the information loss.

Further, whilst these various different methods have their proponents, Ward's method is widely regarded as an efficient method and tends to produce clusters of approximately similar size which may be expected to more fairly reflect the spectrum of feature use to be found in a group of individuals (Everitt, 1980).

Cluster analysis also has the potential to illuminate a secondary aim of this analysis, namely, by use of discriminant function analysis, to examine the contribution that each feature makes to the discrimination process (clustering), taking into account the whole data set. It creates a series of weightings for each feature, indicating its relative contribution to the cluster pattern. These can be used in the second part of this analysis when determining which features to retain and which to discard.

4.4.3 Cluster nomenclature

In order to distinguish between different clustering patterns, the following nomenclature was devised.

In the dendrogram showing the results of a cluster analysis, the clusters at the left hand edge will be referred to as Level One Clusters, the next level up will be referred to as a Level Two Cluster and so on.

If a Level One Cluster contains all of the pieces of handwriting from a given writer (in this case three pieces of handwriting) and no other pieces of handwriting from another participant, this will be called a Perfect Cluster.

If all of the pieces of handwriting from a given writer are adjacent to one another in the dendrogram but are not all in a Level One Cluster, this will be called an Imperfect Cluster.

If all of the pieces of handwriting from a given writer are in the same Level One Cluster but there are other pieces in that cluster from at least one other writer, then this will be called a Mixed Perfect Cluster

Any other pattern of clustering will be called Unclustered.

These terms will be used throughout the remainder of this thesis when discussing clustering patterns.

The clustering at Level One will be taken to be an indication of the largest degree of similarity revealed by the clustering algorithm used. Successively higher level clusters will be taken to show progressively more generalised degrees of similarity to the point where major differences are indicated by large, high level splits in the cluster pattern (for example, see Figure 4.1e asterisk).

4.5 Discussion of cluster analysis

4.5.1 Initial evidence for individual handwriting styles

In section 2.8 of Chapter 2, the purpose of much of this research was shown to be the variability of handwriting and how this changes within individuals and between individuals at different developmental stages. For example, there might be a tendency for pieces of handwriting from a given child to be more similar to other pieces of handwriting from that same child than from his or her peers and that the extent of between writer variation will increase as the children get older.

The cluster dendrogram in Figure 4.1e provides strong support for the first part of this prediction because, of the 45 pieces of writing shown in the dendrogram, 41 (91%) are adjacent to another sample from the same writer.

Looking at the clusters at the extreme left of the dendrograms (the Level One Clusters), it can be seen that eleven of the fifteen participants have their three pieces adjacent (participants 7a, 7b, 7d, 7e, 11a, 11b, 11c, 16b, 16c 16d and 16e). However, of these only seven (participants 7a, 11a, 11b, 11c, 16c, 16d and 16e) form Perfect Clusters with the other four participants forming either Mixed Perfect or Imperfect Clusters.

The final four participants' pieces are Unclustered, although none of these show each piece of handwriting in three different clusters; they each show two of the three pieces in the same Level One Cluster with the third piece in another Level One Cluster.

Despite the minor (in comparison to a random cluster pattern) imperfections of the clustering patterns found, it can be seen that the primary purpose of this initial study has been fulfilled. Pieces of handwriting from the same participant are indeed much more likely to cluster together than they are to be associated with pieces of handwriting from some other person. This suggests that the writers, even at an early age, show a tendency towards having their own style of handwriting. However, it is the *extent* to which these styles differ from their peers that will need to be determined from the larger studies described in Chapters 5 and 6.

At the end of Chapter 2 the possibility was put forward that there might be a tendency for clustering of handwriting from the same participant to be stronger in older children than in younger children. To look at this, it can be seen from the dendrogram, Figure 4.1, that none of the seven year olds, three of the eleven year olds and four of the sixteen year olds produced pieces of handwriting that formed Perfect Clusters. With only five participants in each of the three age groups, however, this finding can only be described as providing some initial, tentative support for the stronger clustering at older ages. Potentially stronger support will come from the much larger cross-sectional study described in Chapter 5.

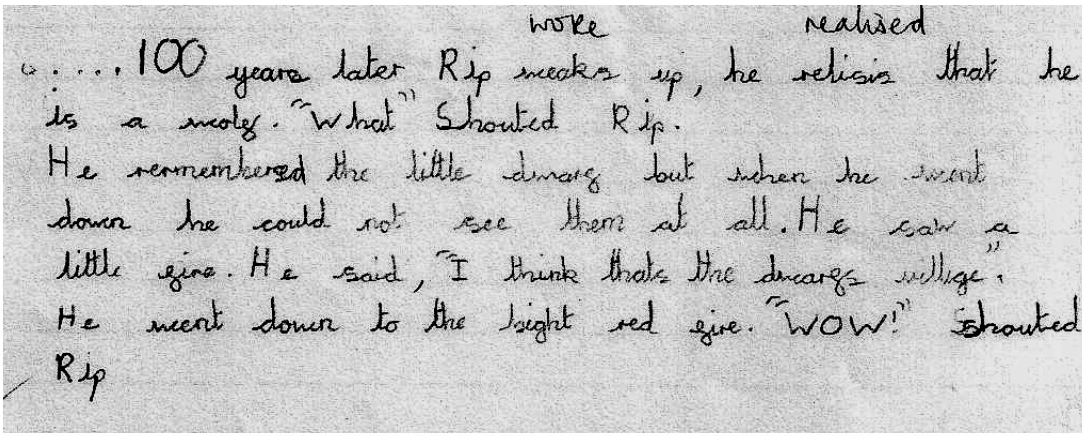
4.5.2 Initial evidence for age differences of handwriting styles

At the end of Chapter 2, the idea that children's' handwriting developed with age was discussed. One possibility for this might be that within writer clustering is stronger as children get older but that individuals of similar age do not necessarily have to cluster with like-aged colleagues. An alternative is that there is some tendency for older children to tend to cluster with peers of similar age and not with those of differing ages.

Two main branches of clusters are apparent from the dendrogram shown in Figure 4.1e and which are indicated by the asterisk. One branch includes 12 of the 15 samples by 16 year olds and the other branch includes 14 of the 15 samples by 7 year olds. The fifteen samples by the 11 year olds are split 9:6 between the older and younger clusters respectively. This provides strong preliminary support for the view that samples from children of similar ages tend to cluster with one another, particularly at the younger and older ages.

What this age division represents in reality can be visualised by means of finding the 'central' point (centroid) for each of the two main clusters and determining which piece of handwriting is closest to each of the two centroids and taking this to be representative or typical of the handwriting in that cluster.

Following this process, Figures 4.2 and 4.3 are written by the participants whose writing is the most typical for each of the two clusters.



woke realised
....100 years later Rip weaks up, he relisis that he
is a woly. "What" Shouted Rip.
He remembered the little dwarg but when he went
down he could not see them at all. He saw a
little gire. He said, "I think thats the dwargs willge".
He went down to the bight red gire. "WOW!" Shouted
Rip

Figure 4.2 Extract from handwriting of participant nearest centroid value of cluster 1 (youngest participants) in Figure 4.1e

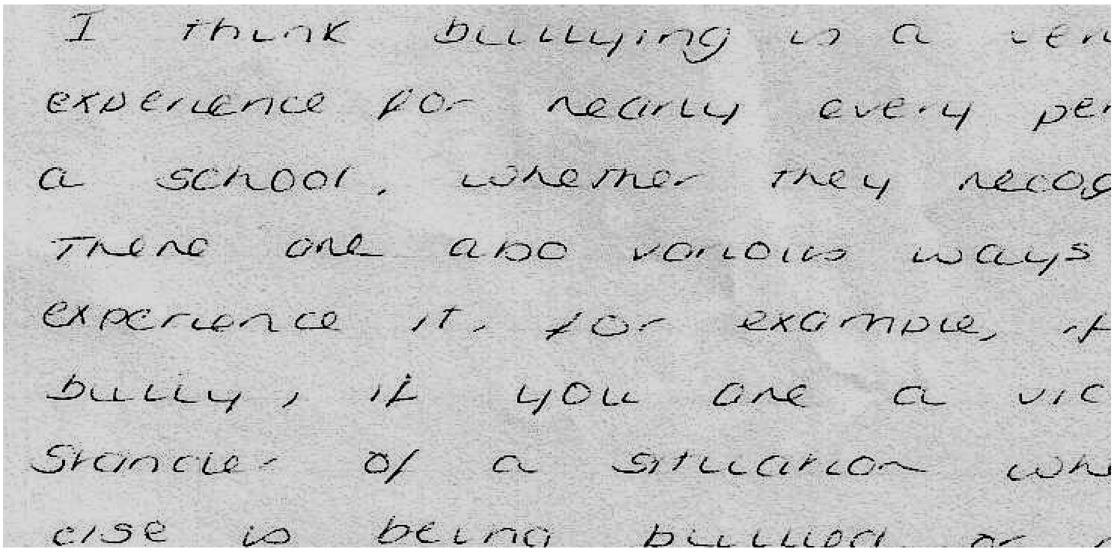


Figure 4.3 Extract from handwriting of participant nearest centroid value of cluster 2 (oldest participants) in Figure 4.1e

The handwriting shown by Figure 4.2 is recognisably child-like whereas that shown by Figure 4.3 is recognisably mature in style. For example, the letter forms in Figure 4.2 are carefully executed, with each letter being recognisable in its own right, irrespective of context, whilst at least some of the letters shown in Figure 4.3 would not be recognisable out of context (for example the letters i, l and u would be difficult to distinguish).

The handwriting in Figure 4.2 has an exaggerated vertical element to it (typified by the long ascenders – to the letters h, l and t for example - and descenders – to the letters g and y for example) whereas in Figure 4.3, the ascenders and descenders are barely noticeable (for example, the letters h and n could be misidentified out of context).

The handwriting in Figure 4.2 seems to conform more to the kind of style of handwriting that might be taught in schools. That is, it appears very correct, almost pedantically written with a view to the careful execution of each letter such as the introductory strokes to letters ate the beginning of words and the pen retracing around the curves of the letter s, for example. In contrast, the sample shown in Figure 4.3 seems to have required less effort and perhaps less thought to have produced, with much more economical movements having been used.

The handwriting from the 11 year olds that appear in the two clusters tends to support these general differences (figures 4.3 and 4.4).

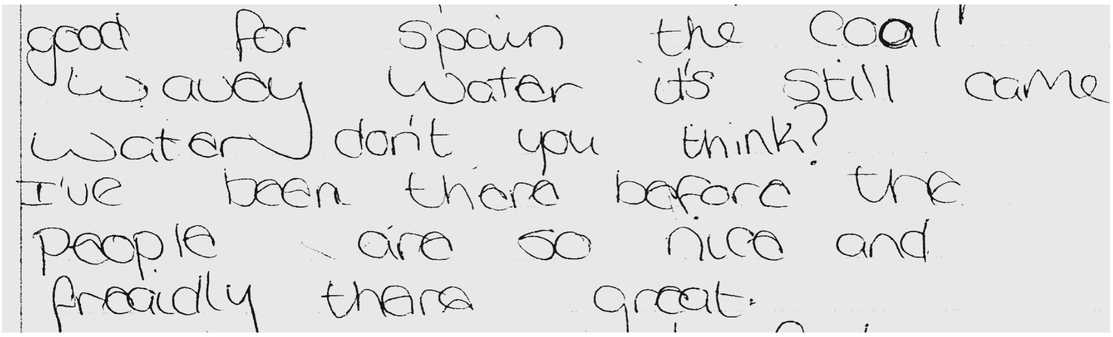


Figure 4.4 Extract from handwriting of an eleven year old clustering with older children

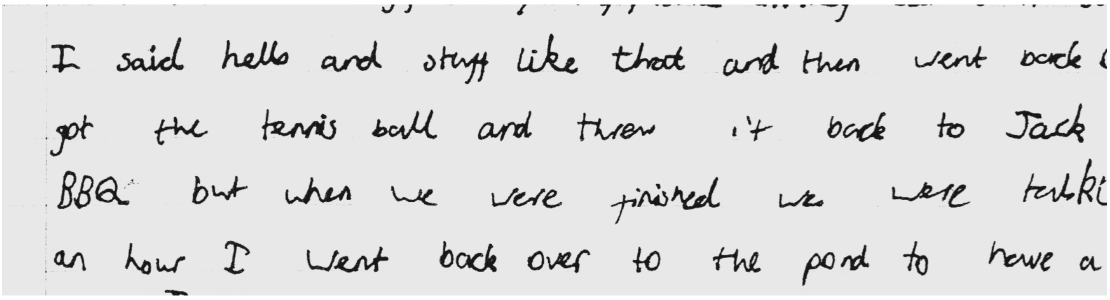


Figure 4.5 Extract from handwriting of an eleven year old clustering with younger children

The level of fluency and skill shown by the pieces of handwriting in Figures 4.4 and 4.5 do not differ as markedly as those in Figures 4.2 and 4.3. However, the dominant theme of the handwriting in the cluster of the oldest participants as typified by these pieces is a move away from exaggerated upright letterforms that are often acquired during the early stages of learning, towards a more rounded, evenly proportioned style. This latter style is likely to be more efficient in terms of minimising unnecessary vertical pen movement and utilising the left to right movement of the writing process, although the roundness may produce unnecessary lateral movement if it becomes exaggerated.

These preliminary findings provide strong support for the effectiveness of the coding scheme, but to make it a practical tool to examine large numbers of pieces of handwriting, it is necessary to refine the scheme to a smaller number of features without losing significantly the effectiveness achieved by the full scheme.

4.6 Coding scheme refinement

4.6.1 Selection of features to retain

A secondary purpose of this preliminary study was to determine which features could be retained and which discarded from the original 34 features to yield a more manageable and practical number of features, mindful of the large-scale studies that are to be carried out and described in Chapters 5 and 6. The data summarised in Table 4.2 shows that some letters occurred less frequently than others and that different features showed different types of distribution, some being very skewed others more evenly distributed. In reality, all 34 features have the potential to show differences between writers. Indeed, there are many other features that could have been devised in addition. The features that are in the coding scheme are therefore not the only features that could have been chosen but are very much a sample of features from the many that could have been devised and which show a range of different categories of handwriting feature such as proportion, shape and symmetry. For this reason, the reduction of features is above all a pragmatic decision which needs to be based on frequency of letter use and the value of a feature to contribute to the clustering of pieces of handwriting. In other words, just because a feature is evenly distributed this in itself may not be helpful if it does not discriminate between writers or writers of different ages.

Therefore, in order to refine the scheme, it was decided to exclude all features (letters) that had a mean frequency of occurrence of less than 14 (see Table 4.2) and to exclude the features showing poorer discriminant functions (see Table 4.2) from the cluster shown by the dendrogram derived using Ward's method, Figure 4.1e.

Whilst the majority of features rejected were chosen on this basis, in the large cross-sectional study that was planned to follow this preliminary study, it was known that participants would be asked to write under different constraints – namely writing more quickly and writing more neatly. The analysis of the data from this preliminary study based on normal school work might not be able to predict which features would show interesting effects when writing under such conditions. For this reason, the author decided to include a small group of features (in particular, t1, i3 and n2) that might show effects when writing under differing circumstances even though they were not strictly those indicated in the lower right region of Table 4.2. By this means it was intended to produce a refined scheme that consisted mainly of those features which were shown to be most effective in this preliminary study but to also include a few features that might be prone to variation under different writing conditions. Likewise, it was decided not to retain those features that it was thought might not be affected by such task constraints.

As a result of this process, the following features were retained:

a2 - low tail retrace -	i2 - high dot -
a3 - closed loop -	i3 - dot to right -
a4 - upward initial pen movement -	n2 - initial downstroke -
d1 - proportionately tall loop -	o1 - starts to right -
d2 - flattened loop -	o2 - tall and narrow -
e2 - high curve bisection -	r1 - open retrace -

r2 - high retrace -

s1 - script style -

s2 - shallow centre axis -

t1 - crossbar longer to right -

t2 - high crossbar -

These features do not represent the only possible coding scheme that has the potential to probe the research questions of this thesis, but rather they are a number of features that have the potential to do so based on the findings of this preliminary study. With larger amounts of handwriting from each participant and larger numbers of participants, it is entirely likely that the rejected features and any number of other features could have been used to show more and more levels of individuality of handwriting.

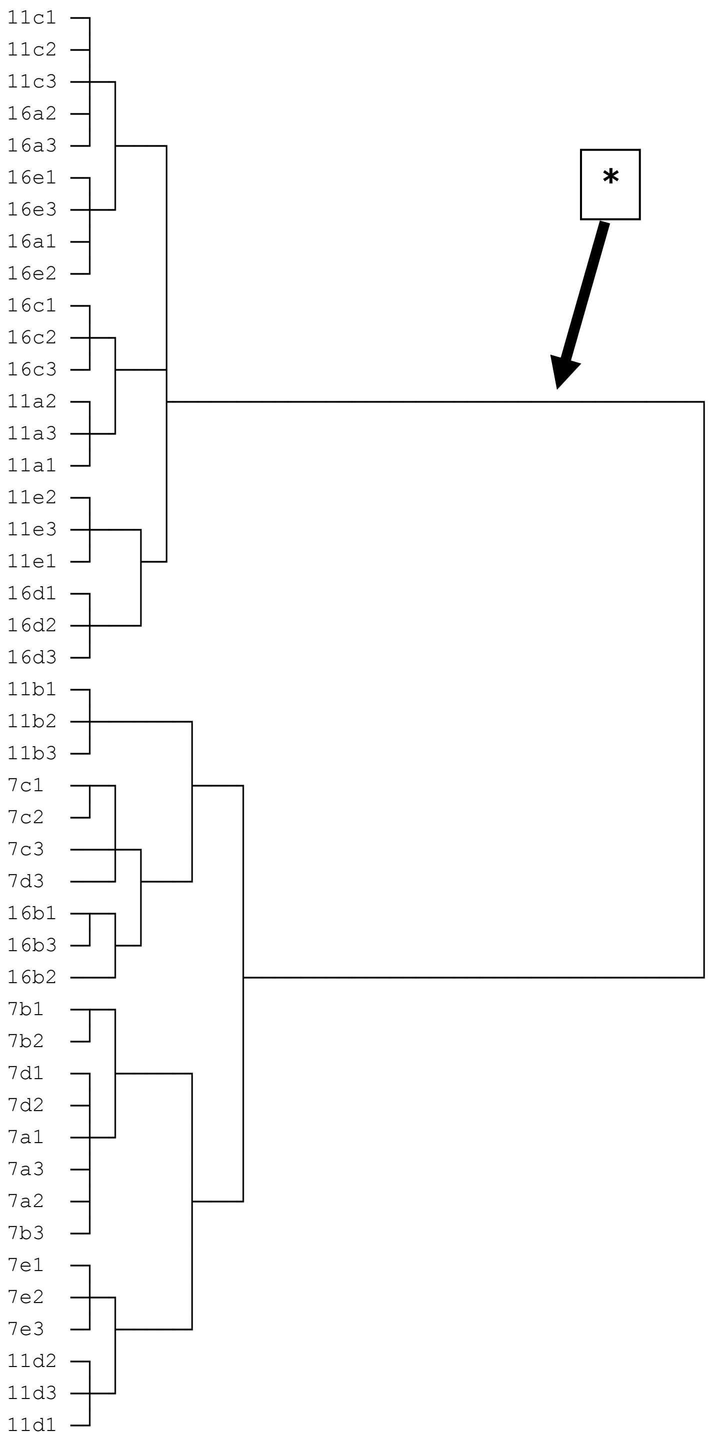
4.6.2 Testing the refined scheme

Having reduced the scheme from the original 34 features to a more manageable seventeen features, it is important that the slimmed down scheme retained the primary capacity of grouping pieces of handwriting from the same individual more closely than pieces form other participants and that the clustering by age was retained. To test this, the data from the seventeen features were again analysed using cluster analysis.

The dendrogram showing the cluster pattern obtained with the seventeen features of the revised scheme is shown by Figure 4.6.

Figure 4.6 Dendrogram showing two main clusters using revised scheme

Case labels formatted to show age group (7, 11 or 16), participant (a-e) and sample number from that participant (1-3). Ward's method used.



It can be seen that the essential characteristics of the cluster pattern are retained in comparison to that shown by Figure 4.1e, namely the within writer clustering and the marked split between the seven and sixteen year olds. Indeed, the revised scheme has eliminated one of the 'anomalous' results of the original cluster pattern (participant 7c). 80% of the samples from fifteen year olds are in the upper cluster and 100% of samples from seven year olds are in the lower cluster in the dendrogram shown in Figure 4.6 in which the asterisk indicates the major split by age of the participants.

The same pieces of handwriting are in the oldest and youngest clusters before and after refining (with the single exception of piece 3 from participant 7c), but the order in which they cluster at the lower levels differs. The Level One Clusters change in that some participants that formed Perfect Clusters (all three samples together at Level One with no other writers' samples in the cluster) before refinement did not form Perfect Clusters after refinement and vice versa. However, the number of participants forming Perfect Clusters remained the same before and after refinement (seven participants) and the number forming Imperfect or Mixed Perfect Clusters (other writers in cluster or clustering at Level Two) also remained unchanged (eleven participants).

In addition, the time needed for scoring a piece of handwriting for the seventeen features will be markedly reduced, thereby making the processing of a large number of pieces of handwriting in the cross-sectional and longitudinal studies a practical possibility.

On this basis, the refinement process shows no evidence of having significantly altered the overall capacity of the scheme to fulfil its intended function in the larger cross-sectional and longitudinal studies that follow and the expectation is that the scoring large amounts of handwriting will be a practical proposition.

4.7 Inter-rater reliability

In view of the considerable amounts of time that scoring takes, it was decided to test inter-rater reliability only on the seventeen features that were retained following the selection process described in section 4.6 above.

One other rater, who has no experience of handwriting examination, was taught how to apply the scheme and underwent a short testing process to ensure that the guidance received was being correctly applied. The teaching involved a careful description of the letter features and some test examples, none of which were then used in the inter-rater assessment.

Having undergone the preliminary instruction, ten randomly selected individual letters were scored for ten randomly selected participants by each rater, so that 100 letters were scored by each of the two raters. The inter-rater reliability was taken to be the proportion of occasions on which the two raters agreed that a feature was either present or absent. The results of this are shown in Table 4.4.

Table 4.4 showing the inter-rater reliability of the seventeen retained features

Feature	Inter-rater reliability
a2 - low tail retrace -	0.99
a3 - closed loop -	0.99
a4 - upward initial pen movement -	0.93
d1 - proportionately tall loop -	0.97
d2 - flattened loop -	0.90
e2 - high curve bisection -	0.92
i2 - high dot -	0.99
i3 - dot to right -	0.93
n2 - initial downstroke -	1.00
o1 - starts to right -	0.93
o2 - tall and narrow -	0.86
r1 - open retrace -	0.93
r2 - high retrace -	0.98
s1 - script style -	1.00
s2 - shallow centre axis -	0.97
t1 - crossbar longer to right -	0.98
t2 - high crossbar -	0.92

The high scores for inter-rater reliability show that the coding scheme is robust and reliable. The least consistent scores are both for similar kinds of feature - 0.86 for feature o2 - tall and narrow and 0.90 for feature d2 - flattened loop. Both of these features require establishing whether the loops of the respective letters are longer in the x- or y-directions. The two features that showed unanimity between the two raters, s1 - script style - and n2 - initial downstroke, both are reasonably clear-cut allograph choices (distinguishable forms of the letter) and so it is not surprising that the scores were so consistent. The remaining thirteen features all show values in the range 0.99 to 0.92. The classifications are therefore close to an objective description of the coded features of handwriting found in a sample of handwriting irrespective of how the piece of handwriting is obtained, be it in a cross-sectional study or a longitudinal study. Therefore, given that the coding scheme is so robust and approaching an objective measure, it is unnecessary to repeat an assessment of inter-rater reliability in the further studies reported in Chapters 5 and 6 since they will involve the examination of samples of handwriting in precisely the same way, the only difference being the conditions under which the samples are obtained.

4.8 Discussion

The aim of the work described in this chapter was to create a detailed coding scheme that would be able to monitor the variation in handwriting of children of various ages from the time when they start to learn to write right through to late adolescence. It drew upon the types of features that have been coded in other published work (primarily in forensic contexts that have the aim of discriminating between writers and not capturing handwriting variation) and also the working knowledge of the author.

It is clear from other published work that there were many different features of handwriting that could have been proposed for this scheme. However, the key principles that were central to the choices made were that (i) the scheme should be relatively straightforward to apply because it was to be used in two much larger studies (ii) it should contain a variety of categories of feature (such as proportions of letters, construction of letters and pen placement) so as to capture a number of dimensions of handwriting variation and (iii) it should contain features that might vary between different writers but also that might vary within the handwriting of a given child at a given time and that this variation might itself change over time as a result of the maturing of that child's handwriting.

It was not possible to be certain as to which features would in fact be best able to fulfil these three requirements of the scheme until it was tried. As a result, the first scheme proposed was large but it was anticipated that it would be refined in the light of experience of using it. It was applied to samples of handwriting from fifteen children from three age groups (7/8, 11/12 and 15/16 year olds) at three different schools. These ages were intended to represent those having just learned to write, those whose writing was close to full maturity and an intermediate group.

It was decided that since this was a preliminary evaluation of the scheme, it would be appropriate to apply the scheme to three samples of everyday schoolwork from each participant, rather than obtain handwriting samples under more controlled conditions.

The objective of the evaluation study was to produce evidence that the scheme at least had the potential to show the kinds of handwriting variation between and within writers that would be the focus of the larger cross-sectional and longitudinal studies. To achieve this objective, cluster analysis was used to analyse the results obtained.

The dendrogram resulting from the initial cluster analysis using the chosen clustering method, Ward's method, (Figure 4.1e) shows that pieces of handwriting from the same individual when scored using this scheme were clustered closely to one another. Without this finding, the ability of the coding scheme to fulfil its intended function would have been highly questionable as it is expected that handwriting from the same child at about the same point in their development would be generally similar from one occasion to another despite containing elements of variation. Hence, with just the small number of participants in this study, the finding that samples from the same child clustered was reassuring and provided strong evidence that the scheme would be able to pick up within writer handwriting traits (style) in larger studies. The clustering patterns for particular children did vary, with some forming Perfect Clusters (all three pieces in the same Level One Cluster with no pieces from other participants), others forming Imperfect Clusters (clustering at Levels One and Two) or Mixed Perfect Clusters (handwriting pieces from other writers present) with the remainder being Unclustered. However, the general trend was towards at least Imperfect or Mixed Perfect Clustering (eleven of fifteen participants) with seven of the eleven forming Perfect Clusters, indicating that for these latter children, their handwriting was unique to them in the context of the other fourteen participants.

Since the clustering was based on a weighted combination of the 34 features used, it did suggest that when taken in combination in terms of their usage, this equates to a 'measurement' of the style of the handwriting. It is therefore reasonable to expect that since the style of handwriting changes with time in children, this scheme will be able to reveal the extent and timing of the developmental changes.

There was also evidence that the handwritings of the older children were clustering together and those of the youngest children were clustering together whilst those of intermediate age were distributed amongst the other two clusters. This provided reason to believe that the scheme had the potential to show that younger children have different styles from their older peers and that children whose age fell between these groups would show different degrees of progress from one state to the other.

The reality of this difference was shown by the centroid samples from the clusters with the oldest and youngest participants (Figures 4.2 and 4.3) and the intermediate progress by those shown in Figures 4.4 and 4.5. Taking these samples as being representative, this suggests that differences between younger and older participants are characterised by the latter being able to write more fluently with smoother pen strokes and transitions between them (although this may not apply to those of intermediate age so much – see Figures 4.4 and 4.5). Older participants write in a style that bears little resemblance to the styles typically taught in schools, whereas the younger children have yet to develop away from taught styles and the older children write with greater economy of movement, for example minimising the heights of the longer letters in relation to other letters. Older children write in a style that is more rounded in which the left to right movement is used by the writer to enhance the execution of the handwriting rather than the more upright style in which the left to right movement is hindered by the use of exaggerated vertical movements of the pen and retracing movements ensuring 'correct' letter formation in younger children's handwriting. Such changes as shown by a small cross-sectional study do not necessarily point to changes within the handwriting of an individual over time, although they are consistent with the findings of Blote & Hamstra-Bletz (1991) who found that there are some general changes in handwriting production from which style changes could reasonably be inferred.

Older children can contextualise the formation of letters so that letter identity is sometimes possible only by reading the whole word, whereas the younger participants tend to write each letter so that it is recognisable in its own right. Contextualisation is an element which researchers do not always consider when looking at analysing handwriting in younger children in that some researchers analyse individual letters with an expectation that they should be recognisable in their own right and formed appropriately (for example use of the Evaluation Tool for Children's Handwriting (Koziatek & Powell, 2002)). Such considerations are not a target of the coding scheme used here, although it is likely that context effects will change over time as the writer becomes more skilful.

It is likely that these kinds of changes in the handwriting of older and younger children will be reflections of the kinds of influence that were discussed in Chapter 2. The younger children may have acquired the basic cognitive and motor skills required to produce recognisable, legible handwriting, but this has not moved markedly towards a more mature style in terms of motor execution (fluency and efficiency) or cognitive development (maturation of style) (Blote & Hamstra-Bletz, 1991). Young writers are likely to require a large amount of their attention for the production of the handwriting (McCutchen, 2000) and its content so that the possibility of change in their handwriting will only tend to occur when the execution becomes more automated at which point the content of the writing may be susceptible to improvement (Jones & Christensen, 1999). Writers of an intermediate age may have improved their motor abilities but not developed their style away from the taught style (figure 4.5) or both aspects may have developed (figure 4.4). The timings of changes in different factors impacting on handwriting production can have complex effects on handwriting which is reflected in the intricate modelling that is needed to describe changes (Abbott, Berninger, & Fayol, 2010).

The 34-feature scheme was time consuming to operate, taking typically 2-3 hours to score one piece of handwriting for all 34 features. In order to reduce the number of features, their value to the scheme was determined. Refinement of the scheme was based on the frequency of occurrence of the letters in text, the discriminant function of the features in the clustering pattern and the author's view as to whether features had the potential to be affected by varying the handwriting constraints (not present in this preliminary study). On this basis, the 34 features were reduced to a 17-feature scheme (see section 4.5 above).

The consequences of reducing the scheme were checked by cluster analysis again (Figure 4.6) and there was very little change in the overall clustering pattern obtained. The main split based on the youngest and oldest participants remained and the pieces in each cluster were identical with the single exception of one piece (piece 3 from participant 7c). Both before and after refining, 11 of the 15 participants' three samples clustered together although the particular children whose three handwriting samples cluster are not identical in the two dendrograms.

Overall, there was no deterioration of the functioning of the refined scheme over the full scheme and thus the refined scheme could be used in the larger studies with reasonable confidence.

The use of the coding scheme was set out in such a way as to make it usable by others and this was verified by an inter-rater reliability assessment. This found all features could be scored with an agreement in the range of 0.86 to 1.0 between two scorers, the second scorer being given just a small amount of preliminary tuition about the application of the scheme (see Table 4.4). This demonstrates that the scheme is reasonably straightforward to apply and that specialist knowledge is not required for its successful use. From this, it is likely that the scoring in the larger cross-sectional and longitudinal studies will be robust.

In summary, this preliminary study has produced a coding scheme that is fit for the purpose of efficiently coding large amounts of handwriting. It produces robust classifications for each of the individual features and has the potential to demonstrate developmental trends in the handwriting from children of widely different ages. The scheme has the potential to show variation in feature use when writing under different conditions and has demonstrated preliminary strong evidence in support of the clustering of individuals' handwriting and the clustering of handwriting by age.

At the end of Chapter 2, a number of questions were posed and some alternative answers suggested. These can now be explored using the refined coding scheme with a view to determining which answers are more likely and what this means for the overall picture of handwriting development in children.

Chapter 5 Cross-sectional study

5.1 Introduction

In this chapter, the coding scheme that was developed and refined in Chapter 4 will be used to probe the three questions posed at the end of Chapter 2 which can be summarised as follows. How does the variability of the handwriting produced by a given child change with age? Is the degree of handwriting individualisation the same at all ages in children? And are children at different ages affected in similar or different ways when producing handwriting under different constraints, such as speed and neatness? These are the questions that are central to an understanding and appreciation of the more general feature-independent processes involved in handwriting development and individualisation in children. Before addressing these questions directly, principal components analysis will be used to determine whether the individual features can be reduced to a set of higher order dimensions and to assess whether these higher order categories vary with age or task.

These are complex questions to ask of a coding scheme because the handwriting from different individuals varies from one to another and our handwriting varies from occasion to occasion. Nonetheless, the coding scheme developed in Chapter 4 has shown preliminary evidence in relation to the first two questions posed above but cast no light on the third question since the handwriting samples used in Chapter 4 were all produced under ostensibly similar text-generating conditions in the normal classroom environment.

The ability to show what may be fairly subtle changes in the patterns of feature use and handwriting variability within and between individuals requires that the coding scheme be applied extensively and that it contains a variety of feature types to capture changes in more than one dimension of handwriting. The scheme fulfils this requirement containing features that include proportions, shape and construction, for example. Thus the coding scheme is not measuring just one dimension of handwriting but a number of dimensions which may change over time either singly or in combination with one another. For example, the height of ascenders (on letters such as b, d and h) may increase or decrease in proportion to the rest of the letter, or the breadth of the letters may increase or decrease (on letters such as the d, o or s) giving a more rounded style. And both such dimensions may or may not change in combination in the handwriting of different individuals. In order to investigate the way letterforms change with age and task, the data will first be analysed by looking at both the full set of individual features and at any higher order dimensions identified by principal components analysis. The consistency with which children form their letters will then be analysed using a global measure of handwriting variation derived from the feature use data (described in section 5.8).

With regard to the question of the trajectory of handwriting variability within an individual child, at the end of Chapter 2 it was suggested that it might be either linear (following essentially just a gradual improvement of an unchanged skill) or it might have an inverted U-shaped component over at least some of the developmental period, reflecting an increased variability of the handwriting as it not only becomes more skilful but also as its style develops. It is not clear at what stage this might occur as in the early stages of learning, there might be a complex inter-play between increasing motor skill and a shifting cognitive model of handwriting production focussing on the letterforms themselves and perhaps more general features such as size and slope, influenced by a variety of factors such as teaching, parental input and so on. In addition, the finite capacity for integrating the various linguistic and motor components required to generate meaningful handwritten text might constrain the ability of the writer to incorporate changes into the handwriting at different developmental stages. However, in order to probe this question, it will be necessary to manipulate the data from the coding scores so as to determine the overall variability of the handwriting produced. Using this, the level of variability in writers of different ages can be determined to see whether the linear, inverted U-shaped or some other trajectory is followed.

With regard to the second question of individualisation, the approach that was used in Chapter 4 can be again adopted with a view to determining whether handwriting samples from a given participant are more or less likely to be similar to one another (as measured by their tendency to cluster together) and whether the degree of association of this kind is greater at particular ages. As mentioned in Chapter 4, the expectation would undoubtedly be that handwriting from a given participant will be at least reasonably similar from one occasion to another, but what is less clear is whether this will vary with the age of the participants and the extent of association that occurs at different developmental stages.

Finally, with regard to the production of handwriting under various constraints, it is likely that the handwriting could show some change in either the formation of letters or in variability. This may be apparent for individual features, groups of features that form any principal components or from an overall measure of handwriting variability. For example, children writing quickly might produce handwriting that is more variable than normal and this may be more apparent in younger children whose handwriting is less automatised than in older children. Indeed, it was suggested in Chapter 2 that a need for faster handwriting production might be one of a number of driving forces leading to change in handwriting style.

Any changes in variability with age or task will need to be considered in the context of the cognitive capacities needed to produce handwriting. It would be reasonable to expect that the need to formulate ideas and text and to produce correct spellings in the composition task will provide a significant burden on a younger child in particular let alone needing to generate appropriate movements of hand, wrist and fingers to produce a handwritten product. In the copying tasks, although the text generation aspects is largely lost, it is replaced with a reading element together with the additional burden to produce handwriting in a particular way, copying neatly or quickly, which might also impact on the variability of the handwriting.

Having summarised the general approaches to the probing of the three main questions in this cross-sectional study, the next stage is to consider some of the practical considerations for obtaining the large amounts of handwriting required to enable potentially statistically meaningful results to be obtained.

5.2 Practical considerations

It was decided that for this cross-sectional study, the samples of handwriting would be obtained under controlled conditions, in contrast to the pieces of handwriting examined in Chapter 4 that were written in the everyday school work of the participants. The reason for this was twofold; it would allow greater control of the frequency of occurrence for the letters being studied by using (for two of the tasks) copying tasks from preset texts and it would also give the opportunity to vary the tasks that the participants were asked to perform, which in turn might give an insight into some of the forces that are involved in driving handwriting development in the context of the capacity to process the cognitive and motor elements of handwriting production under different constraints. The cognitive differences between the generation of text (with associated linguistic elements of sentence structure and spelling, for example) and the copying of text (with associated reading and memory elements) will need to be taken into account when interpreting the findings. Different text generating tasks require different resources; for example text generation requires higher level language inputs and these may be affected by any idea-prompting material, for example as shown by Figure 5.1 (see section 5.4) as compared with the reading and transcription involved in copying text. These may impact upon the memory resources available for the handwriting process itself, especially if this has not become automatised in younger children (Gregg, L.W. and Steinberg, E.R., 1980, Chapter 5).

Obtaining handwriting samples in a classroom environment is challenging when there is no teaching or auxiliary staff available to assist. The desire to obtain samples of handwriting from a large number of participants made it unrealistic to obtain them from one person at a time. Instead, it was necessary to work with groups, but before the optimum number that should be in a group could be decided upon, the nature of the tasks had to be considered. Once this was established, the logistics of obtaining the samples could be tested in a pilot study to make sure that the whole procedure was feasible, achieving the acquisition of the samples with minimum disruption to the children and the school.

In order to obtain handwriting samples that could be used to provide answers to the three questions that are central to this study, it was decided to ask participants to complete three handwriting tasks. The first task was to ask the participants to create their own text and to write it in what they considered to be their normal handwriting. This might be regarded as a benchmark against which the handwriting produced in the other two tasks could be compared. The second task was to ask them to copy some text neatly as if it were a special piece of work; children writing more neatly might be expected to write in a manner that has more opportunity to conform towards a copy book style (or their interpretation or recollection of it). The third task was to again get them to copy some (different) text, but this time writing as quickly as possible whilst not resorting to illegible scribble.

Having chosen this task-based approach, it was necessary to consider other factors that impinge upon the nature of the tasks. In order that the circumstances in which the samples were obtained would be as similar as possible for participants of all ages, the copying tasks should be the same for everyone. The text had to, therefore, be carefully constructed so that it was comprehensible to and capable of being copied by the youngest participants without, on the other hand, being unduly childish for the older participants (who might then regard the exercise as trivial and unworthy of due effort). The amount of writing for the copying exercises had to be sufficient to allow a reasonable number of instances of the relevant letters to be obtained (for the purposes of the coding scheme), especially from the younger groups of writers, without making the pieces too long in total to avoid making the tasks too onerous for the younger participants. The two copying tasks had at least twenty occurrences of each letter that was to be scored, although this would rely on the whole text being accurately copied for some of the less frequently occurring letters, something that it was anticipated that some of the younger writers would fail to achieve under the operational constraints that applied. Draft versions of the texts for copying were checked with and approved by teaching staff as being suitable for the youngest participants in terms of their ability to comprehend the text and to reproduce the words.

A pilot study was undertaken to test the process of obtaining the samples of handwriting. Given the logistical issues involved in the process of obtaining samples, it was decided to work with groups of twelve individuals at a time.

It was thought that this would be the maximum number manageable in view of the likely behaviour and attention demands that were being made.

5.3 Pilot study

A pilot study was carried out on twelve participants aged about 7 years old, none of whom would go on to form part of the main study. Participants were chosen on the basis that they were likely to be cooperative, had a range of handwriting styles and an even mix of boys and girls were present. The teachers were unaware of the details of the coding scheme that was to be used.

The participants were placed into three groups of four (two boys and two girls), the task order balanced between the three groups. Each group of children sat at a separate table. This led to a compromise in which incomplete tasks were taken in from the slower writers on the basis that undue delay waiting for them would be disruptive and might de-motivate them. The process was not hurried nor was it unduly slow so that a reasonably efficient tempo was established in which all of the competing forces of effort, motivation and attention were balanced to produce an acceptable series of handwritten products from all participants. The whole process for the group took about one to one and a half hours. None of the samples obtained was scored as the purpose of the pilot was to test the logistics of the exercise and not to obtain samples that would form part of the main study. The age of the children in the pilot study was quite young and whilst it was possible to make a rough note of the length of time each child took, it was difficult because of the different points at which they finished and were set to start their next tasks.

In summary, the pilot showed that the procedure would allow for a large number of handwriting samples to be collected in a relatively short space of time from a large number of participants with minimal disruption to class time for them. The interaction between individuals within the groups might have led to some individuals producing less handwriting than they might have been capable of in a less disruptive situation. However, no attempts were made by the participants to influence the handwriting of others. Following the successful completion of the pilot study, the approach to obtaining the pieces of handwriting was adopted for the remainder of the cross-sectional study.

5.4 Method

5.4.1 Design and participants

The refined coding scheme described in Chapter 4 was used to study the writings of 144 participants from five schools in central England. These were at two locations: one a county town of a population of about 65,000 operating a change of school at the age of eleven and in which Schools 1 and 4 were located (see Table 5.1 below), the other a small market town about eight miles away with a population of about 15,000 operating a middle school system with changes of school at ages ten and fourteen and at which Schools 2, 3 and 5 were located.

Table 5.1 showing participants' details for the cross sectional study
(Y2 are 6 and 7 year olds through to Y12 who are 16 and 17 year olds.)

Year group	Schools	Mean age (st dev)
2	1 and 2	7 yr, 4 mths (4.2 mths)
4	1 and 2	9yr, 4 mths (3.1 mths)
6	1 and 3	11yr, 5 mths (3.0 mths)
8	3 and 4	13yr, 5 mths (3.3 mths)
10	4 and 5	15yr, 4 mths (3.3 mths)
12	4 and 5	17yr, 4 mths (3.3 mths)

From Table 5.1 it can be seen that for any given year group, the participants came from one of two schools. For each year group at each school, six boys and six girls participated. In addition, for each year group half of the participants came from one location the other half from the second location.

The exclusion criteria were that any potential participant with significant writing or general learning difficulties or who was unlikely to co-operate in a reasonable manner (assessed by the teaching staff) was not invited to participate.

The teachers were encouraged to select from the remaining pool of possible participants an approximately representative group based on a balanced assessment of their general educational levels, their general writing abilities and a spread of birth dates within the year group. The primary objective was to avoid an unrepresentative sample, for example from a group of bright, neat writers. The permission of guardians or parents was obtained prior to the participants carrying out the tasks. As a result, the children were not chosen randomly but rather were chosen with a view to obtaining participants that had a variety of handwriting styles amongst them. Since the teaching staff had no knowledge of the kinds of the particular handwriting features that were to be studied, however, the selection was effectively made blind.

In line with the discussions at section 5.1 above about different tasks, three handwriting tasks were given to each child. Task 1 required the child to write from their own imagination some text about a typical school day or any other appropriate topic. This task would mirror that typically encountered where a child has to generate their own ideas and construct appropriate sentences and spelling and so on as described in models of handwriting production (see

Flower and Hayes (Gregg, L.W. and Steinberg, E.R., 1980, Chapter 1). Tasks 2 and 3 were copying tasks which therefore would require different cognitive elements to be engaged, such as reading the text, the need for memorising short pieces of it with any associated spellings, and then the production of the handwriting itself. Thus, the cognitive demands of the copying tasks are different from those of text generation. The requirement for neatness (Task 2) or speed (Task 3) will add another constraint inasmuch as an element of the writer's overall goal changes (for neatness or speed) although the remaining components will be similar.

Task 1: To compose some text of their own, writing "in their normal writing". To assist all participants, but particularly the younger ones, a series of picture prompts was provided as a source of ideas (see Figure 5.1). This prompt consisted of images only, showing events to be encountered during a typical day at school. However, no constraints were imposed on the content except from older children where requests to include inappropriate topics were discouraged.

Task 2: This was a copying task. The text (see Figure 5.2) was provided on a plain A4 sheet from a word-processed file printed out in the font Tahoma which is a relatively bland font having no particular handwriting-like elements to it that could be used as cues and which is also readily legible. The participants were asked to carry out Task 2 in "neat writing, as if for a special piece of schoolwork".

Task 3: This was essentially similar to Task 2, but the children were presented with a different piece of text (see Figure 5.2) that fulfilled the same criteria as described for Task 2, but this time the participants were encouraged to write "as quickly as possible but not to scribble and make a mess".

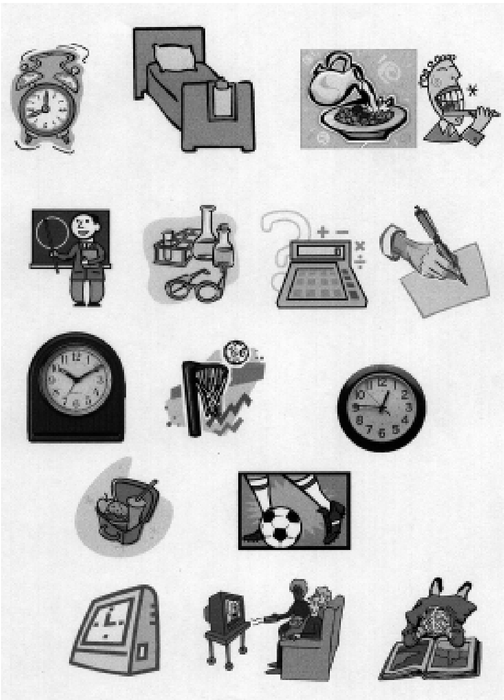


Figure 5.1 showing the picture prompt sheet giving ideas for Task 1

Task 2 – to be written neatly	Task 3 – to be written quickly
I went to see my friend the other day. He lives in a house by the sea. In the shop nearby he can get his food and drink at any time. The shop is open all day and even in the middle of the night. When he runs out of things, he goes round to the shop to see if he can buy some more. Last week he was baking some cakes but he had no eggs. There were no eggs in the shop so he went to the farm at the top of the hill and got 12 eggs from there. The cake was very nice. I had a piece when I went to his house for tea. It was a cream cake with lots of thick cream in the middle.	On my way to work the other day I saw an old lady walking with her dog. The dog had a coat on because it was very cold. The coat that the dog was wearing was the same colour as the coat that the old lady was wearing. They looked quite funny wearing clothes that matched. They were walking slowly because the old lad had a walking stick. She went into a shop. When she came back out I saw that she had three bottles of drink and some crisps in her bag. I wonder if the dog was going to have some of the drink and crisps for its dinner?

Figure 5.2 Texts of the two copying tasks

To minimise any effects of task order, each set of twelve participants (six boys and six girls of a given year group at a given school) were divided randomly into three groups of four consisting of two boys and two girls. The tasks (not the texts) were counterbalanced between the three groups.

Tasks 2 and 3, if finished completely and accurately, would give at least twenty examples of each letter relevant to the 17 scored features. For those letters/features where there were more than twenty examples (for example, the letter e) the first twenty in the text were scored.

5.4.2 Procedure

The way in which the obtaining of the samples was carried out was essentially that described in the pilot at section 5.3. In all cases, the participants taking part in any particular session were in the same classroom and carried out the tasks under my supervision only. In order to reduce undue strain and tiredness on the younger participants, there was a short break between tasks which coincided with the collection of materials at the end of one task and the distribution of materials for the next task. Due to the heavy pressures that teaching staff are under, the tasks were completed as efficiently as possible, causing minimum disruption to class time. Typically, the whole procedure was completed for a given group in about 1.5 hours.

The physical circumstances in which the whole process took place did not permit isolation of each participant from the others; there was discourse between them (albeit with every effort being made to minimise this) but this was not of such a nature as to affect their handwritings, for example by deliberate copying by one participant of the writing style of a co-participant.

The scoring of pieces of writing was carried out systematically over a period of months with pieces from different writers being scored usually at least several days apart. This ensured that any unintentional systematic scoring biases attributable to recalled scoring were kept to a minimum. The scoring procedure and data collection was the same as that used in the scheme development study described in Chapter 4. The scoring was carried out by one scorer only since the scoring was shown to be very robust for all features (see also Chapter 4).

5.5 Results – general comments

The 17 features carried forward from the scheme development study reported in Chapter 4 were scored for each piece of handwriting produced from the three tasks from each of the 144 participants, giving a total of 432 pieces of handwriting to score.

The frequency of occurrence of scored letters for any given piece of writing varied for three main reasons; the age of the participant (and hence the amount of handwriting that they managed to produce), the content of the free composition in Task 1 and the care with which the copying tasks were done (with errors leading to some words being missed out). Younger participants generally wrote less, often much less, than their older counterparts; for example, only seven out of forty eight copying tasks were completed by Y2 participants. In some cases, participants could only manage to write a few words. Whilst it might have been possible to extend the class time taken to obtain fuller writing samples from the younger participants, this option was not pursued because of the degree of disruption to the children's schooling this would entail and keeping the goodwill of school staff, parents and the children themselves was important. In any event, many young children simply do not, on the basis of these findings, have the capacity for sustained handwriting production. Thus the compromise of getting the optimum sample in the time available was settled on.

The times taken to complete the two copying tasks (and hence a measure of the speed difference between writing neatly and quickly) were difficult to assess for the younger participants because they did not sit and write from beginning to end, but rather had to be encouraged constantly to focus on the task in hand. Thus any recorded times would be virtually meaningless in these circumstances. By Y8, however, the degree of concentration was greater and typically the quicker handwriting task was carried out about 10-15% more quickly than the neat handwriting task, but the speed differential varied between writers. Whilst it is arguable that the main point is that the participants believed that they were writing more quickly for Task 3, the (rough) timings do suggest that this was actually happening in most cases. This approach therefore seems to have imposed the desired additional constraint on the participants, requiring them to at least think that they are writing more quickly.

Analysis of the data will be done in stages in the following sections. Firstly, in section 5.6, principal components analysis will be done with a view to determining whether there are trends in feature use that are related to one another showing higher order dimensions of handwriting as it develops. Secondly, an analysis of the use of individual features with age and task will be made (section 5.7) the purpose of which is to assess whether individual features show common trends. Then, in section 5.8, a more general measure of handwriting variation will be used which takes account of overall handwriting variability across all of the coded handwriting features looking for effects of age and task. Finally, the individualisation of handwriting will be considered in section 5.9 using the same cluster analysis approach that was used in Chapter 4.

5.6 Results - Principal Components Analysis (PCA)

As indicated in Chapter 4 which introduced the coding scheme, the particular combination of features used throughout this research is not intended to be definitive but rather represent a (much larger) number of features that could have been chosen. The features were chosen to show various dimensions of handwriting (such as proportion, structure and shape) and, of the seventeen features used in this study it is possible that some will share some underlying properties.

In order to assess whether or not any of the features do share underlying properties that can be subsumed into higher order categories, principal components analysis (PCA) of the feature use scores was carried out. (See Appendix 3 for full output of the principal component analyses.) PCA aims to identify common dimensions underlying a range of measures, with each measure taken to be a partial indicator of the more general, and therefore reliable, underlying dimension. It might be expected that in this study the use of PCA might reveal components that share some of the dimensions described above, such as proportion and shape. But it may also reveal other relationships that had not been deliberately considered in the development stage of the coding scheme.

For this analysis, separate principal component analyses were carried out for each of the three tasks. Decisions about the features to include and the number of components to extract were made on the basis both of the individual patterns of results and the correspondence between the results for each of the 3 data sets. Preliminary analysis of the correlations between the features and of their sampling adequacy (Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy) suggested that 3 features were relatively uncorrelated with other features (their KMO measures of sampling adequacy were below .5 on all 3 data sets). These features were therefore removed from the analysis and the analyses were carried out on the same set of 14 remaining features for the three tasks separately. The number of components to extract was decided on the basis of scree plots, and varimax rotation was used to produce orthogonal components.

The results were very similar for all 3 tasks. The KMO measure of sampling adequacy was .61 for the composing data, .61 for the neat data, and .64 for the fast task data (mediocre but acceptable, according to (Hutcheson & Soforoniou, 1999) and all KMO values for individual items were above .5. Bartlett's test of sphericity indicated that correlations between items were sufficiently large to warrant PCA (χ^2 (91) = 358.56, $p<.001$, for the composing data; χ^2 (91) = 414.22, $p<.001$, for the neat data; χ^2 (91) = 368.38, $p<.001$, for the fast data). Five components had eigenvalues above 1 for the composing and neat task; four components for the fast task. Inspection of scree plots suggested between 2 and 3 components for the composing data, and 2 components for each of the neat and fast sets of data. It was therefore decided to extract 2 components for each data set. These two components together explained 32.34% of the variance for the composing task, 35.08% for the neat task and 34.72% for the fast task.

Loadings greater than .40 on each component are shown in Table 5.2 for each of the three sets of data. Items which load similarly on the components for each of the tasks are shown in bold. Items which do not load to the same extent on a component across all three tasks are shown in normal font, with the loadings less than .40 indicated in parentheses. Also shown are the eigenvalues and the percentage of variance accounted for by each component. Cronbach's alpha for the scales derived from these components are shown at the bottom of the table.

Table 5.2 Loadings on each of the components for the composing, neat and fast writing tasks.

	Task					
	Compose		Neat		Fast	
Feature	Lat Elong	Mov Int	Lat Elong	Mov Int	Lat Elong	Mov Int
a2	(.374)		.481		.524	
a3		**.642**		**.636**		**.631**
a4	**.552**		**.541**		**.493**	
d1		**.665**		**.599**		**.564**
d2	**.755**		**.723**		**.786**	
e2						
i2		**-.457**		**-.510**		**-.456**
n2		**.453**		**.523**		**.576**
o1		**.419**		**.457**		**.572**
o2	**-.755**		**-.757**		**-.755**	
r1	-.481		-.417		(-.241)	
r2	**.554**		**.635**		**.540**	
s2	**.406**		**.464**		**.474**	
t2		**.589**		**.658**		**.593**
Eigenvalues	2.50	2.03	2.67	2.24	2.62	2.24
% variance explained	17.85	14.50	19.11	15.97	18.73	16.00
α	.637	.551	.684	.601	.661	.611

As can be seen in Table 5.2, five items on the first component, and six items on the second component, load very similarly for all three tasks. Two other features (a2 and r1) load more than .40 for two of the tasks but less than .40 for the other task. In both cases the loading is in the same direction for the task where the loading is less than .40. The finding that these factor structures are very similar across the three tasks (with different writing samples) suggests that the factor structure generalises reliably.

Inspection of the item loadings suggests the following interpretations of the two components (see also Table 5.3, which shows the visual forms of the letters concerned).

5.6.1 Component 1: Lateral Elongation.

In component 1, the features d2 (flattened loop) and o2 (tall and narrow which is negatively loaded) are loaded onto the component showing that they both share a theme that can be described as (exaggerated) roundness, characterised by a lateral elongation of loops and general handwriting shapes. This also would explain the loading of s2 on this component as it has a shallow centre axis leading to a squat, flattened letter shape as opposed to a more upright form. The use of an introductory stroke for certain letters (such as feature a4) would possibly be consistent with this flattening element too in as much as it might tend to produce a more rounded letterform, but it is not clear how feature r2 – low retrace – would fit into this unless having an elongated top stroke may also be associated with a low retrace. In addition, two features, namely a2 (low tail retrace) and r1 (open retrace negatively loaded), which load below the 0.4 threshold in some tasks, do appear to be consistent with this interpretation.

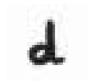
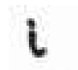
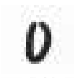
For these reasons, component 1 was named Lateral Elongation.

5.6.2 Component 2: Movement Integration.

Of the six features loading onto component 2, the three highest loadings are a3 (closed loop), d1 (proportionately short loop) and t2 (high crossbar). Each feature has two elements to it, namely the creation and then closure of the loop in the letter a, the loop and then ascender of the letter d and the downstroke and then the crossbar of the letter t, and in each instance there is a need to integrate the pen movement between the elements for the completion of the whole letter. The same can be said of the feature i2 (high dot) which involves combining the i dot and the downstroke. Where the dimension of feature combination is less readily explained is in the feature o1 (starts to right) except that this time the main concern is letter initiation rather than completion, and the feature n2 (initial downstroke) where the absence of the downstroke removes an element of feature combination.

For these reasons, component 2 was named Movement Integration.

Table 5.3 showing the form of the features loading on components 1 and 2

Feature	Component 1 (Lateral Elongation)				Component 2 (Movement Integration)			
	Positive loading		Negative loading		Positive loading		Negative loading	
	Type 1	Type 2	Type 1	Type 2	Type 1	Type 2	Type 1	Type 2
[a2 - low tail retrace -]								
a3 - closed loop -								
a4 - upward initial pen movement -								
d1 - proportionately tall loop -								
d2 - flattened loop -								
i2 - high dot –								
n2 - initial downstroke -								
o1 - starts to right -								
o2 - tall and narrow –								
[r1 - open retrace -]								
r2 - low retrace -								
s2 - shallow centre axis -								
t2 - high crossbar -								

In order to make comparisons of the scores for the different tasks, common scales were constructed for the two components using the items that loaded consistently on the components for the three tasks. Unweighted means of the scores for each component were used. As can be seen in Table 5.2, these scales were not very reliable, with Cronbach's alpha being less than .70 in all cases (ranging from .64 to .68 for component 1, and from .55 to .61 for component 2). Using weighted scores derived from the individual loadings for each task did not make any substantial difference to the reliability so the unweighted scales were used for further analysis. The relatively low reliability of the two scales means that tests of effects of task and year may be reduced in power, particularly for component 2. The relatively low reliability of component 2 may in part explain why this component was harder to interpret.

In summary, the principal components analysis suggests that two broad higher order patterns can be identified in the children's handwriting: one related to the lateral elongation of letterforms, the second related to the movement integration required to complete a letter. The two components will be referred to as Lateral Elongation and Movement Integration respectively. These components, however, should be treated with caution. Almost all of the scores for each of the letters were skewed, very markedly for some of the features in some of the year groups, with some of the scores showing very strong ceiling or floor effects. This reduced the range of many of the variables and hence reduced the size of the correlations between them. Inspection of the raw correlations (see Appendix 3) showed that these were generally low. This may account for the fact that, for all analyses, the percentage of non-redundant residuals with absolute values greater than 0.05 was rather high (69% for the composing task; 72% for the neat task; and 64% for the fast task). Further research with, if possible, a more sensitive scoring system, is therefore needed to confirm these patterns. In the following two sections, the two scales derived from the principal components analysis were used to examine the effects of age of student (measured by school year) and type of writing task.

5.6.3 Lateral Elongation

The mean of the five letter features making up the Lateral Elongation scale (with o2 reverse scored) were calculated to produce a Lateral Elongation score. Data screening showed that these scores were normally distributed and passed Mauchly's test of sphericity. A two-way mixed ANOVA with year as a between factor and task as a within factor was carried out to test whether these factors had an effect on Lateral Elongation. This showed a significant main effect of year ($F(5, 138) = 6.94$, $p < .001$, $\eta^2 = .185$) but no significant main effect of task ($F(2, 276) = 0.851$, $p = .43$, $\eta^2 < .001$) and no significant interaction between year and task ($F(10,276) = 1.598$, $p = .14$, $\eta^2 = .004$).

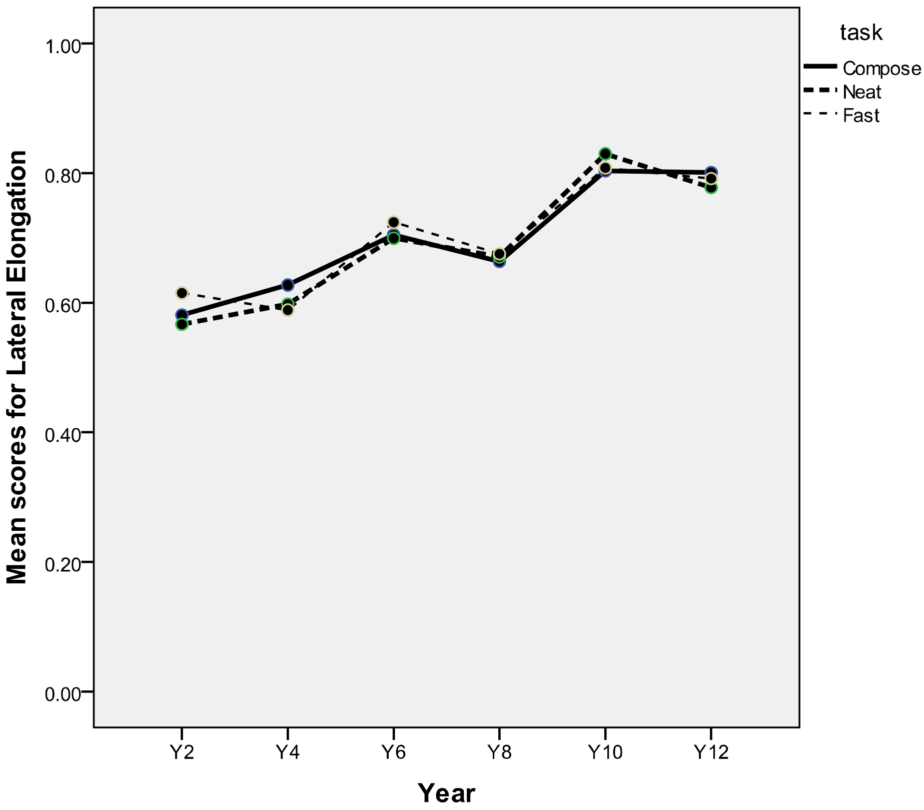


Figure 5.3 Mean scores on Lateral Elongation as a function of task and year

As can be seen in Figure 5.3, which shows the mean scores on the Lateral Elongation component for each of the writing tasks for each year group, the pattern is similar for each of the writing tasks, and there is a general increase of scores with increasing age, with the exception of a plateau between years 6 and 8, and a flattening for the two oldest year groups. Pairwise comparisons with a Bonferroni adjustment for multiple comparisons showed that scores for years 2 and 4 were significantly lower than scores for years 10 and 12 ($p < .005$ in all cases), with scores for year 8 being marginally lower than scores for year 10 ($p = .07$).

5.6.4 Movement Integration

The mean of the six items making up the Movement Integration component (with i2 reverse scored) were calculated to produce a Movement Integration score. Data screening showed that these data were scores were normally distributed and passed Mauchly's test of sphericity. A two-way mixed ANOVA with year as a between factor and task as a within factor was carried out to test whether these factors had an effect on this measure. This showed no significant main effect of year ($F(5, 138) = 1.65$, $p = .15$, $\eta^2 = .052$) or of task ($F(2, 276) = 2.03$, $p = .13$, $\eta^2 < .001$) and no significant interaction between year and task ($F(10,276) = 1.57$, $p = .12$, $\eta^2 = .004$). As can be seen in figure 2, although the youngest pupils, in year 2, appear to score slightly lower than older students, there is otherwise no evidence of a systematic change in scores with age, or of any differences between the tasks.

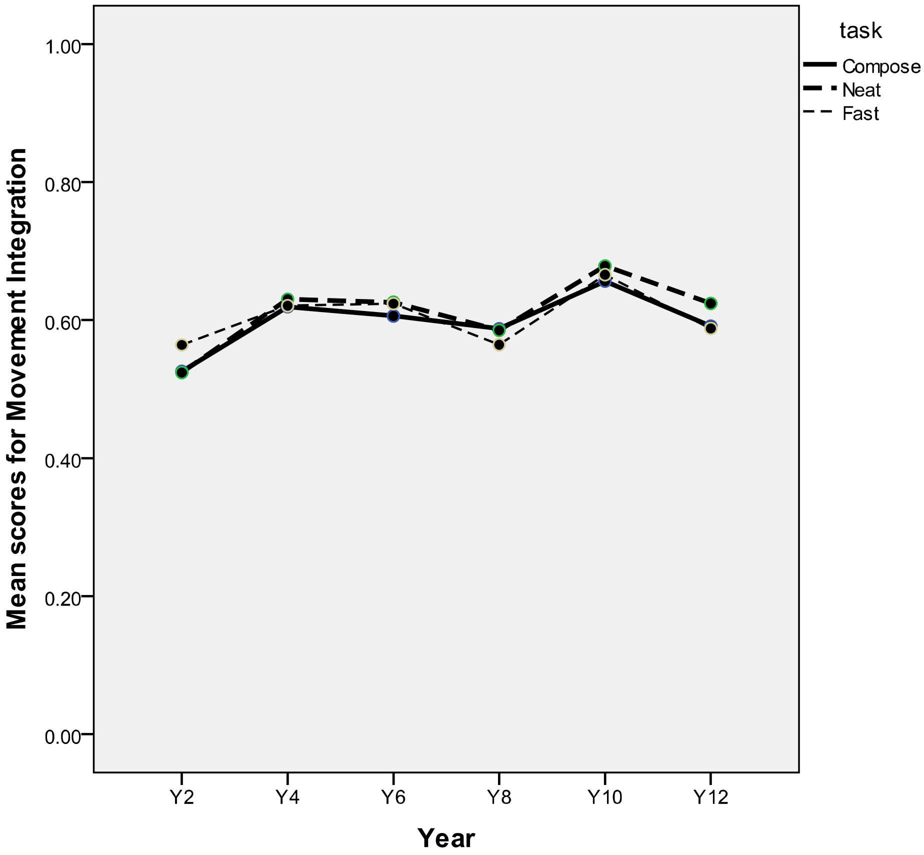


Figure 5.4 Mean scores on Movement Integration as a function of task and year.

Overall, these analyses suggest that two higher order patterns can be identified in the handwriting of these pupils. Two important results should be noted. First, these two components are orthogonally related suggesting that they may be a consequence of different underlying influences. Second, it appears that whereas the Lateral Elongation component changes with age, showing an increased tendency to produce rounded and elongated handwriting, the Movement Integration component appears to remain constant with age. Task appears to have little effect on either component.

5.7 Results - individual handwriting features

Given the relatively low reliability of the scales used in the principal components analysis and the fact that many of the individual scores were not normally distributed, it was decided also to carry out non-parametric tests of the main effects of year and task on individual letters. This was designed to check whether the effects observed with the overall scales were also present for the individual letters contributing to the scales. If they are, then we would expect a4, d2, o2, r2 and s2 to show significant effects of year.

Table 5.4 shows the median and inter-quartile range values for feature use for each feature scored for all age groups and for all tasks. Because medians are used, there are some cases which appear to have identical scores of 0.0 or 1.0 but in fact there are small differences between some of them albeit they are all highly skewed. Kruskal-Wallis tests were used to test the significance of the differences between the year groups and Friedman tests were used to test the significance of differences between the tasks. In order to check whether there were any interactions between age and task, two-way parametric analyses of variance were also carried out (notwithstanding the inappropriate nature of the data for such an analysis). However, none of these were statistically significant, so the analysis presented here is restricted to the main effects of either task or year. Significant effects of age are indicated by bold font in the All Tasks row and significant effects of task are indicated by bold font in the All Years rows. The α level was conservatively set at 0.01 to take account of the many comparisons being made.

In addition, Mann-Whitney U tests were used to make pairwise comparisons for those features showing main effects of age. Wilcoxon signed rank tests were carried out to make pairwise comparisons for the features showing main effects of task. In both sets of tests the α level was again set at 0.01.

Table 5.4 Median (and inter-quartile ranges) for feature use proportions †

Feature	Task	Y2	Y4	Y6	Y8	Y10	Y12	**All Years**
a2 - low tail retrace -	Compose	0.00(0.00)	0.00(0.00)	0.00(0.06)	0.00(0.09)	0.05(0.10)	0.13(0.39)	**0.00(0.08)**
	Neat	0.00(0.00)	0.00(0.00)	0.00(0.00)	0.00(0.05)	0.00(0.14)	0.08(0.19)	**0.00(0.05)**
	Fast	0.00(0.05)	0.00(0.00)	0.00(0.05)	0.03(0.14)	0.05(0.26)	0.20(0.55)	**0.00(0.10)**
	All Tasks	**0.00(0.00)**	**0.00(0.00)**	**0.00(0.00)**	**0.00(0.09)**	**0.05(0.14)**	**0.13(0.35)**	0.00(0.05)
a3 - closed loop -	Compose	0.38(0.46)	0.82(0.34)	0.68(0.44)	0.55(0.67)	0.61(0.32)	0.75(0.55)	0.69(0.53)
	Neat	0.52(0.41)	0.73(0.42)	0.70(0.44)	0.48(0.59)	0.60(0.44)	0.83(0.53)	0.64(0.45)
	Fast	0.56(0.51)	0.80(0.35)	0.70(0.28)	0.40(0.43)	0.60(0.39)	0.75(0.63)	0.63(0.44)
	All Tasks	**0.53(0.42)**	**0.80(0.36)**	**0.70(0.35)**	**0.45(0.55)**	**0.60(0.39)**	**0.75(0.60)**	0.65(0.50)
a4 - upward initial pen movement -	Compose	0.43(0.41)	0.77(0.46)	0.80(0.20)	0.80(0.50)	1.00(0.15)	1.00(0.29)	0.83(0.50)
	Neat	0.50(0.48)	0.86(0.50)	0.83(0.48)	0.83(0.63)	1.00(0.14)	1.00(0.19)	0.85(0.55)
	Fast	0.61(0.33)	0.75(0.54)	0.73(0.40)	0.83(0.54)	1.00(0.24)	1.00(0.35)	0.80(0.50)
	All Tasks	**0.50(0.40)**	**0.80(0.50)**	**0.78(0.39)**	**0.80(0.53)**	**1.00(0.15)**	**1.00(0.25)**	0.84(0.50)
d1 - proportionately tall loop -	Compose	0.00(0.40)	0.25(0.60)	0.37(0.50)	0.69(0.66)	0.87(0.51)	0.57(0.95)	0.43(0.76)
	Neat	0.12(0.33)	0.28(0.69)	0.38(0.49)	0.48(0.71)	0.93(0.46)	0.62(0.91)	0.43(0.78)
	Fast	0.31(0.55)	0.12(0.55)	0.38(0.54)	0.58(0.63)	0.83(0.44)	0.48(0.81)	0.45(0.70)
	All Tasks	**0.12(0.44)**	**0.23(0.60)**	**0.38(0.50)**	**0.59(0.68)**	**0.89(0.44)**	**0.57(0.90)**	0.44(0.75)
d2 - flattened loop -	Compose	0.57(0.73)	0.27(0.61)	0.43(0.67)	0.57(0.67)	0.82(0.46)	0.92(0.50)	0.62(0.68)
	Neat	0.32(0.62)	0.23(0.51)	0.53(0.58)	0.53(0.48)	0.90(0.43)	0.88(0.73)	0.54(0.70)
	Fast	0.43(0.48)	0.23(0.41)	0.68(0.48)	0.60(0.58)	0.88(0.46)	0.90(0.40)	0.60(0.59)
	All Tasks	**0.45(0.67)**	**0.25(0.52)**	**0.56(0.57)**	**0.56(0.55)**	**0.86(0.47)**	**0.90(0.50)**	0.58(0.65)
e2 - high curve bisection -	Compose	0.11(0.39)	0.05(0.11)	0.10(0.28)	0.15(0.36)	0.18(0.32)	0.15(0.24)	0.10(0.29)
	Neat	0.09(0.48)	0.05(0.14)	0.10(0.23)	0.05(0.20)	0.18(0.34)	0.10(0.20)	0.10(0.25)
	Fast	0.11(0.31)	0.10(0.15)	0.15(0.14)	0.10(0.13)	0.25(0.15)	0.15(0.14)	0.15(0.15)
	All Tasks	0.10(0.35)	0.05(0.15)	0.13(0.15)	0.10(0.20)	0.20(0.29)	0.15(0.19)	0.10(0.20)
i2 - high dot -	Compose	0.83(0.63)	0.73(0.28)	0.75(0.36)	0.83(0.40)	0.66(0.34)	0.75(0.57)	0.75(0.38)
	Neat	0.86(0.59)	0.70(0.43)	0.65(0.38)	0.73(0.28)	0.68(0.49)	0.73(0.70)	0.70(0.47)
	Fast	0.71(0.57)	0.60(0.30)	0.64(0.50)	0.77(0.26)	0.66(0.38)	0.72(0.63)	0.70(0.40)
	All Tasks	0.80(0.67)	0.70(0.34)	0.67(0.38)	0.75(0.30)	0.66(0.38)	0.75(0.63)	0.71(0.39)
i3 - dot to right -	Compose	0.36(0.79)	0.46(0.39)	0.64(0.35)	0.69(0.62)	0.73(0.52)	0.55(0.58)	**0.56(0.53)**
	Neat	0.40(0.41)	0.35(0.44)	0.47(0.33)	0.58(0.53)	0.58(0.69)	0.55(0.64)	**0.50(0.50)**
	Fast	0.42(0.44)	0.41(0.37)	0.52(0.37)	0.73(0.46)	0.73(0.47)	0.65(0.63)	**0.59(0.45)**
	All Tasks	0.40(0.55)	0.41(0.39)	0.50(0.35)	0.70(0.55)	0.69(0.53)	0.60(0.61)	0.55(0.51)
n2 - initial downstroke -	Compose	1.00(0.84)	1.00(0.00)	1.00(0.00)	1.00(0.06)	1.00(0.05)	1.00(0.48)	**1.00(0.04)**
	Neat	1.00(0.19)	1.00(0.00)	1.00(0.04)	1.00(0.09)	1.00(0.00)	1.00(0.24)	**1.00(0.05)**
	Fast	1.00(0.33)	1.00(0.00)	1.00(0.00)	1.00(0.23)	1.00(0.05)	0.95(0.74)	**1.00(0.10)**
	All Tasks	1.00(0.33)	1.00(0.00)	1.00(0.00)	1.00(0.09)	1.00(0.05)	1.00(0.48)	1.00(0.05)

o1 - starts to right -	Compose	0.90(0.35)	0.90(0.29)	0.90(0.48)	0.83(0.33)	0.84(0.36)	0.83(0.48)	**0.86(0.36)**
	Neat	0.89(0.45)	0.90(0.23)	0.88(0.44)	0.85(0.50)	0.90(0.35)	0.83(0.40)	**0.89(0.34)**
	Fast	0.90(0.19)	0.92(0.24)	0.95(0.28)	0.90(0.30)	0.95(0.29)	0.95(0.19)	**0.92(0.25)**
	All Tasks	0.90(0.31)	0.90(0.25)	0.90(0.29)	0.85(0.39)	0.90(0.35)	0.85(0.39)	0.90(0.30)
o2 - tall and narrow -	Compose	0.32(0.72)	0.34(0.39)	0.25(0.34)	0.30(0.61)	0.10(0.27)	0.03(0.24)	0.20(0.45)
	Neat	0.35(0.66)	0.60(0.63)	0.15(0.39)	0.25(0.59)	0.08(0.28)	0.00(0.30)	0.20(0.60)
	Fast	0.38(0.56)	0.40(0.55)	0.23(0.35)	0.15(0.50)	0.10(0.39)	0.00(0.31)	0.20(0.45)
	All Tasks	**0.37(0.65)**	**0.40(0.54)**	**0.20(0.36)**	**0.25(0.55)**	**0.10(0.29)**	**0.00(0.24)**	0.20(0.45)
r1 - open retrace -	Compose	0.00(0.32)	0.00(0.09)	0.10(0.16)	0.06(0.24)	0.03(0.12)	0.00(0.14)	**0.00(0.15)**
	Neat	0.00(0.20)	0.00(0.11)	0.05(0.23)	0.05(0.11)	0.00(0.11)	0.03(0.10)	**0.00(0.13)**
	Fast	0.10(0.25)	0.06(0.18)	0.11(0.39)	0.05(0.19)	0.13(0.31)	0.05(0.15)	**0.09(0.20)**
	All Tasks	**0.03(0.27)**	**0.00(0.11)**	**0.09(0.24)**	**0.05(0.16)**	**0.05(0.20)**	**0.05(0.11)**	0.05(0.20)
r2 - high retrace -	Compose	0.83(0.46)	0.69(0.45)	0.90(0.33)	0.93(0.48)	0.97(0.15)	0.95(0.19)	0.90(0.33)
	Neat	0.74(0.48)	0.61(0.49)	0.82(0.26)	0.90(0.40)	0.98(0.15)	0.90(0.24)	0.85(0.39)
	Fast	0.84(0.35)	0.71(0.41)	0.89(0.25)	0.90(0.52)	1.00(0.05)	0.95(0.25)	0.90(0.32)
	All Tasks	**0.81(0.39)**	**0.69(0.42)**	**0.88(0.25)**	**0.90(0.45)**	**1.00(0.13)**	**0.95(0.23)**	0.88(0.35)
s1 - script style - *	Compose	1.00(0.00)	1.0(0.00)	1.0(0.00)	1.00(0.05)	1.00(0.00)	1.00(0.39)	1.00(0.00)
	Neat	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.20)	1.00(0.00)	1.00(0.19)	1.00(0.00)
	Fast	1.00(0.00)	1.00(0.00)	1.00(0.06)	1.00(0.31)	1.00(0.04)	1.00(0.28)	1.00(0.00)
	All Tasks	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.19)	1.00(0.00)	1.00(0.19)	1.00(0.00)
s2 - shallow centre axis -	Compose	0.82(0.55)	0.88(0.34)	0.86(0.59)	0.83(0.50)	0.88(0.39)	0.83(0.56)	0.85(0.50)
	Neat	0.86(0.62)	0.88(0.38)	0.88(0.45)	0.83(0.46)	0.90(0.34)	0.90(0.39)	0.89(0.45)
	Fast	0.90(0.50)	0.89(0.40)	0.92(0.44)	0.80(0.45)	0.90(0.45)	0.75(0.58)	0.85(0.48)
	All Tasks	0.87(0.57)	0.88(0.38)	0.90(0.49)	0.80(0.50)	0.90(0.44)	0.83(0.50)	0.86(0.49)
t1 - crossbar - longer to right	Compose	0.86(0.35)	0.92(0.29)	0.92(0.33)	0.95(0.20)	0.90(0.10)	0.84(0.30)	0.90(0.25)
	Neat	0.78(0.45)	0.79(0.20)	0.93(0.24)	0.90(0.20)	0.90(0.24)	0.85(0.44)	0.90(0.32)
	Fast	0.95(0.40)	0.88(0.31)	0.93(0.24)	0.85(0.28)	0.93(0.19)	0.83(0.34)	0.90(0.30)
	All Tasks	0.85(0.41)	0.86(0.21)	0.92(0.25)	0.93(0.20)	0.90(0.15)	0.83(0.35)	0.90(0.30)
t2 - high crossbar -	Compose	0.72(0.55)	0.50(0.47)	0.60(0.46)	0.50(0.51)	0.60(0.73)	0.58(0.71)	**0.59(0.55)**
	Neat	0.69(0.49)	0.60(0.50)	0.55(0.30)	0.65(0.48)	0.60(0.73)	0.63(0.81)	**0.61(0.52)**
	Fast	0.67(0.54)	0.60(0.41)	0.55(0.39)	0.53(0.49)	0.65(0.69)	0.50(0.79)	**0.55(0.55)**
	All Tasks	0.69(0.52)	0.60(0.45)	0.55(0.34)	0.53(0.45)	0.60(0.70)	0.55(0.75)	0.60(0.55)

†Note: the nearer to 0 or 1 that a value is, the closer the feature corresponds to the associated descriptor. For example, for feature t2 a value of 1 would correspond to all having a high crossbar and a value of 0 would correspond to none having a high crossbar.

Bold font in the All Years column indicate data showing a significant effect of task across all years (n=144, df=2, p< .01)

Bold font in the All Tasks rows shows a significant effect of age shown by Kruskal-Wallis chi-square n=144, df=5, p≤0.01

5.7.1 Main effects of age

The features that show main effects of age do so mainly due to differences between older and younger writers. For feature a2, Y12 differs from Y2, Y4 and Y6 (with older children showing a greater tendency to do low tail retraces); for a4, Y2 differs from Y10 and Y12 (with the older children using an upward pen movement at the start of the letter more often); for d1, the differences are between Y2 and Y8 and Y10 and Y4 differing from Y10 (with the older children having a proportionately taller loop); for o2, Y2 differs from Y10 and y12 and Y4 differs from Y12 (with older children producing a more laterally elongated form of the letter o); and finally for r2, Y4 differs from Y10 and Y12 (with the older children using a lower retrace to the letter r).

5.7.2 Main effects of task

The features that show main effects of task all did so because of a change that occurred when writing fast in comparison with writing either neatly and/or when composing. Specifically, fast writing tends to have a lower retrace to the letter a (feature a2); tends to place the i dot more often to the right (feature i3); is more likely to use an introductory stroke to the letter n (feature n2); is more likely to start the letter o to the right (feature o1); tends to use a more open retrace to the letter r (feature r1); and is more prone to writing an elongated form of the letter s (feature s2). All of these feature usages do make sense in that the writing movements involved tend to be reduced or show a driving effect of the left to right movement that is likely to be exaggerated when writing fast.

5.7.3 Comparison with results of principal components analysis

The Lateral Elongation component resulting from the principal component analysis in the previous section contained five main features, namely a4, d2, o2 (negatively loaded), r2 and s2. As noted above when examining the main effects of age, all individual features (except s2) also show significant main effects of age, providing additional support for the reliability of the outcome of the PCA. Features a4, d2 and r2 show a linear increase with age and o2 shows a corresponding linear decrease with age (as it is negatively loaded). The feature s2 does not show a significant effect of age but it does only load weakly onto the Lateral Elongation component. Of the two features that were marginally excluded from this component, a2 and r1, a2 does show a significant effect of age but r1 does not. None of the features making up the Lateral Elongation component show significant main effects of task.

The Movement Integration component had six features loading onto it of which two show significant main effects of age (namely features a3 and d1) whereas the remaining features do not show significant effects of age (namely features i2, n2, o1 and t2). The effects of age on a3 and d1 are not simple linear increases or decreases, but show a less coherent pattern of change with age. Overall, the six features that contribute to the Movement

Integration component do not show reliable or apparently meaningful changes with age, consistent with the finding that the Movement Integration component itself shows no significant effect of age. Features n2 and t2 both show main effects of task with the use of the introductory stroke to the letter n being less pronounced and the crossbar of the letter t being lower when writing quickly. None of the other features loading on this component showed significant effects of task, which is consistent with there being no effect of task on the higher order component.

5.8 Results - overall handwriting variation (OHV)

The preceding analysis focussed on differences in the way letters are formed by children of different ages and for different writing tasks. A second question to be addressed that is central to this research is how consistently letter forms are used, because it is hypothesised that variation of handwriting features will be associated with any change in letterform that occurs as children get older.

The value of feature use proportion can range between 0 (not used at all) and 1 (always used). The further away the feature use proportion is from either 0 or 1, the more variable the use of that feature is. Hence, the proportion value can be manipulated to produce a measure of within-piece variability for a given feature, showing how consistent use of that feature is in a piece of handwriting. For example, a proportion score of 0 or 1 shows that there is no variation in use of that feature (within-piece variability is 0) whereas a feature use score of 0.5 would show maximal variation of use for that feature with both types used equally (within-piece variability is 1). The within-piece variability can therefore be calculated by the following equation to show the variability of a piece of handwriting for one of the given seventeen features of the coding scheme:

$$\text{Within-piece variability} = 1 - [2\text{x abs(proportion} - 0.50)]$$

In order to create a measure of overall handwriting variation the mean within-piece variability of the seventeen features in a given piece of handwriting by a given writer was calculated. This becomes a measure of handwriting variability that is no longer feature-specific but rather is a measure of the average variability of features by that writer at that time and this measure will be called the overall handwriting variation – OHV.

$$OHV = \frac{\Sigma(\text{within piece variability for all features})}{17}$$

This is a measure that takes account of the fact that for a particular writer at a given time, there will be variation in the handwriting and the extent of this may vary both between writers but also the extent of handwriting variation may change over time in the same individual.

The consistency (or lack of variability) of handwriting might be expected simply to get greater with time as the skill is improved and automated. This would correlate with a decrease in the OHV of the handwriting with increasing age of the children. However, any evidence for an increase in OHV would be consistent with other factors coming into play, interfering with the downward trend expected from simple skill improvement.

Table 5.5 shows the mean and standard deviation of the OHV scores in each of the six year groups for the composition, neat copying and fast copying tasks.

Table 5.5 Means and standard deviations for the overall handwriting variation (OHV) scores for each task by year group.

Year group	**Compose** **OHV** *SD*	**Neat** **OHV** *SD*	**Fast** **OHV** *SD*
2	**0.27** *0.08*	**0.30** *0.09*	**0.33** *0.07*
4	**0.30** *0.08*	**0.31** *0.07*	**0.33** *0.08*
6	**0.33** *0.10*	**0.35** *0.10*	**0.37** *0.12*
8	**0.31** *0.09*	**0.33** *0.09*	**0.33** *0.09*
10	**0.28** *0.09*	**0.26** *0.10*	**0.31** *0.10*
12	**0.27** *0.09*	**0.25** *0.09*	**0.28** *0.09*

The values in Table 5.5 are plotted and shown in Figure 5.3 which shows the mean OHV scores across all participants in each year group for each of the three handwriting tasks.

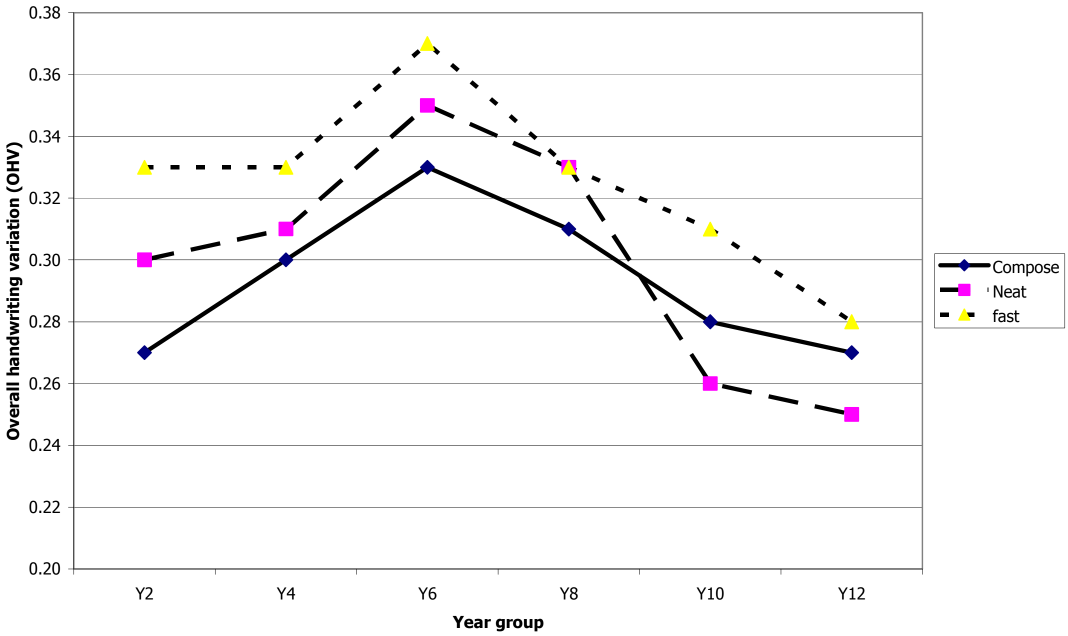


Figure 5.5 showing the mean overall handwriting variation (OHV) across all features and across all participants in each age group (Task 1=compose, Task 2=neat copying and Task 3=fast copying)

From Figure 5.5, it can be seen that the trend in OHV is similar for all three tasks, with an increase in variation from Y2 to Y6 and then a progressive decrease in variation until it is at its lowest by Y12. This inverted U-shaped pattern is suggestive and is consistent with the suggestion that learning handwriting involves an interaction between the cognitive and motor components leading to an increase in the OHV of a piece of handwriting in the children in the middle age groups. However, although the general shape of the trend is the same for all three types of task, there is also evidence that the effects of the task changes as the children get older. At younger ages, fast copying produces the highest OHV, and composition the least OHV, and neat copying producing an intermediate level of OHV. At Y8, however, neat copying shows a marked decrease in variability, and by Y10 and Y12 this shows the lowest level of variability of all the tasks. The difference between composition and fast copying is initially large, but reduces with age until, by Y12, fast copying is only marginally more variable than normal composition.

In order to determine whether these differences were statistically significant, a 6 (age group) by 3 (task) 2 way mixed ANOVA was conducted with age group as a between factor and task as a within factor. The use of parametric statistics is predicated on the data showing a reasonably normal distribution. A visual inspection of the data histograms indicated that this was the case and adjustments for possible lack of sphericity did not indicate that this assumption had been violated. The ANOVA showed a significant main effect of age group ($F(5,138)=3.24$, $p=0.008$. $\eta^2=.08$). There was also a significant main effect of task ($F(2,276)=15.77$, $p<0.001$, $\eta^2=.02$). However, there was also a significant interaction between age and task ($F(10,276)=2.00$, $p=0.033$, $\eta^2=.01$).

In order to test whether the main effect of age group was similar across tasks, simple effects of age group were analysed using one-way between subjects ANOVAs followed by polynomial contrasts for each task separately. These showed that although the overall ANOVA was not significant for the composition task ($F(5,138)=1.75$, $p=.13$, $\eta^2=.06$), there was a highly significant quadratic effect (contrast difference = .047, se = .018, $p=.008$). For the fast copying task, the overall ANOVA was marginally significant ($F(5,138)=2.15$, $p=.06$, $\eta^2=.07$) and there was a marginally significant quadratic effect (contrast difference = .037, se = .019, $p=.06$). Finally, for the neat copying task, the overall ANOVA was highly significant ($F(5,138)=5.11$, $p<.001$, $\eta^2=.16$), and there was a highly significant quadratic effect (contrast difference = .059, se = .018, $p=.001$).

From this, it can be seen that the composition task and neat copying task show a statistically significant quadratic component and that the fast handwriting task is only just outside the conventional limit for significance. The significance of these findings will be considered in combination with the findings relating to individualisation (see section 5.7) and the effects of constraining conditions (see below) in the Discussion section at the end of this chapter.

In order to assess the effects of the different types of task for each year group on the overall handwriting variation, one-way (task) within subjects ANOVAs were carried out for each year group separately. The results are shown in Table 5.6.

Table 5.6 Overall handwriting variation (OHV) - the significance levels and effect sizes of task for each year group

Year group	F(2,46)	p	η^2
2	7.235	0.002	0.11
4	2.493	0.094	0.03
6	3.590	0.036	0.02
8	0.847	0.495	0.01
10	6.785	0.003	0.05
12	6.474	0.007	0.03

Bonferroni correction $\alpha=0.05/6=0.0083$

The figures in Table 5.6 show that there is a significant effect of task in the Y2, Y10 and Y12 participants. Although year 6 was not significant at the adjusted alpha level it would be significant at an unadjusted level and therefore is worth being explored further, unlike the results for years 4 and 8 which are clearly not significant.

In order to determine the source of these effects, a set of post hoc pairwise comparisons were carried out for the Y2, Y10, Y12 and the Y6 year groups following the results in Table 5.6. To take account of the number of tests, Tukey's q value for the critical t was calculated to be 2.41 with $\alpha = 0.05$. The results are recorded in Table 5.7.

Table 5.7 OHV - showing the t values of task across pairs of tasks for the different age groups

Year group	Composition v Neat	Composition v Fast	Neat v Fast
2	1.73	3.93*	2.08
6	1.87	2.62*	0.97
10	2.21	1.73	3.36*
12	2.20	0.93	3.50*

Tukey's q value for critical t calculated to be 2.41 with $\alpha=0.05$, * significant at 0.05

These results show that at Y2, the fast copying task produced significantly more variation than the composition task (with the neat copying task lying in between and not significantly different to either). This difference is still present for the Y6 participants, where there is significantly greater variability when writing fast compared to normal composition. Although the difference at Y4 is not statistically significant it is still in the same direction. Generally, then, these results suggest that at younger ages (up to Y6) being asked to write faster than normal appears to reduce the extent to which children can produce consistent letter forms. However, by Y8, this difference begins to reduce (there is no significant effect of task), and remains reduced to a non-significant level at Y10 and Y12. At Y10, neat copying produces significantly less variability than fast copying and also produces, for the first time, less variability than the composition task, although composition produces handwriting this is not statistically significant from either neat or fast copying.

This pattern persists at Y12 where neat copying is significantly more consistent than fast copying.

A possible explanation for this pattern of differences is that, although there is a general inverted U-shape for all tasks, once writing becomes more controlled after Y6, variability generally reduces with age, so that, by Y12, neat, careful handwriting is at its most consistent. Increased speed still induces increased variability, as at Y2, but now normal composition is generally carried out in a faster manner so that it is more like fast copying than neat copying.

5.9 Results - individualisation of handwriting

In this section the degree of similarity of pieces of handwriting from participants (in the context of handwriting produced by their peers) and how this changes with age will be considered. It might, for example, be expected that handwriting of a young child will be more similar to that of his or her peers because of the similar teaching processes to which they are exposed. What is less clear is what might occur in older children. Experience would suggest that the handwriting becomes increasingly individualised and differentiated from their peers as the children get older. Support for this would be firstly a pattern of pieces of handwriting from the same author tending to cluster and for pieces from different writers not clustering. The second pattern in support of this would be evidence that the within writer clustering was greater for older children than for younger children.

The proportion data from the three pieces from each participant within each age group were analysed separately by year group using cluster analysis. In Chapter 4 a number of clustering algorithms were tried and Wards method was chosen as being appropriate. This will be used again in these analyses. The dendrograms obtained for each of the six year groups are shown in Appendices 4.1 to 4.6.

As can be seen from observing the dendrograms Appendices 4.1 to 4.6, the number of Level One clusters (those at the far left of the dendrograms) varies between the six year groups. In Table 5.9 the number of pieces of handwriting in each of the Level One clusters is counted and the distribution

Table 5.8 showing number of Level One Clusters based on dendrograms, Appendices 4.1 to 4.6

Age	No. of Level One Clusters	No. of members in Level One clusters							
		1	2	3	4	5	6	7	8
Y2	31	10	8	9	3	0	0	1	0
Y4	37	13	14	9	1	0	0	0	0
Y6	27	3	7	14	2	1	0	0	0
Y8	21	0	0	17	2	1	0	0	1
Y10	22	0	2	14	4	2	0	0	0
Y12	24	0	1	22	1	0	0	0	0

recorded for each year group. From Table 5.8 it can be seen that the majority of the Level One clusters across all ages have four or less members (96.5%). This would be consistent with many of the writers producing three pieces of handwriting which cluster together. Confirmation comes from the examination of the individual Level One clusters in the dendrograms and this shows that 80 of the 144 children (55.5%) have their three pieces of handwriting forming Perfect Clusters (see Table 5.9).

Table 5.9 the number of Perfect Triples shown by the dendrograms in Appendices 4.1 to 4.6 (% of maximum of 24)

Year group	No. of Perfect Clusters
2	8 (33.3%)
4	8 (33.3%)
6	13 (54.2%)
8	17 (70.8%)
10	12 (50%)
12	22 (91.6%)
Total	80 (55.5%)

The likelihood of forming Perfect Clusters with such numbers of participants is very remote (see Discussion in Chapter 4) and therefore this strong tendency for the three pieces of handwriting from a single child to form a Perfect Cluster in so many of the participants is very strong evidence in support of the general tendency for individualisation across all ages.

In addition, however, the proposition that there is a greater tendency for pieces from the same writer to cluster as age increases is supported by the figures in Tables 5.8 and 5.9. The values in Table 5.8 show that the children in Y2 and Y4 produce more one-member and two-member Level One clusters than in the older children. The production of one- and two-member Level One clusters suggests that the handwriting of the Y2 and Y4 children is less similar from one occasion to another for the three pieces. The pieces of handwriting were obtained under three different conditions (normal, neat and fast) and it is possible that this is a preliminary indication that changing the circumstances in which they write may affect the feature use in these youngest children more than in the older groups. These effects will be considered in more detail in Chapter 6.

The children of Y6, Y8 and Y10 show a reduced tendency to form one- and two-member Level One clusters compared to the Y2 and Y4 children, but rather produce a larger number (compared to Y2, Y4 and Y12) of four- and five-member Level One clusters. This suggests that the children in Y6, Y8 and Y10 are producing handwriting that is more consistent for the three tasks which is confirmed by the larger number of Perfect Clusters in Table 5.10. The low number of Perfect Clusters in Y10 (compared to Y6 and Y8) is an anomaly. It suggests that some of the Y10 children are writing more like one another than do their Y8 and Y12 colleagues and even their Y6 colleagues. Why this should be is not clear. It is conceivable that some of the participants are influencing one another in the way they write. This is one of the factors that affects the development of handwriting (see Chapter 2), but it would be surprising to see such an effect at such a late stage in the developmental process.

The children in Y12 have an almost perfect tendency to form Perfect Clusters, with 22 of the 24 participants doing so. Given the extremely remote likelihood of forming such a near-perfect cluster pattern at random, this finding shows that by Y12 most participants' handwriting is highly distinctive and consistent, qualities that are requirements for its individualisation.

5.10 Discussion

The coding scheme that was devised in Chapter 4 contained a range of types of handwriting feature that were deliberately chosen as representing a variety of handwriting dimensions that occur in some of the more frequently used letters in English. This was done so as to have the potential to capture changes of feature use and variation in feature use in children of different ages.

The analysis of the data was carried out with three objectives. Firstly, the letterforms were investigated to test whether age and/or type of task had systematic effects on the way letters are formed during handwriting. Secondly, the consistency (variability) with which letters were formed within samples was examined to test whether this changed with age and task. Thirdly, the data were evaluated to test the hypothesis that handwriting becomes more highly individualised as children get older.

5.10.1 Individual features and principal components analysis

The individual features were analysed using principal component analysis with a view to determining whether the set of individual features could be reduced to meaningful higher order dimensions. Two components were found and were tentatively identified as involving lateral elongation of letterform and movement integration within letters. In order to test the generality of these dimensions, further work is needed to examine other handwriting features that might share these higher order features. For example, an elongated and flattened form of the letter c or a broad and shallow form of the letter u might well fit in with the lateral elongation component. Likewise, the proportion of the loop of the letter b (mirroring that of feature d2) or the height of the crossing stroke in the letter f (mirroring feature t2) might also fit with the Movement Integration component. If these novel features were found to load on the same dimensions this would provide confirmation of the validity of the interpretations given to the components.

The Lateral Elongation component showed a significant effect of age. One possible explanation for this could be that this is a consequence of increased speed at older ages. However, this appears unlikely as there was no effect of task on this component (i.e. the faster condition was no different to the other conditions). Furthermore, the exaggerated right to left movement that lateral elongation implies, producing flattened letterforms such as a squashed letter o, appears to be contrary to the natural impetus of left to right movement that produces fast and efficient handwriting (Sassoon, 1990). An alternative possibility is that writing becomes more efficient if it involves an oscillation in one dimension (horizontal rather than vertical). A key question, therefore, for future research is to establish whether a laterally elongated style is associated with more or less efficiency and speed within a given age group. If it turns out that it is less efficient as a form of writing then an alternative explanation for its increased use with age would be required. For example, it may be that lateral elongation makes for more legible script, or that it is in some way more aesthetically pleasing. To investigate this, therefore, future research needs to be carried out to examine, first, whether the lateral elongation dimension can be replicated, and second how it relates to other measures such as speed, legibility, and aesthetic ratings.

The Movement Integration component is less coherent in concept and therefore it is more difficult to articulate what it may reflect in terms of general characteristics of the writing process. The fact that there was no clear effect of age or task on this component suggests that it may be a stylistic factor rather than a developmental one. It might be related to factors such as carefulness and precision of handwriting execution which in turn may have some underlying relationships to other traits of the writer. The first important step for future research is to establish whether this dimension can be replicated.

In order to test the validity of the findings of the PCA, an analysis of individual features of handwriting was carried out. Four of the five features of the Lateral Elongation component individually showed significant effects of age which provides good support for the conclusion that elongation and flatness of letterform increases with age.

Although there were no significant effects of task for the two higher level dimensions, there were significant task effects for some of the individual features. These were all consistent with a contrast between the neat and fast tasks indicating that speed has consistent effects for specific letterforms which are similar at all age levels.

5.10.2 Overall handwriting variability (OHV)

In order to move back from the fine detail relating to isolated individual features mentioned in the previous section towards a more general measure of the handwriting, the overall handwriting variability (OHV) was used which was based on the mean within piece variability across all features for a given writer. This measure was therefore intended to be capturing an average feature variability since some features would vary more than others in a given writer at a given time and rather than consider these individually, a more global measure might reveal clearer and more robust trends in handwriting production.

The changes in OHV are shown in Figure 5.3 and, together with the associated statistical analyses, show strong evidence for the proposition that handwriting variability increases after the initial learning phase and then decreases after it has peaked, a pattern that is consistent with the inverted U-shaped trajectory of skill acquisition that is anticipated by Karmiloff-Smith's model of representational redescription (Karmiloff-Smith, 1992). In addition, OHV showed a more coherent picture of the effects of task on handwriting variability than did the individual features.

The finding of the inverted U-shaped trajectory as shown by Figure 5.3 for mean OHV does not mean that each child follows the same feature changing pattern as his or her peers. Each child can follow its own inverted U-shaped trajectory but each child's trajectory can be caused by changes to different features use changes and this will lead to each child's handwriting developing along its own (unique) path, diverting away from any taught components that were in common with his or her peers.

Trends showing the trajectory of learning for the skill of handwriting could have been simply linear and downwards showing a gradual improvement of an initially learned but then unchanging skill or some other non-linear pattern. Such non-linear alternatives might apply to individuals for some of the ten plus years in which the handwriting skill develops, but to show this a prolonged longitudinal study would be required. An insight into such events is reported in a longitudinal study reported in Chapter 6 in which a number of writers are followed for three years each.

At the time when the variation in handwriting is at its greatest (about Y6 – see Figure 5.3 above) it might be expected that the imposition of a constraint would not lead to a large relative increase in handwriting variation since the handwriting is already more variable in these writers. In contrast, at the times when handwriting variation is at its least (in Y2 and Y12) it might be expected that the imposition of a constraint would produce a greater relative change in variation. The findings in this chapter show that there is an effect of task on the handwriting of the Y2, Y10 and Y12 participants after taking account of the interaction between the tasks and their ages. The effect of task is greatest (statistically significant) in the youngest (Y2) and the oldest (Y10 and Y12) participants and not in the children in the intermediate years. This provides general support for the proposition that disruption to handwriting is likely to lead to greater changes in variability in those whose handwriting is least variable normally.

The extra demand in the younger children of writing more quickly, in particular, might be expected to interfere with the accuracy of text generation in the tasks either in terms of its sense (when producing their own text) or when copying (leading to potential misreading or inaccurate memory of words to write). The accuracy of text production was not an aspect of this research that was considered. The requirement to write more neatly might not be expected to lead to a loss of accuracy, perhaps if anything a greater attention to detail might equate to greater accuracy of copying. The different ways in which the text is generated prior to execution (such as composition, copying and dictation) could be the focus of future research particularly in the context of the importance of handwriting automaticity and the benefits that that brings (Graham, Berninger, Abbott, Abbott, & Whitaker, 1997).

It might be anticipated that the youngest participants would be able to cope with writing neatly (slowly) better than writing quickly since writing slowly (carefully) is already the normal habit. In contrast, it might be expected that the older children who already write skilfully (quickly) would be able cope with writing quickly better than writing neatly (requiring more care and attention). The findings in Table 5.5 show a statistically significant effect of writing quickly as against the normal handwriting task in the Y2 participants. The figures in Table 5.5 also provide evidence to support the view that asking these older writers to slow down and write neatly causes the variation in their handwriting to change, but in this case, the writers are able to reduce further the variation in their handwriting from that shown by their normal handwriting. Indeed, it is only in the Y10 and Y12 age groups that the participants have the lowest variation in their neat handwriting task rather than the normal, composition task. In contrast, all year groups show the greatest variation in the handwriting produced quickly, although it is only in Y2 where this is statistically significant. The plots in Figure 5.3 show that the 'changeover' of this effect occurs at around Y8 in which the fast and neat tasks both have very similar increases (that are statistically not significant) in variation compared to the composition task. In other words, before Y8, any disruption (writing quickly or neatly) leads to an increase in variation, whereas after Y8, such is the skill of the writers, the variation of their handwriting decreases significantly when asked to write neatly and only slightly increases when asked to write quickly.

Given the potential for the constraints imposed by the copying tasks to lead to some alterations in the handwriting of the children, the fact that the clustering tendency remains despite this is testimony to the general level of individual styles that are emerging and the capacity of even the younger children to deal with the change in circumstance. This would tend to suggest that although different handwriting tasks require different cognitive elements, such as idea generation and reading and the implications this has for memory and cognitive capacities (Graham et al., 1997) the clustering remains reasonably tight. However, the clustering does become more consistent as children get older and this offers some support to the view that in younger children the different tasks may be causing some disruption to (and hence increased variation of) the handwriting.

5.10.3 Individualisation

Cluster analysis found a clear trend for the individualisation of handwriting as children get older, albeit the pattern was not as clear cut as that reported in the preliminary study in Chapter 4 which had just fifteen writers as opposed to the 144 writers in this cross-sectional study. The coding scheme used contains just seventeen of a potentially much larger population of possible handwriting features that can be used to describe handwriting. The implementation of a coding scheme that included more features, especially relating to other letters of the alphabet, would have the potential to give yet greater evidence of individualisation.

There is conclusive evidence supporting the suggestion that handwriting samples from a given writer are more like other samples from that same writer than samples from other writers. The values in Tables 5.9 and 5.10 are derived from the dendrograms for each year group (Appendices 4.1 to 4.6). These values show a very strong tendency for three pieces of handwriting from the same child to cluster together far and above what would be predicted if the clustering were random. This is despite the fact that the three pieces were written under different conditions.

However, a second element to this was whether the extent of clustering was the same for writers of all ages. Tables 5.9 and 5.10 again provide strong support for the view that younger children show a strong but imperfect clustering tendency but the oldest (Y12) children show almost perfect clustering (each writer's three pieces forming a cluster at Level One with no other writers in their cluster). One confounding factor in this could have been the fact that the three pieces were obtained under different writing conditions (normal, neat and fast). This might have had the effect of changing the each child's handwriting to some degree, thereby reducing the tendency to cluster with other pieces of their handwriting. However, as was shown in Section 5.7, the interactions of age and task were somewhat variable and the reduced tendency to from Perfect Clusters in the younger participants cannot readily be explained only by changes in variability caused by task, although that might have contributed.

These findings support the view that the handwriting is not only becoming more variable in children as they approach the age of about eleven, but also from this increased variation, each child is adopting his or her own combination of handwriting features of which (on the downward slope of the inverted U) they will retain only some. Each child is following their own inverted U-shaped trajectory as their handwriting becomes more consistent at school-leaving age and is less like that of their peers. The process of individualisation is close to completion.

Chapter 6 Longitudinal study

6.1 Introduction

In Chapter 5, evidence was found for answers to the three central questions posed by this research at the end of Chapter 2 relating to the trajectory of the learning process for handwriting acquisition, the process of individualisation and the effects of writing under different conditions. Whilst these findings provide compelling answers to the questions, there remains the uncertainty as to whether these processes occur in the handwriting development of individuals or whether they are trends that are only apparent in groups of individuals. As a result of this, a longitudinal study was undertaken and is described in this chapter with a view to determining that these processes do indeed occur in the handwriting of children of different ages.

Assuming that the range of internal factors (such as general cognitive and fine motor skill) are broadly similar in groups of individuals of the same age, then age effects might be expected to, at least in part, reflect improvements in the ability to execute efficient handwriting as individuals develop. However, it is also possible that external factors might influence groups of participants that are subjected to those factors. These might include a change of style or emphasis in the way that handwriting is taught (or indeed how related subjects such as spelling and literacy are taught), or it might be due to the adoption of different educational materials and methods (for example, a new set of textbooks and practise exercises). The timing of such occurrences will vary from child to child and for this reason the timing of developmental changes in the handwriting of a given child are likely to be difficult to predict and will vary markedly between from one to another.

But whatever the external influences are, it is impossible to evaluate their combined effects on the handwriting of a given child from a cross-sectional study, not least because the process of handwriting acquisition is such a prolonged one with the potential for any number of positive and negative influences. One thing that can be relied upon is that for most children, as they get older their writing improves; improves in the sense that it becomes quicker and more automatic – whether it becomes more legible is not a dimension of handwriting that is considered in this research.

Changes in handwriting do not occur, at one extreme, at a uniform rate over time, or, at the other extreme, in sudden quantum changes. Rather, as Inglis & Connell (1964) suggest, development happens in sharp and usually small changes which are then incorporated into the writing process, stabilise and possibly even regress if such changes are difficult to acquire (an obvious example being learning joined up writing which often causes deterioration in the writing for a while).

It is not necessarily the case that development will occur particularly rapidly at any point in the academic year, but perhaps the break during the long summer holiday and the associated marked 'jump' in academic expectation starting a new academic year might lead to more changes between academic years. It would be reasonable to expect that at the commencement of the academic year, participants essentially re-discover their writing ability that they had at the end of the previous one and that the new, often increased, pressures in the new academic year may lead to a greater rate of development in the early part of the new school year as students adapt new strategies for writing more and more quickly.

There are very few longitudinal studies reported that deal with handwriting development. Blote and Hamstra-Bletz (1991) analysed handwriting in a group of young children for a period of five successive years. They found that there was not a great deal of qualitative change in the handwriting of children over this time but rather more of a quantitative change in terms of the overall fluency and smoothness of writing. In addition, there was evidence of a change in the handwriting especially in the patterns of letter joins used. They also found that the relationships between writing speed and form is not linear and is not the same at different ages. Slow writers tended to lack skill and fast writers tended to lack care and hence the latter group in particular would benefit from slowing down.

Another longitudinal study considered the trajectory of handwriting improvement in children as they get older in terms of their performance in relation to that of their peers. Marr & Cermak, (2003) found that there was a moderately consistent pattern of handwriting performance in the ninety three children that they studied from pre-school for three years but the general improvements in handwriting skill varied from child to child, with, in particular, greater relative improvements in the handwriting of the less skilful children, suggesting that their initial difficulties were more a matter of timing rather than ability.

Consistency of levels in language were reported by Abbott and colleagues (2010). They used structural equation modelling to explore the longitudinal relationships in children aged 6-14 between handwriting and handwriting, handwriting and spelling and handwriting and composition. The latter two studies mirrored work done previously in cross-sectional studies (Berninger et al., 1998 and Graham et al., 1997). The findings of the longitudinal study (Model 1 in (Abbott et al., 2010)) did not provide support for the view that there is an ongoing developmental relationship between handwriting production and either spelling or composition, the authors concluding that longitudinal studies are an important tool in understanding changes over time rather than relationships at a point in time.

No longitudinal studies, however, have been carried out which examine the detailed structural changes that occur in specific letter forms in handwriting style and which have in turn been used to consider changes in handwriting variability in children. Longitudinal studies have tended to find that handwriting as a skill measured by general factors such as speed and fluency plateaus as handwriting instruction tails off and children's motor skills (quantitative elements) have maximised (Blote & Hamstra-Bletz, 1991). The longitudinal study reported in this chapter completes the picture by specifically looking at the qualitative aspect of handwriting (style) and how this changes with time. Given the theoretical issues that arise from cross-sectional studies as opposed to longitudinal studies, for example as exposed by the longitudinal study of Abbott (2010), this longitudinal study will complement that reported in Chapter 5. It will show whether or not the trends that occur across groups of children are in fact occurring in individuals and to what extent the dynamics of such changes are similar given the likelihood that the development process of handwriting may have some gradual and some more rapidly introduced components.

6.2 Method and participants

Given the time constraints that apply to a PhD research project, there were limits on the period of time over which particular individuals could have their handwriting monitored. For this reason, it was decided to follow a number of participants for three years. The age of the children followed could then be set at intervals that would allow successive cohorts to have their ages overlapping at the beginning and end of the three-year period. Thus, cohorts starting at five year olds, eight year olds, eleven year olds and fourteen years old were chosen. These participants were different from those that took part in the cross-sectional study reported in Chapter 5. Parental consent for their participation was obtained.

For ease of reference, the following convention will be used to describe the year groups: 5_0 will refer to the (academic) year in which a child was five years old; 5_1 to the next year; and 5_2 to the third year and so on for ages 8, 11 and 14. For comparison purposes, ages and year groups convert as follows:

Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12
5_0	5_1	5_2	8_0	8_1	8_2	11_0	11_1	11_2	14_0	14_1	14_2

It was decided to follow the handwriting development of four boys and four girls in each age group, giving thirty-two participants. The choice of participants was made after discussion with their teachers. Any children with general learning difficulties or specific problems with their handwriting were excluded but otherwise no particular selection criterion for participants was used. It was decided that this study would use schoolwork produced in the normal course of class activities since this would cause virtually no disruption to class time and would be likely to produce natural handwriting samples. One final consideration required knowledge of the family backgrounds of the participants because with such a study there is always the possibility of children leaving the area for family reasons and hence dropping out of the study. Thus, the teachers were asked to specifically choose children whose family, to the best of their knowledge, had been resident in the same area for a number of years (for example, they may have had older siblings taught in the same school).

Apart from these considerations, the teachers were asked to select a reasonably representative sample of participants whose handwriting would vary across the various dimensions that can be used to describe handwriting such as neatness, roundness, scruffiness and so on. However, as with the cross-sectional study, the teachers were unaware of the detailed nature of the study that was to be carried out on the samples of handwriting from the students selected. In the event, none of the participants did leave the area during the three years and so all thirty-two participants were successfully followed for the duration of the study.

The collection of the samples of handwriting was generally spread out over the academic year since in some instances the schoolwork was required by the school as part of assessment programmes for the various children. It was decided to score three samples from each participant each academic year since handwriting does vary naturally from one occasion to the next and so by obtaining three samples it was considered that this would provide an adequate sample of the handwriting of each participant at that time; a single piece of handwriting would have been less representative. It would also give an opportunity to see some of the more rapidly acquired changes in handwriting that may periodically occur. Thus, each academic year ninety-six pieces of work were collected from the thirty-two participants and scored, giving a grand total of 288 pieces over the three years.

For each participant the pieces scored tended to be from roughly the same period of the year (although a spread of weeks or a month or two was not uncommon), but for different year groups the pieces were from different parts of the calendar year so as to spread out the task of scoring. The collection of samples was dictated by a number of circumstances. Clearly, attempting to collect three samples in the first week of the academic year would be unlikely to yield three pieces of writing (particularly since for the older two age groups, all of the work was collated by the English departments in the school). As a result, most visits to the schools to collect samples tended to be from around January through to July with collections at term ends being ideal as it gave holiday periods during which the scoring could be done whilst causing no disruption to the school.

The participants within a given age group came from the same school. The five year olds came from one school, the eight year olds from a second school and both the eleven and fourteen year olds came from the same, third school.

Samples were scored over a period of weeks, with samples from the same participant being scored well apart in time to avoid accidentally remembered scoring. Each feature was scored up to a maximum of twenty instances for each piece of handwriting. The proportion score for each of the seventeen features was scored and recorded following the method described in Chapter 4.

6.3 Results – general observations

The first general observation is perhaps not very surprising, namely that the virtually all of the samples obtained from the 5_0 participants, with one notable exception, were unable to produce enough handwriting to give usable data. Most of the 5_0 participants still required considerable input from the teaching staff. The input showed that the children were receiving plenty of encouragement both of a general kind, but also there are some more detailed comments from the teachers that relate to various aspects of the writing. Some might be fairly general, such as praising writing that is written on the line or the level of neatness. The amounts of writing were often just the child's name and some letters were highlighted as needing particular attention, which were then repeated several times until satisfactory.

In some of these very early samples, letter form is wrong and letter construction is inappropriate. There may also be a mixing of upper and lower case styles and the need to maintain a reasonable size and inter-letter proportion is clearly beyond some of the children. For these reasons, the 5_0 pieces were not used in the analysis,

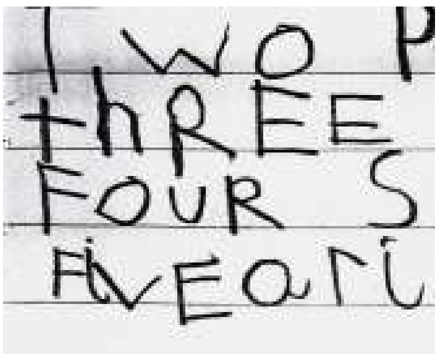


Figure 6.1 showing handwriting from a 5_1 pupil

But by 5_1 the improvement in the handwriting in all of the participants was such that all provided pieces of handwriting that were capable of being scored, albeit some were still borderline in terms of the amount of handwriting, having some features with fewer than ten occurrences in a piece of handwriting.

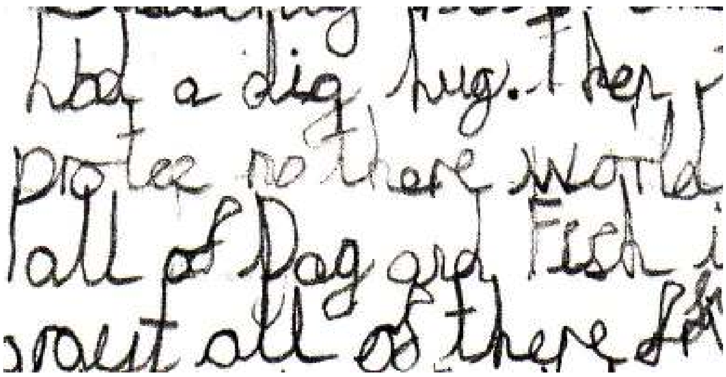


Figure 6.2 showing handwriting from the same pupil as Figure 6.1 but in the following academic year

But by 5_1 the improvement in the handwriting in all of the participants was such that all provided pieces of handwriting that were capable of being scored, albeit some were still borderline in terms of the amount of handwriting, having some features with less than ten occurrences in a piece of handwriting. The samples from the older participants were capable of being scored, although some of the 8_0 pieces showed that even children of that age may have difficulty in producing larger amounts of handwriting.

The data obtained in the longitudinal study will be analysed as follows. The two components resulting from the principal components analysis on the cross-sectional data will be examined to see how they behave based on the longitudinal data. Then the overall handwriting variation (OHV) of the children will be examined to see how this changes within the handwriting of the same individuals and finally the individualisation of the handwriting of the children will be examined to see if the trends found in the cross-sectional study are repeated here.

6.4 Results – descriptive statistics and Principal Components Analysis

The data obtained from the longitudinal study are shown in Table 6.1

The notation for each year cohort is, for example, 5_1, 5_2 and $5_{3,}$ relating to the first, second and third years of obtaining samples from the children aged five at the commencement of the study. The next cohort, starting when aged eight, are similarly represented as 8_0, 8_1 and so on for all participants.

The data from the longitudinal study that are summarised in Table 6.1 were used to determine whether or not the two dimensions identified in the cross-sectional study in Chapter 5 behaved similarly. The two higher order characteristics of the children's writing that were identified were called Lateral Elongation, which showed a significant increase with age in the cross-sectional study, and Movement Integration, which showed little evidence of a change with age in the cross sectional study.

Table 6.1 Longitudinal study data showing median (inter-quartile) for use of each coded feature

	5_1	5_2	8_0	8_1	8_2	11_0	11_1	11_2	14_0	14_1	14_2
a2 – low tail retrace	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.05)	0.00 (0.18)	0.00 (0.05)	0.00 (0.05)	0.00 (0.03)
a3 – closed loop	0.75 (0.52)	0.76 (0.39)	0.80 (0.49)	0.76 (0.26)	0.90 (0.44)	0.85 (0.35)	0.75 (0.30)	0.80 (0.63)	0.75 (0.45)	0.65 (0.48)	0.55 (0.55)
a4 – upward initial movement	0.10 (0.39)	0.30 (0.48)	0.60 (0.38)	0.69 (0.28)	0.85 (0.18)	0.88 (0.25)	0.53 (0.57)	0.70 (0.69)	0.90 (0.25)	0.93 (0.25)	0.95 (0.15)
d1 – proportionately short loop	0.20 (0.56)	0.06 (0.15)	0.05 (0.29)	0.30 (0.48)	0.37 (0.61)	0.21 (0.49)	0.58 (0.73)	0.45 (0.69)	0.73 (0.79)	0.83 (0.89)	0.70 (0.90)
d2 – flattened loop	0.24 (0.35)	0.48 (0.51)	0.23 (0.55)	0.28 (0.41)	0.50 (0.52)	0.34 (0.60)	0.43 (0.59)	0.70 (0.34)	0.25 (0.69)	0.37 (0.66)	0.63 (0.70)
e2 – high curve bisection	0.15 (0.15)	0.20 (0.20)	0.30 (0.51)	0.30 (0.39)	0.33 (0.49)	0.18 (0.29)	0.23 (0.41)	0.23 (0.44)	0.10 (0.22)	0.13 (0.35)	0.20 (0.19)
i2 – high dot	0.50 (0.48)	0.79 (0.43)	0.61 (0.42)	0.49 (0.40)	0.60 (0.45)	0.73 (0.44)	0.65(0.45)	0.55 (0.68)	0.65 (0.39)	0.63 (0.36)	0.65 (0.54)
i3 – dot to right	0.39 (0.46)	0.55 (0.29)	0.43 (0.40)	0.44 (0.38)	0.53 (0.39)	0.60 (0.30)	0.75 (0.32)	0.67 (0.39)	0.68 (0.33)	0.63 (0.45)	0.68 (0.37)
n2 – initial downstroke	1.00 (0.00)	1.00 (0.00)	1.00 (0.13)	1.00 (0.00)	1.00 (0.05)	1.00 (0.00)	1.00 (0.00)	1.0 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
o1 – starts to right	0.82 (0.33)	0.93 (0.19)	0.80 (0.30)	0.83 (0.36)	0.91 (0.24)	0.85 (0.31)	0.83 (0.58)	0.90 (0.34)	0.73 (0.38)	0.73 (0.41)	0.85 (0.49)
o2 – tall and narrow	0.42 (0.45)	0.28 (0.53)	0.56 (0.29)	0.50 (0.50)	0.32 (0.39)	0.20 (0.51)	0.23 (0.35)	0.15 (0.22)	0.35 (0.63)	0.40 (0.44)	0.25 (0.45)
r1 – open retrace	0.00 (0.51)	0.00 (0.19)	0.00 (0.09)	0.00 (0.05)	0.00 (0.00)	0.00 (0.09)	0.03 (0.14)	0.05 (0.15)	0.08 (0.24)	0.18 (0.27)	0.10 (0.15)
r2 – low retrace	0.65 (0.51)	0.76 (0.52)	0.75 (0.48)	0.76 (0.47)	0.88 (0.29)	0.68 (0.34)	0.80 (0.33)	0.90 (0.35)	0.85 (0.44)	0.90 (0.15)	0.90 (0.29)
s1 – script style	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.15)	1.00 (0.00)	1.00 (0.20)	1.00 (0.10)	1.00 (0.29)	1.00 (0.45)	0.75 (0.63)	0.90 (0.30)
s2 – shallow centre axis	0.98 (0.32)	0.98 (0.15)	0.68 (0.55)	0.85 (0.35)	0.95 (0.29)	0.83 (0.38)	0.83 (0.40)	0.90 (0.60)	0.78 (0.53)	0.68 (0.64)	0.65 (0.56)
t1 – crossbar longer to right	0.82 (0.41)	0.87 (0.38)	0.90 (0.20)	0.93 (0.17)	0.95 (0.19)	0.95 (0.39)	0.98 (0.22)	0.95 (0.14)	0.90 (0.28)	0.93 (0.28)	0.95 (0.24)
t2 – high crossbar	0.90 (0.38)	0.88 (0.22)	0.44 (0.56)	0.63 (0.40)	0.58 (0.45)	0.61 (0.48)	0.68 (0.60)	0.75 (0.84)	0.58 (0.55)	0.68 (0.73)	0.63 (0.73)

In order to examine these effects in this longitudinal study, scores were calculated using the same set of scale items for the two components as had been identified in chapter 5. These scores were normally distributed with no evidence of outliers. Within subjects comparisons generally had sphericity, but in cases where this was absent, the Greenhouse-Geisser statistic was used to correct for lack of sphericity. All between subjects comparisons had homogeneity of variance. In order to analyse the effects, one way within subjects ANOVAs were used to test the significance of age differences within age cohorts. In other words, within subjects comparisons were made of children as they developed through ages 5, 6 and 7; 8, 9 and 10; 11, 12 and 13; and finally 14, 15 and 16. Between subjects t tests were used to compare adjacent age groups across cohorts (i.e. 7 versus 8; 9 versus 10; and 12 versus 13).

6.4.1 Lateral Elongation

The mean scores on this component as a function of age are shown in Figure 6.3. As a visual representation of the fact that the four cohorts involve the same children in each cohort having their handwriting analysed in three successive years, but with each cohort having different children in it, the results are presented in separate panels. Note that the initial measuring point for the five year olds is not plotted because these samples were extremely poor and only three were able to be scored at all

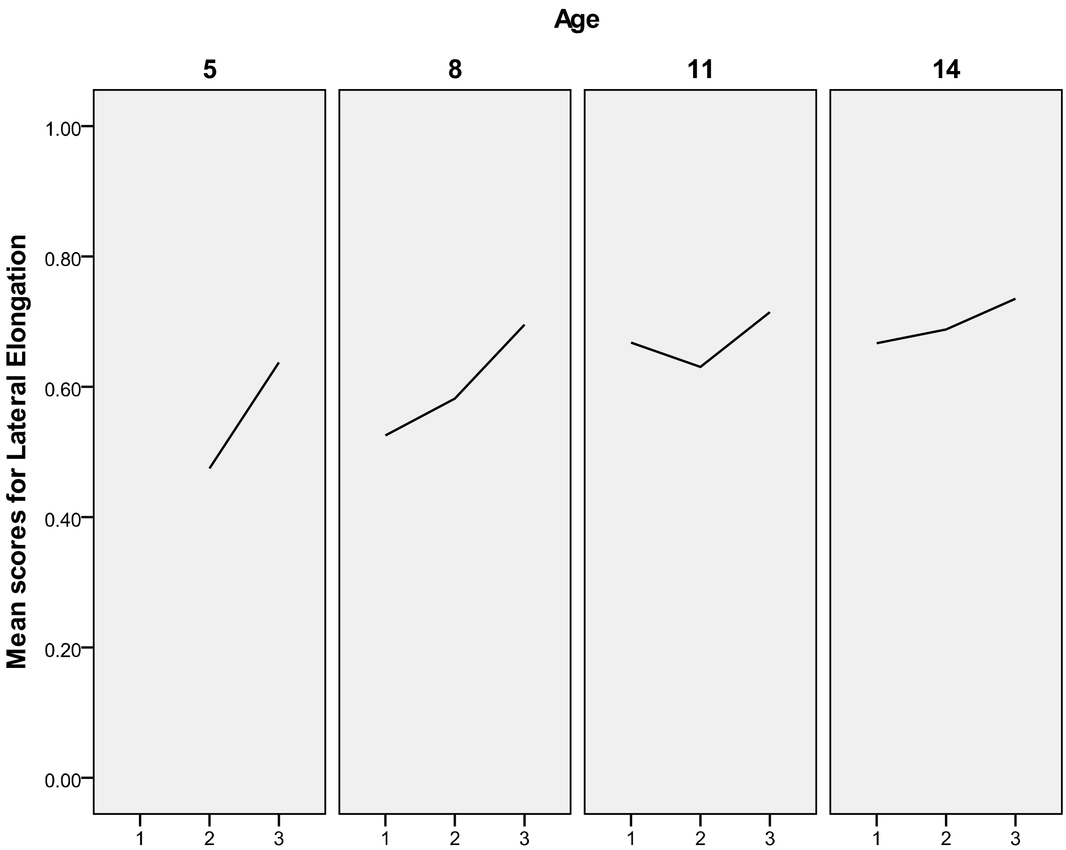


Figure 6.3 Mean score on Lateral Elongation component as a function of age changes within each of the age cohorts.

As can be seen in the Figure 6.3, with the exception of the change from 11 to 12 within the 11 year old cohort, the scores within each cohort show a consistent increase with age. This appears to be strong support for the increase in the Lateral Elongation with age found in the cross sectional study. By contrast, the transition between age cohorts is much less clear cut, with little evidence of a clear increase, and, in the case of the transition from 7 to 8, a suggestion that scores decline between these ages. It should be remembered, however, that these comparisons are of different children, and that with a small sample of participants in each cohort, this may only represent individual differences between small numbers of children. It is also worth noting that each of the age cohorts does appear to be scoring higher than the previous younger cohort, and that, overall, there is an increase in the Lateral Elongation component from a mean of 0.47 (sd = .15) at age 6 to a mean of 0.73 (sd = .18) at age 16.

In order to test the significance of the differences within age cohorts, one way within subjects ANOVAs, followed by Bonferroni-adjusted pairwise comparisons, were carried out separately for each cohort. These showed: (a) a significant increase in Lateral Elongation between the ages of 6 ($M = .47$, $sd = .15$) and 7 ($M = 0.64$, $sd = .11$) within the 5 year old cohort ($F(1,7) = 15.12$, $p = .006$); (b) a significant effect within the 8 year old cohort ($F(2, 14) = 6.45$, $p = .01$) , with the 10 year olds ($M = 0.70$, $sd = 0.08$) scoring significantly higher than the 9 year olds ($M = 0.58$, $sd = 0.06$ $p = .015$) and the 8 year olds ($M = 0.52$, $sd = 0.15$, $p = .05$) , but with no significant difference between the 8 and 9 year olds ($p = 1.0$); (c) a non-significant overall effect within the 11 year old cohort (Greenhouse-Geisser $F(1.08, 14 = 1.73$, $p = .23$), with the children at age 13 ($M = 0.71$, $sd = 0.16$) scoring significantly higher by the pairwise comparison than when they were 12 ($M = 0.63$, $sd = 0.14$, $p = .03$) but with no difference from when they were 11 ($M = 0.68$, $sd = .12$, $p = 1.00$); (d) a significant effect within the 14 year old cohort ($F(2,14) = 4.06$, $p = .04$), with the children scoring significantly higher when they were aged 16 ($M = 0.74$, $sd = 0.18$) than when they were

14 (M = 0.67, sd = .20, p = .025) but with no significant difference to when they were 15 (M = 0.69, sd = 0.14, p = .22).

Overall, these analyses provide clear evidence of significant increases in the Lateral Elongation component as the children grow older within each age cohort, with some plateaus where differences failed to reach significance, but no significant decreases with age at any point.

Although there appeared to be decreases in the Lateral Elongation component between the transition ages across cohorts, none of these comparisons were significant using between subjects t tests (with no adjustment made for multiple testing). For the comparison between the 7 year olds (in the 5 year .old cohort) and the 8 year olds (in the 8 year old cohort), t(14) = 1.67, p = .12; for the comparison between the 10 year olds (in the 8 year old cohort) and the 11 year olds (in the 11 year old cohort), t(14) = 0.55, p = .59); for the comparison between the13 year olds (in the 11 year old cohort) and the 14 year olds (in the 14 year old cohort), t(14) = 0.52, p = .61). These results are compatible with the assumption that the apparent decreases between cohorts are simply a consequence of individual differences between the children within the different age cohorts. There is no evidence, therefore, that Lateral Elongation decreases significantly at any point during the development of these children.

Overall, these results provide strong support for the findings of the cross sectional study, and suggest that the Lateral Elongation component increases as children grow older. Note also that the scores for equivalent age groups are similar in the two studies: 7 year olds in this study scored a mean of 0.64 compared to a mean of 0.59 in the cross sectional study; 16 year olds cored .74 in this study; 17 year olds scored 0.78 in the cross sectional study.

6.4.2 The Movement Integration component

Exactly the same analytic strategy was used to assess whether the Movement Integration component varied with age. The means in each condition are shown in figure 6.4.

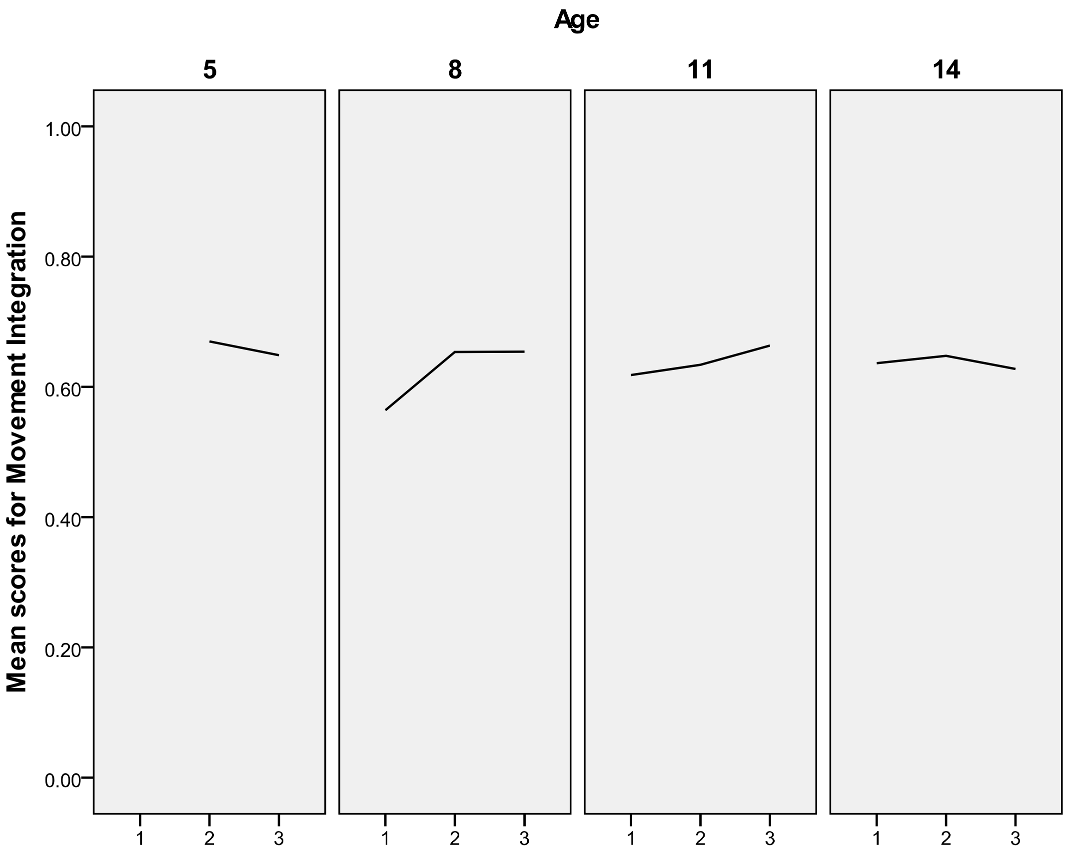


Figure 6.4 Mean score on Movement Integration component as a function of age changes within each of the age cohorts.

As can be seen in Figure 6.4, there was very little evidence that the Movement Integration component varied systematically with age. For two of the age cohorts the scores rise slightly as the children grow older, with this being most pronounced for the 8 year old cohort from age 8 to 9. For the other two cohorts there is a slight decrease as children grow older but this is a minimal difference. Overall the scores range between 0.56 and 0.67, and even this is possibly an exaggeration of the range as it reflects the particularly low score of the 8 year olds.

Only one of the one-way within subjects ANOVAs showed significant effects within the cohorts. For the 8 year old cohort, ($F(2,14) = 4.09$, $p = .04$), with children scoring significantly lower when they were aged 8 ($M = 0.56$, $sd = 0.07$) than when they were aged 9 ($M = ,0.65$, $sd = 0.05$, $p = .03$), but not than when they were aged 10 ($M = 0.65$, $sd = 0.08$, $p=.19$). None of the remaining tests were significant: for the 5 year old cohort, ($F1, 7) = 0.55$, $p = .48$); for the 11 year cohort, ($F(2,14) = 0.39$, $p = .68$); for the 14 year old cohort, ($F(2,14) = 0.60$, $p = .56$). Similarly, only one of the between subjects t tests showed a significant effect: the 7 year olds (from the 5 year old age cohort) ($M = 0.65$, $sd = 0.06$) scored significantly higher than the 8 year olds (from the 8 year old cohort) ($M = 0.56$, $sd = .07$) ($t(14)= 2.65$, $p = .02$, 2 tailed test). For the comparison of the 10 year olds (from the 8 year old cohort) ($M = 0.65$, $sd = 0.08$) with the 11 year olds (from the 11 year old cohort) ($M =0.62$, $sd = 0.11$), ($t(14) = .0.72$, $p = .48$); for the comparison of the 13 year olds (from the 11 year old cohort) ($M = 0.66$, $sd = 0.19$) with the 14 year olds (from the 14 year old cohort) ($M = 0.64$, $sd = 0.18$), $t(14 = 0.29$, $p = 0.78$, 2 tailed test.

Overall, the results for this component are similar to the cross sectional study and show little evidence of any systematic change of the Movement Integration component with age. Although 8 years olds do seem to have scored significantly lower than the 7 year olds and than when they themselves were 9, this does not seem to be part of a more general pattern. This is in marked contrast to the results for the Lateral Elongation component, and provides further support for the findings of the cross sectional study reported in Chapter 5.

6.5 Results – overall handwriting variation (OHV)

In Chapter 5, evidence was shown from the cross-sectional data to support the inverted U-shaped trajectory for handwriting development (as measured by variability across all features) as opposed to a linear model (consistent with a gradual improvement of an unchanging skill).

In order to determine whether or not the trends are in fact occurring in the handwriting of individual children, the variation of the handwriting in the pieces collected in this longitudinal study were similarly analysed, using the variable OHV as a measure of handwriting variation (see Chapter 5). The main drawback to doing this with the longitudinal data is that the number of participants is much smaller and being able to reach statistically significant conclusions much less likely.

Nonetheless, if the mean OHV scores obtained from the longitudinal study are considered in a similar way to that discussed in Chapter 5 and are plotted the result is shown by Figure 6.5. As a visual representation of the fact that the four cohorts involve the same children in each cohort having their handwriting analysed in three successive years (labelled First, Second and Third), but with each cohort having different children in it, the results are presented in separate panels.

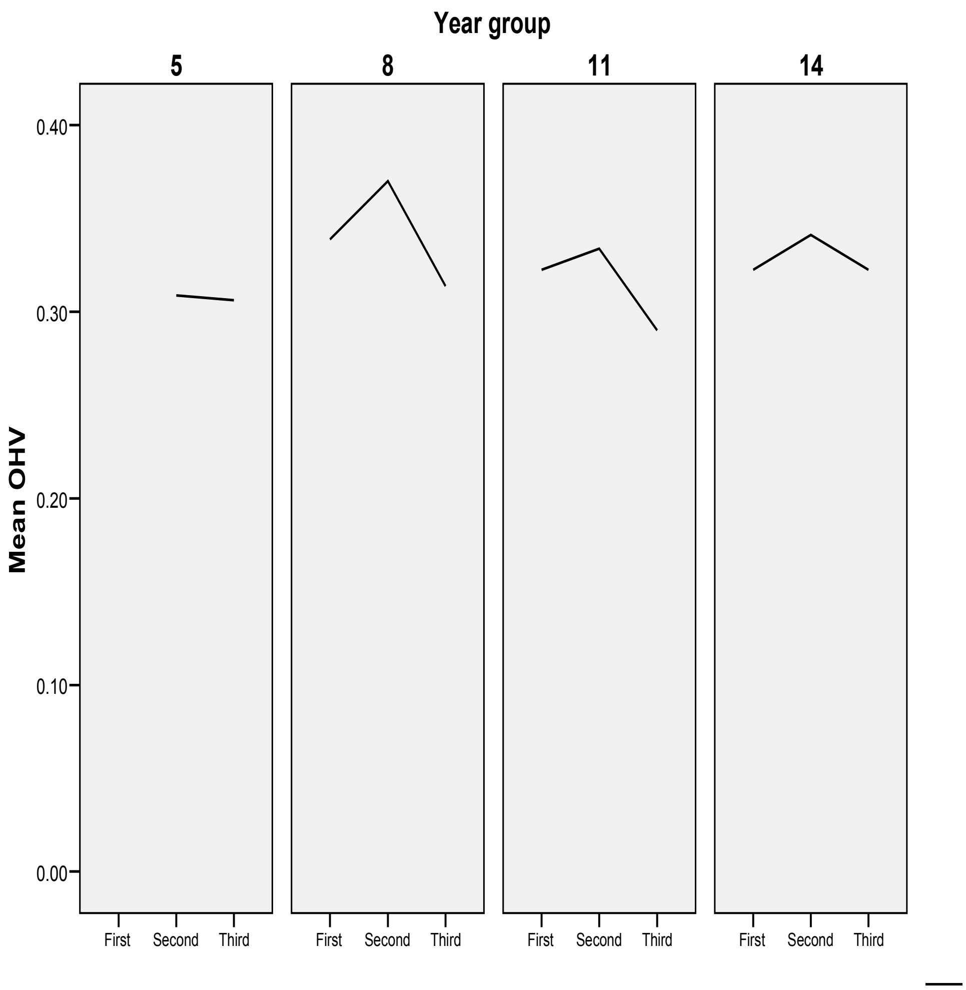


Figure 6.5 showing the mean OHV data from the longitudinal study

The first year data for the five-year old cohort is very unreliable as the majority of these young children were unable to produce sufficient handwriting to be scored and it would probably be unwise to attribute any significance to the very steep rise shown.

As can be seen in Figure 6.3, there is a general increase in variability from year 5 to year 8 followed by a decline in variability compared to year 8 in years 11 and 14. This is broadly similar to the inverted U-shape found in the cross-sectional data, and the peak variability occurs at a similar age to that observed in the cross-sectional data. However, there is also some evidence for scalloping or inverted U shapes within each of the year groups. In order to evaluate the significance of these differences, two separate sets of analyses were carried out. First, one-way repeated measures ANOVAs were carried out within each age cohort to test whether there were significant changes in variability over the three years of testing. These were followed by within subjects contrasts and pairwise comparisons to evaluate the significance of the differences between adjacent time periods for each age cohort. Second, in order to evaluate the differences between the maximum and minimum variability within each of the age cohorts, between subjects 't' tests were carried out making adjacent comparisons of the final testing point within the 5 year old cohort, the middle testing point of the 8 year old cohort, the final testing period of the 11 year old, and the middle testing point of the 14 year old cohort.

The first set of analyses showed that: (i) There was no significant difference in mean variability within the 5 year old cohort ($F(1,7)=.012$, $p = .92$, $\eta^2<.001$). (ii) Although the main effect of time of testing for the 8 year old cohort was not significant ($F(2,14)=2.07$, $p=.16$, $\eta^2=.12$), this was a large effect size, and the quadratic contrast test was significant ($F(1,7)=8.38$, $p=.023$. Pairwise contrasts showed that there was a marginally significant difference between the mean variability at time points 1 and 2 ($M=0.34$, $sd=0.08$ v. $M=0.37$, $sd=0.06$; $t(7)=1.94$, $p=.09$) and a marginally significant difference between time points 2 and 3 ($M=0.37$, $sd=0.06$ v. $M=0.31$, $sd=.045$; $t(7)=1.93$, $p=.09$). These analyses suggest that mean variability within the 8 year old cohort rises from time point 1 to a peak at time point 2 and then declines at time point 3. (iii) Although the main effect of time of testing within the 11 year old cohort was not significant ($F(2,14)=1.23$, $p=.32$, $\eta^2=.04$), there was a significant difference for the pairwise comparison between mean variability at time points 2 and 3 ($t(7)=2.75$, $p=.03$). This suggests that mean variability continues to decline within the 11 year old cohort from time points 2 and 3. (iv) There was no significant main effect of time of testing within the 14 year old cohort ($F(2,14)=0.58$, $p=.57$, $\eta^2=.007$) and neither of the pairwise comparisons approached significance ($p>.48$). This suggests that there is no significant change in mean variability at different time points for the 14 year old cohort.

The second set of comparisons showed that there was a significant increase in mean variability from the final testing point for the 5 year old cohort (i.e. at age 6) to the middle testing point for the 8 year old cohort (i.e. at age 9) ($t(14)=2.70$, $p=.009$, 1 tailed test). There was also a significant decrease in mean variability between the middle testing point for the 8 year olds and the final testing point for the 11 year olds ($t(14)=1.76$, $p=.05$, 1 tailed test). There was, however, no significant difference in mean variability between the final testing point for the 11 year old cohort and the middle testing point for the 14 year old cohort ($t(14)=0.52$, $p=.61$, 2 tailed test).

Taken together, these two sets of analyses suggest that, within the 8 year old cohort there is a significant change in mean variability at the 9 year old testing point, with the variability increasing up to this point and then declining, and that this maximum point is higher than the variability for the 6 years olds and the 13 year olds. This supports the findings from the cross sectional study suggesting an inverted U-shape for the mean variability scores. This should, however, be treated with caution given the selective nature of the statistical tests and low sample size. It should also be noted that age at which variability reaches a maximum in this study is lower than the age suggested by the cross sectional study.

6.6 Results -individualisation

The next stage was to analyse the longitudinal data obtained using cluster analysis with a view to determining whether or not it follows a similar pattern supporting the individualisation process as shown by the cross-sectional data obtained in Chapter 5. This would add extra support to the cross-sectional findings by showing that the trends apparent in a group of writers were occurring developmentally in the handwriting of individual children.

The nine pieces of handwriting (three from each of three successive years with the exception of the Y5 cohort where only the second and third years' data were usable) from each participant were scored for the seventeen features in the refined coding scheme devised in Chapter 4.

The clustering process used was with Ward's method for the reasons described in Chapter 4. The dendrograms produced from the cluster analyses for each year group are shown in Appendices 5.1 to 5.4.

Before analysing them further, the general cluster patterns of the four dendrograms can be seen to differ. The trend in cluster pattern appears much more complex and fragmented in the five-year old, eight-year old and eleven-year old cohorts when compared to the much more even 'flatter' cluster pattern found in the fourteen-year old cohort. This will be reflected in the analyses that follow. The high level splitting (towards the right of the dendrograms) which equates with greater changes in feature use, is most marked in the fourteen-year old cohort where two main high level clusters can be seen. The higher level clustering in the eleven-year old cohort appears to be less fragmented than that shown by the two youngest cohorts, suggesting that it has an intermediate level of organisation of the clusters.

In general, the distribution of the clusters at both the Level One scale and at the higher level scales mirrors that found in the cross-sectional data reported in Chapter 5.

In order to analyse the clustering patterns, the size of the Level One clusters (those at the extreme left hand side of the dendrograms) in the dendrograms shown in Appendices 5.1 to 5.4 was determined and they are shown in Table 6.2.

Table 6.2 Level One groupings based on the dendrograms in Appendices 5.1 to 5.4 in longitudinal study

Age cohort	No. of Level One clusters	No. of members in Level One clusters									
		1	2	3	4	5	6	7	8	9	10
5	32	17	14	1	0	0	0	0	0	0	0
8	37	16	11	6	4	0	0	0	0	0	0
11	23	5	5	4	2	5	2	0	0	0	0
14	12	1	1	2	1	0	0	2	2	1	2

This method of analysis is analogous to that used on the cross-sectional data in Chapter 5 when examining this same prediction. The pattern of membership of the clusters of Level One clusters can be compared to the corresponding cross-sectional figures in Table 5.8.

Table 5.8 showing number of Level One clusters based on dendrograms, Appendices 4.1 to 4.6 in cross-sectional study (copied from Chapter 5)

Age	No. of Level One clusters	No. of members in Level One clusters							
		1	2	3	4	5	6	7	8
6	31	10	8	9	3	0	0	1	0
8	37	13	14	9	1	0	0	0	0
10	27	3	7	14	2	1	0	0	0
12	21	0	0	17	2	1	0	0	1
14	22	0	2	14	4	2	0	0	0
16	24	0	1	22	1	0	0	0	0

Interpreting the comparison between these two tables is hindered by the obvious fact that there are nine samples from each writer in the longitudinal data and just three samples from each writer in the cross-sectional data. However, despite this and the additional factor that the handwriting samples used in the cross-sectional study were obtained under different conditions (normal composition, neat copying and fast copying tasks) to those in this longitudinal study (all during course of schoolwork), it can be seen that the large number of one and two member Level One clusters in the younger participants (the 5 and 8 year old cohorts in Table 6.2) is comparable to those shown for the 6– and 8- year olds in Table 5.8. The smaller numbers of Level One clusters in the two older cohorts in the longitudinal study compares with the older three groups in the cross-sectional study and this suggests that by late adolescence the handwriting for the various participants is settling into more consistent styles which can be distinguished from their peers.

The data in both tables also reveal the same trend from the 5- and 6- year old participants to their 8-year old colleagues, namely an initial increase in the number of Level One clusters which then reduces again in the next age groups. This shows that at the age of about eight, the children's handwriting is at its least consistent from one occasion to another. This is not the same age at which handwriting variation (in a single piece) peaks (see Chapter 5) which is at the age of about ten or eleven.

Table 6.1 clearly shows that in the older children there is a much stronger tendency for their handwriting samples to form large 'clusters' – adjacently placed samples on the dendrograms - (in two cases, the maximum nine in a cluster). In the younger children, especially in the group commencing at 8 years old, the samples for a given participant are much less well related to one another in terms of their clustering properties. Overall, this provides further support for the propositions that there is a tendency for pieces of handwriting from the same participant to cluster and that this tendency increases with age.

6.7 Discussion

This longitudinal study examined the handwriting of 32 participants over three successive years covering a period that spanned a typical school career. The purpose was to establish whether or not the trends of handwriting change found in groups of individuals in the cross-sectional study in fact occurred in the handwriting of individuals.

The analysis of the principal components identified in the cross-sectional study, namely Lateral Elongation and Movement Integration, were found to be similar in the longitudinal study despite the relatively small numbers of participants in the latter study. A particularly notable finding here was that, in all age cohorts, the same children showed clear significant increases in lateral elongation as they grew older. This provides some confirmation that the components themselves are reasonably reliable in that they show similar effects of age and that they are indeed occurring in the handwriting of individual children over time. Further study to show that these components develop over much longer periods in individual children would confirm that these components are real and may also provide some insight as to what is causing them by suitable questioning of the children to see how aware they are of the changes that are occurring in their handwriting.

Another point of comparison between the cross-sectional and longitudinal data is that provided by Tables 5.9 and 6.2. The trends shown cannot be compared directly since the numbers of participants differs, the cross-sectional samples were obtained under differing handwriting constraints and the same participants were involved in larger proportions of the longitudinal pieces. Nonetheless, there is a clear tendency for the handwriting of each of the participants to cluster with other samples of their handwriting. Further, the younger participants' pieces of handwriting form smaller clusters than that shown by their older colleagues. Thus, the findings from the cross-sectional study that samples of handwriting from a given writer are more similar to one another and that this is increasingly true as they get older is true not just as a trend amongst a group in the cross-sectional study but is happening in the individuals followed in the longitudinal study.

The data in Tables 5.8 and 6.2 also show another detail of similarity, namely the increase in the number of Level One clusters from children aged about five or six to those aged about eight and for the number of Level One clusters to gradually decrease thereafter. This initial increase in the variation from one piece to another in the handwriting of eight year olds shows that in those just beginning to learn to write, there is a stronger carry over from one occasion to the next than is shown by those who are a little older. It is unlikely that the eight year olds are less able to remember what they are trying to reproduce in their handwriting in comparison to their younger colleagues. Rather, this suggests that the eight year olds typically are less concerned about the need to reproduce their handwriting consistently from one occasion to another, perhaps conscious that their teachers are not so concerned with teaching them handwriting for its own sake any longer.

These are some early signs that variability will increasingly become an important property of handwriting in children of this post-teaching phase.

However, the variation within a piece of handwriting is not yet maximal (see Chapter 5 and section 6.5 above) which tends to occur at about ten or eleven years of age. The findings in section 6.5 are based on a smaller number of participants than the equivalent finding based on the cross-sectional data that is reported in Chapter 5. Nonetheless, the trend does appear to be that the largest within piece variation occurs at about eleven years old. This distinction between the consistency of the handwriting from one occasion to another and the variation shown within a single piece of handwriting suggests that there are different factors causing these two effects since they appear to be occurring at different ages. This will be discussed further in Chapter 7.

Despite the different conditions that applied to the participants in the cross-sectional and longitudinal studies, the findings broadly support one another in their conclusions which confirm that the trends from the cross-sectional study are occurring in the handwriting of individuals.

Chapter 7 Discussion

7.1 Introduction

The aim of this research has been to study the development of handwriting in children from the styles that they are taught in school (and elsewhere) to mature handwriting production as they approach the end of their schooling a decade or more later. The primary motivation was provided by the author's interest in understanding the processes involved in the origins of handwriting individuality which must be considered in the process of author identification in forensic matters, usually concerning the handwriting of adults. However, the handwriting of adults is influenced by their experiences when learning to write at school. For this reason, this research considered the changes in handwriting that occur throughout childhood, with the inference that changes in the handwriting during this time are the primary source for the individualisation of handwriting in adults.

In this chapter, the key points arising from this research will be considered in the context of previous practical and theoretical work. Future developments and improvements suggested by this research will also be outlined. Firstly, the points will be summarised here but then elaborated on in separate sections in the remainder of the chapter.

The notion of handwriting variability and the creation of a coding scheme to capture and measure it was a crucial first step in this research. The coding scheme was devised to incorporate a number of dimensions of handwriting such as proportions, structure, shape and symmetry. The choice of which letters and features to use was driven in part by the frequency of occurrence of letters in English, by the information published in the literature and by working knowledge that the author possesses of the kinds of relatively subtle features there are in handwriting. The coding scheme devised was tested and refined and has produced results which support the view that the coding scheme is robust and is capable of showing variability in handwriting in children, achieving an aim that has not been reported elsewhere. In addition, principal components analysis has suggested that, although correlations between individual features were relatively low, there may be two underling dimensions in the features examined – Lateral elongation and Movement integration. These findings will be considered further in section 7.2.

Variability in the way letterforms are produced by individual writers was considered in the cross-sectional study for different tasks in children of different ages. Given that handwriting is a highly learned and practised skill, it is only to be expected that individual writers will tend to use similar forms of a letter from one occasion to another. This was reflected in the generally skewed data relating to feature use (see Chapter 5). That is not to say that feature use was completely invariant and, moreover, when the variability of feature use was in turn considered across all of the coded handwriting features, the overall handwriting variability (OHV) was found to be more normally distributed.

Measures of OHV could then be made in children of different ages and performing different tasks to see whether age and/or task affected handwriting variability. The issues relating to the variability of handwriting are developed in section 7.3.

In order to then address the primary source of motivation for this research, any changes in overall handwriting variability might reasonably be expected to be mirrored by an increasing tendency for children's handwriting to become individualised. This was studied in both the cross-sectional and longitudinal studies reported in Chapters 5 and 6 respectively. The implications of this research for handwriting individualisation are described in section 7.4.

Through all of the following sections, possible uses of and extensions to the coding scheme approach are considered where relevant. Handwriting style is clearly an important aspect of handwriting production in that it is the actual manifestation of the handwriting of an individual and not something that can be described in just a few dimensions such as speed and size. The assessment of handwriting style and its variability can be achieved and specific coding schemes could be devised to explore further other aspects of handwriting such as gender differences and perhaps to improve the understanding of handwriting problems.

7.2 Critique of methodology and coding scheme

Describing handwriting is a difficult thing to do in the experience of the author. Describing its variation, let alone measuring it, is even more difficult to achieve. However, if meaningful data were to be obtained to show the developmental trends that were at the heart of this research, the first step was to create a coding scheme to capture and measure handwriting variation and to include features which might reasonably be expected to show changes over time in the handwriting of children.

Published information about handwriting features generally focuses either on general dimensions of handwriting such as slope or size (for example, Graham & Weintraub, (1996)) or on particular letter-specific features usually in the context of forensic document examination (for example, (Nicholson, 1984)).

Forensic handwriting coding or classification schemes attempt to measure the frequency of feature use in particular letters in the population, giving forensic handwriting experts information that might assist their assessment of the evidence in casework when finding such features. For example, information about structural variants of the letter A and the frequency of occurrence maybe established. However, frequency of feature use may vary from place to place, over time or amongst different groups of writers depending upon their cultural background (Cheng et al., 2005). The potential for feature use to vary depending upon the cultural and educational background of the participant is of course relevant to forensic studies. In this research, the aim was to measure change in handwriting of individuals and to show how this leads to individualisation, not just to distinguish between adult writers on the basis of differing handwriting features.

The coding scheme devised for this research contained features that were expected to be widely used (in the author's experience) bearing in mind the scheme's purpose was to measure change in feature use not to measure the frequency of feature use itself. This important distinction meant that the coding scheme could be applied to handwriting in a wide variety of styles written neatly, scruffily, left- or right-handed by people from a variety of educational and social backgrounds. The primary concerns for including features into the scheme were that they be based on frequently used letters and that the features captured normal expected variations in these features – having a category that coded use of some obscure form of the letter Z would clearly be of little value.

The coding scheme also had to fulfil practical considerations of ease of use, giving unambiguous scoring as far as possible (robustness) and contain a sensible number of features that could be scored in a reasonable time but which had the capacity to provide measures of change in handwriting variability. The robustness of the coding scheme was amply demonstrated by the high degree of agreement between two raters for all of the features in the scheme (see section 4.7) and given the range of styles of handwriting included in the rater testing process, the coding scheme can be considered to be providing an objective measure of feature use irrespective of the handwriting style being analysed.

The coding scheme was therefore a compromise and did not contain as many features as it could have done had time not been a constraint. Other coding schemes could be devised which contain a different set of letter-specific features which could well show the same effects as those described in Chapters 4-6.

Having devised a coding scheme which deliberately included features that were not likely to be related, it would be possible to devise a scheme in which included features were more likely to be linked, for example with letters that like d2 and o2 had elongated, flattened loops (such as a, b, g, p). The connection between such categories would not necessarily be complete because letter forms have their own planning motor routines even where the final product may be similar (A. M. Wing & Nimmo-Smith, 1987). Nonetheless, by using such a coding scheme, similar features could be tracked developmentally. For example, the flatness or the roundness of the handwriting style could be monitored over time to assess to when and to what extent these more general properties emerge and to see whether they change in tandem with one another or whether traits appear in one letter and then are adopted in other letters. Future research could explore the two components identified as Lateral Elongation and Movement Integration with the aim of finding additional support for the tentative nature of their interpretation from data that were not as reliable as they might have been.

In addition, it would be possible to devise coding schemes that were targeted at other higher order dimensions that might be considered relevant such as precision of execution of letterforms.

This research has shown preliminary evidence that higher order properties of handwriting can emerge from the measurement of a number of potentially related letter features. It would then be possible to see when some of these general properties of handwriting emerge as children get older and relate these, where relevant, to analogous developmental attributes in other learning domains.

Changes in handwriting properties were assumed by the author to have been driven, at least in part, by the need to write more quickly. The finding that handwriting becomes more laterally elongated as children get older could be interpreted as a symptom of the need to write more quickly as the emphasis on left-to-right movement increases. However, the increased movement involved in the right-to-left element of this would seem to slow down the writing process (in comparison with a more upright, forward sloping handwriting style). Furthermore there was no evidence that scores on this dimension varied for the fast, neat and copy tasks. Further research could be focussed on determining the relationship between handwriting style, as characterised as laterally elongated, and the speed of handwriting and perhaps other dimensions such as the legibility of the handwriting and the impression it makes on the reader as such factors are important to older students (Summers & Catarre, 2003). By contrast, there was no evidence that the movement integration dimension varied with age. This may, in part, be because the scale used to measure this dimension was less reliable than the scale used to measure lateral elongation. Clearly, one avenue for future research is to develop more reliable measures of the two dimensions, perhaps by developing more fine-grained and hence less skewed measures of the individual features. Assuming that future research confirms the present findings, and that movement integration is not associated with changes in age, an important question is what factors are responsible for variations in this dimension. One possibility is that it may be related to how children are taught writing. For example, some teaching schemes focus on teaching children to print letters first, where the emphasis is on producing letters individually in their correct forms, while other schemes focus on teaching cursive writing earlier on, where the emphasis is on the overall flow of writing, and less on correctness of individual forms (Sassoon, 1983). If this were so, this would explain why there were no relationships with age for this dimension, and would suggest instead that it reflected differences in the way children were taught to write.

With regard to the individualisation of handwriting, the more coding features that can be included into a scheme the greater the scope for more and more accumulative differences to be found between writers. Ultimately such a process would begin to mimic the examination process used by forensic document examiners who have to consider differences across all handwritten characters when comparing handwriting. In the study reported in Chapter 4 with just fifteen participants, the cluster analysis of the data produced near perfect separation of the fifteen writers. In the much larger study in Chapter 5, the clustering still provided compelling evidence of individualisation but it was not perfect. The inclusion of more coding features would probably improve that, producing a clearer separation of handwriting samples between writers and greater linkage of samples for the same writers.

This ability for a coding scheme to distinguish between writers based not only on the features in their handwriting but also on the variability of their use has potential value in forensic applications, but the manual coding of handwriting samples is time consuming and if it were to be contemplated in a very wide range of features, some level of automation would be required.

The automated analysis of handwriting is a rapidly developing discipline that has the goals of either the (forensic) identification of writers or the transcription of handwriting into editable text (for example allowing handwriting input to be transformed into editable text for word processing). In the forensic context, to be able to take a piece of handwriting, analyse it and identify its author is the long term goal and considerable resources have been devoted to this and some of the results are working their way into forensic document examination (Saunders, Davis, & Buscaglia, 2011). The principles currently focus on distinguishing between writers based, not so much on structural features (which require a degree of interpretation by the viewer), but more on the shape of curves (Marquis, Schmittbuhl, Mazzella, & Taroni, 2005a). Such an approach to an examination of the handwriting of children might also yield useful insights into the variability of shape in particular as the handwriting develops away from the taught style, at the same time potentially showing how the combination of letterforms in writers gradually contributes to an increasing individualisation of their handwriting. This research suggests that automated handwriting recognition could usefully direct its attention not just to the structure or shape of handwriting but also to its variability, a variability that is itself a property of the handwriting of an individual, a principle well known to forensic document examiners (Ellen, 1993).

The coding scheme principle could be applied to handwriting written in other scripts such as Arabic or Chinese with a view to measuring handwriting variation in children. The principles on which handwriting variability are based are independent of the precise script used. Alphabetic writing systems are used throughout Europe and the Americas, but in eastern countries, syllabic systems (for example Thai) or logographic systems (for example Chinese) are used (Huber & Headrick, 1999). Nonetheless, the process of learning to write in any writing system is likely to have similar requirements of fine motor control for the execution and also appropriate language skills. The writing systems themselves may contain intrinsic levels of complexity that might enable different systems to be more or less readily learned on the one hand and then executed efficiently on the other. For example, most pen strokes in Chinese are straight lines which will influence the criteria for determining authorship in a forensic context (Leung, Tsui, Cheung, & Chung, 1985). This in turn may be a reflection of a more limited scope for handwriting variability during development in children. A coding scheme to measure handwriting variation in Chinese children, for example, may be a challenge, perhaps requiring the use of computer-assisted processes to measure subtle changes to individual pen strokes and their angles of intersection.

The coding scheme used in this research was devised with the intention of capturing changes in handwriting across the whole age range from the earliest learning to mature writers at the end of their school careers. The large sample size in the cross-sectional study produced findings that were more robust statistically than those on the smaller longitudinal study. Nonetheless, the findings in the latter study were at least partially consistent with the findings from the larger study. This suggests that the effects are indeed quite large and that they may also not be too much influenced by the type of handwriting sample (requested handwriting as opposed to day-to-day sample). It would then be possible to consider a larger longitudinal study with more participants and following each participant over a longer period of time so as to avoid the semi-longitudinal format of overlapping cohorts used in the longitudinal study reported in Chapter 6.

More frequent sampling rates based on weeks or months rather than annual cycles might enable researchers to observe handwriting changes "as they happen". However, taking the evidence of individualisation, particularly in the longitudinal study, in combination with the evidence of consistency across tasks, this suggests that changes in handwriting are gradual and generally are resistant to sudden changes.

7.3 Handwriting variation and skill development

This research aimed to establish that children's handwriting varied over time and in so doing became individualised. It also aimed to determine whether the nature of the handwriting task might affect the handwriting process and its variability. The cross-sectional study described in Chapter 5 was based upon handwriting obtained at request and written in the form of free composition and copying tasks.

The knowledge by a writer that a piece of handwriting that they are about to produce will be scrutinised in some research could affect the handwriting either by wilful change by the writer or by some unconscious change (such as anxiety or desire to impress). This phenomenon is well known to handwriting experts (Ellen, 1993). The participants in this study were all children and whilst their handwriting may show some effects caused by the situation in which samples of handwriting were produced, it is likely that changes would be minor not least because the obtaining of handwriting took up a fair amount of time and it would be difficult to maintain deliberate changes, in particular, over such a time period. The studies in Chapters 4 and 6 used pieces of handwriting obtained in everyday school work at times when the participants did not know that their handwriting would be examined. The general similarity of findings between the three studies provides some further reassurance that the circumstances in which the handwriting samples were obtained did not greatly influence the handwriting itself.

The different handwriting tasks that were used in the cross-sectional study, however, might have impacted upon the handwriting. Gould found that writing in free composition requires a set of skills that have been described in Chapter 2, from idea generation, through various linguistic phases to the biomechanical execution of letter production (Gregg, L.W. and Steinberg, E.R., 1980, Chapter 5). Copying requires similar skills in the latter phases but the initiation of what to write requires reading skills which are fed into the execution phase. As described in Chapter 2, the writing process requires the integration of a variety of skills and these are competing for working memory resources (Kellogg, Olive, & Piolat, 2007). The different nature of the handwriting tasks might be expected to impact upon the handwriting produced particularly where the process of handwriting production is not so highly developed. A primary goal of handwriting tuition is often seen as automaticity with the implied diminution of memory resources that achieving that goal would bring to the writer. This in turn would free up resources for the more important elements of idea generation and content appropriately constructed and spelt (Graham et al., 1997). In the cross-sectional study, the composition task was assisted by a visual picture prompt which may on the one hand have made idea generation simpler but on the other hand may have interfered with and reduced the freedom of the idea generating process. The copying tasks in this research were reviewed by teaching staff of the youngest participants and were considered appropriate. If the words used in the text were unfamiliar (thereby increasing the attention required just to read the words or, worse still, to deconstruct the word into a series of letters) then that would be expected to make a significant impact on the attention required to transcribe them. Nonetheless, some of the words may not have been familiar to some of the youngest writers. The ability to read and the accuracy of the reading process require appropriate eye movement and this can be affected by the linguistic content of the text being read causing different degrees of fixation on the text (Drieghe, Desmet, & Brysbaert, 2007).

The fact that in the cross-sectional study two of the tasks were copying tasks and one was a composition task might therefore have affected the handwriting produced. Similar effects have been reported for composition versus dictated text (Bereiter & Scardamalia, 1987). Whilst the text generation aspect is different, the motor production element may not be so affected if it has reached a high level of automaticity and is therefore not competing for working memory resources,. But in the younger participants such automaticity is less established (Rueckriegel, et al. 2008) and thus the differences in text generation modes might influence the appearance of the handwriting itself. The nature of any such influence could be a general one, such as loss of fluency or variation in letter size, or it might be more letter-specific with reduced attention to detailed structure and formation. The extent of the effect of different handwriting tasks on the fine detail of handwriting could be the subject of further studies particularly focussing on children whose handwriting has not yet reached a more mature level of automaticity. However, the indications from the findings in Chapter 5 are that there is relatively little interaction between age and task when looking at the individual coded features but when overall handwriting variability is used, there is an interaction between age and task.

In the cross-sectional study, the acquisition of handwriting skill was measured by means of the overall handwriting variability (OHV) – see section 5.8. The variability of handwriting increased for all handwriting tasks from Y2 to Y6 and then decreased steadily thereafter. This upslope of the inverted U-shaped learning trajectory may be because the repertoire of handwriting movements increases after the initial learning phase causing the increase in variability of the handwriting product. The neurological processes involved in handwriting production are therefore controlling the neuromusculature of the hand and fingers in a less tightly controlled way. Conversely, on the downslope of the inverted U the neurological control of handwriting movement must be more closely constrained. The increasing automaticity of handwriting as children get older has been shown by Rueskriegel et al. (2008) so the increase in variability suggests that the neurological processes are becoming increasingly plastic and the decrease in variability would suggest that certain neurological connections have become preferred. This would be consistent with the Siegler's model of development (Siegler, 1989) and in particular with the importance of within-subject variability in children (Siegler, 2002). The understanding of within subject variability is a crucial requirement to understanding developmental changes. And as the (fine-grained) quality of features describing changes improves, so does the understanding of the neurological processes improve. In this research, the fine-grained coding scheme provides high quality information about variability above and beyond that which general descriptors such as slope and fluency can give. The inverted U-shaped trajectory for handwriting variability is built upon a coding scheme that incorporates features that show relatively low inter-correlations, and yet when combined portray a convincing picture of overall developmental change. In order to measure more fine-grained aspects of handwriting it is likely that it will be necessary to use of digitising tablets to get the most objective data. By these means it will be possible to improve further on the quality of the data relating to within subject variability and thereby improve the understanding of the mechanisms underlying handwriting production.

At the neurological level, there has been a tendency to assume that motor and cognitive capabilities are separate. However, there is a growing body of evidence that suggests that they may be more integrated than had previously been realised (see Rosenbaum, Carlson, & Gilmore, (2001)). If indeed the two modalities are closely integrated, then this would indicate closer neurological connections and this is the subject of neuro-imaging studies that are beyond the scope of this research. However, the cerebellum in particular seems to have roles in both motor and cognitive domains particularly associated with predictive elements of behaviour (Courchesne & Allen, 1997). This would tie in with the linkage between the cognitive and motor elements that form part of the model for handwriting generation put forward, for example by Van Galen (1991). The initiation of a sequence of finely controlled and sequentially timed movements are required for this link to be effective (Kandel, Orliaguet, & Boe, 2000).

Notwithstanding the neurological processes that are needed to produce handwriting, the production of handwriting occurs in a more general, social context – handwriting has a purpose. In this latter context there are two kinds of explanation as to why there is an inverted U-shaped change in handwriting variability. One is based upon unintended factors, such as a need to write material that is more complex in content. The second is the intentional manipulation of handwriting by the writer under various influences such their desire to produce handwriting of a particular appearance.

Learning handwriting usually starts with unjoined letters before moving on to joined letters (Sassoon, 1990). This creates the possibility that this transition could be responsible for a (temporary) decrease in skill as the new movements are learned. But the findings in Chapter 5 show the largest handwriting variation to be in Y6 by which time the transition to joined handwriting would have occurred. Nonetheless, some of the increased variability during the earlier phases of learning could well be attributable to learning joined letters. A coding scheme that was particularly sensitive to joined letters could be devised to highlight potential changes, focussing on joining elements between letters. Indeed, the notion of firstly teaching unjoined letters that have clear introductory and exit strokes has been advocated as a means of reducing any effects of moving on to joined handwriting (Sassoon, 1983). Further, the increased variability when writing quickly (see Figure 5.3) produced levels of variation that were more in keeping with the normal handwriting task in the subsequent older year groups. This would be in keeping with increased handwriting speed being a factor in increasing handwriting variation which in turn provides features of handwriting production that become the habitual way of producing handwriting. The criteria for such feature selection and retention are likely to be complex and reflect the kinds of influence described in Chapter 2, such as a desire to write in a particular style or reflecting the dexterity of the writer.

7.4 The development of handwriting style and individualisation

The notion that a child writes similarly from one occasion to another is extremely probable since learning skills does not involve a fundamental re-learning each time the skill is executed except perhaps in the very earliest stages of learning. However, over the course of a decade or so, that habitual handwriting pattern does in fact change both in terms of skilfulness (Rueckriegel, et al. 2008) but also in terms of appearance (style).

The higher order components of style were explored using principal components analysis on the cross-sectional data and two components were tentatively identified as Lateral Elongation and Movement Integration, with the former increasing significantly with age and the latter showing no significant effect of age. These components behaved in a similar way in the longitudinal study. The coding scheme was devised so that a variety of categories of letterform were captured. However, given that there are higher order components to handwriting, these may be revealed since it is likely to be the case that certain letterforms are influenced by how (some) other letters are written (Eldridge et al., 1985). The two components identified here could be explored in further studies incorporating features which specifically are aimed at these two components, such as an elongated and flattened letter c or broad, flat letter u for the Lateral Elongation component or the proportion of the loop of the letter b (mirroring that of feature d2) or the height of the crossing stroke in the letter f (mirroring feature t2) might also fit with the Movement Integration component. Other higher order components could be proposed and suitable metrics devised to test them by using other specific letter features. For example the categories of letter closure or precision of execution could be proposed as higher order components and suitable features scored to investigate these further. Other means of measuring handwriting which were rejected for this study because they were too general, such as speed, slope and size, might also be measured and their relationships to the higher order components explored. Indeed, other non-handwriting factors may also be studied such as gender and handedness. For instance, the notion of rounded handwriting, which probably equates to some degree to Lateral Elongation, has been found to be a feature that is connected with the handwriting of female adults whereas other descriptor categories such as confident and hurried have been negatively associated with the handwriting of female adults (Burr, 2002). In that study, consistency of handwriting was not significantly associated with gender in adults.

However, the greater consistency of handwriting in the older children is in keeping with the maturation process of the handwriting towards a stable style in each individual. This is in contrast to the less consistent output from the younger children on different occasions. The least consistency was not shown by those that were just learning to write but rather by those in the next age bracket at about Y4 (around nine years old). These findings suggest that the taught style in the youngest participants is being carefully reproduced on each occasion but that this phase is followed by one of greater inconsistency. This might reflect an attitude in the slightly older writer of being less concerned with the careful reproduction of the taught style and more of a concern with what they are writing. The increasing demands of complex text generation might also be expected to influence this and the cessation of formal handwriting lessons might be interpreted as a licence to 'do one's own thing' by the children, a message that will tend to be reinforced as teachers show more concern for content rather than the form of the handwriting. In addition, of course, the use of keyboarding skills has replaced to a significant extent the need for handwriting. However, it would be surprising if personal motivational factors did not at least control some elements of the handwriting style (proportion, slope and size for example) and appearance (such as neatness). The literature does contain reports of children's attitudes to the process of writing (as opposed to handwriting). For example Olinghouse & Graham (2009) reported that reflecting on aspects of story generation was best done by those best able to write. However, there does not appear to be a reported survey detailing attitudes to handwriting and any reflective comments and attitudes to it.

The process of handwriting individualisation is at the heart of this research and there are no reported studies which attempt to understand the process in terms of detailed changes to letterforms in the handwriting of children or how these feed into a more general picture of style variability. There are various studies in the forensic literature that discuss handwriting individuality, for example Srihari et al. (2002) analysed samples of handwriting from 1500 people and used computer-based algorithms of a number of handwriting features to discriminate between them with about 98% success. This example is typical of many other studies many of which provide complex mathematical modelling approaches to the problem of machine identification of handwriting involving a wide variety of writing scripts such as Chinese, Arabic and Korean. For the forensic document examiner these studies are of interest but in the real world of casework in which circumstances dictate how much handwriting is available for analysis and always only the static image is available, the impact on the work of the handwriting expert has yet to be felt. The individualisation process that such studies consider is aimed at the handwriting of adults, and thus is the result of what has happened once the developmental process is over. No attention has yet been addressed to the issue of trying to monitor the individualisation process as it is happening in children. Nonetheless, the proposition that the handwriting of an adult is unique to its writer has not only been given support by the finding of increasing individualisation with age but also a mechanism for it has been identified, namely increasing variability during the post-learning phase.

The coding scheme used in this research and the periods over which handwriting were assessed were such that it was not possible to get an approximation to real time changes in handwriting. A longitudinal study that looked in detail at certain aspects of letter formation could be devised to show in detail such changes. This would require frequent sampling (for example weeks rather than annually) and could look at the geometry of certain letter components or their structure, for example, tracking ‘micro-changes’ to individual features as they occur by means of image processing perhaps in conjunction with a manual coding scheme. The findings of such a study would shed light on the dynamics of change, for example showing that in the youngest children changes are more associated with more intense instruction, as suggested by Inglis & Connell (1964). Alternatively, changes in older children may be more gradual reflecting an ever increasing need for efficient handwriting production.

7.5 Causes of change in handwriting style

The drivers for change in handwriting are many and have been discussed throughout this thesis. The causes for the increase in handwriting variation at around the age of ten or eleven are likely to be many; some suggestions are considered in Chapter2. One of the most influential is likely to be the need to write at different speeds when writing in different contexts. For example, writing neatly when required to do so or writing quickly as the pressure to get information down increases in successive stages of a typical school career. The need for speed in handwriting is undoubtedly an important functional element (Sassoon, 1983).

In Chapter 5 it has been shown that handwriting speed leads to changes in handwriting variation. In the children aged about six up to ten or eleven, writing more quickly produced an increase in variation of a magnitude that approximated to that of those in the following year group. In other words, in terms of handwriting variation, asking a child of say eight years old to write faster produced overall handwriting variation that was of a similar magnitude to that in the composition handwriting of their slightly older colleagues. That is not to say that writing quickly is the only driver for change in handwriting style, however. Further research is needed to explore the extent of the relationship between writing quickly and the overall variability of handwriting. Ideally this would be in the context of a longitudinal study showing how at a given age writing quickly would increase variability and that later (perhaps a year or so) that increased level of variability became the norm during the upslope phase shown by the learning trajectory in Figure 5.3.

As indicated in Chapter 2, there are likely to be many other factors impinging on handwriting development in the individual child. A coding scheme such as that devised for this research could be used to study some of these in more detail. For example, the effect of the gender of the writer on handwriting style and variability could be studied. It is already known that girls and boys develop along different trajectories for some dimensions of handwriting. The mechanisms for gender differences have been researched by a number of researchers. For example Meulenbroek & Van Galen (1989) found that in adults, females use less pen pressure and write more slower than males and Weintraub & Graham (2000) found that handwriting quality was accounted for by visuo-motor factors and not gender in twelve year old children. Further research could be undertaken to determine whether changes in handwriting variability and the onset of individualisation occurs at the same time or at different times in boys and girls and correlating this with underlying cognitive and motor capabilities so as to gain a more detailed insight into why changes occur when they do. In turn this may contribute to an understanding of the difficulties that some children have with their handwriting (referred to in Chapter 2). Hence, the teaching of handwriting to children can be tailored to the needs not just of the class but also to the individual child

7.6 Implications for teaching of handwriting

The teaching of handwriting is a skill that teachers need themselves to be taught since, as has been shown, there are many factors that can impact upon it. The first consideration is for teachers to have a general understanding of the value of handwriting in the educational process. Is it simply a tool to produce marks of communication on a piece of paper that should at least be decipherable? Or is it more than that – with a need to be neat or even attractive? This may seem to be a trivial consideration, but if teachers or parents are more concerned with form than content, then the balance between them may become distorted and the child may come to believe that they are required to improve appearance at the expense of content. Such a notion is substantiated by findings that teachers prefer to read and give higher marks to those pieces of handwriting that are better presented (Eames & Loewenthal, 1990). If children are giving extra (unwarranted) attention to the appearance of their handwriting, then given that they have finite working memory capacity, the quality of the writing's content may suffer. Instead, children should be encouraged to produce handwriting that is fluent and as automated as possible so as to free up their attention for what they are writing.

In this research, the same text was used for copying tasks for all participants across ages ranging from five to seventeen years old. In a future study the linguistic complexity of the text could be varied and the effect of this on the handwriting style and its variability would help determine the effects that this would have on the handwriting. Such a study could be important when assessing the extent to which the cognitive components of text generation interfere with and constrain text production which in turn might have implications for the timing of introducing different handwriting tasks in the learning process. The value of legible, or even 'nice' handwriting as assessed by teachers or parents may then be understood in terms of the relative merits of what is written and what it looks like on the page.

In the dynamic learning situation typified by the classroom, such considerations are very difficult to determine in that children's linguistic abilities are continually changing although they do seem to develop in line with those of their peers (Abbott et al., 2010). Nonetheless, the finite cognitive resources that are available to a writer will become constrained if the linguistic demands increase significantly as they strive to develop and improve them in terms of intellectual content and linguistic complexity. This might well then impact on the available resources for the distal elements of handwriting production, particularly for those children that have not yet achieved a high degree of automaticity. Indeed, failure to deal with the mechanics of handwriting production in young children may have detrimental consequences to their education even into the later stages of tertiary education (Summers & Catarre, 2003).

The style and legibility of handwriting and the efficiency with which it is written are connected (Graham, Weintraub, & Berninger, 1998) and hence the priorities that the young writer adopts when balancing these considerations might be expected to impact on the finished product. The demands imposed by either writing more neatly (in the belief that the work will attract higher marks) or more quickly (so as to produce a greater amount of writing in the time available) might impact on the quality and quantity of the content as the demands of execution compete with those of text creation.

This tension between quality and quantity and legibility and content is ultimately tested in examination conditions. Further studies could be made using similar principles to those used in this research with a view to assessing the effect of the constraints imposed by examination conditions, such as anxiety, severe time constraints and the rapid transcription of knowledge to the page.

The measurements of handwriting that have been used in research that looks at handwriting quality and writing quality all focus on general qualities such as fluency and consistency of handwriting production. None have looked at either the style of the handwriting, the variability of the letterforms comprising that style, or the dynamics of change in the handwriting style. This research has shown that change to the handwriting style of individual children varies over time and this is likely to have been caused by many factors which affect each child differently as they try to assimilate them into their everyday handwriting. One factor that is rarely mentioned is motivation and this is a constant theme in the teaching of handwriting to young children as described by Sassoon (1983). It applies not only to children for whom handwriting is relatively straightforward, but also to children with handwriting difficulties (dysgraphias). The causes of writing difficulties in children vary. Some will relate to difficulties with control of movement and others will relate to language problems.

The findings of this study in relation to the component identified as Lateral Elongation are of potential interest inasmuch as they suggest the possibility that writers may not adopt styles that are optimal in terms of speed but may compromise this so as to benefit from other factors that they may consider important such as the legibility and aesthetic effect of their handwriting. This aspect could be explored further both in terms of whether or not certain inefficient styles of handwriting should be discouraged and with a view to understanding why some writers appear to make choices of handwriting style that are not ideal if it were to turn out that certain styles are prone to fatigue, for example.

The literature relating to remediation for children that suffer primarily with movement-related handwriting problems is extensive (Berninger et al., 1997). Indeed many of the ways of measuring handwriting in children have the explicit aim of determining which children are most in need of help and how to measure the effectiveness of that help, for example the Children's Handwriting Evaluation Scale (CHES) (Phelps et al., 1985) and other schemes are summarised in section 3.1. The common element to these measures is that the problem is generally regarded to be at the point of execution and this is determined by the quality and quantity of the output, that is the handwriting itself.

Children with linguistic problems present with a variety of symptoms which are attributed to problems in various components of the brain's language system which have been shown to have consequences for writing production (Dockrell, Lindsay, Connelly, & Mackie, 2007). The problems that such children have vary, for example they include sentence recall and phonological processing and may manifest themselves in reading and writing difficulties. The measurement of writing output in such children necessarily includes a linguistic assessment of the writing but it can also involve an evaluation of handwriting output.

The integration of the linguistic and movement aspects is also, therefore, central to the effective production of handwriting (Berninger et al., 2006) and in some instances that may be a cause of the problems for those with dysgraphias. By looking at the dynamics of handwriting production, linguistic development and style changes in handwriting, a greater understanding of how best to offer remedial help may be achieved. It is perhaps no coincidence that such help is best given to individual children (Sassoon, 1983).and even then their motivation to succeed may affect the outcome just as much as any other diagnosed factors

7.7 Conclusion

This research project has shown that it is possible to create a coding scheme that can be used to track changes in the normal, everyday handwriting of children across all age groups. Its ability to do this is centred on its focussing on the variability of feature use and how this variability itself changes with time. All previously published schemes have seen variability as a function of handwriting that is best avoided, but this research shows that it is placed at the heart of a coding scheme it can be a sensitive measure of change irrespective of the styles of handwriting that are being measured. This finding in itself is of some importance and it should encourage others to seek insights from changes in variation in handwriting.

The finding of two higher order dimensions underlying the individual features is a potentially important avenue for future research. However it needs to be treated with some caution because of the highly skewed scores for some features for some age groups. Future research needs to focus on creating a more normally distributed set of feature scores to provide a better basis for PCA and factor analysis. If this can be achieved, this approach promises to provide a more global characterisation of stylistic features of overall samples, and the factors influencing these global dimensions can then be explored in more detail.

The patterns of variation change found show unequivocally that the complex interaction of a generally improving motor skill with a changing cognitive input will cause the variability of handwriting to increase in the early years of childhood peaking at about 10 years of age (but varying from one child to another) and to then gradually decline as the handwriting stabilises in its style thereafter. This pattern is reminiscent of the skill learning model put forward by Karmiloff-Smith (1992) but her model envisaged a well-defined learning phase at the end of which the skill was effectively acquired. No such well-defined endpoint occurs in acquiring the skill of handwriting. Nonetheless, the increase in variability occurs and it suggests that during this more variable phase, the writer is able (either deliberately out of choice or unconsciously when needing to change – for example to write more quickly) to use and retain some of the variants and to let other variants fall by the wayside in what might be called a refining stage. Such a process will lead to a gradual reduction in variability. This learn-experiment-refine process may be a model that is applicable to other learning situations and can be considered to be a variant on Karmiloff-Smith's model with the difference being the presence of the final refining stage.

The primary driver for this research was the desire to understand the process of individualisation of handwriting in children, since this leads on to the axiomatic view that no two people (adults) write alike which underpins the identification of handwriting in forensic contexts. A degree of consistency of handwriting has been shown to be present very early on but the degree of individualisation at this stage is not so marked as it later becomes. The extent of individualisation markedly increases as the children get older to the point where, at about eighteen years of age, the samples of handwriting from each participant were uniquely related to one another and differed from samples from other writers. The coding scheme contained only seventeen features of handwriting; the scope for further coding features is extremely large as handwriting varies along many dimensions and there are plenty of other letters of the alphabet that could have been coded. This does not even include the many other features such as block capital letters, numerals and punctuation marks that handwriting experts consider as important when identifying handwriting (Ellen 1993). Thus the finding of individuality and style development based on just seventeen features provides powerful support for the forensic handwriting expert who asserts that each person writes differently. Also, this is reasonable in the context of the considerable complexity of the motor and cognitive elements required for handwriting production – the notion that two people share similar motor and cognitive capacities with respect to handwriting production is very improbable.

This research has fulfilled its primary purpose of providing evidence for the development of both style and individualisation of handwriting in children and has shown that the assertion by handwriting experts that the handwriting of each person is unique is a reasonable one. It has also shed light on the process of individualisation which is based on the increase in variability of the handwriting as the child gets older with some variants being retained and others not. It is not surprising that such complex processes occur differently in each of us and that they are manifested in our individually unique handwriting.

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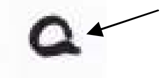
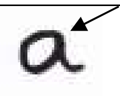
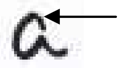
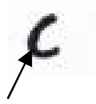
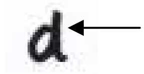
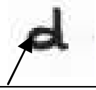
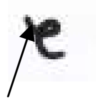
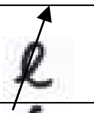
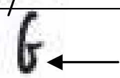
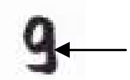
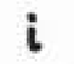
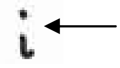
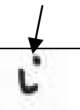
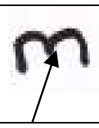
-Appendix 1 Glossary of terms

Ascender	The tall part of a letter above the line as found in the letters b, d, f, h, k, l and t.
Between piece variation	The variation of feature use (letter form) found in more than one piece of handwriting produced on different occasions (within a relatively short time period) by a given writer.
Between writer variation	The variation in feature use or feature variability between different writers
Bisection	The cutting of a pen stroke by another or the same curved stroke as found in the letters b, d, e, f, g, k, p, q, t and x.
Descender	The long part of a letter below the line as found in the letters f, g, j, p, q and y.
Developmental variation	The change in feature use (style) over prolonged periods of time for a given writer.
Feature	A letter or part of a letter that is scored on the basis of being present or not being present in a piece of handwriting from a given participant.
Feature variability	The amount that the writer's proportion score departs from 0 or 1 (invariant habit) for a given feature. Random feature use will give a feature variability score of a maximal 1.0. Invariant use of a feature would give a variability score of 0.
Fluency	This refers to a number of properties of handwriting including the evenness of the letterforms, the smoothness of the ink line and the rhythm of the handwriting.
Forensic handwriting comparison	The process of determining who produced handwriting based on a combination of distinctive features.
Individualisation	The end product of handwriting development in an individual resulting in it having a unique combination of properties enabling it to be

	distinguished from the handwriting of others.
Loop	Rounded, closed part of a letter as found in the letters a, b, d, e, g, o, p and q.
Overall handwriting variability (OHV)	The mean value of feature variation taken across all features and all writers of a given age performing a given task.
Proportion score (of use of a feature)	Each feature is scored on the basis of being present or not. The proportion of times it is present in the total number of observations provides a proportion score of the use of that feature.
Skill	An ability that allows a goal to be achieved with generally increasing ease as a result of practice.
Within piece variation	The variation of feature use (letter form) found within a single piece of handwriting produced on essentially one occasion by a given writer.
Within writer variability	The variability of a given feature in a piece of handwriting from an individual participant.

Appendix 2 Detailed description of letterforms used in the coding scheme

Feature descriptor	Type 1	Type 2
a1 - standard allograph –with Type 1 being the usual taught style.		
a2 - low tail retrace –with Type 1 showing a retrace of less than 50% of the overall letter height.		
a3 - closed loop –Type 1 with the closure complete.		
a4 - upward initial pen movement,		
c1 - low point of curve –with Type 1 having leftmost point below 50% of height of letter		
d1 - proportionately tall loop –with Type 1 having loop higher than 505 of ascender height.		
d2 - flattened loop –with Type 1 having loop broader than it is tall.		
e1 - standard allograph –with Type 1 being the usual taught style.		
e2 - high curve bisection –with Type 1 having bisection above midpoint of overall height.		
e3 - upward axis –with Type 1 having the axis upwards.		
f1 - tail turns to right -		
g1 - short tail –with Type 1 having loop taller than tail		
i1 - i dot present.		
i2 - high dot –with Type 1 having dot higher than 50% of main letter height.		
i3 - dot to right of main letter.		
k1 - one penstroke.		
l1 – looped.		
m1 - high centre –with Type 1 centre being above 50% of height of overall letter.		

m2 - pointed tops.	m	m
n1 - curve high to right –with Type 1 having curve to right of midpoint.	n	n
n2 - initial downstroke.	n	n
o1 - starts to right –with Type 1 starting to right of midpoint.	o	o
o2 - tall and narrow –with Type 1 taller than it is wide.	o	o
p1 -curve high to right –with Type 1 having highest point of curve to right of midpoint.	p	p
r1 - open retrace – with Type 1 having clear opening between initial downstroke and rest of letter.	r	r
r2 - low retrace with Type 1 having top initial stroke below remainder of letter.	r	r
s1 - script style.	s	s
s2 - shallow centre axis –with Type 1 having axis of centre part at <45º to horizontal.	s	s
t1 - crossbar longer to right -	t	t
t2 - high crossbar –with Type 1 having crossbar above 50%height of overall letter.	t	t
th1 - t shorter than h.	th	th
u1 - tail present -	u	u
u2 - lowest point to right –with Type 1 having lowest point to right of midpoint of letter.	u	u
w1 - left side wider.	w	w

Appendix 3 PASW output showing principal components analysis based on cross-sectional data in Chapter 5

```
GET
  FILE='C:\Users\David\Desktop\PASW\100807 Master plus survey.sav'.
DATASET NAME DataSet2 WINDOW=FRONT.
GET
  FILE='C:\Users\David\Desktop\PASW\Final plot data.sav'.
DATASET NAME DataSet2 WINDOW=FRONT.
DATASET ACTIVATE DataSet1.
DATASET CLOSE DataSet2.
GET
  FILE='C:\Users\David\Desktop\PASW\Final version\310508 master.sav'.
DATASET NAME DataSet3 WINDOW=FRONT.
DATASET ACTIVATE DataSet1.
DATASET CLOSE DataSet3.
FACTOR
  /VARIABLES Ca2 Ca3 Ca4 Cd1 Cd2 Ce2 Ci2 Cn2 Co1 Co2 Cr1 Cr2 Cs2 Ct2
  /MISSING LISTWISE
  /ANALYSIS Ca2 Ca3 Ca4 Cd1 Cd2 Ce2 Ci2 Cn2 Co1 Co2 Cr1 Cr2 Cs2 Ct2
  /PRINT INITIAL DET KMO REPR EXTRACTION ROTATION
  /PLOT EIGEN
  /CRITERIA FACTORS(2) ITERATE(25)
  /EXTRACTION PC
  /CRITERIA ITERATE(25)
  /ROTATION VARIMAX
  /METHOD=CORRELATION.
```

General Linear Model

Notes

Output Created		08-Jul-2011 02:21:52
Comments		
Input	Data	C:\Users\David\Desktop\PASW\100807 Master plus survey.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	368
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.

Syntax		GLM MeanCF1 MeanNF1 MeanFF1 BY Y /WSFACTOR=task 3 Polynomial /METHOD=SSTYPE(3) /PLOT=PROFILE(Y*task) /EMMEANS=TABLES(Y*task) /EMMEANS=TABLES(Y) COMPARE ADJ(BONFERRONI) /EMMEANS=TABLES(task) COMPARE ADJ(BONFERRONI) /PRINT=DESCRIPTIVE ETASQ OPOWER HOMOGENEITY /CRITERIA=ALPHA(.05) /WSDESIGN=task /DESIGN=Y.
Resources	Processor Time	00:00:01.154
	Elapsed Time	00:00:01.431

[DataSet1] C:\Users\David\Desktop\PASW\100807 Master plus survey.sav

Within-Subjects Factors

Measure:MEASURE_1

task	Dependent Variable
1	MeanCF1
2	MeanNF1
3	MeanFF1

Between-Subjects Factors

		Value Label	N
Year	2	Y2	24
	4	Y4	24
	6	Y6	24
	8	Y8	24
	10	Y10	24
	12	Y12	24

Descriptive Statistics

	Year	Mean	Std. Deviation	N
MeanCF1	Y2	.5811	.20941	24
	Y4	.6273	.15113	24
	Y6	.7046	.17036	24
	Y8	.6638	.21985	24
	Y10	.8037	.14256	24
	Y12	.8009	.18209	24
	Total	.6969	.19687	144
MeanNF1	Y2	.5667	.18234	24
	Y4	.5977	.16435	24
	Y6	.6996	.18807	24
	Y8	.6708	.22580	24
	Y10	.8298	.14035	24
	Y12	.7778	.21603	24
	Total	.6904	.20710	144
MeanFF1	Y2	.6151	.15994	24
	Y4	.5887	.15250	24
	Y6	.7243	.16652	24
	Y8	.6756	.23436	24
	Y10	.8082	.13721	24
	Y12	.7917	.19320	24
	Total	.7006	.19247	144

Box's Test of Equality of Covariance Matrices[a]

Box's M	52.069
F	1.639
df1	30
df2	43038.132
Sig.	.015

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

Box's Test of Equality of Covariance Matrices[a]

Box's M	52.069
F	1.639
df1	30
df2	43038.132
Sig.	.015

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

a. Design: Intercept + Y
 Within Subjects Design: task

Multivariate Tests[d]

Effect		Value	F	Hypothesis df	Error df	Sig.
task	Pillai's Trace	.013	.899[a]	2.000	137.000	.410
	Wilks' Lambda	.987	.899[a]	2.000	137.000	.410
	Hotelling's Trace	.013	.899[a]	2.000	137.000	.410
	Roy's Largest Root	.013	.899[a]	2.000	137.000	.410
task * Y	Pillai's Trace	.105	1.535	10.000	276.000	.127
	Wilks' Lambda	.897	1.528[a]	10.000	274.000	.129
	Hotelling's Trace	.112	1.521	10.000	272.000	.131
	Roy's Largest Root	.074	2.045[c]	5.000	138.000	.076

a. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

d. Design: Intercept + Y
 Within Subjects Design: task

Multivariate Tests[d]

Effect		Partial Eta Squared	Noncent. Parameter	Observed Power[b]
task	Pillai's Trace	.013	1.797	.203
	Wilks' Lambda	.013	1.797	.203
	Hotelling's Trace	.013	1.797	.203
	Roy's Largest Root	.013	1.797	.203
task * Y	Pillai's Trace	.053	15.348	.755

	Wilks' Lambda	.053	15.279	.752
	Hotelling's Trace	.053	15.210	.750
	Roy's Largest Root	.069	10.223	.668

b. Computed using alpha = .05

d. Design: Intercept + Y
Within Subjects Design: task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
task	.991	1.280	2	.527

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

b. Design: Intercept + Y
Within Subjects Design: task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
task	.991	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.
a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.
b. Design: Intercept + Y
Within Subjects Design: task

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
task	Sphericity Assumed	.008	2	.004	.851
	Greenhouse-Geisser	.008	1.982	.004	.851

	Huynh-Feldt	.008	2.000	.004	.851
	Lower-bound	.008	1.000	.008	.851
task * Y	Sphericity Assumed	.067	10	.007	1.498
	Greenhouse-Geisser	.067	9.908	.007	1.498
	Huynh-Feldt	.067	10.000	.007	1.498
	Lower-bound	.067	5.000	.013	1.498
Error(task)	Sphericity Assumed	1.242	276	.005	
	Greenhouse-Geisser	1.242	273.457	.005	
	Huynh-Feldt	1.242	276.000	.005	
	Lower-bound	1.242	138.000	.009	

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
task	Sphericity Assumed	.428	.006	1.701	.195
	Greenhouse-Geisser	.427	.006	1.686	.195
	Huynh-Feldt	.428	.006	1.701	.195
	Lower-bound	.358	.006	.851	.150
task * Y	Sphericity Assumed	.140	.051	14.979	.742
	Greenhouse-Geisser	.140	.051	14.841	.739
	Huynh-Feldt	.140	.051	14.979	.742
	Lower-bound	.194	.051	7.490	.514

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source	task	Type III Sum of Squares	df	Mean Square	F	Sig.
task	Linear	.001	1	.001	.218	.641
	Quadratic	.007	1	.007	1.468	.228
task * Y	Linear	.038	5	.008	1.729	.132
	Quadratic	.029	5	.006	1.273	.279
Error(task)	Linear	.613	138	.004		
	Quadratic	.629	138	.005		

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source	task	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
task	Linear	.002	.218	.075
	Quadratic	.011	1.468	.225
task * Y	Linear	.059	8.643	.583
	Quadratic	.044	6.365	.441

a. Computed using alpha = .05

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
MeanCF1	2.021	5	138	.079
MeanNF1	1.643	5	138	.153
MeanFF1	3.702	5	138	.004

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Y

Within Subjects Design: task

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	209.240	1	209.240	2307.170	.000	.944
Y	3.148	5	.630	6.942	.000	.201
Error	12.515	138	.091			

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Noncent. Parameter	Observed Power[a]
Intercept	2307.170	1.000
Y	34.708	.998

a. Computed using alpha = .05

Estimated Marginal Means

1. Year * task

Measure:MEASURE_1

Year	task	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Y2	1	.581	.037	.508	.654
	2	.567	.038	.491	.643
	3	.615	.036	.544	.686
Y4	1	.627	.037	.554	.701
	2	.598	.038	.522	.674
	3	.589	.036	.517	.660
Y6	1	.705	.037	.631	.778
	2	.700	.038	.624	.776
	3	.724	.036	.653	.796
Y8	1	.664	.037	.591	.737
	2	.671	.038	.595	.747
	3	.676	.036	.604	.747
Y10	1	.804	.037	.730	.877
	2	.830	.038	.754	.906
	3	.808	.036	.737	.880
Y12	1	.801	.037	.728	.874
	2	.778	.038	.702	.854
	3	.792	.036	.720	.863

2. Year

Estimates

Measure:MEASURE_1

Year	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Y2	.588	.035	.517	.658
Y4	.605	.035	.534	.675
Y6	.709	.035	.639	.780
Y8	.670	.035	.600	.740
Y10	.814	.035	.744	.884
Y12	.790	.035	.720	.860

Pairwise Comparisons

Measure:MEASURE_1

(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Y2	Y4	-.017	.050	1.000	-.167	.133
	Y6	-.122	.050	.247	-.272	.028
	Y8	-.082	.050	1.000	-.232	.067
	Y10	-.226*	.050	.000	-.376	-.076
	Y12	-.202*	.050	.001	-.352	-.053
Y4	Y2	.017	.050	1.000	-.133	.167
	Y6	-.105	.050	.576	-.255	.045
	Y8	-.066	.050	1.000	-.215	.084
	Y10	-.209*	.050	.001	-.359	-.059
	Y12	-.186*	.050	.005	-.335	-.036
Y6	Y2	.122	.050	.247	-.028	.272
	Y4	.105	.050	.576	-.045	.255
	Y8	.039	.050	1.000	-.111	.189
	Y10	-.104	.050	.590	-.254	.046
	Y12	-.081	.050	1.000	-.231	.069
Y8	Y2	.082	.050	1.000	-.067	.232
	Y4	.066	.050	1.000	-.084	.215
	Y6	-.039	.050	1.000	-.189	.111
	Y10	-.144	.050	.072	-.294	.006
	Y12	-.120	.050	.272	-.270	.030
Y10	Y2	.226*	.050	.000	.076	.376
	Y4	.209*	.050	.001	.059	.359
	Y6	.104	.050	.590	-.046	.254
	Y8	.144	.050	.072	-.006	.294
	Y12	.024	.050	1.000	-.126	.174
Y12	Y2	.202*	.050	.001	.053	.352
	Y4	.186*	.050	.005	.036	.335
	Y6	.081	.050	1.000	-.069	.231
	Y8	.120	.050	.272	-.030	.270
	Y10	-.024	.050	1.000	-.174	.126

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Univariate Tests

Measure:MEASURE_1

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	1.049	5	.210	6.942	.000	.201
Error	4.172	138	.030			

The F tests the effect of Year. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Univariate Tests

Measure:MEASURE_1

	Noncent. Parameter	Observed Power[a]
Contrast	34.708	.998

The F tests the effect of Year. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

3. task

Estimates

Measure:MEASURE_1

task	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.697	.015	.667	.727
2	.690	.016	.659	.721
3	.701	.015	.671	.730

Pairwise Comparisons

Measure:MEASURE_1

(I) task	(J) task	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.007	.008	1.000	-.013	.027

	3	-.004	.008	1.000	-.023	.015
2	1	-.007	.008	1.000	-.027	.013
	3	-.010	.008	.547	-.029	.008
3	1	.004	.008	1.000	-.015	.023
	2	.010	.008	.547	-.008	.029

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.013	.899[a]	2.000	137.000	.410	.013
Wilks' lambda	.987	.899[a]	2.000	137.000	.410	.013
Hotelling's trace	.013	.899[a]	2.000	137.000	.410	.013
Roy's largest root	.013	.899[a]	2.000	137.000	.410	.013

Each F tests the multivariate effect of task. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

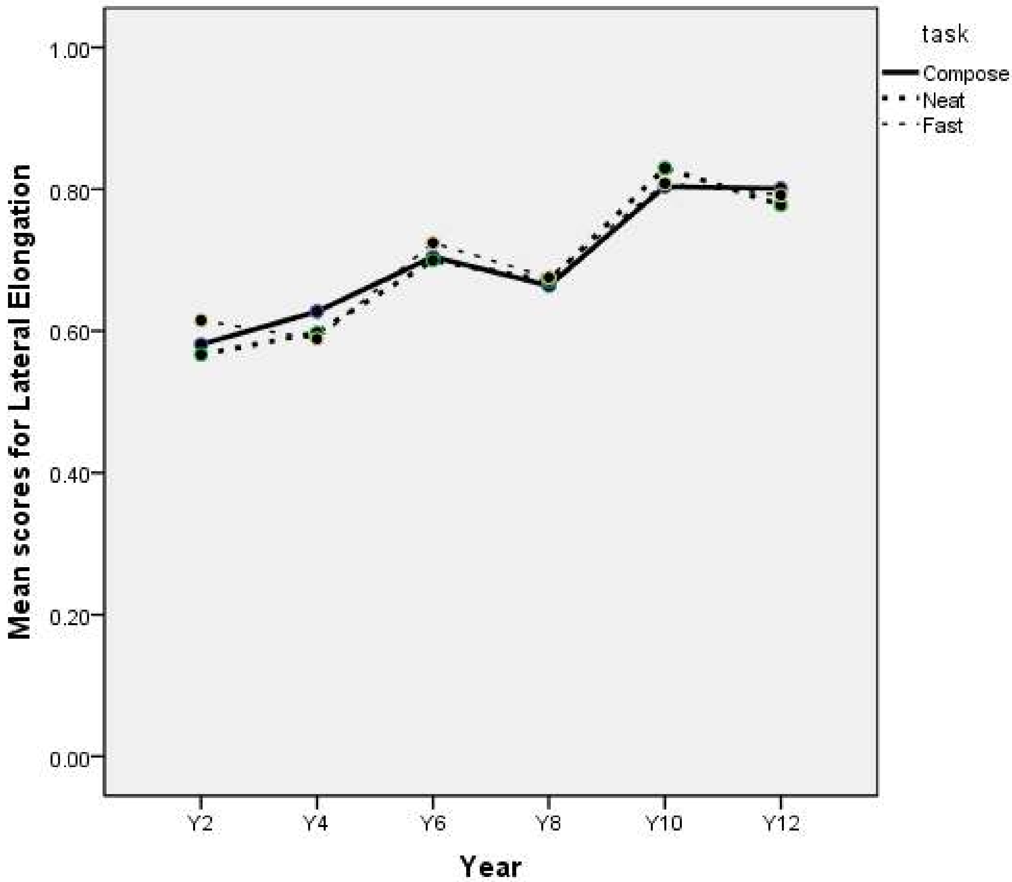
Multivariate Tests

	Noncent. Parameter	Observed Power[b]
Pillai's trace	1.797	.203
Wilks' lambda	1.797	.203
Hotelling's trace	1.797	.203
Roy's largest root	1.797	.203

Each F tests the multivariate effect of task. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

b. Computed using alpha = .05

Profile Plots




```
COMPUTE MeanCF2=MEAN(Ca3,Cd1,revCi2,Cn2,Co1,Ct2).
EXECUTE.
COMPUTE MeanNF2=MEAN(Na3,Nd1,revNi2,Nn2,No1,Nt2).
EXECUTE.
COMPUTE MeanFF2=MEAN(Fa3,Fd1,revFi2,Fn2,Fo1,Ft2).
EXECUTE.
RELIABILITY
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  /SCALE('CF2') ALL
  /MODEL=ALPHA
  /STATISTICS=CORR
  /SUMMARY=TOTAL.
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Reliability

Notes

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[DataSet1] C:\Users\David\Desktop\PASW\100807 Master plus survey.sav

Scale: CF2

Case Processing Summary

		N	%
Cases	Valid	144	39.1
	Excluded[a]	224	60.9
	Total	368	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.555	.551	6

Inter-Item Correlation Matrix

	Ca3	Cd1	revCi2	Cn2	Co1	Ct2
Ca3	1.000	.201	.086	.261	.171	.283
Cd1	.201	1.000	.269	.126	.129	.288
revCi2	.086	.269	1.000	-.035	.041	.212
Cn2	.261	.126	-.035	1.000	.212	.219
Co1	.171	.129	.041	.212	1.000	.082
Ct2	.283	.288	.212	.219	.082	1.000

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Ca3	2.9808	.817	.351	.144	.485
Cd1	3.1091	.732	.357	.151	.479
revCi2	3.2687	.905	.206	.102	.548
Cn2	2.7292	.865	.264	.129	.524
Co1	2.8235	.915	.214	.067	.544
Ct2	3.0197	.795	.392	.174	.465

```
RELIABILITY
  /VARIABLES=Na3 Nd1 Nn2 No1 Nt2 revNi2
  /SCALE('NF2') ALL
  /MODEL=ALPHA
  /STATISTICS=CORR
  /SUMMARY=TOTAL.
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Reliability

Notes

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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the procedure.
Syntax		RELIABILITY /VARIABLES=Na3 Nd1 Nn2 No1 Nt2 revNi2 /SCALE('NF2') ALL /MODEL=ALPHA /STATISTICS=CORR /SUMMARY=TOTAL.
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[DataSet1] C:\Users\David\Desktop\PASW\100807 Master plus survey.sav

Scale: NF2

Case Processing Summary

		N	%
Cases	Valid	144	39.1
	Excluded[a]	224	60.9

	Total	368	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.601	.601	6

Inter-Item Correlation Matrix

	Na3	Nd1	Nn2	No1	Nt2	revNi2
Na3	1.000	.194	.239	.213	.309	.220
Nd1	.194	1.000	.151	.076	.372	.253
Nn2	.239	.151	1.000	.204	.292	.018
No1	.213	.076	.204	1.000	.176	.065
Nt2	.309	.372	.292	.176	1.000	.226
revNi2	.220	.253	.018	.065	.226	1.000

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Na3	3.0719	.817	.392	.166	.533
Nd1	3.1972	.748	.355	.173	.552
Nn2	2.7765	.908	.296	.135	.572
No1	2.9088	.917	.228	.077	.597
Nt2	3.0751	.766	.485	.249	.491
revNi2	3.3097	.891	.270	.112	.582

```
RELIABILITY
  /VARIABLES=Fa3 Fd1 Fn2 Fo1 Ft2 revFi2
  /SCALE('FF2') ALL
  /MODEL=ALPHA
  /STATISTICS=CORR
  /SUMMARY=TOTAL.
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Reliability

Notes

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	N of Rows in Working Data File	368
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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the procedure.
Syntax		RELIABILITY /VARIABLES=Fa3 Fd1 Fn2 Fo1 Ft2 revFi2 /SCALE('FF2') ALL /MODEL=ALPHA /STATISTICS=CORR /SUMMARY=TOTAL.
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[DataSet1] C:\Users\David\Desktop\PASW\100807 Master plus survey.sav

Scale: FF2

Case Processing Summary

		N	%
Cases	Valid	144	39.1
	Excluded[a]	224	60.9
	Total	368	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.611	.614	6

Inter-Item Correlation Matrix

	Fa3	Fd1	Fn2	Fo1	Ft2	revFi2
Fa3	1.000	.119	.257	.317	.288	.185
Fd1	.119	1.000	.117	.231	.298	.264
Fn2	.257	.117	1.000	.224	.284	.099
Fo1	.317	.231	.224	1.000	.173	.070
Ft2	.288	.298	.284	.173	1.000	.214
revFi2	.185	.264	.099	.070	.214	1.000

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Fa3	3.0461	.791	.375	.189	.554
Fd1	3.1514	.737	.336	.163	.575
Fn2	2.7728	.814	.316	.132	.578
Fo1	2.8053	.861	.337	.157	.572
Ft2	3.0861	.741	.433	.200	.528
revFi2	3.2711	.852	.282	.107	.590

```
GLM MeanCF2 MeanNF2 MeanFF2 BY Y
  /WSFACTOR=task 3 Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(Y*task)
```

```
/EMMEANS=TABLES(Y*task)
/EMMEANS=TABLES(Y) COMPARE ADJ(BONFERRONI)
/EMMEANS=TABLES(task) COMPARE ADJ(BONFERRONI)
/PRINT=DESCRIPTIVE ETASQ OPOWER HOMOGENEITY
/CRITERIA=ALPHA(.05)
/WSDESIGN=task
/DESIGN=Y.
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General Linear Model

Notes

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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		GLM MeanCF2 MeanNF2 MeanFF2 BY Y /WSFACTOR=task 3 Polynomial /METHOD=SSTYPE(3) /PLOT=PROFILE(Y*task) /EMMEANS=TABLES(Y*task) /EMMEANS=TABLES(Y) COMPARE ADJ(BONFERRONI) /EMMEANS=TABLES(task) COMPARE ADJ(BONFERRONI) /PRINT=DESCRIPTIVE ETASQ OPOWER HOMOGENEITY /CRITERIA=ALPHA(.05) /WSDESIGN=task /DESIGN=Y.

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[DataSet1] C:\Users\David\Desktop\PASW\100807 Master plus survey.sav

Within-Subjects Factors

Measure:MEASURE_1

task	Dependent Variable
1	MeanCF2
2	MeanNF2
3	MeanFF2

Between-Subjects Factors

		Value Label	N
Year	2	Y2	24
	4	Y4	24
	6	Y6	24
	8	Y8	24
	10	Y10	24
	12	Y12	24

Descriptive Statistics

	Year	Mean	Std. Deviation	N
MeanCF2	Y2	.5256	.16842	24
	Y4	.6192	.13589	24
	Y6	.6060	.11765	24
	Y8	.5877	.16837	24
	Y10	.6564	.18984	24
	Y12	.5913	.23798	24
	Total	.5977	.17546	144
MeanNF2	Y2	.5240	.17230	24
	Y4	.6303	.14467	24
	Y6	.6259	.11662	24
	Y8	.5852	.15870	24
	Y10	.6783	.17027	24

	Y12	.6241	.24738	24
	Total	.6113	.17652	144
MeanFF2	Y2	.5640	.16081	24
	Y4	.6209	.13491	24
	Y6	.6239	.10414	24
	Y8	.5643	.17039	24
	Y10	.6657	.17269	24
	Y12	.5878	.24989	24
	Total	.6044	.17225	144

Box's Test of Equality of Covariance Matrices[a]

Box's M	75.922
F	2.390
df1	30
df2	43038.132
Sig.	.000

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

a. Design: Intercept + Y
Within Subjects Design: task

Multivariate Tests[d]

Effect		Value	F	Hypothesis df	Error df	Sig.
task	Pillai's Trace	.026	1.833[a]	2.000	137.000	.164
	Wilks' Lambda	.974	1.833[a]	2.000	137.000	.164
	Hotelling's Trace	.027	1.833[a]	2.000	137.000	.164
	Roy's Largest Root	.027	1.833[a]	2.000	137.000	.164
task * Y	Pillai's Trace	.113	1.651	10.000	276.000	.092
	Wilks' Lambda	.889	1.662[a]	10.000	274.000	.089
	Hotelling's Trace	.123	1.673	10.000	272.000	.087
	Roy's Largest Root	.104	2.866[c]	5.000	138.000	.017

a. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

d. Design: Intercept + Y

Within Subjects Design: task

Multivariate Tests[d]

Effect		Partial Eta Squared	Noncent. Parameter	Observed Power[b]
task	Pillai's Trace	.026	3.666	.377
	Wilks' Lambda	.026	3.666	.377
	Hotelling's Trace	.026	3.666	.377
	Roy's Largest Root	.026	3.666	.377
task * Y	Pillai's Trace	.056	16.513	.792
	Wilks' Lambda	.057	16.624	.795
	Hotelling's Trace	.058	16.732	.798
	Roy's Largest Root	.094	14.329	.831

b. Computed using alpha = .05

d. Design: Intercept + Y

Within Subjects Design: task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
task	.989	1.573	2	.455

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

b. Design: Intercept + Y

Within Subjects Design: task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Epsilon[a]		
	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
task	.989	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.
b. Design: Intercept + Y
Within Subjects Design: task

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F
task	Sphericity Assumed	.013	2	.007	2.032
	Greenhouse-Geisser	.013	1.977	.007	2.032
	Huynh-Feldt	.013	2.000	.007	2.032
	Lower-bound	.013	1.000	.013	2.032
task * Y	Sphericity Assumed	.052	10	.005	1.575
	Greenhouse-Geisser	.052	9.887	.005	1.575
	Huynh-Feldt	.052	10.000	.005	1.575
	Lower-bound	.052	5.000	.010	1.575
Error(task)	Sphericity Assumed	.906	276	.003	
	Greenhouse-Geisser	.906	272.884	.003	
	Huynh-Feldt	.906	276.000	.003	
	Lower-bound	.906	138.000	.007	

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
task	Sphericity Assumed	.133	.015	4.064	.417
	Greenhouse-Geisser	.134	.015	4.018	.415
	Huynh-Feldt	.133	.015	4.064	.417
	Lower-bound	.156	.015	2.032	.293
task * Y	Sphericity Assumed	.114	.054	15.750	.768
	Greenhouse-Geisser	.115	.054	15.573	.764
	Huynh-Feldt	.114	.054	15.750	.768
	Lower-bound	.171	.054	7.875	.537

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source	task	Type III Sum of Squares	df	Mean Square	F	Sig.
task	Linear	.003	1	.003	1.018	.315
	Quadratic	.010	1	.010	3.000	.086
task * Y	Linear	.026	5	.005	1.622	.158
	Quadratic	.026	5	.005	1.530	.184
Error(task)	Linear	.442	138	.003		
	Quadratic	.464	138	.003		

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source	task	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
task	Linear	.007	1.018	.170
	Quadratic	.021	3.000	.405
task * Y	Linear	.056	8.112	.552
	Quadratic	.053	7.649	.523

a. Computed using alpha = .05

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
MeanCF2	3.594	5	138	.004
MeanNF2	3.775	5	138	.003
MeanFF2	4.183	5	138	.001

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Y

Within Subjects Design: task

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	157.850	1	157.850	1901.398	.000	.932
Y	.687	5	.137	1.655	.150	.057
Error	11.456	138	.083			

Tests of Between-Subjects Effects

Measure:MEASURE_1

Transformed Variable:Average

Source	Noncent. Parameter	Observed Power[a]
Intercept	1901.398	1.000
Y	8.275	.561

a. Computed using alpha = .05

Estimated Marginal Means

1. Year * task

Measure:MEASURE_1

Year	task	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Y2	1	.526	.036	.455	.596
	2	.524	.035	.454	.594
	3	.564	.035	.495	.633
Y4	1	.619	.036	.549	.689
	2	.630	.035	.561	.700
	3	.621	.035	.552	.690
Y6	1	.606	.036	.536	.676
	2	.626	.035	.556	.696
	3	.624	.035	.555	.693
Y8	1	.588	.036	.517	.658
	2	.585	.035	.515	.655
	3	.564	.035	.495	.633
Y10	1	.656	.036	.586	.727
	2	.678	.035	.609	.748
	3	.666	.035	.597	.735
Y12	1	.591	.036	.521	.662
	2	.624	.035	.554	.694
	3	.588	.035	.519	.657

2. Year

Estimates

Measure:MEASURE_1

Year	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Y2	.538	.034	.471	.605
Y4	.623	.034	.556	.691
Y6	.619	.034	.551	.686
Y8	.579	.034	.512	.646
Y10	.667	.034	.600	.734
Y12	.601	.034	.534	.668

Pairwise Comparisons

Measure:MEASURE_1

(I) Year	(J) Year	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Y2	Y4	-.086	.048	1.000	-.229	.058
	Y6	-.081	.048	1.000	-.224	.063
	Y8	-.041	.048	1.000	-.185	.102
	Y10	-.129	.048	.122	-.272	.014
	Y12	-.063	.048	1.000	-.207	.080
Y4	Y2	.086	.048	1.000	-.058	.229
	Y6	.005	.048	1.000	-.139	.148
	Y8	.044	.048	1.000	-.099	.188
	Y10	-.043	.048	1.000	-.187	.100
	Y12	.022	.048	1.000	-.121	.166
Y6	Y2	.081	.048	1.000	-.063	.224
	Y4	-.005	.048	1.000	-.148	.139
	Y8	.040	.048	1.000	-.104	.183
	Y10	-.048	.048	1.000	-.192	.095
	Y12	.017	.048	1.000	-.126	.161
Y8	Y2	.041	.048	1.000	-.102	.185
	Y4	-.044	.048	1.000	-.188	.099
	Y6	-.040	.048	1.000	-.183	.104
	Y10	-.088	.048	1.000	-.231	.056
	Y12	-.022	.048	1.000	-.165	.121
Y10	Y2	.129	.048	.122	-.014	.272
	Y4	.043	.048	1.000	-.100	.187
	Y6	.048	.048	1.000	-.095	.192
	Y8	.088	.048	1.000	-.056	.231

	Y12	.066	.048	1.000	-.078	.209
Y12	Y2	.063	.048	1.000	-.080	.207
	Y4	-.022	.048	1.000	-.166	.121
	Y6	-.017	.048	1.000	-.161	.126
	Y8	.022	.048	1.000	-.121	.165
	Y10	-.066	.048	1.000	-.209	.078

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Measure:MEASURE_1

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	.229	5	.046	1.655	.150	.057
Error	3.819	138	.028			

The F tests the effect of Year. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Univariate Tests

Measure:MEASURE_1

	Noncent. Parameter	Observed Power[a]
Contrast	8.275	.561

The F tests the effect of Year. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Computed using alpha = .05

3. task

Estimates

Measure:MEASURE_1

task	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.598	.015	.569	.626
2	.611	.014	.583	.640

Estimates

Measure:MEASURE_1

task	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	.598	.015	.569	.626
2	.611	.014	.583	.640
3	.604	.014	.576	.633

Pairwise Comparisons

Measure:MEASURE_1

(I) task	(J) task	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.014	.007	.171	-.031	.004
	3	-.007	.007	.945	-.023	.009
2	1	.014	.007	.171	-.004	.031
	3	.007	.006	.871	-.009	.023
3	1	.007	.007	.945	-.009	.023
	2	-.007	.006	.871	-.023	.009

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.026	1.833[a]	2.000	137.000	.164	.026
Wilks' lambda	.974	1.833[a]	2.000	137.000	.164	.026
Hotelling's trace	.027	1.833[a]	2.000	137.000	.164	.026
Roy's largest root	.027	1.833[a]	2.000	137.000	.164	.026

Each F tests the multivariate effect of task. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

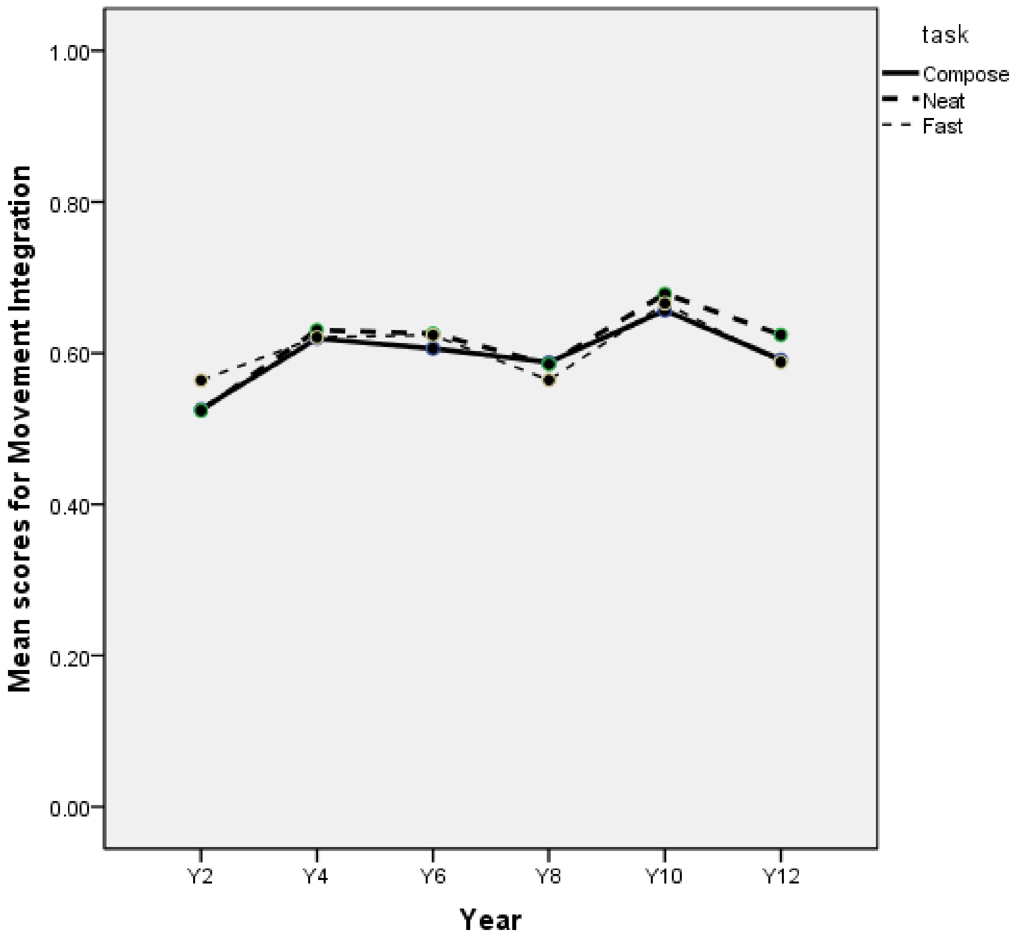
Multivariate Tests

	Noncent. Parameter	Observed Power[b]
Pillai's trace	3.666	.377
Wilks' lambda	3.666	.377
Hotelling's trace	3.666	.377
Roy's largest root	3.666	.377

Each F tests the multivariate effect of task. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

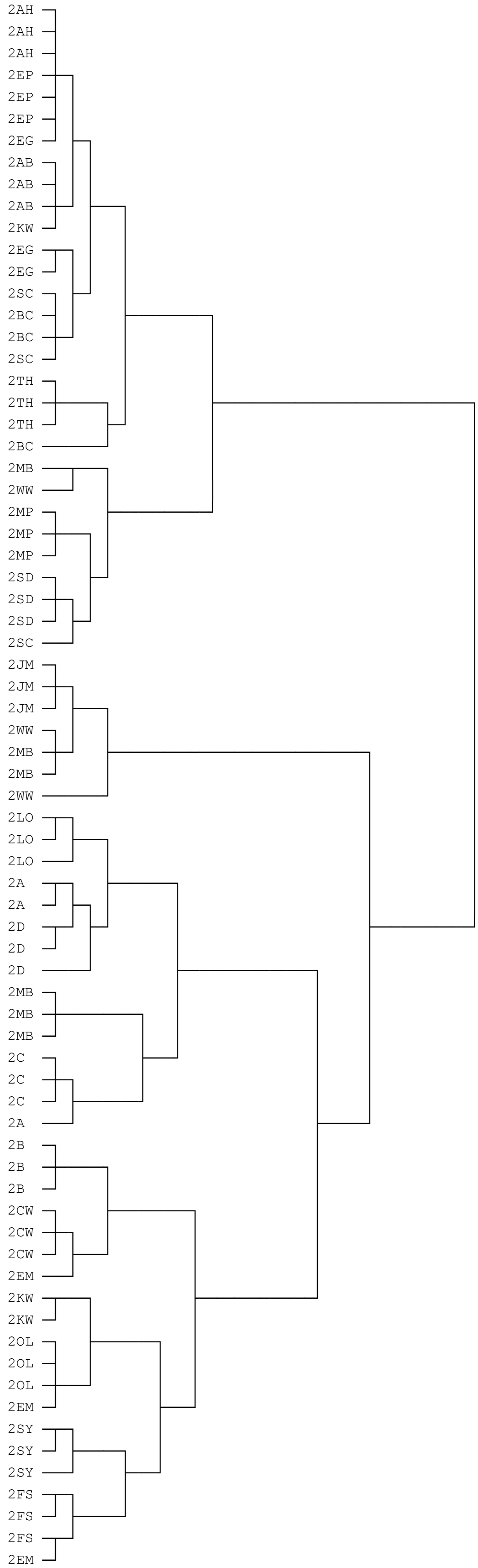
b. Computed using alpha = .05

Profile Plots

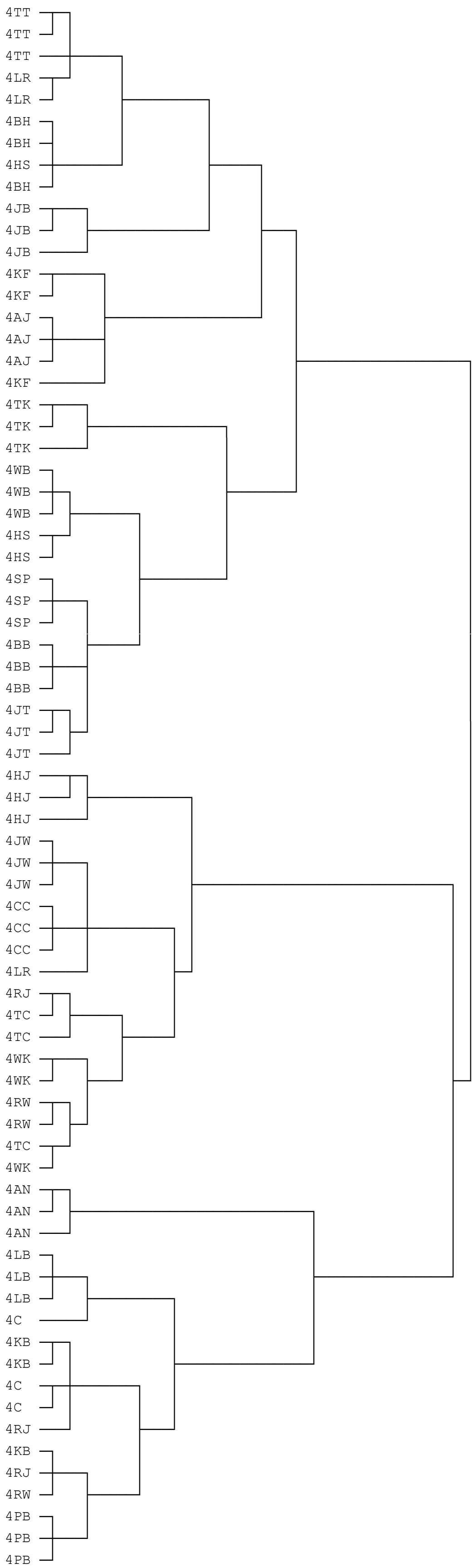


Appendix 4.1 dendrogram of cross-sectional data from Y2 participants

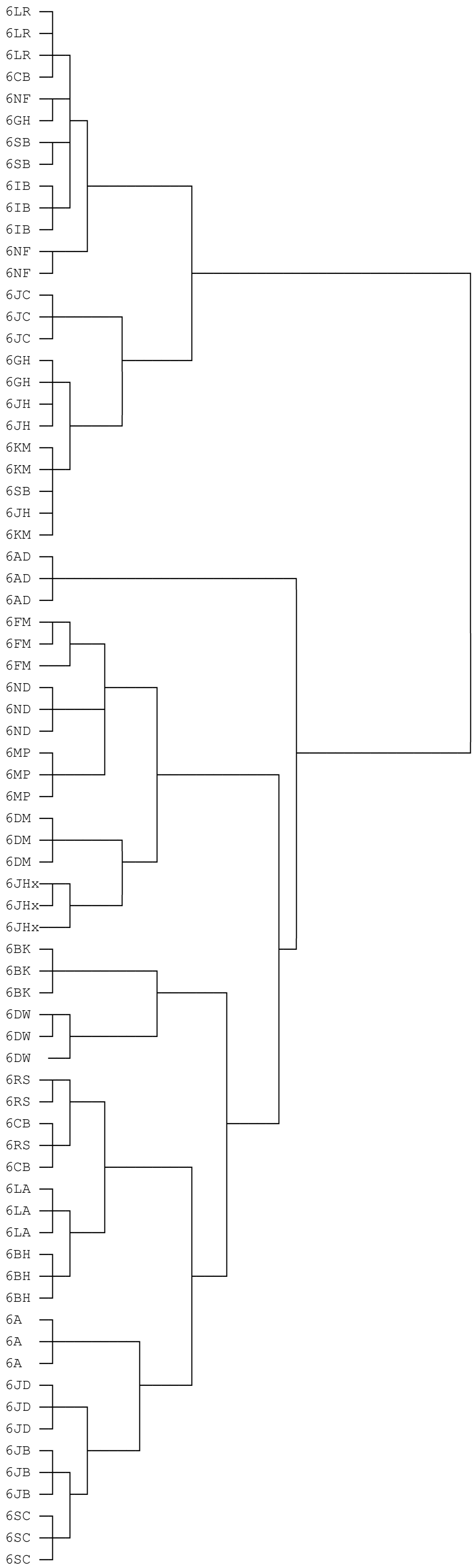
(The numeral indicates the year group and this is followed by initials)



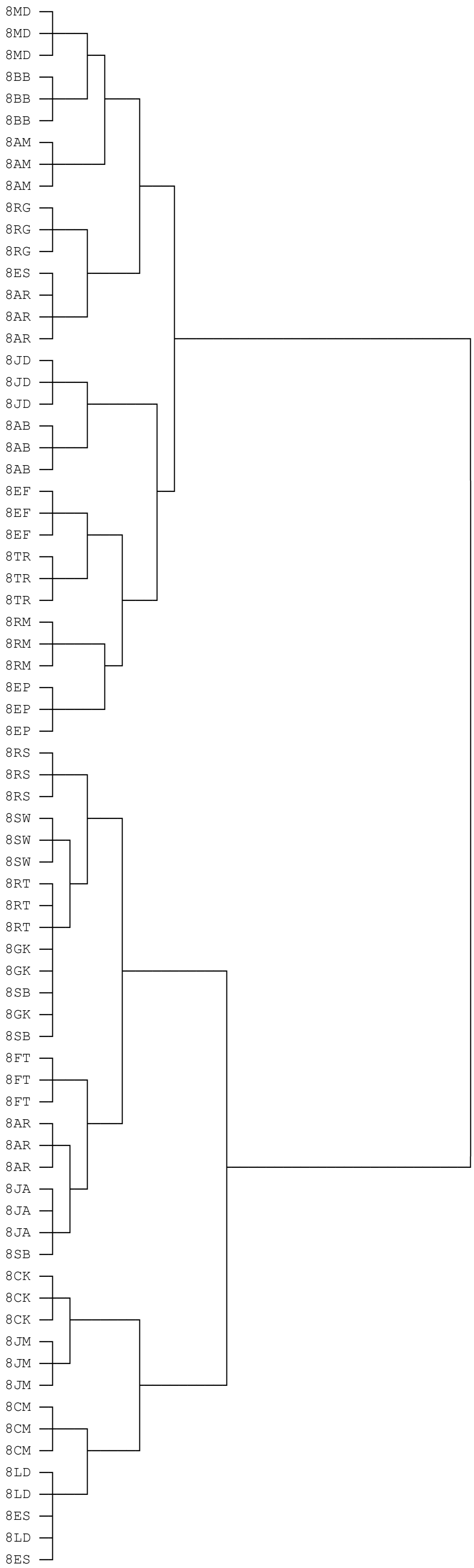
Appendix 4.2 dendrogram of cross-sectional data from Y4 participants
(The numeral indicates the year group and this is followed by initials)



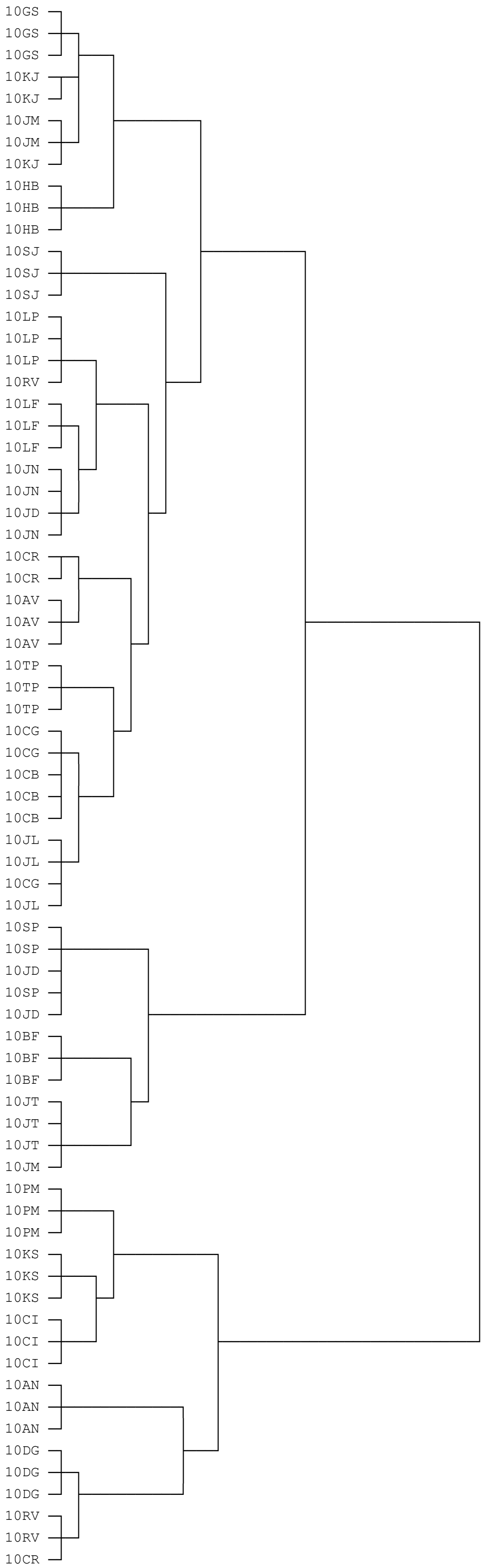
Appendix 4.3 dendrogram of cross-sectional data from Y6 participants
(The numeral indicates the year group and this is followed by initials)



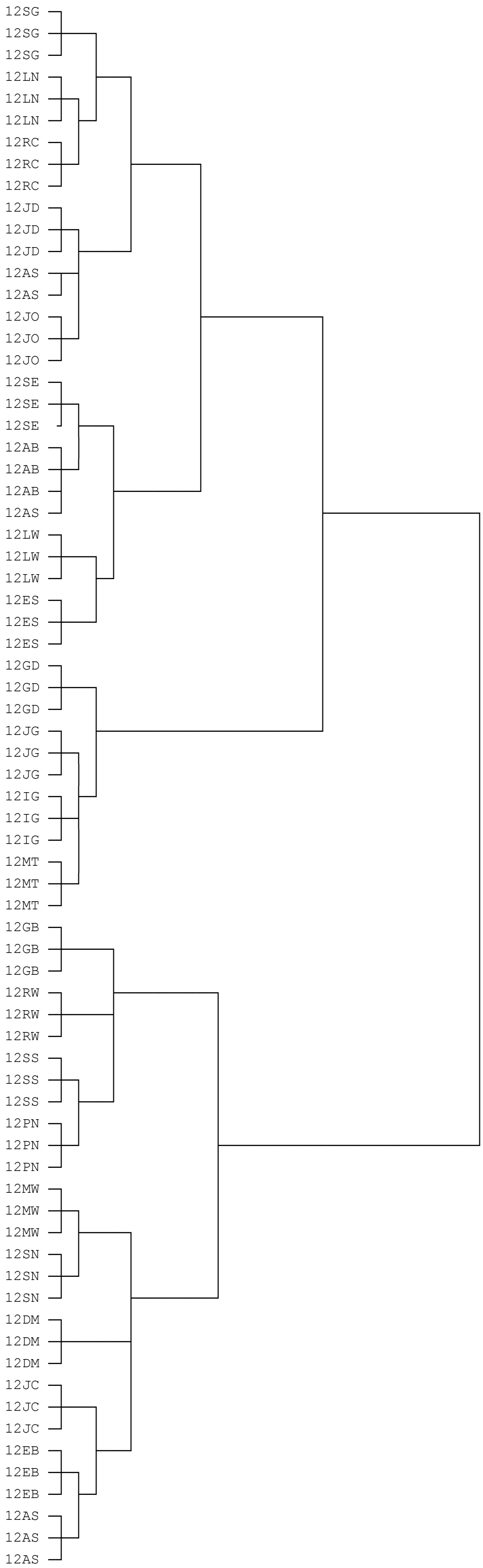
Appendix 4.4 dendrogram of cross-sectional data from Y8 participants
(The numeral indicates the year group and this is followed by initials)



Appendix 4.5 dendrogram of cross-sectional data from Y10 participants
(The numeral indicates the year group and this is followed by initials)

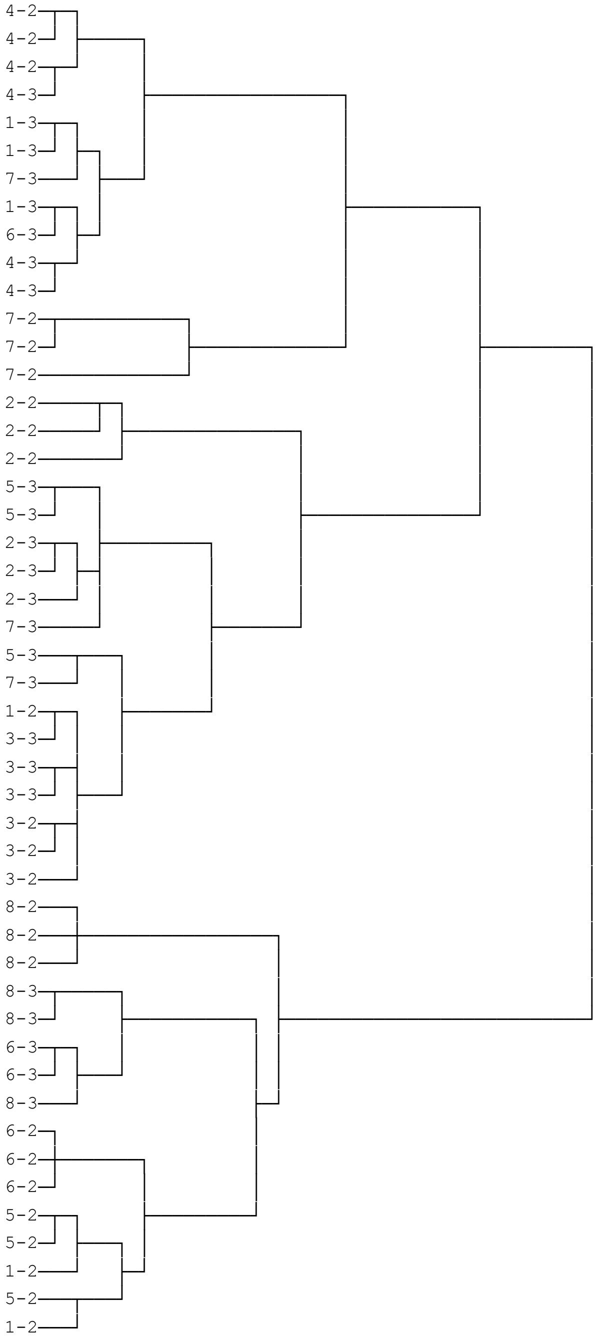


Appendix 4.6 dendrogram of cross-sectional data from Y12 participants
(The numeral indicates the year group and this is followed by initials)



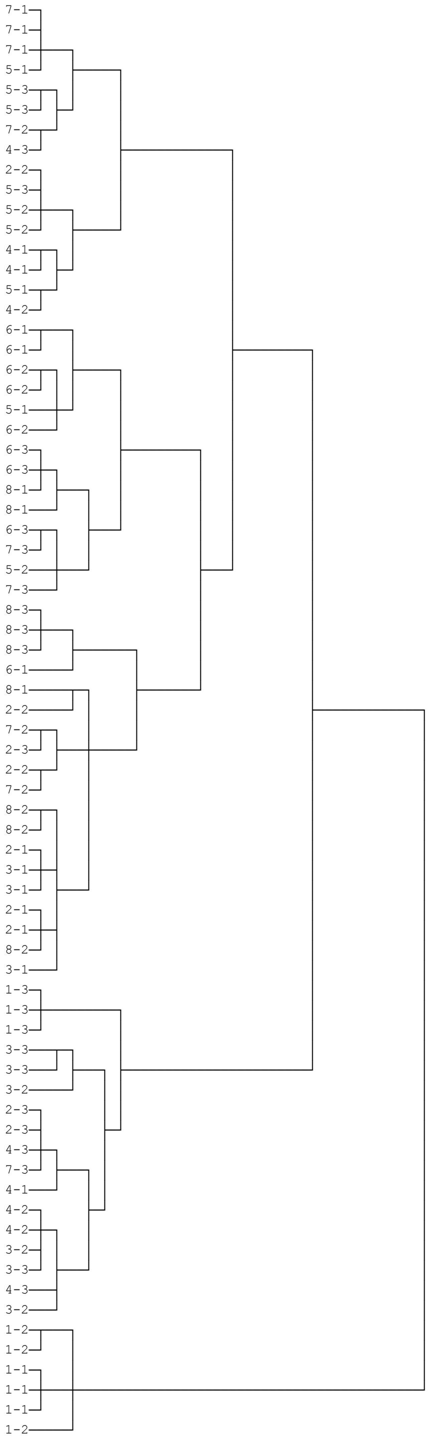
Appendix 5.1 Longitudinal study. Dendrogram of the two final years of data from the five year old group

The first digit is the participant identifier; the second digit indicates the second or third year of the study in which the sample was obtained (the first year pieces in this cohort were not used because so few had enough handwriting to code).



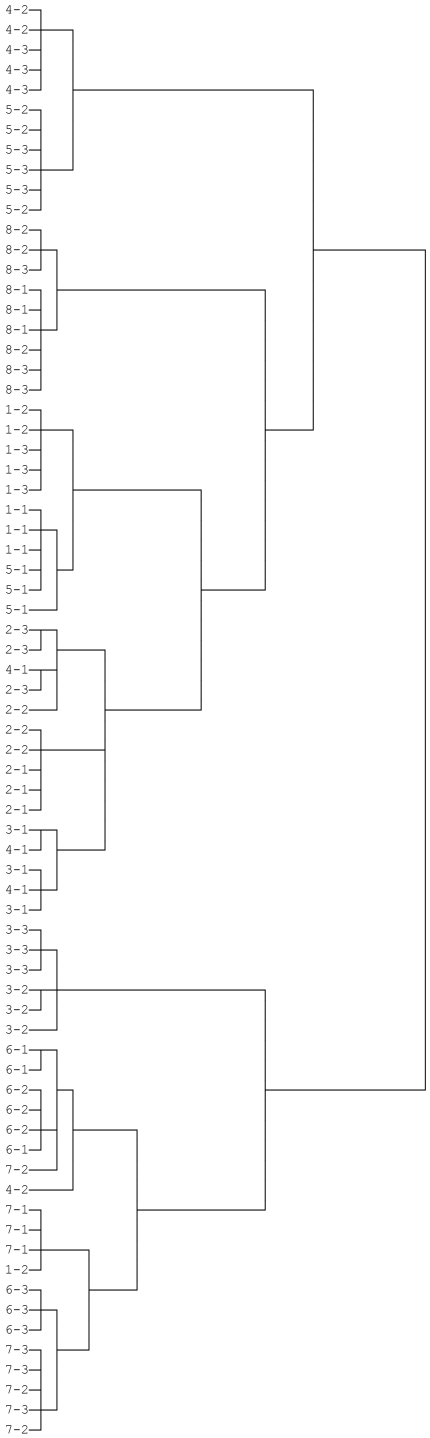
Appendix 5.2 Longitudinal study. Dendrogram of data from the eight year old group

The first digit is the participant identifier; the second digit indicates the second or third year of the study in which the sample was obtained.



Appendix 5.3 Longitudinal study. Dendrogram of data from the eleven year old group

The first digit is the participant identifier; the second digit indicates the second or third year of the study in which the sample was obtained.



Appendix 5.4 Longitudinal study. Dendrogram of data from the fourteen year old group

The first digit is the participant identifier; the second digit indicates the second or third year of the study in which the sample was obtained.