A STUDY OF KEYING SKILLS
AND VARIOUS ALPHANUMERIC KEYBOARDS

by

JANET MARY MARTIN B.Sc.

A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of the Loughborough University of Technology

May 1981

Supervisor: Professor B. Shackel MA, FBPsS
Department of Human Sciences

ACKNOWLEDGEMENTS

I am indebted to Professor Brian Shackel for initiating this S.R.C. funded research and for his invaluable advice throughout the last three years. I would like to thank the HUSAT Research Group for providing many varied diversions from this thesis. I would also like to thank Mr. John Smith, the Department Programmer and Mr. Max Hunt of the Computer Centre. I would also like to acknowledge Mr. Murray Sinclair for his statistical help and the many technicians who struggled to build equipment and keyboards with limited resources. Finally I would like to thank Mrs. Sherry Herbert for typing this thesis.

CONTENTS:

CONTENTS

Page

CHAPTER 1: INTRODUCTION 1

1. PREFACE 2

2. HYPOTHESISED ADVANTAGES OF KEYING SKILLS 3

3. JUSTIFICATION OF THIS RESEARCH 5

4. THE STRUCTURE OF THE THESIS 7

PART I: THE SEQUENTIAL KEYBOARDS

CHAPTER 2: THE GENESIS OF QWERTY AND A QWERTY USERS' SURVEY 9

1. INTRODUCTION 10

1.1 The QWERTY Keyboard 10

1.2 The Disadvantages of the QWERTY Layout 13

1.3 In Defence of QWERTY 18

2. METHODOLOGY 20

2.1 The Questionnaire 20

2.2 Selection of Subjects 25

2.3 Pilot Study I 25

2.4 Pilot Study II 26

2.5 Analysis of Data 26

3. RESULTS 27

4. DISCUSSION 35

4.1 Training of Keyboard Operators 35

4.2 Keyboard Arrangement 35

4.3 Aspects of Fatigue 40

4.4 Beginner Typists' Questionnaire Survey 43

4.5 Implications for the Future 44

5. CONCLUSIONS 46

CHAPTER 3: A REVIEW OF THE LITERATURE AND RECENT RESEARCH ON QWERTY SEQUENTIAL KEYBOARDS 47

1. LITERATURE REVIEW OF SEQUENTIAL KEYBOARDS 48

1.1 Early Challenges to the QWERTY Keyboard 48

1.2 The Orthographic Keyboard 51

1.3 The Dvorak Simplified Keyboard (D.S.K.) 52

1.4 Experimental Comparisons of the QWERTY and Dvorak Keyboards 56

1.5 Review of Post-Dvorak Alphanumeric Keyboards 57

CONTENTS (continued) Page

1.6 The Ward Keyboard 58
1.7 The Minimotion Keyboard 59
1.8 The Rhythmic Keyboard 60
1.9 The Alphabetical Layout 62
1.10 The Alphametric Keyboard (A.M.K.) 65
1.11 The Kroemer Keyboard 65
1.12 Suggested Revision of the QWERTY Layout 67
1.13 The P.C.D. - Maltron Keyboard 68
2. EXPERIMENTAL STUDY OF THE MALTRON KEYBOARD 71
2.1 Summary of Results 73
2.2 Analysis of Questionnaire Data 73
3. CONCLUSIONS 77

CHAPTER 4: THE 'STATE OF THE ART' ON SEQUENTIAL KEYBOARDS 78
1. SUMMARY OF RESEARCH ON ALPHANUMERIC KEYBOARD LAYOUTS 79
2. PAST RESEARCH ON KEYBOARD DESIGN 81
3. THE FUTURE OF THE QWERTY KEYBOARD 82
3.1 Introduction 82
3.2 The QWERTY Layout 82
3.3 Keyboard Design 84
3.4 Standardisation of Keys 85
4. DIRECTION OF FURTHER RESEARCH 86
5. THE KEYPEN CONCEPT 88
6. CONCLUSIONS 89

PART II: THE CHORD KEYBOARDS

CHAPTER 5: A LITERATURE REVIEW OF CHORD KEYBOARDS 90
1. INTRODUCTION 91
2. BRIEF HISTORY OF CHORD KEYING UP TO 1970 93
2.1 The Printing Industry 93
2.2 Early Attempts at Chord Keyboard Design 93
2.3 Chord Keyboards in the Post Office 95
2.4 IBM Chord Keyboard Developments 98
2.5 Review of Other Chord Keyboards 99
3. EXPERIMENTAL COMPARISONS OF SEQUENTIAL AND CHORD KEYBOARDS 104
3.1 Discussion of Methodology 104
3.2 Brief Review of Experimental Work 105

CONTENTS (continued) Page

4. CHORD KEYBOARD DEVELOPMENTS WITHIN THE LAST DECADE 109

4.1 Introduction 109

4.2 The ANTEL Chord Keyboard 109

4.3 The Writehander 111

4.4 The Microwriter 112

4.5 The IBM Chord Keyboard 113

5. CHORD KEYBOARDS - AN APPRAISAL 115

6. PROPOSED EXPERIMENTAL WORK 117

7. CONCLUSIONS 119

CHAPTER 6: A PRELIMINARY INVESTIGATION INTO VARIOUS SHAPES FOR A SMALL CHORD KEYBOARD 120

1. INTRODUCTION 121

2. BRIEF REVIEW OF THE RELEVANT LITERATURE 122

3. METHODOLOGY 124

4. RESULTS 127

5. DISCUSSION 128

5.1 Shape 1: The Hemisphere 128

5.2 Shape 2: The Cylinder 129

5.3 Shape 3: The Rectangular Box 130

5.4 Suggestions of Alternative Shapes for Future Development 130

6. SUMMARY OF RESULTS 132

7. CONCLUSIONS 133

CHAPTER 7: A STUDY OF THE MOTOR ASPECTS OF CHORD KEYING 135

1. INTRODUCTION 136

2. TWO STUDIES OF PERFORMANCE ON CHORD KEYBOARDS 137

2.1 Ratz and Ritchie's Experimental Work on a Chord Keyboard 137

2.2 Seibel's Experimental Work 140

2.3 Conclusion 143

3. METHODOLOGY 144

3.1 Pilot Study I 144

3.1.1 Experimental Design 144

3.1.2 Description of Equipment 144

3.1.3 Experimental Procedure 144

3.1.4 Analysis of Data 145

3.1.5 Discussion of Pilot Study I 146

CONTENTS (continued) Page

3.1.5.1 The Physical Design of the Keyboards 146
3.1.5.2 Stimulus-Response Compatibility 147
3.1.5.3 The Experimental Environment 147
3.1.5.4 Problem Areas 148

3.1.6 Conclusions 149

3.2 Pilot Study II 149

3.3 The Main Study 150

3.3.1 Experimental Design 150
3.3.2 Selection of Subjects 150
3.3.3 Description of Equipment 151
3.3.4 Experimental Prcedure 152
3.3.5 Data Analysis 154

4. RESULTS 155

5. DISCUSSION 160

5.1 Summary of Keyboard Results 160

5.1.1 First Impressions of the Keyboards 160
5.1.2 Enjoyment of Keyboard Operation 160
5.1.3 Ease of Operation 160
5.1.4 The Size and Shape of the Keyboards 161
5.1.5 The Position of the Keys 161
5.1.6 The Weight of the Keyboards 162
5.1.7 Mode of Operation 162
5.1.8 Comfort of Operation 163
5.1.9 Aspects of Fatigue 163
5.1.10 The Stimulus Display 164
5.1.11 Conclusions from the Subjective Data 164

5.2 Summary of Chord Results 165

5.3 Criticisms of the Experiment 167

5.4 Implications of the Experimental Findings 168

6. CONCLUSIONS 169

CHAPTER 8: A STUDY OF THE COGNITIVE ASPECTS OF CHORD KEYING 170

1. INTRODUCTION 171

2. BRIEF REVIEW OF THE RELEVANT LITERATURE 172

2.1 Experimental Proposals 176

3. METHODOLOGY 178

3.1 Pilot Study 178

3.1.1 Introduction 178
3.1.2 Results 179
3.1.3 Discussion 180
3.1.3.1 The Aims of the Pilot Study 180
3.1.3.2 Length of Experiment 181
3.1.3.3 Selection of Subjects 181
3.1.4 Conclusions 182

CONTENTS (continued) Page

3.2 The Main Study 182

3.2.1 Experimental Design 182
3.2.2 Selection of Subjects 183
3.2.3 Description of Equipment 183
3.2.4 Experimental Procedure 183
3.2.5 Data Analysis 184

4. RESULTS 186

5. DISCUSSION 192

5.1 Implications of the Chord Rank Chart 192

5.2 Application of these Findings 193

5.3 Long Term Memory Study 194

5.4 Methods Used to Remember Chord Patterns 195

6. CONCLUSIONS 200

7. THE FOLLOW-UP STUDY - AN INVESTIGATION INTO THE USE OF MNEMONICS FOR LEARNING THE CHORD COMBINATIONS 201

7.1 Introduction 201

7.2 Methodology 201

7.3 Results 203

7.4 Discussion 204

7.5 Conclusions 206

CHAPTER 9: A SURVEY OF USERS' ATTITUDES TOWARDS CHORD KEYBOARDS 207

1. INTRODUCTION 208

1.1 Problems of Attitude Testing 208

1.2 Compilation of the Attitudes Questionnaire 210

1.3 Objectives of the Experimental Investigation 211

2. METHODOLOGY 213

2.1 The Pilot Study 213

2.1.1 Selection of Subjects 213
2.1.2 Description of Equipment 213
2.1.2.1 The Chord Keyboard 214
2.1.2.2 The Role of the Commodore PET Micro-computer 214
2.1.2.3 The Mnemonics Chart 214
2.1.3 Experimental Procedure 215
2.1.4 Discussion 217
2.1.5 Conclusions 217

2.2 The Main Study 217

2.2.1 Selection of Subjects 217
2.2.2 Description of Equipment/Experimental Procedure 218
2.2.3 Data Analysis 218

CONTENTS (continued) Page

3. RESULTS 219

3.1 Section A of the Questionnaire 219

3.2 Section B of the Questionnaire 224

4. DISCUSSION 227

4.1 General Form and Physical Design Aspects of the Keyboard 227

4.1.1 The Size of the Keyboard 227
4.1.2 The Shape of the Keyboard 227
4.1.3 The Keys 228
4.1.4 The Mnemonics Chart 232
4.1.5 Physical Formation of the Chords 233
4.1.6 Aspects of Fatigue 233
4.1.7 The Chord Keyboard Concept 234

5. CONCLUSIONS 237

PART III: GENERAL DISCUSSION

CHAPTER 10: A DISCUSSION OF SEQUENTIAL AND CHORD KEYBOARDS 238

1. OVERVIEW - SEQUENTIAL KEYBOARDS 239

1.1 The QWERTY Keyboard 239

1.2 The Question of Fatigue 241

1.3 The Future of the QWERTY Keyboard 243

1.4 Alternative Sequential Keyboards 244

1.5 Summary 245

2. OVERVIEW - CHORD KEYBOARDS 246

2.1 State of the Art of Chord Keyboards 246

2.2 The Development of a Chord Keyboard 248

2.3 Hypothesised Advantages of Chord Keying 249

2.4 Summary 251

3. APPLICATIONS OF THIS RESEARCH 252

3.1 Sequential Keyboards 252

3.2 Chord Keyboards 252

3.2.1 The Design of Chord Keying Devices 252
3.2.2 The Motor Aspects of Chord Keying 253
3.2.3 The Cognitive Aspects of Chord Keying 255
3.2.4 Motor Versus Cognitive Aspects 256
3.2.5 Attitudes Towards Chord Keyboards 258
3.2.6 Summary 259

4. THE PRACTICAL IMPLEMENTATION OF THESE RESEARCH FINDINGS 261

5. PROBLEMS ASSOCIATED WITH KEYBOARD RESEARCH 265

CONTENTS (continued) Page

5.1 General Difficulties 265

5.2 Specific Problem Areas Relating to the Work 266

6. THE FUTURE OF THE ALPHANUMERIC KEYBOARD 270

6.1 Input by Speech Recognition 270

6.2 Input by Character Recognition 271

6.3 Summary 272

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS 273

1. CONCLUSIONS 274

2. RECOMMENDATIONS 277

3. EPILOGUE 278

REFERENCES 279

APPENDICES 298

LIST OF FIGURES

Page

Figure 2.1: The Standard QWERTY Layout (ANSI X4.7 - 1966, American National Standard Typewriter Keyboards) 11

Figure 2.2: The Griffith's Hypothesis 12

Figure 2.3: Distribution of Finger Strokes on Individual Typewriter Keys 15

Figure 2.4: Frequency Distribution of Subjects' Ages 25

Figure 2.5: Frequency Distribution of Lengths of Training 27

Figure 2.6: Frequency Distribution of Speeds Obtained at End of Training 27

Figure 2.7: Frequency Distribution of Time Taken to Reach Proficiency 27

Figure 2.8: Frequency Distribution of Subjects' Satisfaction with Keyboard Layout 28

Figure 2.9: Frequency Distribution of Subjects Experiencing Difficulty in Certain Finger Movements 28

Figure 2.10: Frequency Distribution of Subjects Making More Errors on Some Keys than Others 29

Figure 2.11: Frequency Distribution of Subjects' Preferences with Regard to Change in the Position of the Typewriter Keys 29

Figure 2.12: Frequency Distribution of Subjects' Preferences with Regard to Increasing the Workload of the Thumbs 30

Figure 2.13: Frequency Distribution of Subjects' Experience of Moving Head when Working 30

Figure 2.14: Frequency Distribution of Subjects Experiencing Neck-ache 30

Figure 2.15: Frequency Distribution of Subjects Experiencing Back-strain 31

Figure 2.16: Frequency Distribution of Subjects Experiencing Aching Shoulders 31

Figure 2.17: Frequency Distribution of Subjects Experiencing Tired Arms 31

Figure 2.18: Frequency Distribution of Subjects Experiencing Tired and Aching Fingers 32

Page

Figure 2.19: Frequency Distribution of Subjects' Enjoyment of Typing 32

Figure 2.20: Frequency Distribution of Subjects' Preferences with Regard to Typing and Handwriting 32

Figure 2.21: Frequency Distribution of Subjects' Preferences with Regard to Suitability of Typewriter to Both Left and Right Handed Individuals 33

Figure 2.22: Frequency Distribution of Subjects' Reactions to a Smaller, Lighter, More Compact Typewriter 33

Figure 2.23: Frequency Distribution of Subjects' Reactions to a Hand-sized Chord-keying Device 33

Figure 3.1: The Blickensderfer (1897) 48

Figure 3.2: The Rowell Keyboard (1909) 49

Figure 3.3: The Combinational Keyboard (1920) 49

Figure 3.4: The Banaji Keyboard (1920) 50

Figure 3.5: The Wolcott Keyboard (1920) 51

Figure 3.6: The Hoke Keyboard (1924) 51

Figure 3.7: The Orthographic Keyboard (1930) 52

Figure 3.8: The Dvorak Simplified Keyboard (1936) 52

Figure 3.9: QWERTY Keyboard: Percentage workload on each finger, for left and right hands 53

Figure 3.10: Dvorak Simplified Keyboard: Percentage workload on each finger, for left and right hands 53

Figure 3.11: Summary of Dvorak's Findings 57

Figure 3.12: Rearrangement of Typewriter Keyboard (1934) 58

Figure 3.13: The Ward Keyboard (1936) 59

Figure 3.14: The Minimotion Keyboard (1949) 60

Figure 3.15: Performance Ratings 60

Figure 3.16: The Rhythmic Keyboard (1953) 61

Figure 3.17: The QWERTY and Alphabetical Keyboards used by Hirsch (1958) 64

Figure 3.18: The Proposed Alphametric Keyboard (1972) 65

Figure 3.19: The Kroemer Keyboard Model (1972) 66

Figure 3.20: Revised QWERTY Layout (1974) 67

Figure 3.21: The P.C.D. - Maltron Keyboard 69

Figure 3.22: Diagrammatic Representation of the Letter Layout of the Maltron Keyboard 70

Figure 3.23: Graph of Mean Keying Rate against Exercise Number 72

Page

Figure 4.1: Table of Results (Gordan et al., 1975) 83

Figure 4.2: The Contoured Keyboard (August 1979) 85

Figure 5.1: Wick's Composing Machine Chord Keyboard (1879) 94

Figure 5.2: The Unitype Chord Keyboard (1898) 94

Figure 5.3: The Levy Keyboard (1955) 96

Figure 5.4: The Double-banked Binary Keyboard (1963) 97

Figure 5.5: Ayres' Word Writing Machine (1965) 100

Figure 5.6: Keyset Units used by Hillix and Coburn (1961) 103

Figure 5.7: Conrad and Longmans' Chord Keyboard Layout (1965) 106

Figure 5.8: The Three Keyboards used by Bowen and Guinness (1965) 107

Figure 5.9: The ANTEL Chord Keyboard (1973b) 110

Figure 5.10: The Writehander (1978) 111

Figure 5.11: The Microwriter (1978) 112

Figure 5.12: The IBM Chord Keyboard (1978) 114

Figure 6.1: The Outline of Webb and Coburn's Keyboard (1959) 123

Figure 6.2: The Three Models used in this Study 126

Figure 6.3: The Three Modified Shapes 134

Figure 7.1: The Chord Rank Chart (Ratz and Ritchie, 1961) 138

Figure 7.2: The Chord Rank Chart showing Average DRTs and Percentage Errors (Seibel, 1962) 142

Figure 7.3: Diagrammatic Representation of the Apparatus 144

Figure 7.4: Diagrammatic Representation of the Apparatus 151

Figure 7.5: Group Means for Response Times Plotted against Trial Number 156

Figure 8.1: Levy's Allocation of Chords to Letters 172

Figure 8.2: Chart of ASCII Code and Corresponding Finger and Thumb Positions for the Writehander 174

Figure 8.3: Endfield's Mnemonic Chart 175

Figure 8.4: Chord Combinations Available with a 5-key Chord Keyboard 179

Figure 8.5: Chord Patterns plus Letter Shape Integrations Proposed and Tested 202

Page

Figure 9,1: Diagrammatic Representation of the Chord Keyboard System 213

Figure 9.2: Artist's Impression of the Proposed Chord Keyboard 229

Figure 9.3: Characteristics of the Keys on the Hemispherical Keyboard 230

Figure 10.1: Profile of a Key Column 241

Figure 10.2: The Two Numeric Layout Standards 263

Figure 10.3: Reasons given by 12 Subjects for Terminating the Experimental Trials 268

CHAPTER 1

INTRODUCTION

1. PREFACE

The desire to make a permanent record of one's thoughts and conversation has existed for many centuries. The development of writing instruments was a slow process. It took over 4000 years for the quill pen to replace the reed pen (Mussin, 1980), and it was not until 1785 that the pencil was invented. In 1884, the fountain pen was introduced, which was followed by the more recent development of the ball-point pen ('biro') towards the end of the second World War (1944). One of the reasons for the continuing production of writing implements was the requirement for speed. The need to go faster has always been fundamental to Man's existence. For example, as long ago as 63 BC Marcus Tullius Tiro invented a system of shorthand in order to ensure he had a complete record of Cicero's orations. Since then over a thousand systems of shorthand have been devised for the English language alone. This method of abbreviating words provides one approach for speeding up the 'speech-to-text' process. An alternative is to use a keying device.

The development of keying devices was similar to the invention of writing instruments, in that initial production was slow, but the number and versatility of devices rapidly increased as their potential was realised. The first 'writing machine' is thought to have been invented in 1714 (Richards, 1964), and during the nineteenth century many typewriters were manufactured. As a result the number of keying devices produced has steadily increased throughout the last 100 years. This trend has continued during the last two decades and it is hypothesised that many more keyboards will emerge during the 1980's as technology becomes more sophisticated.

2. HYPOTHESISED ADVANTAGES OF KEYING SKILLS

The history of keying devices is intrinsically linked with the development of the printing industry and communication aids for the disabled. It is unlikely that the speed potential of the alphanumeric keyboard would have been realised, since speed was not a primary factor which the early typewriter inventors would have taken into consideration. Early keyboard operators (circa 1870) hit the keys with one or two forefingers (Beeching, 1974). Therefore it could be hypothesised that the main reason for the production of the printed word on a typewriter was legibility and style. McGurrin in 1877 was one of the first individuals to touchtype and after this date, the concept of the secretary sitting behind a typewriter emerged (Beeching, 1974). Today, the speed of keying provides one of the primary reasons why this mode of communication is preferred to other techniques such as handwriting. An 'average' keyboard operator will enter between 20,000 and 30,000 keystrokes per hour, which is approximately 2·8 - 4 times faster than writing at a speed of 24 words per minute (Turn, 1974).

As a sensori-motor skill, touchtyping is comparatively easy to learn. After ten hours of training, individuals can expect to type at a speed of 10 - 12 words per minute (Sight and Sound Education Ltd. - Personal Communication). A comparison of learning to type with learning to write suggests that the former may have certain advantages over learning to handwrite. There are many difficulties inherent in producing an 'A' on paper. For example, the rules of writing English demand that the letter a is oriented in the correct spatial position otherwise it could become another letter (o) and the individual has to learn that an extra stroke also converts the letter a into another letter (d). In 1975, there were estimated to be two million illiterate adults in this country (Richards, 1978). The use of keying devices for these individuals might help them communicate the 'written' word, since it is easier to learn to press buttons to produce letters than learn to write (Campbell, 1973).

Illiterate adults cannot write, which usually implies that they cannot read as well. Campbell (1973) found that the use of typewriters facilitated the acquisition of reading skills. Therefore it could be predicted that the application of keying devices may offer certain benefits for the illiterate population of this country.

3. JUSTIFICATION OF THIS RESEARCH

This research is primarily concerned with alphanumeric sequential and chord keyboards. The term 'sequential keyboards' may be slightly misleading, since not all keyboards in this category are covered. For example, the linotype machines used in the printing industry are omitted.

The most well known of the sequential keyboards is the standard QWERTY keyboard. This original typewriter layout has been in use for over 100 years and, despite doubts about its efficiency, attempts to establish alternative designs and develop new keyboard layouts have met with little success. One of the reasons for this research is to assess the controversy surrounding QWERTY and to make recommendations with regard to the future of this century old keyboard. A research thesis provides one of the few means by which an unbiased, non-commercial view of the situation can be attained.

Recent technological trends have shown an increase in the use of micro-electronics and hence the miniaturisation of equipment. There are several advantages to be attained from reducing the size of the standard keyboard. For example, a pocket sized keyboard would be easier to transport, and hence its portability could increase its frequency of use as well as making operation possible in hostile environments. Small keyboards are more likely to be powered by batteries, thus eliminating the need to locate electric points and disguise trailing wires. This has resulted in a revived interest in alphanumeric keyboards. Some individuals have designed small keyboards retaining the full alphanumeric set of keys: for example, the Pocket TTY 'alphanumeric calculator', manufactured by G.R. Electronics Ltd. Often keyboard designers have reduced key dimensions and the spacing of keys to such an extent that keying is awkward, slow and uncomfortable (for example, MINNIE - the National Physical Laboratory's experimental keyboard). A further solution to the problems which arise by miniaturising a keyboard is to convert it into a chord keyset. A typical chord keyboard would consist of between five and 12 keys: alphanumeric characters are attained by 'patterned pressing' of the keys.

The increase in the development of alphanumeric keyboards demonstrates the current interest in this field. Hence this is an appropriate time to investigate these keyboards and evolve recommendations concerning future developments.

A further reason for the revived interest in keyboards stems from an increase in their use by a wider range of occupational groups and level of staff. Many more individuals now use keyboards as part of their daily work - examples include micro-computer programmers, process control operators, journalists, and office managers who have their own 'personal' computers. Many of these groups do not find the standard QWERTY unit wholly satisfactory for their needs. This keyboard allows rapid touchtyping over long periods of time, but often the training needed to achieve this is not justified or wanted by the occasional user. Hence a chord keyboard might suit their requirements. There is a paucity of knowledge about chord keying and this research attempts to rectify this situation.

The hypothesised advantages of keying discussed in the previous section stress the importance of this area of human skill. Further research on keying skills may benefit both those individuals who use alphanumeric keyboards on an occasional basis and those who use them frequently.

4. THE STRUCTURE OF THE THESIS

The thesis is divided into three parts. Part I (Chapters 2,3 and 4) covers the sequential keyboards, while Part II (Chapters 5,6, 7,8,9) concentrates on chord keyboards. The final section of the thesis (Part III - Chapters 10 and 11) includes the general discussion chapter and the conclusions.

After this introductory chapter, the thesis commences with the genesis of the QWERTY keyboard. Much controversy surrounds this standard keyboard and the author decided to approach some users of QWERTY in order to find out their attitudes. It is perhaps surprising to note that no previous practical research of this nature has been carried out and reported in the open literature. The merits and shortcomings of the QWERTY keyboard have usually been debated theoretically.

Throughout the thesis, a standard usage of 'keyboard layout' and 'keyboard design' have been closely adhered to. 'Keyboard layout' refers to the arrangement of the alphanumeric keys, that is which alphabet letter belongs to which key, while 'keyboard design' defines the shape etc. of keys and the general form of the keyboard. Chapter 3 reviews the literature on sequential keyboards, refers to the Maltron keyboard, and concludes with some experimental work on keyboard design.

Chapter 4 is a discussion chapter for Part I of the thesis. It reviews the evidence collected from the two experimental studies concerning the QWERTY and the Maltron keyboards, and makes various recommendations on sequential keyboard layout and design.

Part II of the thesis begins with Chapter 5, which covers a literature review on chord keyboards.

Chapter 6 describes a preliminary experiment investigating the general form of chord keying devices. This study was conducted in order to design the chord keyboards to be used in the experiment, described in Chapter 7.

This seventh chapter concentrates on the motor aspects of chord keying, and studies various chord keyboard designs through a reaction time experiment. It also discusses the problems of (1) whether the time taken to form chords relates to the shape of the keying device, and (2) the allocation of chords to alphanumerics.

In contrast, Chapter 8 studies the cognitive aspects of chord keying, and again the problem of allocating chords to alphanumerics is tackled, but from a different angle.

Chapter 9 surveys users' attitudes towards chord keyboards. The results from the experimental work in Chapters 6,7 and 8 are combined to set up a chord keyboard system. An experimental assessment of the attitudes of the potential user population is conducted.

The final part of the thesis (Chapters 10 and 11) consists of a general discussion encompassing all the previous chapters. Chapter 11 lists the conclusions of this research and makes a series of recommendations.

PART I:

THE SEQUENTIAL KEYBOARDS

CHAPTER 2

THE GENESIS OF QWERTY AND A QWERTY USERS' SURVEY

1. INTRODUCTION

1.1 The QWERTY Keyboard

The need to provide writing machines for the blind was one of the primary factors influencing the experimental development of the typewriter. During the late eighteenth and early nineteenth century there were twenty-three different methods available for making embossed printing (Richards, 1964). These developments, together with the fact that Man has always been keen to increase the speed at which thought and speed can be recorded, led to the concept of a 'writing machine'. The first patent (British Patent No. 395 (Richards, 1964)) for such a device was granted to Henry Mill in 1714. Unfortunately no details exist either of its appearance or its mechanism. It was not until 1829 that the first machine known to have been capable of practical work was invented by William Burt (U.S. Patent No. 259 (Richards, 1964)). This device was called the 'Typographer' and resembled a sundial on a wooden box: it had a complex mechanism by which detachable racks slid across the paper to give both narrow and wide line spacing. Four years later in France, Xavier Progin produced a typewriter with the familiar circular typebar basket (French Patent No. 3,748) and made the claim that he could 'write' almost as fast as a pen (Richards, 1964). All subsequent developments were based on this design.

It was not until 1866 that the first typewriter to become a commercial success was developed by two Americans, C.L. Sholes and C. Glidden. At that time, both men were working on a machine for consecutively numbering rail tickets, bank notes and the pages of books, and it was from this device that the concept of a machine to print letters emerged. The end-result, the Sholes, Glidden and Soulé typewriter was patented in June 1868 (U.S. Patent No. 79,265 (Richards, 1964)). This patent was later superceded by other patents as the mechanical structure and keyboard of the typewriter were modified. The first patent which actually shows the QWERTY layout is dated August 1878; previous patents had shown a two row keyboard with the letters arranged in alphabetical order (that is, from N to Z, and A to M) (Beeching, 1974).

In 1874 the Remington Arms Company began manufacturing the typewriter in quantity, but it was another two years before the device made its first public appearance. The original typewriter keyboard positioned the M immediately adjacent to the letter L. This is the only change that has occurred and the ubiquitous QWERTY layout now serves as a model for keyboards of computer keysets, cash registers and the more recently developed word processors (Figure 2.1).

1 2 3 4 5 6 7 8 9 0 - =
Q W E R T Y U I O P ½
A S D F G H J K L ; '
Z X C V B N M , . /

Figure 2.1: The Standard QWERTY Layout (ANSI X4.7 - 1966, American National Standard Typewriter Keyboards)

The original QWERTY keyboard was intended for 'hunt and peck' operation and not touch typing, although the inventors' aim was to design a machine that could print words at a speed equivalent to handwriting. In 1877, McGurrin astonished observers by typing with all ten fingers (Beeching, 1974). Over the years, researchers and keyboard designers have been concerned with the logic behind the placement of the letters on the QWERTY keyboard. One common idea was that letters which frequently fell together in English text (for example, Q is always followed by U, and TH and E) were located in different quadrants of the typebar circle. This was to avoid the mechanical problems of typebars clashing as they returned to their rest position. It is thought that Sholes and Glidden were not interested in the keyboard layout and that it was Densmore who conceived the idea of separating common digrams. Densmore compiled a list of the frequency of juxtaposition with which the letters in English text occurred and this list formed the basis for the layout. Hence, the suggestion that the QWERTY keyboard was deliberately designed to slow down the typist (Cocking, 1970).

Stage I: The Alphabet

```
                A B |
        C D E F G   | H I J K L M
                    | N O P
                  Q | R
                S T | U
                  V |
                W X | Y
left hand       Z · | ? : -        right hand
```

Stage II: Spread Horizontally

```
        A          B |
          C D E F G  | H I J K L M
                     | N       O P
        Q            |         R
          S        T |       U
left           V     |           right
hand      W X        | Y         hand
        Z        ·   |   ?   ;   -
```

Stage III: The Preproduction Layout

```
Q W E · T   Y I U O -
A S D F G   H J K L M
Z C X V B   N ? ; R P
```

Figure 2.2: The Griffith's Hypothesis

Although this concept of conflicting typebars is plausible, it is not supported by statistical examination. Griffith (1949) defined 'close' typebars as any two having not more than four others intervening on consecutive strokes: statistical analysis of the English language revealed that the QWERTY keyboard actually uses more 'close' typebars (26%) than a randomly arranged keyboard (22%). Griffith put forward the idea that the QWERTY keyboard was merely alphabetical in origin. By clever manipulation of the letters of the alphabet, he was able to arrive at the QWERTY keyboard (see Figure 2.2). Although such a manipulation is feasible, is it a realistic assumption that Sholes, Glidden and Densmore would have worked through such an elaborate procedure in order to achieve their keyboard arrangement?

A third explanation is connected with the fact that Sholes and Glidden were compositors in the printing industry. It has been suggested that the QWERTY layout was similar to the printer's lower case font arrangement of letters (Phillips, 1968).

There appears therefore to be no obvious reason for the placement of letters in the QWERTY layout, and doubts concerning its origin still remain. However, it would appear to be a realistic assumption that the QWERTY keyboard is alphabetical in origin, since F,G,H,J,K,L and M appeared on the home (middle) row. U.S. Patent No. 79,868 (Sholes, Glidden and Soulé, 1868) shows the typewriter keyboard arranged alphabetically over two rows, and it is hypothesised that Densmore in order to avoid the mechanical problems experienced with the typebars, rearranged some keys to arrive at the QWERTY layout.

1.2 The Disadvantages of the QWERTY Layout

It was not until the early 1930's that the efficiency of the standard keyboard was seriously questioned. Dvorak and a team of industrial engineers tested 250 variations of keyboards and concluded that the QWERTY design was one of the worst possible arrangements for touch typing (Dvorak, 1943).

Dvorak went even further than this and argued that it was possible to achieve better arrangements than QWERTY by drawing the characters from a hat. He stated that the defects in the QWERTY layout created difficulty and delay in mastering the skill of typewriting, and also resulted in lowered typing rates, more errors, and increased mental tension and fatigue.

Dvorak's main criticisms of the QWERTY layout were:

(a) It overloads the left hand - 57% of typing is carried out by the non-preferred hand for the majority of the population.

(b) It overloads certain fingers. For example, the little fingers are overworked in that on a manual machine they have to strike the shift-keys, shift-lock and the back-space - the heaviest key of all.

(c) Too little typing is carried out on the home (middle) row of keys (32%), for example, only about 100 words can be typed exclusively on the home row. Consequently too much typing (52%) is carried out on the back row, and too little (16%) on the front row.

(d) Excessive row-hopping is required in frequently used sequences, often from the front to the back row, and back to the front again. For example, in such high frequency same finger letter sequences as 'br, ec, ce, ry, ny, my, um, un, mu, nu, mi, ni, im, in, om, on, mo, no'.

(e) Many common words are typed by the left hand alone. Davis (Ward, 1936) discovered that 300 words from a sample of 3,000 words from Fink and Wagnall's Collegiate Dictionary were typed with the right hand alone, while 2,700 words were typed with the left hand. Examples included 'was, were, extra, address'.

Griffith (1949) supported Dvorak's view that a well designed keyboard should minimise consecutive strokes on different keys typed by the same finger (that is, (d) above). Typing on a QWERTY keyboard results in about 7% of all motions being consecutive strokes on different keys using the same finger, whereas on a well-designed keyboard, these can be reduced to

It can thus be seen that the QWERTY layout confers anomalies of work load across the hands, fingers and rows when typing English text. Ferguson and Duncan (1974) further demonstrated this point by calculating the distribution of finger strokes on individual typewriter keys using a large sample of the English language (see Figure 2.3). It can be shown that the load is distributed haphazardly and inappropriately, with the main exceptions of Z and X. It would be a natural assumption for the load to decrease from the index to the little finger in accordance with the decreasing order of strength of these fingers.

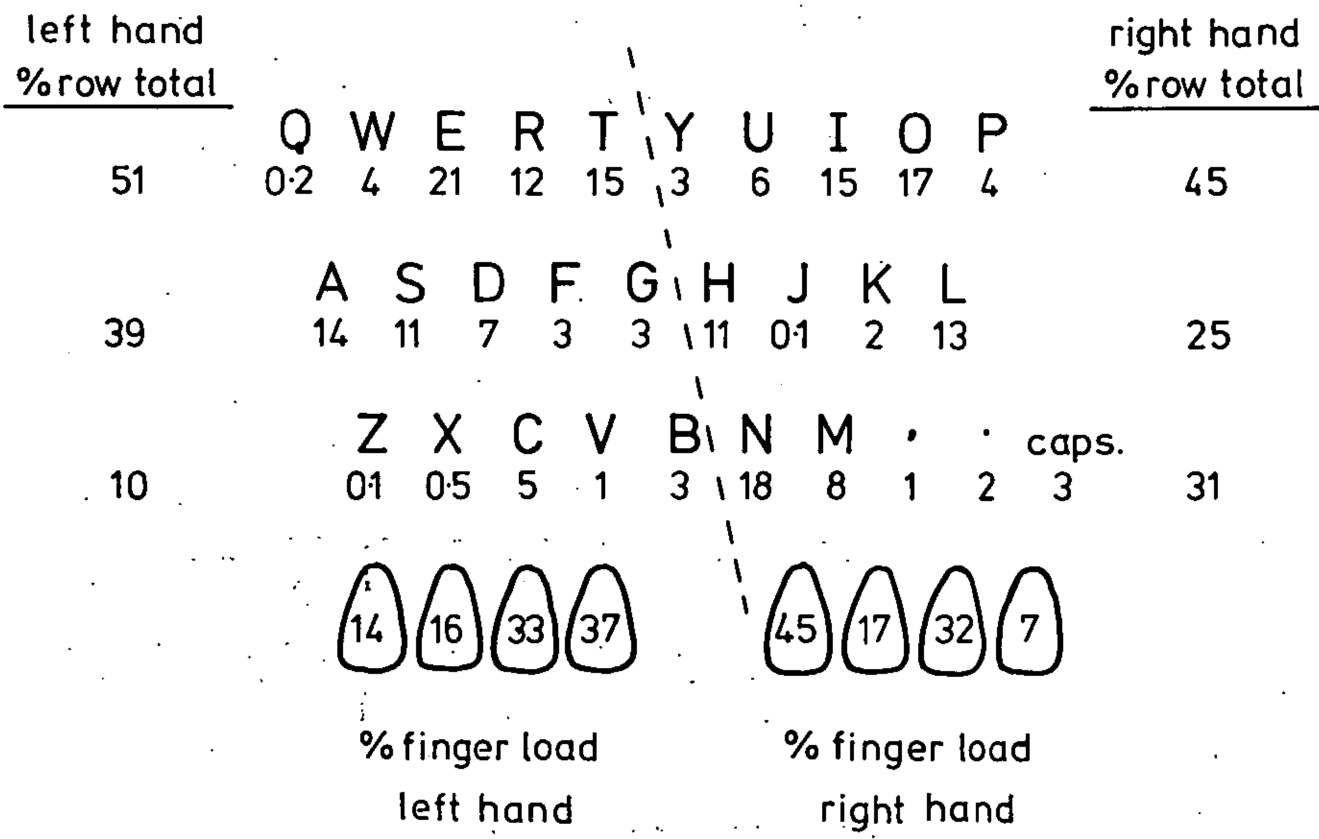


Figure 2.3: Distribution of Finger Strokes on Individual Typewriter Keys

It is worth noting that on the home row of the QWERTY layout, only A, S, H and L rank among the ten most common letters; moreover the unimportant letters J and K are under the most agile fingers of the right hand.

When typing, two-handed motions are easier and faster than only using one hand - analogous to beating a drum with two drum-sticks, as opposed to one. Hünting, Läubli and Grandjean (1980) have shown that digrams requiring the use of two hands are faster to execute than those made with different fingers on one hand. Griffith (1949) stated the following disadvantages of the QWERTY layout:

(a) Forty-eight per cent of all motions to reposition the fingers laterally between consecutive strokes are one-handed rather than easier two-handed motions. On a well-designed keyboard, such one-handed motions can be reduced to 33%, making 67% two-handed.
(b) The QWERTY layout requires reaches from the home row for 68% of all typing: on a well-designed keyboard these reaches can be reduced to 29%, thus enabling 71% of all strokes to be on the home row.
(c) It has been established that the easiest movements for the typist to make are two-handed motions without reaches from the home row, for example, dkdkdkdk. On the QWERTY keyboard, such motions are 4% and the word 'half' appears to be the only common word that can be written with them. Griffith suggested that on a well-designed keyboard, two-handed motions without reaches could be increased to 34%, and whole sentences written with them.

One of the characteristics of the QWERTY keyboard is that the vertical lines of keys slope diagonally from left to right. On the early typewriters, it would have been necessary to space the keys accordingly in order to conform to the mechanical constraints of the typebars. Martin (1972) put forward the idea that this resulted in the letter most likely to be typed next being obscured by the typist's hand. Hence, speed of operation was reduced, and the risk of the typebars jamming was lessened.

The original typewriter would have been intended to be used for 'sight' typing, that is, when the typist looks at the keyboard, rather than 'blind' typing, where each finger of each hand has a number of keys assigned to it. The fingers rest on the row of 'home keys' and each finger moves from this position to strike a key and then returns. Each finger has a defined and limited number of tracks, so the typist can type without looking at the keyboard. It is standard practice for typing schools to teach 'blind typing' (for example, Sight and Sound Education Ltd.) since it enables faster typing and less movement of the head. However it is thought that most typists abandon 'blind typing' once their training is over, and adopt 'sight typing', since the shape and arrangement of the QWERTY keyboard are unsuitable for 'blind typing'.

Biegel in 1934 pointed out the following criticisms of the QWERTY keyboard:-

(a) The ring (third) finger and little fingers have to be stretched when moving from the home row of keys to the third and fourth rows. This reduced the strength of the stroke, and leads to the edge of the fingertip rather than the centre being used to hit the keys.

(b) The division of the keys into 'strips' for the different fingers is made by oblique lines which are parallel, so that the strips for the fingers of the right hand are the same shape as those for the fingers of the left hand, regardless of the fact that the hands are not congruent, but inverse images of each other.

(c) Tracks from the home keys are difficult to follow so that often the wrong key is struck.

With the advent of the electronic era, the design of the QWERTY keyboard could have been changed with the minimum of fuss to remedy the points mentioned above. However, the QWERTY keyboard remains the de facto standard for communications and computer interface keyboards (Alden, Daniels, and Kanarick, 1972) despite suggestions that the arrangement and design are less than efficient (Phillips and Kincaid, 1971).

1.3 In Defence of QWERTY

Kinkead (1975) found that the standard QWERTY layout is operated during touch typing at near maximum speeds. He made an analysis of keying times and concluded that an imaginary 'optimal' layout using a higher percentage of fast keystrokes would be only 8% faster. However research of this nature on a device such as the ubiquitous QWERTY keyboard is fruitless, since it merely supports the fact that given time and motivation, an individual can become skilled on any inefficiently designed device, within reason.

It has already been established that the QWERTY layout confers anomalies of load on the fingers, hands and rows of keys. Kinkead timed and analysed 115,000 keystrokes from 22 typists in order to determine the real differences in keying time between hands, rows, columns and individual keys. If some fingers, rows or types of keystrokes were constantly faster than others, then an optimal keyboard layout could be determined which matched these faster keystrokes to the occurrence of letter groupings in the English language. The data generated was used to predict keying times for the 135 most frequent digrams in the English language. These 135 account for 83% of all digrams; the other 17% occurring so rarely that their analysis is non-productive and tedious. Results showed that more than 95% of all keystrokes on the QWERTY layout are made within 0·333 seconds, and that the keying times for the QWERTY and Dvorak layouts were the same, that is, 125 milliseconds/keystroke for the 83% of keystrokes analysed. Research into digram keying times for typists (Fox and Stansfield, 1964) has shown that the highest rates are achieved and maintained over short bursts, and when successive taps are produced by fingers on alternate hands.

Kinkead concluded therefore that the ideal keyboard would ensure that almost all keystrokes alternated from one hand to the other, the slowest keystrokes being those made by the same finger. The QWERTY keyboard does this, whether by accident or design, very well, and hence in Kinkead's opinion the standard keyboard is nearly optimal in layout for speed.

Kinkead (1975) is supported by Thomas (1972). Thomas suggested that the QWERTY layout to some extent helped to speed up the typing operation. He came to this conclusion because some of the most frequent digrams (Baddeley, Conrad, Hull, Longman, Rabbitt, Skoulding and Stewart, 1958-1962) are keyed by alternate hands. Thus common letter sequences involve either alternate hands being used, the whole hand being moved over the keyboard or non-adjacent fingers being moved sequentially. This results in more overall kinaesthetic feedback from the control movements than from the sequential movement of adjacent fingers. When learning to type, feedback (visual, tactile, kinaesthetic) is an important factor, although this is not true for the skilled keyboard operator (Alden et al., 1972). One explanation for QWERTY's success may be the extra feedback that is gained from stretching, reaching, and alternating hands when learning to type. Support is given to this explanation by the fact that 'hunt and peck' typing, which relies heavily on visual scanning of the keyboard, does not reach the speeds gained by touchtyping. Touch typing courses such as 'Sight and Sound' can train novices to speeds of 20 words per minute in 12 hours, whereas 'hunt and peck' typists rarely meet such speeds even after much lengthier self-training sessions.

It is therefore apparent that controversy still revolves around the QWERTY keyboard, and it is disputable whether this original typewriter layout, which has monopolised the keyboard market, should have been adopted as the International Standard. However, although many analytical and experimental investigations have been carried out on QWERTY and other keyboards (see the literature review in Chapter 3), there appear to have been relatively few studies of the attitudes of users. It was therefore decided to approach a sample of everyday users of QWERTY in order to discover their opinions of the merits and shortcomings of the keyboard.

2. METHODOLOGY

2.1 The Questionnaire

It was decided that a questionnaire survey was the most appropriate way to discover the views of a large population of QWERTY keyboard users. A questionnaire of 30 questions, divided into four sections (see Appendix A2.1) was formulated as follows.

Section A: Training of Keyboard Operators

Questions 1 and 2 (description of job and age of subject, respectively) were asked in order to supply background information, so that the user population could be classified.

Questions 3, 4, 5 and 6 were specifically interested in the training that the typists had undergone. One of the reasons for exploring this area was that the author was developing a keyboard training programme.

Question 3 (How did you learn to type?) was particularly interested in whether individuals were motivated enough to teach themselves keying skills. It also provided background information to the user population.

Question 4 (How long did this training last?) gave the author an insight into the length of time required to learn to type. This question was followed by Question 5 (At what speed were you typing at the end of this training?), and it was anticipated that statistical analyses would reveal the degree of association between length of training and typing speed: the optimal training period could then be calculated.

Question 6 (Time taken after training to become competent using a keyboard) was designed to reveal whether there was a correlation between length of training and time needed to reach proficiency after training. Improvement in keyboard skills has been shown to continue for over 12 months after the end of formal learning (Conrad, 1960; Klemmer and Lockhead, 1962).

Section B: Keyboard Arrangement

Question 7 (Are you satisfied with the arrangement of keys on the typewriter keyboard?) was an open-ended question asked in order to gain some feedback on whether the users of QWERTY were satisfied with the layout. As outlined in the introduction, past research has suggested that the QWERTY layout may not be the most efficient for rapid touch typing.

Unlike Question 7, Question 8 (Are there some finger movements between keys which are more difficult to do than others?) and Question 9 (Are there any keys or sequences of keys with which you seem to make more errors than others?) were more specific. They were asked to clarify some of the points raised in the introduction. For example, Biegel (1934) suggested that the ring and little fingers have to be stretched when moving from the home row of keys to the third and fourth rows. Question 8 attempted to discover if this was true in practice. It also endeavoured to find out if typists feel that they make more mistakes on some keys, or rows of keys than others. If a typist repeatedly mistakes a particular letter, it would suggest that the key is wrongly placed.

Question 10 (If you could move the typewriter keys around, are there any keys that you would change?) probed how satisfied the user was with the QWERTY layout.

Question 11 (Would you prefer it if the thumbs were given more work to do?) was asked with the recently marketed Maltron keyboard in mind. This keyboard utilises the thumbs by giving them up to eight keys each to operate. For example, the most common letter of the English alphabet 'E' is allocated to the right hand thumb. The reason for using this design is that the thumbs have a larger area of the brain controlling their use than the fingers; hence they have greater mobility and flexibility (Malt, 1977). Haaland (1962) verified that the thumb is the most resistant to fatigue, and that susceptibility to fatigue increases progressively from the index to the little finger.

Question 11 was aimed at discovering what the typist felt about increasing the use of the thumbs, since at present, the left hand thumb is totally redundant and the right hand thumb operates the space bar. Question 12 concluded the section on keyboard arrangement. This question asked the users to imagine that they were designing a keyboard from first principles, and was intended to establish where individuals would expect to find the keys in an alphanumeric array.

<u>Section C: Fatigue</u>

Questions 13-21 dealt with the comfort of operating a keyboard. Over the last 100 years, many keyboards have challenged the QWERTY layout; the main emphasis for improving the layout has been placed upon speed, that is, increasing speed of learning the keyboard and speed of operation. This facet of past research is interesting, since there are relatively few keyboards that seriously require the use of high speed keying. As Dunn (1971) pointed out - "the highspeed keying promoted during the so-called 'World Championships' might have had some significance in 1945, but not today."

In recent years, keyboard designers have moved away from the question of speed to reducing tension and fatigue (Kroemer, 1972; Duncan and Ferguson, 1974; Malt, 1977). Duncan and Ferguson suggested that the QWERTY layout influenced 'unnatural' postures of the trunk, head, shoulders, arms and hands. Kroemer had previously pointed out that the tension in the forearm and shoulder muscles necessary to maintain the position of the fingers on the QWERTY keyboard leads to muscular fatigue and strain. Experimental evidence concerning ill health amongst keyboard operators has been provided by Osanai (1968) and Komoike and Horiguchi (1971). Osanai stated that the most frequent complaints had concerned pains in the shoulders, the arms, the hands and the back. He predicted that these pains were caused by repetitive quick motions of the hand and the fingers, as well as static muscular tension to sustain the working posture, and he noticed an increased hardness of the muscles, and tenderness when pressure was applied to them.

Komoike and Horiguchi studied the health hazards of typists during the years between 1961 and 1971. They concluded that skilled keyboard operators suffered from stiff shoulders, myalgia, arthralgia especially in the right upper limb and finger tremor. Ferguson (1971) interviewed 516 male operators of teleprinter, teletype and telex keyboards. He identified 14% of subjects with occupational cramp and 5% with occupational myalgia. Ferguson and Duncan (1974) supported the findings of this Australian study by stating that occupational cramp in the ring and little fingers was found amongst QWERTY keyboard operators. This would appear to result from the relatively great load of typing which falls on these weaker digits.

Questions 13-21 covered various aspects of fatigue. Question 13 was concerned with whether it was a problem for the typist to move her head so frequently; Questions 14, 15, 16, 17 and 18 were interested in whether the typist suffered from neck-ache, back-strain, aching shoulders, tired arms, and aching fingers, respectively. These six questions were adapted from a survey carried out amongst keyboard operators in the newspaper industry (Malde, Heller and Stewart, 1978). Question 19 asked the typist to remember if she suffered from parts of her body aching, when she first began learning to type. This question was related to the keyboard training programme, in order to discover what one might expect from beginner typists and to try and alleviate any problems. Question 20 was an open-ended question included to ensure that all aspects of this topic had been covered. Question 21 concluded this section: it asked the users to recommend any improvements that would make operation of a typewriter more comfortable.

The aims of this section were threefold: it was intended to find out how severe the problems of discomfort were, to locate areas in which improvements were warranted, and to make some suggestions to this effect.

Section D: Miscellaneous

The final section of the questionnaire was an assortment of questions. Question 22 (Do you enjoy typing?) and question 23 (Do you prefer typing to handwriting?) plus questions 24 and 25, covered the likes and dislikes of typing and the typewriter: they were important questions since they attempted to find out how the user felt about typing. The keyboard as a data entry device has many theoretical advantages over such methods as voice recognition and character recognition systems. It was therefore a worthwhile exercise to discover the popularity of the keyboard amongst the everyday users. There was also a trend in the 1970's towards personal computing and the continuing need for handwriting may be questioned. Hence questions 22 and 23.

Question 26 was a remnant from Section B on keyboard layout and user satisfaction. The question, "Do you think that the typewriter is equally suited to both left and right-handed people?" was asked because research (Dvorak, 1943) has shown that it overloads the left-hand. This question aimed to find out if the user population was aware of this. Retrospectively, it might have been advantageous to ask individuals if they were left or right-handed. This finding could then have been correlated with the data from question 26.

The next question, "Do you know of any other devices like the typewriter which produce typewritten words?" was asked purely for the author's peace of mind. It helped ensure that she was familiar with all the major alternatives to typewriters.

Question 28 was asked with the Maltron keyboard in mind - the most recently developed QWERTY keyboard, which weighs only 1·5 lbs. The question read, "Do you think that a smaller, lighter, more compact version of the typewriter would be useful?"

Question 29 was seeking the subjects' views towards a hand-sized, chord-keying device by asking the question, "Do you think that you would like to use a hand-sized, typing device with only five keys - typing would be carried out by pressing combinations of these keys?" It also indicated the trend towards smaller keying devices (for example, the Canon Communicator, which is worn on the wrist) and personal computers.

The final question, number 30, invited comments and criticisms from the users with regard to the questionnaire and typewriting in general.

2.2 Selection of Subjects

University secretaries constituted the group of skilled keyboard operators who were approached for the questionnaire survey. Questionnaires with an accompanying introductory letter were sent to 140 female secretaries working at Loughborough University of Technology. Subjects were asked to complete the questionnaires and return them via the internal mailing system. Two reminder letters were posted to those subjects who had not returned their questionnaires: a total of 112 questionnaires (80%) were returned. Figure 2.4 shows the range of subjects' ages.

2.3 Pilot Study I

After the initial compilation of the questionnaire, it was circulated amongst researchers and lecturers who were skilled in questionnaire design. The original draft consisted of 51 questions (see Appendix A2.2). This was piloted using secretaries in the Department of Human Sciences as subjects.

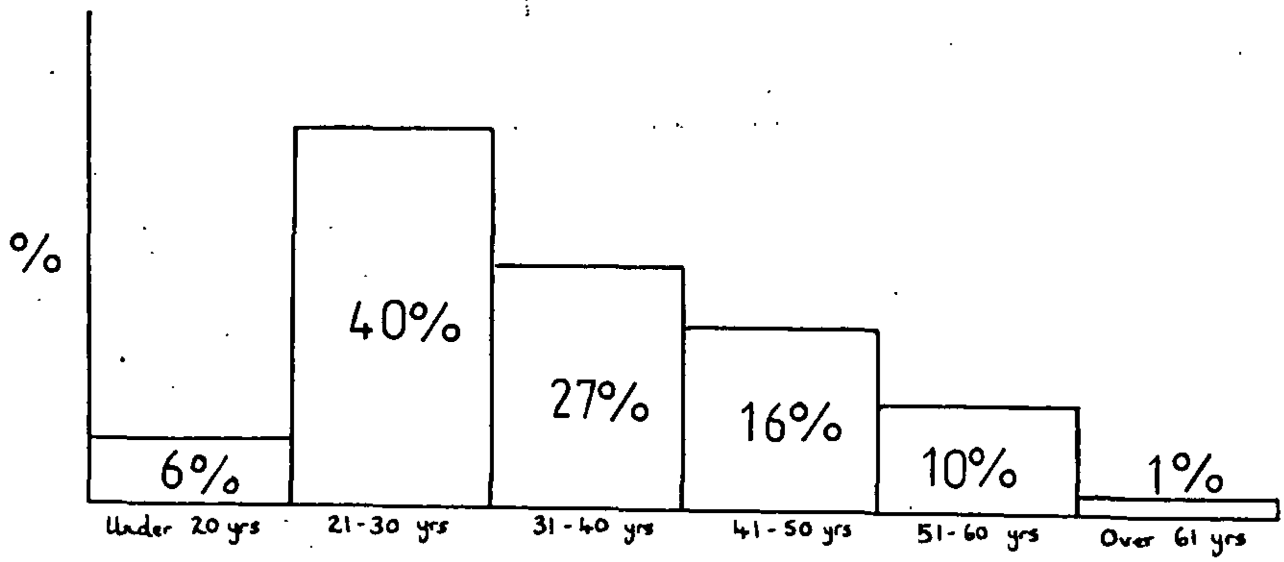


Figure 2.4: Frequency Distribution of Subjects' Ages

This study indicated the questionnaire was too long and that the prospect of completing 51 questions might deter some individuals. The number of questions examining the subjects' satisfaction with the keyboard was reduced and the questions concerned with keyboard parameters (that is, spacing, feel, travel of the keys) were eliminated. The wording of several questions was altered to avoid possible ambiguity.

2.4 Pilot Study II

The questionnaire, after the changes had been implemented following Pilot Study I, was posted to 20 University secretaries. Data collected from these subjects enabled a practice run on the computer to be carried out. No changes were made to the format of the questionnaire, and it was then posted to the remaining 110 subjects. This constituted the main study. Over a period of three months, reminders were sent out and when it seemed likely that no more replies would be received, the data analysis was initiated.

2.5 Analysis of Data

The results from the questionnaire were analysed both quantitatively and qualitatively. All answers (excluding unquantifiable data) were classified and coded onto punch-cards; one card was allocated to each subject. The Statistical Package for the Social Sciences (SPSS) 'Crosstabs' program at Nottingham (Nie, Bent, and Hull, 1970) was used to obtain frequency distributions, contingency coefficients and chi-squared tables. A computer package program, called 'Nonpar Corr', was used to calculate Spearman's rank correlation coefficients on appropriate ordinal data (Siegel, 1956). Content analysis of the answers was also carried out.

3. RESULTS

The results are presented by a series of histograms, and correlation matrices. These data are discussed and related to other findings in the next section.

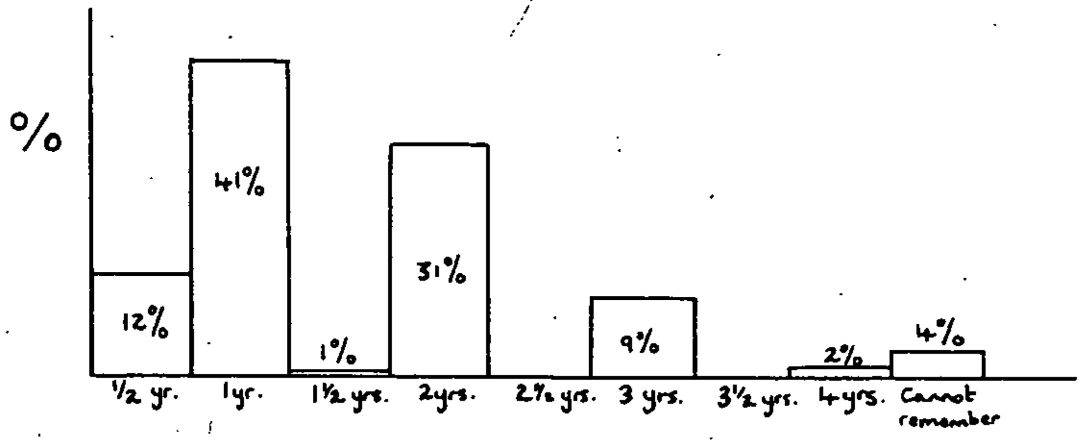


Figure 2.5: Frequency Distribution of Lengths of Training

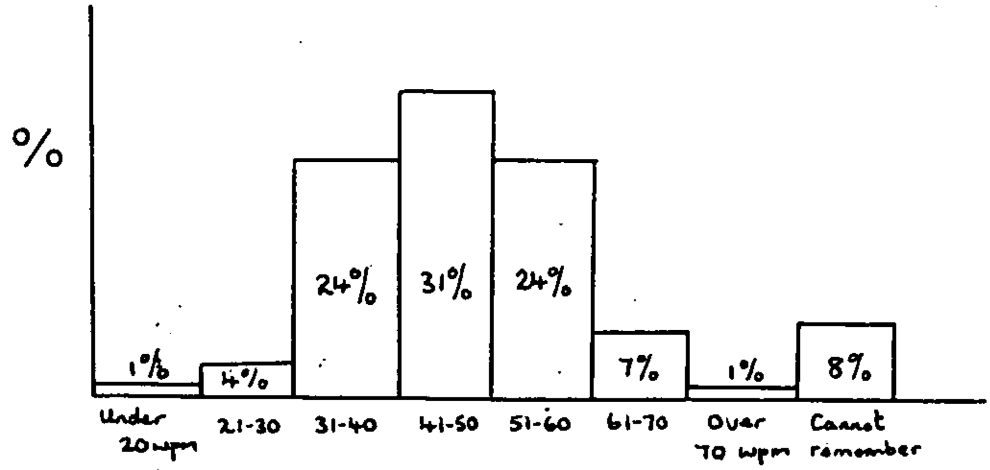


Figure 2.6: Frequency Distribution of Speeds Obtained at End of Training

Figure 2.7: Frequency Distribution of Time Taken to Reach Proficiency

Spearman's Rank Correlation Matrix

	Speed of Typing	Time Taken to Reach Proficiency
Length of Training	$p \leq 0.003$	Not sig. ($p \leq 0.227$)
Time Taken to Reach Proficiency	Not sig. ($p \leq 0.423$)	x

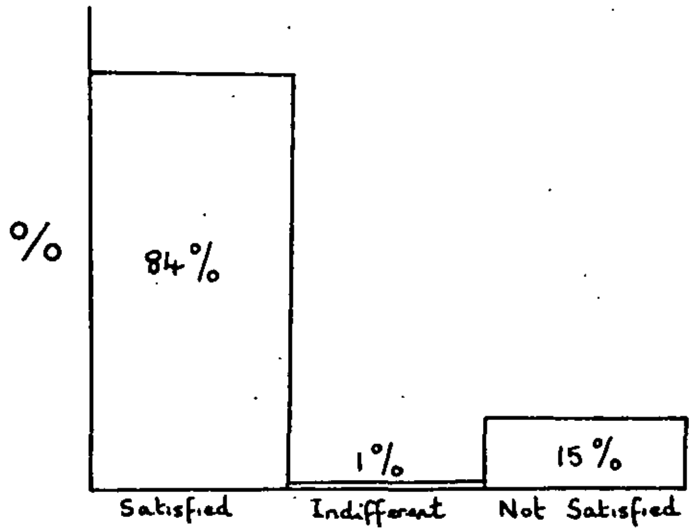


Figure 2.8: Frequency Distribution of Subjects' Satisfaction with Keyboard Layout

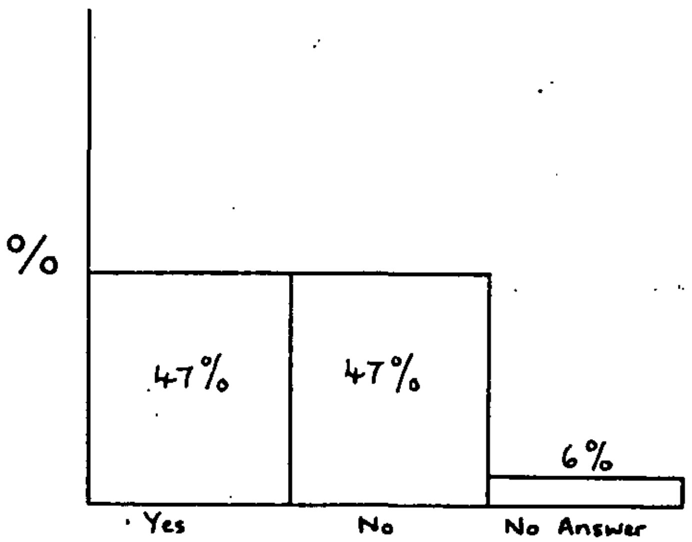


Figure 2.9: Frequency Distribution of Subjects Experiencing Difficulty in Certain Finger Movements

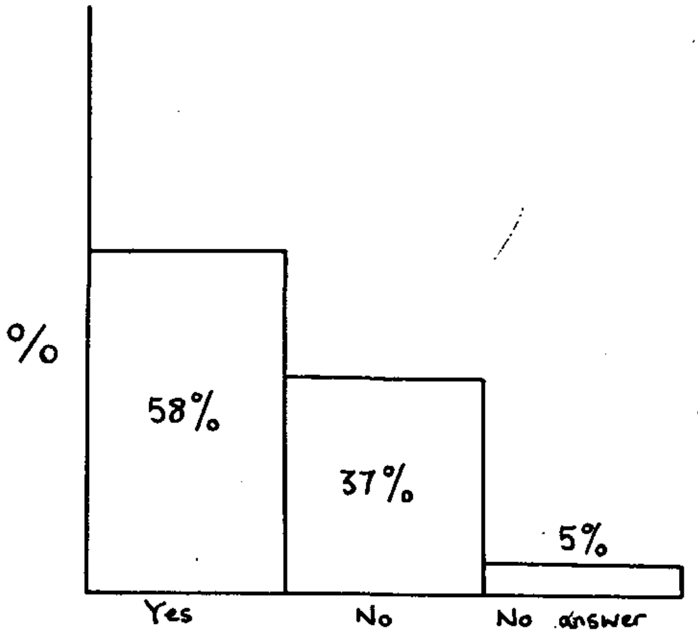


Figure 2.10: Frequency Distribution of Subjects Making More Errors on Some Keys than Others

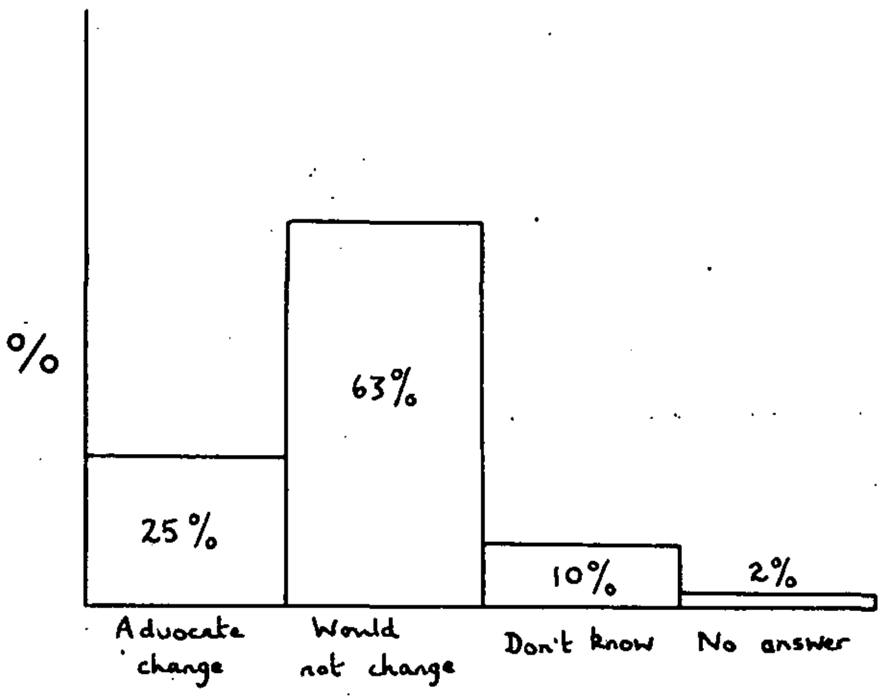


Figure 2.11: Frequency Distribution of Subjects' Preferences with Regard to Change in the Position of the Typewriter Keys

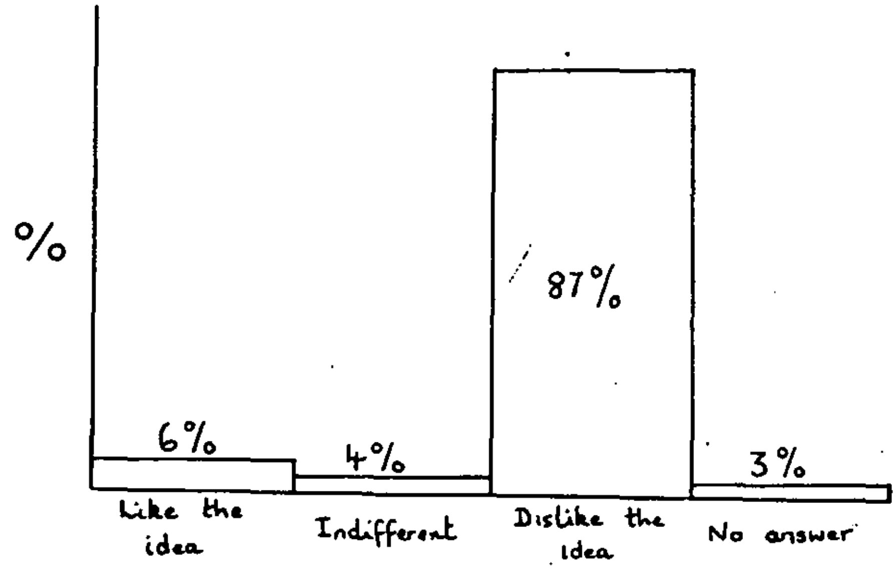


Figure 2.12: Frequency Distribution of Subjects' Preferences with Regard to Increasing the Workload of the Thumbs

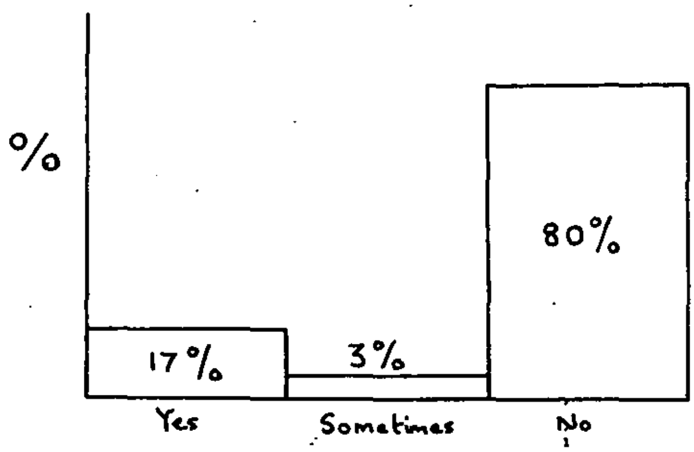


Figure 2.13: Frequency Distribution of Subjects' Experience of Moving Head when Working

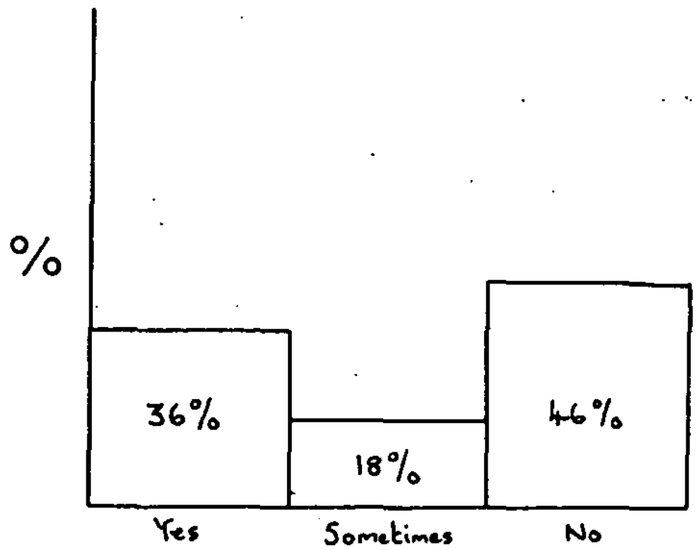


Figure 2.14: Frequency Distribution of Subjects Experiencing Neck-ache

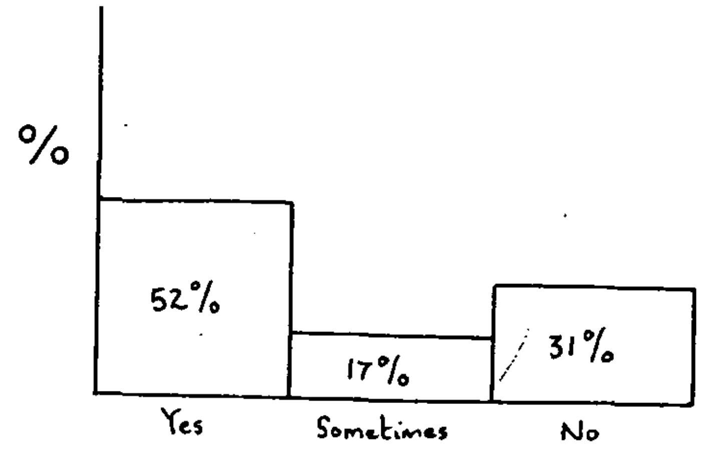


Figure 2.15: Frequency Distribution of Subjects Experiencing Back-strain

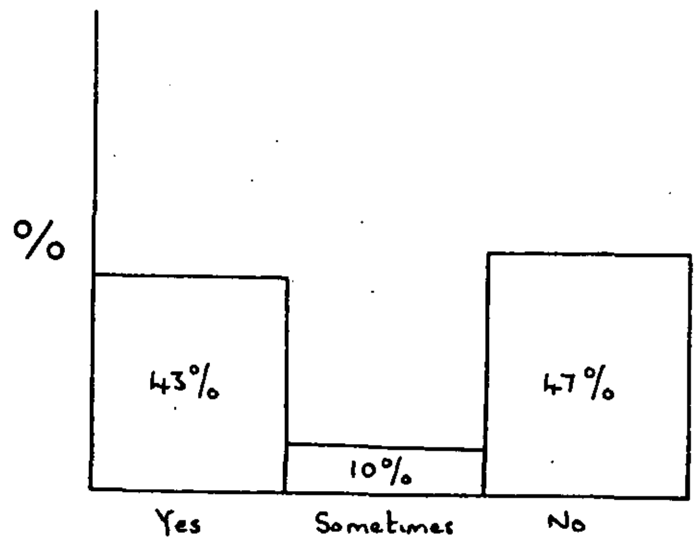


Figure 2.16: Frequency Distribution of Subjects Experiencing Aching Shoulders

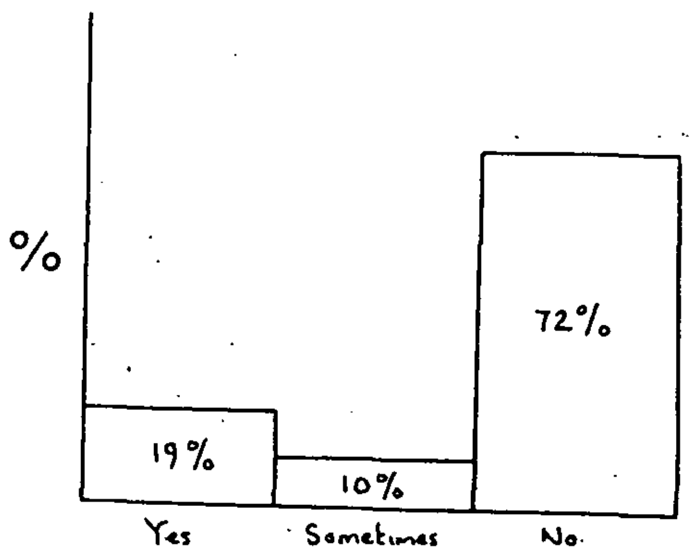


Figure 2.17: Frequency Distribution of Subjects Experiencing Tired Arms

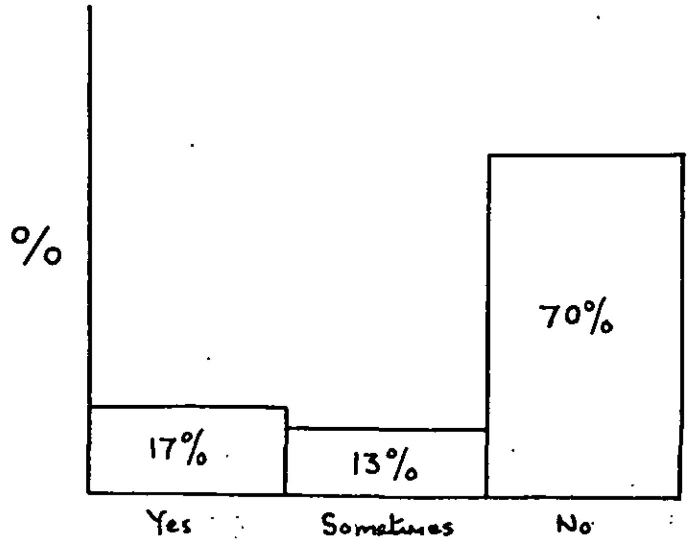


Figure 2.18: Frequency Distribution of Subjects Experiencing Tired and Aching Fingers

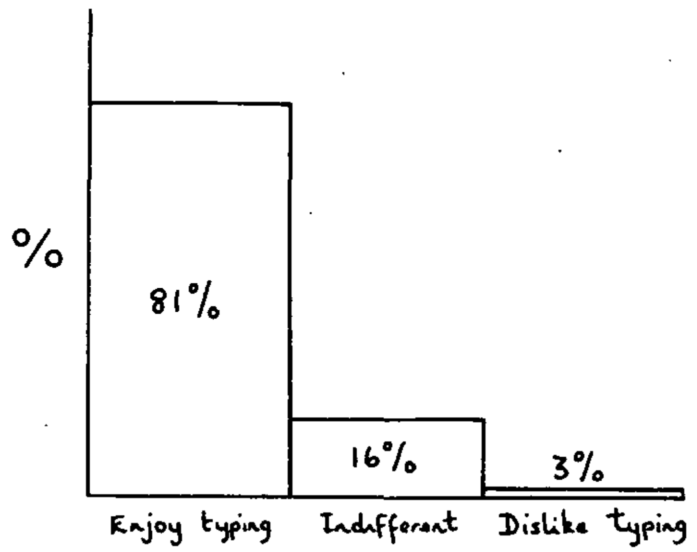


Figure 2.19: Frequency Distribution of Subjects' Enjoyment of Typing

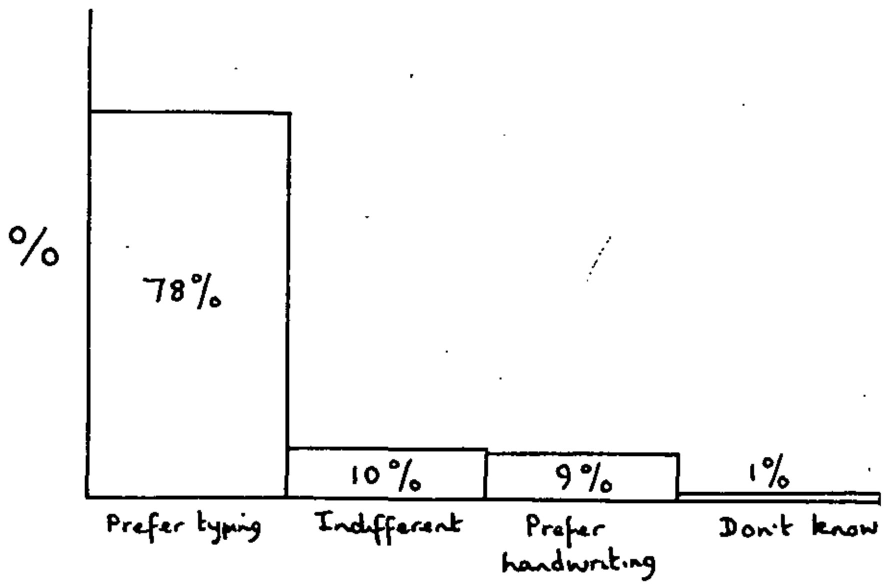


Figure 2.20: Frequency Distribution of Subjects' Preferences with Regard to Typing and Handwriting

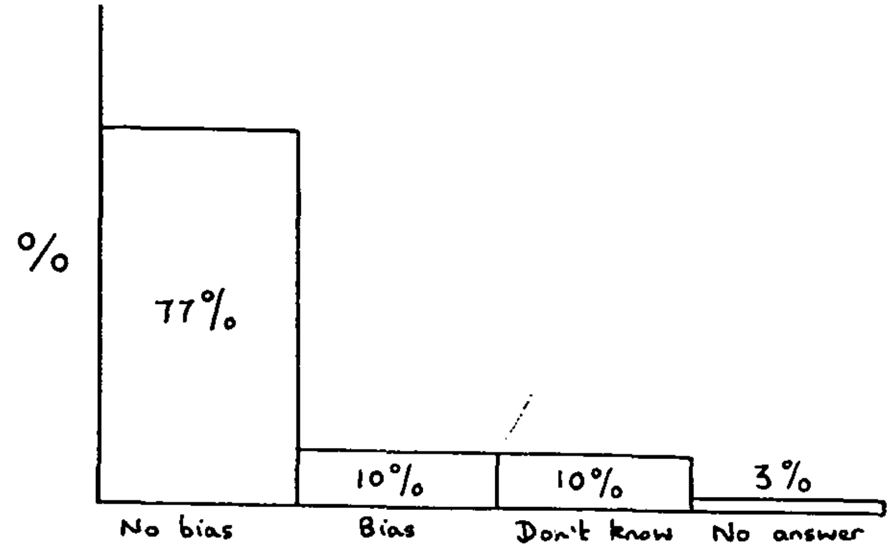


Figure 2.21: Frequency Distribution of Subjects' Preferences with Regard to Suitability of Typewriter to Both Left and Right Handed Individuals

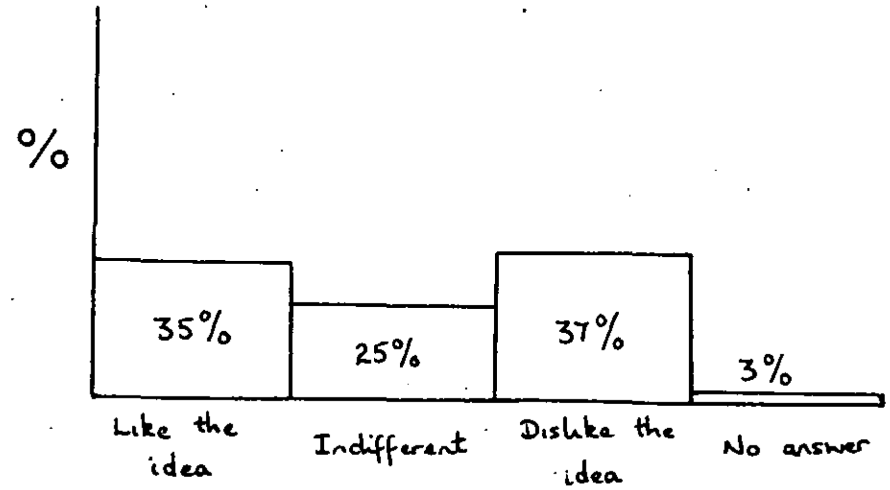


Figure 2.22: Frequency Distribution of Subjects' Reactions to a Smaller, Lighter, More Compact Typewriter

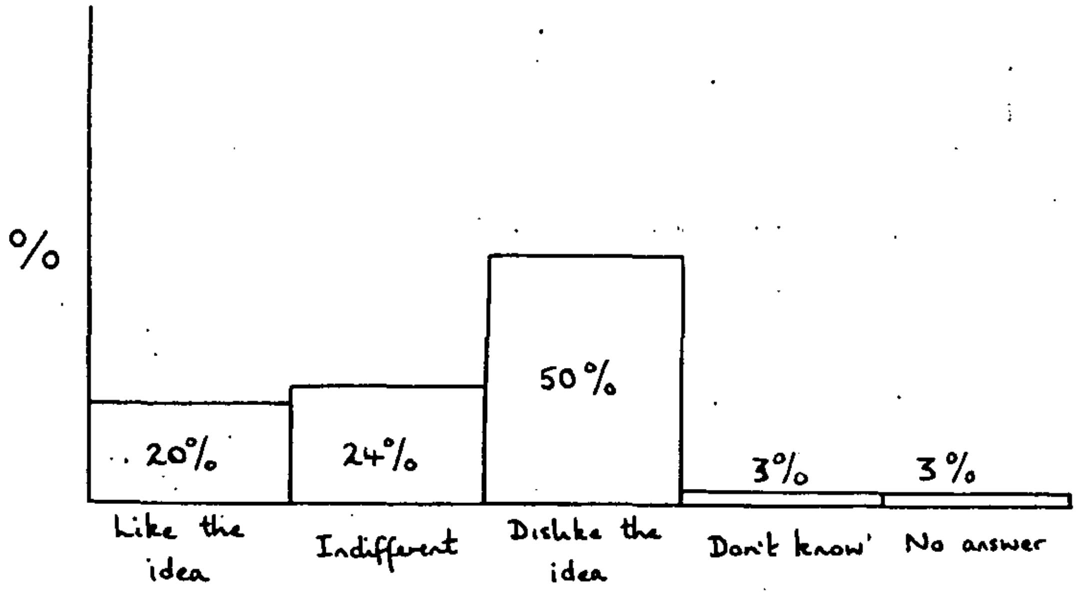


Figure 2.23: Frequency Distribution of Subjects' Reactions to a Hand-sized Chord-keying Device

Contingency Coefficient Matrix I

		Neck-ache	Back-strain	Aching Shoulders	Tired Arms	Aching Fingers
Q.14	Neck-ache	X	X	X	X	X
Q.15	Back-strain	0.39592**	X	X	X	X
Q.16	Aching shoulders	0.49025**	0.45823**	X	X	X
Q.17	Tired arms	0.30141*	0.33188**	0.16159 (n.s.)	X	X
Q.18	Aching fingers	0.09646 (n.s.)	0.14621 (n.s.)	0.19029 (n.s.)	0.11961 (n.s.)	X

* Values significant at 5% level

** Values significant at 1% level

(n.s.) = not significant

Contingency Coefficient Matrix II

		Satisfaction	Enjoy	Prefer	Small	Chor
Q.7	Satisfaction with QWERTY layout	X	X	X	X	X
Q.22	Do you enjoy typing?	0.13095 (n.s.)	X	X	X	X
Q.23	Do you prefer typing to handwriting?	0.03765 (n.s.)	0.01906 (n.s.)	X	X	X
Q.28	Do you like the idea of a smaller, more compact typewriter?	0.16920 (n.s.)	0.14586 (n.s.)	0.09771 (n.s.)	X	X
Q.29	Do you like the idea of a chord keyboard?	0.21997 (n.s.)	0.13505 (n.s.)	0.22681 (n.s.)	0.16901 (n.s.)	X

* Values significant at 5% level

** Values significant at 1% level

(n.s.) = not significant

4. DISCUSSION

4.1 Training of Keyboard Operators

The first section of the questionnaire was concerned with the training of the typists. The majority of the typists (over 95%) had attended technical college or privately run courses. Only three individuals were motivated enough to teach themselves to type and then take up employment using their new skill. The average time spent training was in the region of 18 months (see Figure 2.5) and the typing speeds obtained at the end of the training period ranged from less than 20 words per minute to over 70 words per minute (see Figure 2.6). The average typing output was between 40 and 50 words per minute. A significant correlation ($p \leq 0.003$) was found between length of time spent learning to type, and the eventual speed reached. This supports the logical conclusion that the longer spent learning to type, the faster the keying output in words per minute. The relationship between the length of training and the time taken to reach proficiency was not found to be significant ($p \leq 0.227$).

It has already been established that keying performance continues to improve for over a year (Klemmer and Lockhead, 1962) and from this survey the mode training length has been shown to be 18 months. It is not realistic to expect an experimental keyboard training programme to continue for such a long period of time. Therefore a shorter more intensive training course would result in lower typing speeds.

4.2 Keyboard Arrangement

Eighty-four per cent of typists questioned were satisfied with the keyboard layout. Of the 15% who answered 'no' to this question, there were two main complaints. They requested greater standardisation of the QWERTY layout, namely the positioning of the question mark, the comma, the apostrophes, the underscore and the hyphens. One subject said that often after changing the golf ball, the keys did not correspond to the head being used.

This statement was supported by another comment involving the fact that a golf ball occasionally has no semi-colon. The other criticism of the layout concerned the question mark, which is frequently placed on the shift above the comma. When typing in upper case, the typist has to release the shift lock, in order to type a comma. This arrangement creates unnecessary work for the typist, due to the frequency of the comma in English prose. Some subjects disliked the use of the capital 'L' for the number one, and the capital 'O' for a nought, and suggested that these symbols had their own keys.

Question 8 was concerned with which finger movements between keys created problems for the typist. Forty-seven per cent of typists experienced difficulties with some finger movements between keys. Content analysis of the answers to this question revealed that the keys typed by the little fingers, especially those of the left hand (Q, A, Z and shift-lock) were awkward to reach. One typist stated that it was difficult to apply pressure with the little fingers, because of the angle that they were hitting the keyboard, and another complained that the little finger movement from 'A to Z' was awkward to carry out. The keys that are operated by the little finger of the left hand also came under criticism, in particular 'P, O, I and U'. One subject stated that she disliked typing sequences such as QUA and PLOY; because the little fingers had to hit adjacent keys repeatedly. Other subjects elaborated upon this point by saying that they disliked typing words, which only warranted the use of one hand. Examples given included, OPINION, RESERVED, DESECRATE, SEWERS, EXCAVATE. Finger movements involving the little finger create so many problems for one typist that she wrote

"Little fingers - I never use them for typing."

Several typists found it a problem reaching the top row of numbers and due to low frequency of use, touchtyping on the top row was difficult to execute. Likewise, reaches to the bottom row, especially the keys, Z, X and B were not easy. Suggestions to overcome the former problems included placing a separate keyboard (for numbers and fractions) adjacent to the main keyboard.

Question 9 continued the theme of the previous two questions and was concerned with keys, or sequences of keys which frequently resulted in errors being made. Again the keys operated by the little fingers and the numbers came under attack, and to a lesser extent the bottom row. Fifty-eight per cent of subjects indicated that they repeatedly made errors on some keys. The keys C and V on the bottom row were cited on 10 occasions as frequently causing errors. One typist said that often common sequences take over, and the word AN becomes AND, and IN becomes ING. A similar problem occurs with letters that commonly end words, for example, tolerate<u>d</u> becomes tolerate<u>s</u>. Straight forward transposition errors often occur because the typist is keying too fast, for example 'FROM and FOR' would become 'FORM and FRO', and are probably not specifically related to any letter or key position.

Further analysis of the answers to this question revealed that every letter had been cited as creating errors. Each typist probably has her own quirks and subsequent errors.

Two other points of interest did arise from this question; one typist found that the characters J, K, L and '-' had unintentionally intruded into her work, because she was resting her hands lightly on the home row which she returned to after each key pressing. A second typist found that upon returning her hands to the home row, her right hand would rest over the keys K, L, -, ", instead of the home keys J, K, L, -. This would suggest that even for a skilled typist who has mastered the keyboard layout, some tactile feedback of the positioning of one's fingers could be important. As would be expected, there was a significant correlation between difficult finger movements and errors made ($p \leq 0.002$).

Question 10 also probed how satisfied the subjects were with the QWERTY arrangement of keys. Twenty-five per cent said that they would change the position of some of the keys on the keyboard. Again the letter A came under criticism: suggestions included changing its position with the key J or S. Stutsman (1959) investigated the effects of reversing only the A and J keys with a sample of four typists, but details of the experimental results are not available. The advantage of this approach is that it does not involve readjusting to a completely alien keyboard layout. It would also aid the beginner typist who is struggling to depress the A key with a rarely used little finger on a manual machine. Two subjects suggested changing the position of the keys 'B and C' for 'M and N', and these letters, like the letter V were found to be unsatisfactorily placed. Reallocation of these letters would however create a massive upheaval in the QWERTY layout.

On the IBM golf ball, the positioning of the erasing key next to the shift-lock was thought to be a bad design. The presence of the fractions, $\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$ and $\frac{7}{8}$ was thought unnecessary and it was suggested that these keys should be replaced by the fractions 1/3 and 2/3 and square brackets. Evans and Martin (1970) pointed out the need for half-size numbers for use as indices in place of the redundant fractions. Likewise the dollar sign found on an IBM standard typewriter was deemed a superfluous extravagance. One subject when asked which keys she would move around replied "most of them!" Another interesting observation was that it was not the positioning of the letters which created the problems, but the diagonal configuration of the keys; hence a change in keyboard design might prove profitable. An example of such a change can be demonstrated by the Maltron keyboard.

The next question was specifically asked with the recently developed Maltron keyboard in mind. The majority of the user population (86%) were against the introduction of keys for the thumbs; one subject admitted that she never used her right thumb to operate the space bar, instead she operated it with her index finger of her right hand. The majority of subjects (77%) thought that the typewriter was equally suited to both left and right handed individuals, but several typists noted that the QWERTY layout overloaded the left hand, and hence the left-handed might be at an advantage.

Question 12 invited the subjects to design their own alphanumeric keyboards. Two popular suggestions involved arranging the letters according to Dvorak's Simplified Keyboard and an alphabetical layout. Other ideas included laying out the letters according to frequency of use, for example, placing the vowels in the middle of the keyboard and the other letters around them with the least used letters such as X and Z on the periphery. A similar suggestion was to place the numbers on the top row, the letters on the middle two rows (arranged according to frequency) and the punctuation symbols on the bottom row.

Suggestions were put forward for various modifications to the positioning of the numbers on the QWERTY keyboard. One subject suggested that they should be paired with the letters, for example, A-1, B-2, C-3, but offered no explanation for what would occur to the upper case capitals. A similar proposition was to pair the numerics and place on the same keys, so that 50% of the numbers would be typed using the shift lock. Again the suggestion for a smaller separate numeric keyboard was made, and one subject proposed that the keys should be laid out in an arc and the keyboard separated into two halves to make operation more comfortable.

Forty-eight per cent of those questioned said that if they had to design a keyboard layout, they would keep to the standard QWERTY arrangement of keys. There could be several reasons for this. Skilled typists are conditioned to accept the QWERTY layout, as one subject said - "once you have learnt to type, it is immaterial where the keys are as typing becomes automatic". Again the idea that given time and motivation any keyboard layout can be learnt and operated at high speeds is resurrected. This suggests that a questionnaire survey of beginner typists might be a more valid exercise to find if naive users are satisfied with the QWERTY keyboard.

A second reason originates from the fact that skilled typists are reluctant to change to a different letter layout because of the amount of re-training necessary. As one subject succinctly put it, "it is more difficult to learn the layout, than to operate it once learnt". Although it has been suggested (S.W. Hobday - Personal Communication) that learning different keyboard layouts is analogous to learning to play various musical instruments, there is no reason, at present anyway, why a typist should motivate herself to learn a new alphanumeric array.

4.3 Aspects of Fatigue

Section C of the questionnaire examined the extent to which subjects suffered from fatigue during typing. The first question of this section enquired whether it was a problem for the typist to move her head when typing. It was assumed that a typist did move her head during operation of the typewriter: there is in fact some dispute amongst the user population as to whether this does occur.

It was discovered from the next three questions that over 50% of the typing population did suffer from aching necks, backs and shoulders. Arms and fingers were not seriously affected by fatigue, as shown by the results from Questions 17 and 18. Cross-tabulation of these results, as would be expected, reached significant levels. For example, there was a very high correlation between neck and back ache ($p \leq 0.0005$), neck and shoulders ache ($p \leq 0.0000$), and shoulders and back ache ($p \leq 0.0000$). These findings are supported by two Swedish studies. In 1976, Skandia insurance company carried out a survey among computer operators in order to determine the discomfort they experienced (Datasaab, 1976). The percentage distribution of discomfort was as follows: eyes (54.8%), head (30.3%), neck (15.2%), back (43.7%), shoulder (25.1%) and wrist (18.8%). A similar survey was conducted by the Swedish National Board of Occupational Safety and Health in July 1979. They studied operator discomfort in computer terminal operation and reached the following percentage distribution: eyes (75%), back/shoulders (55%), head/neck (35%), arms/wrists (25%) and legs (15%).

However neither of these studies supply full experimental details or references, so the results should be treated accordingly.

Grandjean and Vigliani (1980) carried out an investigation into the incidence of 'almost daily' pains experienced by a sample of 78 typists. They found that 5% of these individuals suffered from "more or less permanent aches" of the neck, shoulder and right hand, and 4% from pains in the right arm. However, direct comparison with the results from the study described in this Chapter is not possible, because of the difference in the questions asked to collect the data.

Quantitative results from the next question can only be considered tentatively as more than 15% of the user population could not remember if parts of their body ached when first learning to type, thus reducing the validity of the results (Oppenheim, 1966). Some subjects, who did remember, declared that "everything" ached when they first began to learn to type. The most common complaints included the back, shoulders, and the little finger of the left hand and the right thumb, through the repeated action of hitting the space bar. Stiff wrists were another symptom. It seems likely therefore to expect beginner typists to suffer from a multitude of 'aches and pains' as part of the package of learning a new skill.

Forty-three per cent of typists stated that they suffered from some other form of fatigue. Thirty of these 48 subjects were troubled by eyestrain and related headaches. Some of these suggestions might have stemmed from the recent controversy concerning eye problems and visual display terminal (VDT) operation. Various factors were attributed to this eye fatigue; these included the glare from the white walls of the office and the white paper, and on the IBM standard typewriter the continual straining to see what has been typed, because the golfball obscures the letters just produced. This latter situation is aggravated by the fact that there are no paper props at the back of typewriters.

Other factors included bad handwriting, small print, artificial light, pencil written work, the immense concentration needed to type figures and equations and excessive amounts of copy-typing. Other typists suffered from general tiredness, for example, boredom from sitting and typing all day, and mental fatigue resulting from an office environment with noisy ventilation fans in the roof and the continual ringing of telephones.

Many improvements were suggested to make operation of the typewriter more comfortable. The repeated request was for more comfortable, better designed, adjustable chairs with greater back support and arm rests. One typist stated that "the machines are O.K. - it's the awful chairs". There were also requests for adjustable desks, because the ability to alter the height of the chair was wasted if the end-result was knees pressed under the desk. One subject thought that chair and desk design was more important than keyboard and typewriter design. Other suggestions included desks with wells, because all typewriters gradually slide across the desk, and a foot stool for those typists who cannot place their feet flat on the floor.

There were many requests for a document holder that could be attached to the back of the typewriter. This would prevent the typist continually having to look down at her work. Another frequent request was for a sound-proof typewriter with perhaps a detachable keyboard, and more automation of the typing operation. For example, an automatic carriage return key on all typewriters, an automatic change-over of golf-ball heads, and paper insertion. A half-space bar or key, a key to move the carriage up and down a half-space and a warning sign to signal the approach of the bottom of the paper were other suggestions. One subject thought a smaller keyboard would aid operation of the typewriter, while others stated that more consideration should be given to the office environment.

As with any lengthy, repetitive, motor task, typing will eventually result in fatigue. The problem is to decide how severe the situation is and to discover ways of alleviating it. Various suggestions were proposed by the typists, which are feasible and easy to implement, and several recommendations could be made to keyboard designers and manufacturers to improve operation of the typewriter.

4.4 Beginner Typists' Questionnaire Survey

Since the questionnaire for the skilled University typists had been extensively piloted, it was decided to administer an abbreviated form of this questionnaire to individuals learning to type. The author had visited three London typing schools and from these selected Sight and Sound Education Ltd. to provide the source of beginner typists. They were willing to co-operate and 75 questionnaires (see Appendix A2-3) were delivered to their London headquarters. Sixty-three questionnaires were returned. However, the author did not have direct control over the administration of the questionnaires and hence the level of typing skill of the subjects was unknown. Since it was evident from the questionnaire results, that some individuals had only just begun to learn to type, little emphasis should be placed on the results. The main findings from this study were:-

(a) Sixty per cent of the beginner typists were satisfied with the arrangement of keys on the QWERTY keyboard. This was markedly less than the number of skilled typists (84%).
(b) Fifty seven of the sixty-three beginner typists experienced difficulties with some finger movements. These included touch typing on the row of numbers and on the periphery of the keyboard (that is, the letters Z, A, P and shift key), and the letters on the bottom left-hand row, that is, Z, X, C, B. The only other key to be repeatedly mentioned was the letter F, especially the finger movement from the F to the B key. This latter difficulty could be alleviated by using the right index finger to type the B key and not the left.

(c) Forty of the sixty-three unskilled typists consistently made errors on some keys. It was very interesting to see that these keys included those which had caused difficult finger movements, plus the top right-hand row (Y, I, O, U, P) which had not been mentioned previously.

(d) Fourteen individuals stated that they would change some of the typewriter keys. Suggestions included omitting the fractions, exchanging the keys Y, U, I, O, P for O, P, I, Y, U, and "moving the A key, which is typed by the weakest finger of the left hand".

(e) Thirty-seven of the beginner typists said that they enjoyed typing, while seventeen stated they preferred typing to handwriting. Eighteen individuals were indifferent.

A comparison of the skilled and beginner typists' results showed findings in keeping with the level of the skill of the subjects. For example, more unskilled typists experienced difficult finger movements and created more errors. Approximately 22% of the beginners wanted to change the QWERTY keyboard, whereas 25% of the skilled individuals requested a change. This was the only result, which showed a similarity across the two groups. Fewer beginner typists (59%) enjoyed typing, but this may be explained by the fact that the individuals who dislike typing are more likely to have abandoned this skill before becoming expert typists; hence more skilled typists (81%) stated that they enjoyed typing.

4.5 Implications for the Future

Typing was enjoyed by 81% of the skilled subjects and 74% of the beginner typists: 78% of those questioned in the main survey preferred typing as a medium for 'written' communication. Subjects liked the speed and efficiency of typing and the neatness, clarity and professionalism of the finished piece of work. Several individuals compared typing with handwriting and concluded that typing was easier and less fatiguing to do. It is easier to read and to correct, but frequent typing leads to poor handwriting and impatience at the slow output. Subjects disliked manual and heavy typewriters, the noise that they made, messy correcting fluids, correcting errors and typing mathematical equations and symbols.

In the main questionnaire survey, questions 28 and 29 were concerned with discovering subjects' reactions to a smaller, lighter typewriter and a chord keyboard. The former was received with mixed feelings; some subjects (35%) thought such a device would be useful, and a number (37%) rejected the idea. The chord keyboard concept did not fare so well with a larger percentage of subjects (that is, 50%) disliking the proposition of using such a device.

Recent rapid developments in electronics have produced enormous implications with regard to the use of computers. Within the last couple of years there has been a universal trend towards personal computing, in particular, the use of chord keyboard. Although the prospect of a smaller, lighter keyboard, such as the Maltron or a portable typewriter, was received favourably by the subjects, the concept of chord keying was not. However, the context in which the latter question was asked suggests that little attention should be paid to the results. It is unfair to expect individuals to comment on a device which they have not seen or experienced and against which they may be considered to have a vested interest because of their own acquired skill at typing.

There appears to be obvious potential in extending the use of keyboards in the general population. Although it must be borne in mind that the subjects in the main study constituted a specialised group of regular keyboard users, it appears that keying is a preferred medium for communication than hand-writing. One problem, which does emerge with keying for long periods of time, is the detrimental effect it has on one's hand-writing, and there appears to be no obvious solution to this.

5. CONCLUSIONS

The primary objective of the questionnaire survey was to establish skilled users' attitudes towards the QWERTY keyboard. It was concluded for the following reasons that QWERTY users were not satisfied with the standard keyboard.

(a) Fifteen per cent of skilled typists answered 'no' when asked if satisfied with the QWERTY layout.
(b) Forty-seven per cent experienced difficulties with some finger movements between keys.
(c) Fifty-eight per cent repeatedly made errors on some keys.
(d) Twenty-five per cent stated that they would change the position of the keys on the keyboard.
(e) Over fifty per cent of the typists suffered from aching necks, backs and shoulders.

If the individuals who use the QWERTY keyboard every day are not fully satisfied with the standard, the problem of developing a more efficiently arranged keyboard arises. Hence a literature review of sequential keyboards was carried out, in order to assess the possible alternatives and the reasons why they have failed to become accepted in the keyboard market.

The majority of typists are unwilling to change to a different keyboard, because of the amount of re-training required. It is difficult with a skilled group of QWERTY users to justify the need or create the motivation to learn a new layout. It was concluded from the survey that moderate changes in the design of the keyboard, and more attention given to the work-place and environment, would aid rather than hinder the skilled and beginner typist, and would lead to more comfortable, less fatiguing operation of the keyboard.

CHAPTER 3

A REVIEW OF THE LITERATURE AND RECENT RESEARCH ON QWERTY SEQUENTIAL KEYBOARDS

1. LITERATURE REVIEW OF SEQUENTIAL KEYBOARDS

1.1 Early Challenges to the QWERTY Keyboard

The QWERTY keyboard was designed in 1874 but it was not referred to as the standard and universal keyboard until 1905 when a large international meeting was called to establish a standard keyboard (Mares, 1909). During this period other keyboards, for example, the Prouty (1888), the Fitch (1889), the Ideal Keyboard (Hammond, 1893), the Blickensderfer (1897) and the Caligraph (date unknown), were devised and published,* but their only impact on the alphanumeric keyboard world was to appear on the pages of history books. The Blickensderfer keyboard (see Figure 3.1) was based on a scientific analysis of the letters in English text since no less than 70% of letters could be written using only the bottom line. This finding is significant since it demonstrates that within thirty years people were challenging the origins of the QWERTY keyboard. It also strengthens the hypothesis that the standard keyboard existed purely because it was part of the first practical typewriter on the market.

Z X K G B V Q J
P W F U L C W M Y
D H I A T E N S O R

Figure 3.1: The Blickensderfer (1897)

From 1909, a steady procession of alphanumeric layouts claiming to be more efficient than QWERTY were developed. Rowell (1909) rearranged the QWERTY keyboard by grouping the most commonly used letters in the centre of the keyboard. Computation showed that nine letters (H,O,R,S,E,A,T,I,N) represented 69% of the total number of letters used, whereas the six letters (F,C,M,D.L,U) were present 19% of the time. The end-result was the arrangement of keys for the typewriter keyboard shown in Figure 3.2.

* All these keyboards are quoted in Mares (1909).

Z J F H O R D W , ;
X K C S E A L Y G .
Q V M T I N U P B

Figure 3.2: The Rowell Keyboard (1909)

During the year 1920, keyboard designers were exceptionally prolific and three keyboard layouts were patented. Nelson (1920) produced the 'Combinational Keyboard' which was based on a study of the manual, linguistic and psychological habits of Man. This keyboard was the outcome of seven million separate scrutinies of various styles of English prose and the end-result was the discovery of the 38 most frequent digrams upon which the keyboard layout was based. Nelson also studied consonantal and diphthongal combinations, and the frequency of vowels and semi-vowels.

Z G D N I O U F Q
V W H T S E A R B J
K X C P L M Y

Figure 3.3: The Combinational Keyboard (1920)

Note: The letters between the dotted lines make up 97% of English words.

In April 1920, Banaji patented his typewriter keyboard. His layout was a modification of QWERTY, since ten letters remained in the same position (see Figure 3.4). The reasoning behind this layout was concerned with allocating the letters Q and X to the index fingers in order to reduce the amount of typing that these digits had to do. Banaji obviously felt that the index fingers were under pressure typing the letters G and H. The letters V and P were also moved since Banaji concluded that VE and PO were common prefixes.

G V E R T Y P O U H
F A D S Q X L K I
Z - W M B C N J ; ,

Figure 3.4: The Banaji Keyboard (1920)

It is interesting to note that a common criticism of the QWERTY keyboard is the placement of seldomly used letters under the index fingers of both hands, namely G and H. Therefore, Banaji's reasoning is contrary to common belief since he places two of the least frequently used letters in the most privileged keyboard position. Banaji admitted that the main feature of his keyboard concerned the punctuation marks which were located on both shifts and perhaps this rather than the modification of layout should be remembered.

The third keyboard designer of 1920 was Wolcott who rearranged the QWERTY layout so that no lateral shifting of the hands occurred. To achieve this he based his keyboard layout on the following three features.

(a) Division of the most frequently used characters into two groups separated by a group of less frequently used characters.

(b) The arrangement of the least frequently used characters in a group at the centre of the keyboard.

(c) The arrangement of the letter keys so that those on each side of a median line through the keyboard represent approximately half of the total characters used.

Wolcott's layout (see Figure 3.5) is based on the same principle as Banaji in that the least frequently used letters (J,Q,Z and X) are placed under the index fingers. No experimental work has been carried out on these three 1920 keyboards and since they were granted their patents there has been no further interest in their existence.

2 3 4 5 6 7 8 9 -

G Y N I Z X S R M P

B U A T J Q E O D W

K F C L ; / H , . V

Figure 3.5: The Wolcott Keyboard (1920)

Hoke in the 1920s was the first individual to consider altering the design of the keyboard itself. He split the keyboard (see Figure 3.6) and placed the heaviest keys in the centre, but still retained the diagonal sloping of the columns of keys. Hoke's main emphasis was on developing a 'balanced' keyboard, so that both hands carried out a similar amount of keying.

Y D M C W [SHIFT KEY] Q F V L K

R N T H U S I E O A

B P G J X [SHIFT LOCK] Z ? ; . ,

Figure 3.6: The Hoke Keyboard (1924)

None of the keyboards developed to challenge the QWERTY design before 1930 had any lasting effects. Presumably by this time the increase in the number of typewriters had made more people aware of the shortcomings of the original layout, and after this date more publicity was given to reforming the typewriter keyboard. Moreover, designers were using a more scientific and analytical approach to redesigning the QWERTY keyboard.

1.2 The Orthographic Keyboard

Gilbert (1930) proposed an improvement of the QWERTY layout based upon the principles of the English language. He worked through all the alphanumerics and punctuation methodically reviewing the merits and occurrence of digrams, trigrams, diphthongs, etc. His reformed keyboard was named the Orthographic Keyboard* (see Figure 3.7), and retains some similarity to QWERTY.

* "Orthos = correct, and orthographic = correct writing".

For example, the positioning of the letters Q, W, T, H, I, K, X, V, and N. Again less frequently used letters (F. P, B and H) are placed in the centre of the keyboard, and since Gilbert made no reference to previous keyboard research it is not possible to determine whether he was continuing the theme of the 1920 keyboards. At the end of his 94 page book on this keyboard, Gilbert predicted that the QWERTY keyboard would fail. His reasons for this forecast were that QWERTY was not co-ordinated for the English language and not adapted to the hands of the typist.

Q W S T F P C L Y ?
J R E A B H U O I K
X V D M Z G N , . ;

Figure 3.7: The Orthographic Keyboard (1930)

Six years after the conception of the orthographic keyboard, Dvorak and his colleagues made a serious, prolonged attempt to reject the QWERTY keyboard and replace it with the Dvorak Simplified Keyboard (D.S.K.).

1.3 The Dvorak Simplified Keyboard

This keyboard was designed on the basis of scientific data relative to the frequency of use of different letters, and the frequency of two, three, four and five letter sequences. Dvorak's aim was to arrange the keys in a four row, 42-key keyboard, overcoming the defects that he saw in QWERTY.

? , . P Y F G C R L /
A O E U I D H T N S -
' Q J K X B M W V Z

Figure 3.8: The Dvorak Simplified Keyboard (1936)

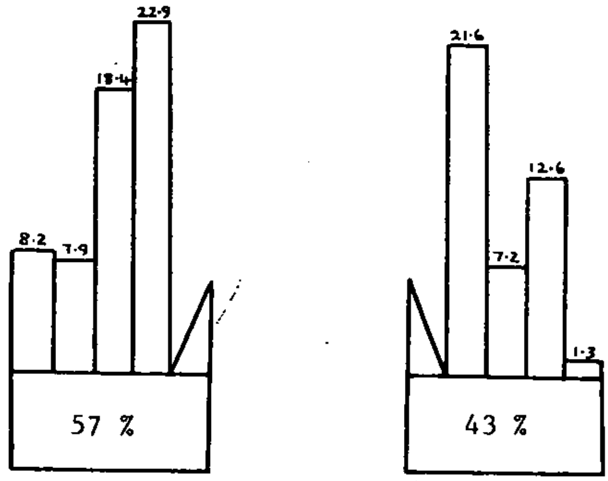


Figure 3.9: QWERTY Keyboard: Percentage workload on each finger, for left and right hands

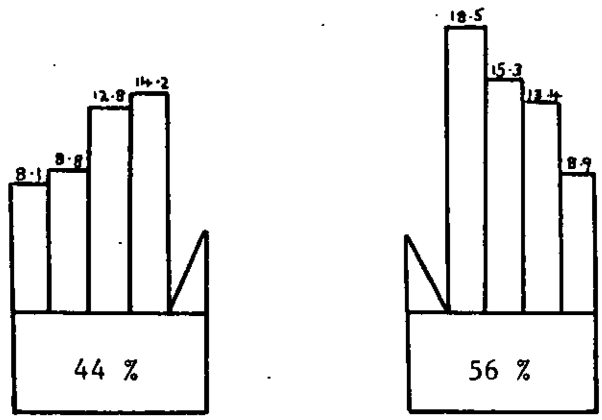


Figure 3.10: Dvorak Simplified Keyboard: Percentage workload on each finger, for left and right hands

The D.S.K. was designed to the following criteria:

(a) The right hand was given more work (56%) than the left hand (44%) - see Figure 3.10.

(b) The amount of typing assigned to different fingers is proportionate to their skill and strength. For example, frequently used letters such as 'E' were placed under strong fingers.

(c) Seventy per cent of typing was to be carried out on the home row - the most frequently used letters 'A, O, E, U, I, D, H, T, N, S' were arranged on this row. Consequently, only 22% and 8% of typing was carried out on the back and front rows, respectively.

(d) Letters often found together such as QU were assigned positions so that alternate hands could be involved in striking them.

(e) Finger motions from row to row were reduced by more than 90%. Difficult and awkward reaches from the home row were minimised by assigning the least frequently used keys to these positions.

(f) Thirty-five per cent of all words (used in English text) were typed exclusively on the home row. This amounted to more than 3,000 words.

The primary aim of Dvorak's keyboard was to allocate more work to the home row and hence achieve a more equitable distribution of work between the eight fingers.

Although the key placement on the Dvorak keyboard has been carefully planned, it does not seem to offer the advantageous load redistribution suggested. If the finger-typing loads for the weaker digits (that is, the ring and little fingers) are examined for both the Dvorak and QWERTY layouts, it can be seen that only the load on the little finger of the left hand has been reduced, and then by a mere 0.1%. The load on the left ring finger has increased, and 'A' is still typed by the little finger of the left hand on the Dvorak keyboard. The identical positioning of the 'A' on the QWERTY layout has received much criticism from skilled typists (see Chapter 2).

Several experimental studies comparing the Dvorak and QWERTY keyboards have been conducted. During the Summer of 1932, Dvorak trained 83 students at Washington University. He found that there was a general gain of 1.1 net words per minute for every hour of practice compared with a gain of 0.2 net words per minute for every hour on QWERTY. See Figure 3.11.

	Senior High School				Junior High School	
	QWERTY			DVORAK	QWERTY	DVORAK
Semester I	16.5	-	-	37.5	10.6	27.1
Semester II	28.4	26.1	25.6	48.0	21.4	36.1
Semester III	35.5	35.0	34.4	-	26.8	-
Semester IV	40.9	41.0	39.3	-	33.4	-

Figure 3.11: Summary of Dvorak's Findings

During the period 1931-1935, Dvorak and Dealey experimented extensively with the new keyboard. However no details of these studies were published and this has led individuals to doubt the superiority of the Dvorak Simplified Keyboard. Although no comprehensive account of a controlled experiment has been published, many studies have supported the claims of the rearranged keyboard: Seibel (1972) concluded that it is quicker to learn and leads to a higher output in terms of words per minute.

The Dvorak layout was the subject of intensive investigation by the U.S. Navy (1944) and the Australian Post Office (1952-53). They concluded that if adverse factors in training and work situations were altered, the Dvorak keyboard would probably result in a "very substantial increase in the efficiency of typists."

In 1939 the University of Chicago reported that the Dvorak keyboard had been successfully employed as part of a programme to teach school-children touchtyping (TIME, March 20th 1939). Teachers reported that the children were learning to type twice as fast on the Dvorak keyboard and were able to exceed 50 correct words per minute. An unpublished H.M. Treasury Organisations and Methods Department Report (circa. 1948) described a very thorough study in which approximately 50 females were trained on the Dvorak keyboard over a three-month period (B. Shackel - Personal Communication). Results obtained were favourable towards the reformed keyboard, but although a statistically significant improvement was found it was concluded that this was not large enough to justify changing over to the Dvorak keyboard. The U.S. National Bureau of Standards carried out an investigation into the Dvorak keyboard and surveyed the assessments made from 1930 onwards by U.S. Agencies and Universities (Phillips, 1968). Again, no concrete experimental evidence was published, but this report concluded that the Dvorak keyboard was superior to the standard QWERTY keyboard.

It is nearly 50 years since Dvorak challenged QWERTY's monopoly of the keyboard market, and the Dvorak keyboard, unlike more recently developed keyboards, is still in existence and struggling to be recognised.

In 1970, Cocking listed some of the advantages of the Dvorak keyboard in the national press:-

(a) It improves typing speeds by an average of 35%.
(b) It cuts training time by half.
(c) It reduces fatigue enormously. Finger travel for a fast typist is cut from about 20 miles per day to about one mile.
(d) By eliminating 98% of 'finger hopping', the error rate is considerably lessened.

The Dvorak keyboard was also discussed in 'Computers and Automation' (February 1971). Questions raised in this article concentrated on the problems of relearning a new keyboard after QWERTY. Again, scanty reference was made to an experiment in which beginner and skilled typists trained on the Dvorak keyboard. Although no quantitative data are presented, conclusions favour the Dvorak keyboard for speed and ease of learning. Harnett (1972) described two, one-subject, experiments on the Dvorak keyboard. Both females achieved spectacular results, for example, 50 words per minute after five hours of training for a novice typist, and four hours for a 50 words per minute QWERTY typist to learn accurate typing at 35-40 words per minute. However because there are no experimental or statistical details available, such findings must be regarded with scepticism.

1.4 Experimental Comparison of the QWERTY and Dvorak Keyboards

Although there is suggestive evidence available that the Dvorak keyboard is superior to QWERTY, only one controlled experimental comparison has been reported in the open literature. This was by Strong in 1956. Strong trained 20 female subjects on the standard QWERTY and Dvorak Simplified Keyboards. All subjects were initially skilled QWERTY operators. A group of ten subjects were trained on the Dvorak keyboard until each individual had reached the speed she had typed on the standard keyboard prior to beginning her training on the Dvorak keyboard. Each subject was then tested to determine typing speed, accuracy, manual dexterity, general intelligence and mechanical ability.

The second part of the experiment involved more training for the experimental group on Dvorak's keyboard and supplementary training on the QWERTY keyboard for the control group. Subjects learning the Dvorak keyboard received a minimum of 100 hours of instruction. The Dvorak group did not fare as well as the control group on the tests and it was concluded that adoption of this keyboard could not be justified based upon the findings of this experiment. The study was however unfairly biased in favour of the QWERTY control group, because the experimental group had to cope with the confounding effect of previous experience on the QWERTY keyboard.

1.5 Review of Post-Dvorak Alphanumeric Keyboards

Three years after the invention of the Dvorak Simplified Keyboard, a Dutch designer Biegel (1934) developed a sequential keyboard according to the following criteria:

(a) The load on the little fingers must be reduced by placing the keys that are heaviest to strike in the middle of the keyboard, where they can be struck by the strongest fingers.

(b) The shape of the keyboard must be such that the hands can take up a natural position, oblique to the body.

(c) The keys must be arranged so that the groups of keys for the right and left hands are the inverse images of each other.

(d) The keys must be arranged so that every finger, when moving from one row to another, always follows the same straight line. These lines must be parallel for the fingers of each hand. See Figure 3.12.

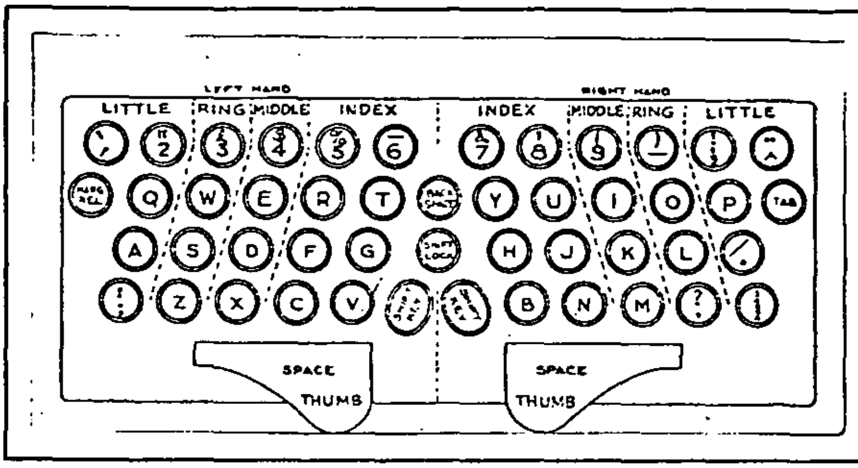


Figure 3.12: Rearrangement of Typewriter Keyboard (1934)

The only research carried out on this modified QWERTY keyboard was by Biegel himself: he concluded that it was no more difficult to become accustomed to the rearranged keyboard than to a new make of typewriter. Although Biegel retained the original QWERTY layout, thus overcoming many of the problems of retraining typists, and improved upon the design of the keyboard, his rearranged typewriter keyboard has never been adopted. In contrast to Biegel's work, Ward (1936) concentrated on keyboard layout and used a methodical approach to the positioning of alphanumeric keys.

1.6 The Ward Keyboard

Ward (1936) approached designing a keyboard through a study of the English language. He analysed:

(a) The use-frequency of each letter.

(b) The rank of letter-frequencies in order of occurrence.

(c) The ratio of vowel strokes to consonant strokes.

(d) The optimal position of letters of varying use-frequencies on a keyboard, so that a minimum number of words can be typed with one hand.

Ward anticipated that a keyboard designed using principles he had obtained from the above, would reduce difficult finger reaches and stroking patterns to a minimum, and help to balance hand, finger and row loads. The end result was a keyboard layout, as shown in Figure 3.13.

	7	5	3	/	9	0	2	4	6	8
?	:	,	U	V	C	D	H	P	M	—
.	I	O	A	E	R	T	S	N	L	-
	Z	Q	J	X	K	F	G	W	Y	B

Figure 3.13: The Ward Keyboard (1936)

Ward concentrated on the use-frequency of letters as one of the major factors in positioning letters on his keyboard. He attempted to centre the hand, and finger loads on the keyboard, and on the fingers with the greatest motor control. No experimental evidence has been found to support the Ward keyboard and it appears to have generated minimal interest amongst keyboard designers and researchers.

Although the Dvorak keyboard has been the most persistent alternative to QWERTY, there have been others. These include the Minimotion and Alphabetical layouts.

1.7 The Minimotion Keyboard

This keyboard was designed in 1949 by Griffith with the aim of overcoming the defects of the QWERTY layout. Griffith's general design objective was to determine the optimum arrangement of letters for typing 'average' English with the greatest possible ease. The objectives can be summarised as follows:-

(a) To minimise one-handed motions.
(b) To minimise reaches from the home row and to maximise two-handed motions on the home row.
(c) To minimise hurdles (that is, one-handed motions over the home row).
(d) To divide the stroking load equitably between the hands.
(e) To minimise awkward fingerings of one-handed motions, yet load the fingers equitably.

In order to achieve these objectives, Griffith carried out a very thorough analysis of the English language. Using a representative sample of 100,000 words, Griffith performed a statistical analysis of word usage, single and adjacent letter usage, and punctuation.

The end result was the Minimotion keyboard (see Figure 3.14).

2	3	4	5	6	7	8	9	0	Z	
.	,	U	Y	-	W	F	G	D	C	J
I	A	E	O	H	L	N	T	S	R	Q
;	/	"	K	?	B	M	P	V	X	

Figure 3.14: The Minimotion Keyboard (1949)

The Minimotion keyboard has received little support, although experimentally it has been demonstrated that slightly better keying rates than QWERTY can be achieved (Stewart, 1973a). See Figure 3.15.

Expert Operators (Similar skill and proficiency levels)	Inherent Relative Speed	Inherent Relative Time
QWERTY	101	99
DVORAK	111	90
MINIMOTION	112	89
RANDOM	100	100

Figure 3.15: Performance Ratings

Griffith's keyboard layout is unusual in that it has 11 alphabetical keys on the home row instead of the expected ten. It is therefore not immediately apparent which hand types the keys in the centre of the keyboard. Such a layout will also result in one of the little fingers being overworked.

A similar approach to the design of an alphanumeric keyboard layout was made by Maxwell four years later. Maxwell (1953) analysed the 5,000 most frequently used words in the English language and based his layout on the results.

1.8 The Rhythmic Keyboard

This keyboard, as the name suggests, was designed to give the typist the maximum amount of rhythm in her typing. Unlike Griffith, Maxwell (1953) was primarily concerned with arranging the keys so that alternate hands would be required to type the most common words.

Maxwell studied the types of movements made by the typist on the QWERTY keyboard. He divided them accordingly:

(a) Balanced hand movements, requiring the alternate use of the hands (47%).
(b) Inward rolling hand movements (22.2%).
(c) Outward rolling hand movements (18.6%).
(d) Repetitious stroking with the same finger, but not on the same key (9%).
(e) Repetitious stroking with the same finger on the same key (3.2%).

Maxwell concluded that approximately 88% of typing on the QWERTY keyboard was carried out using synchronized hand and finger movements. He then continued to assign the maximum amount of work to the strongest fingers, and after having made 44 changes to the QWERTY layout, Maxwell arrived at the 'rhythmic keyboard'. See Figure 3.16.

```
 2  3  4  5  6  7  8  9  0  @
.  B  O  I  Q  F  R  C  P  ,  ?
Y  S  A  E  U  D  H  T  N  W  -
 ½  ;  X  K  Z  L  M  G  J  V
```

Note: the S is the only letter in the same position as on the QWERTY keyboard.

Figure 3.16: The Rhythmic Keyboard (1953)

It soon becomes apparent that a perfect rhythmic setting will be impossible to obtain; rearranging a keyboard becomes a compromise. This layout however, unlike QWERTY, the Dvorak Simplified Keyboard and the Maltron Keyboard, has avoided assigning the 'A' to the little finger of the left hand - a feature much disliked by skilled typists. The rhythmic keyboard also changed the position of several punctuation keys, exchanging the quotation mark, back space, margin release, and the hyphen keys, with the one-half (½), left-hand shift-lock, right-hand shift-lock and the cent (c) sign keys.

Several of these changes have been recommended by skilled typists (see Chapter 2).

1.9 The Alphabetical Layout

The alphabetical keyboard as the name suggests is an arrangement of the keys in the sequence of the alphabet. The advantage of such an arrangement is that it is easy for the unskilled user to find a key, but once training has made touch typing automatic, the alphabetical array confers anomalies of load on the fingers.

There is some evidence however, that for typists who do not use the typewriter frequently, the alphabetical rather than the QWERTY design is more suitable, for example, airline reservation systems. Bodenseher (1970) produced a special purpose keyboard with the keys arranged in alphabetical order on the grounds that this was the layout that people would expect and be familiar with. He arranged the numerals as on a desk calculator, while function keys were grouped in patterns for identification, according to function and frequency of use. Bodenseher concluded that this keyboard showed a reduction in error-rate of about 25% when compared with a typewriter keyboard. He also claimed that it reduced learning time, and allowed experienced users to enter statements about twice as fast as on the standard QWERTY keyboard. It is not clear however, whether these advantages arise from the alphabetical layout or the arrangement of the numeral and special function keys, and the fact that there was no shift operation, thought to be a major source for errors on a typewriter (Bodenseher, 1970).

The alphabetical layout after QWERTY is one of the most researched keyboards. Unlike the Dvorak keyboard, studies on this layout have been well documented thus allowing the observer to reach a less biased decision concerning its merits. One of the first experimental comparisons was by Hirsch in 1958.

Hirsch carried out an investigation into the typing performance of 'non-typists' on the standard QWERTY keyboard and an alphabetically arranged keyboard.

An 'independent subjects' design was used and 40 subjects completed seven hours of practice interspersed with ten-minute test sessions. All subjects were administered a pre-practice and a post-practice test. It was shown that the pre-test scores of the group using the alphabetical keyboard were not as high as the pre-test scores of the group using the QWERTY layout. Hirsch (1970) provided a possible explanation for this result. He stated that the standard typewriter was designed with the most frequently used letters clustered in the centre of the keyboard. Secondly, the alphabetical keyboard probably required a memory search to locate the letter in its position in the alphabet, followed by a visual search to find the key on the board, where it is located regardless of its frequency of use.

Hirsch obtained his subjects by requesting non-typists and received 55 volunteers from which, on the basis of a typing pre-test, he selected 40. Since Hirsch classified 15 of the initial 55 (self-styled non-typists) as typists, it seems reasonable to assume that a fair proportion of the actual subjects were at least partially familiar with the QWERTY keyboard. The two keyboards used, were different in shape; for example, the alphabetical layout had 11 keys in the third row and four in the fourth row, whereas QWERTY had nine in the third row and seven in the fourth row (see Figure 3.17). All these factors would have favoured the QWERTY layout. Consideration should also be given to the fact that Hirsch used 'plain language' material familiar to the subjects. Examples included the subject's name and address, so the results may not be applicable to coded or highly non-redundant material. This approach also introduced variability in the training tests.

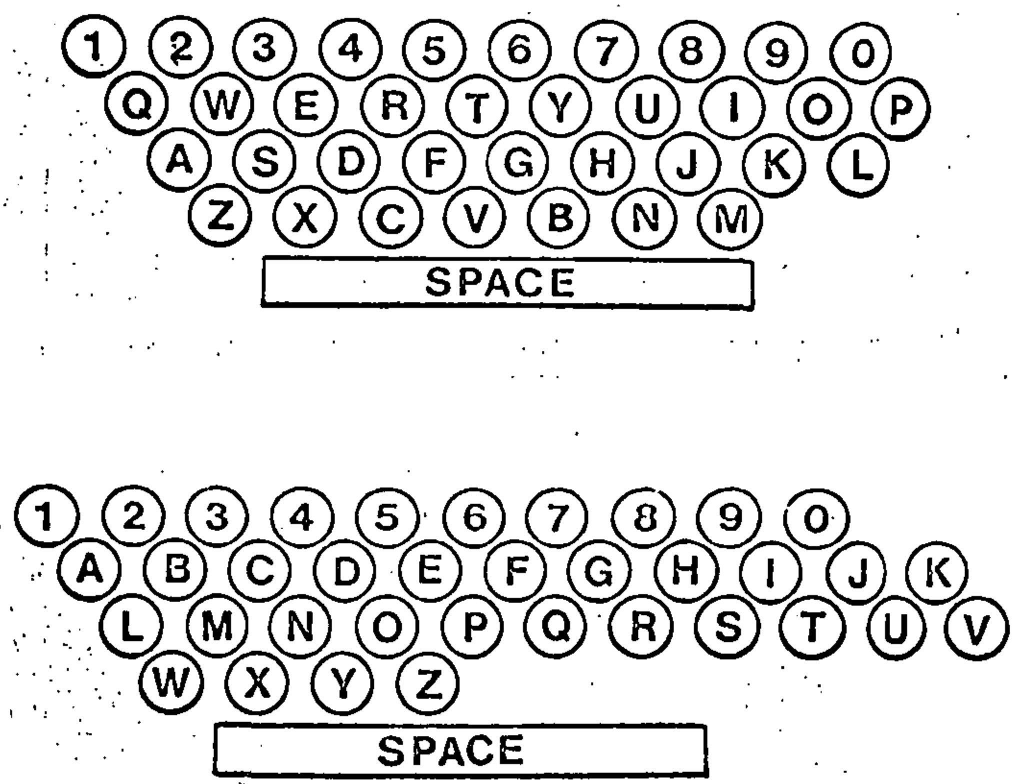


Figure 3.17: The QWERTY and Alphabetical Keyboards used by Hirsch (1958)

A second experiment comparing the QWERTY keyboard with an alphabetical arrangement was carried out by Michaels (1971). Michaels used a 'repeated measures' design with 30 subjects. The subjects were divided into three groups according to the level of typing skill they professed, and were pair-matched across the two keyboards.

Subjects keyed for two sessions of about 1½ hours daily with a 30 minute break. The complete test sequence for each subject included 25 five-minute periods on the keyboard used first and 25 on the other keyboard. Again, it was concluded that the alphabetically arranged keyboard showed no advantages over QWERTY for speed of typing, error rate or learning speed. Operators with little or no typing skill, for whom the alphabetical arrays are frequently intended, were as fast or faster with the QWERTY arrangement, while skilled typists produced nearly twice as much work using the QWERTY keyboard.

It is also of interest to note that the skilled typists keyed numerics more slowly on the alphabetical keyboard, although this field on both keyboards was identical. The experiment was unfairly biased towards the QWERTY keyboard, because the skilled users were obviously more adept on this layout than the alphabetical.

1.10 The Alphametric Keyboard (A.M.K.)

In 1972, Martin revised the Dvorak Simplified Keyboard to take account of metrication (see Figure 3.18). He stated that there could be no doubt about the superiority of the Dvorak keyboard over QWERTY. Martin suggested that the alphametric layout should be adopted as a standard, since it appeared logical to couple an international agreement on metrication with an international agreement on a keyboard layout. Although, Martin declared that the best features of an IBM standard typewriter and the Dvorak keyboard had been combined in his proposed alphametric keyboard, little has been heard of this development.

= 1 7 5 3 9 2 4 6 8 — / &
(: , . P Y F G C R L)
A O E U I D H T N S -
' Q J K X B M W V Z

Figure 3.18: The Proposed Alphametric Keyboard (1972)

1.11 The Kroemer Keyboard

Klockenberg in 1925 published a book dealing with the efficient design and operation of the typewriter. He proposed that the keyboard sections allotted to each hand should be tilted concurrently to the left and right sides. Kroemer used this suggestion when designing his keyboard, in an attempt to reduce postural muscular strain in typists. He separated the two halves of the keyboard, and angled them backwards 15^{o} from the centre, and tilted them down laterally. Klockenberg also suggested that the key rows should be slightly arched on each half of the keyboard - in keeping with the natural arcs that the fingertips make (see Figure 3.19).

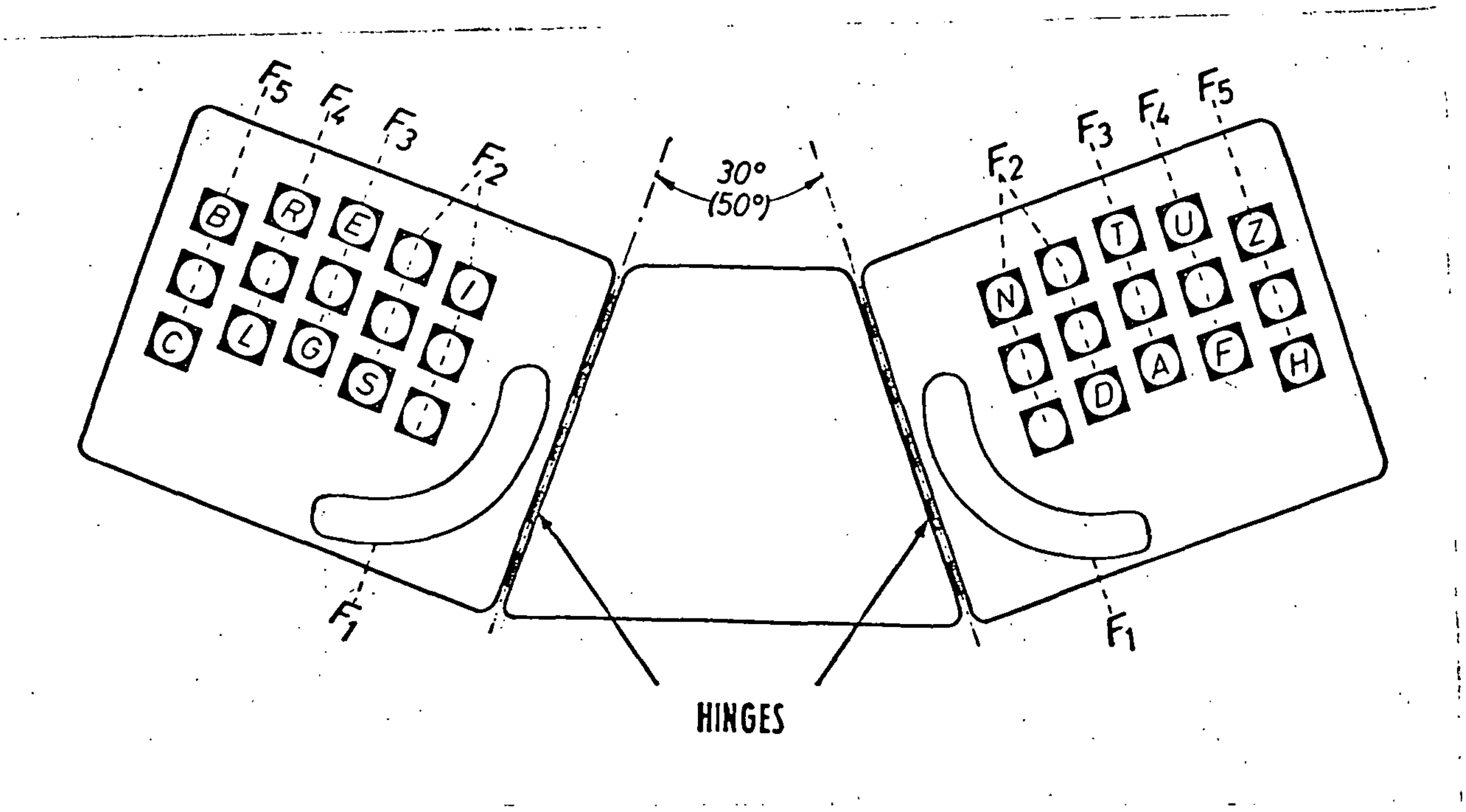


Figure 3.19: The Kroemer Keyboard Model (1972)

Kroemer (1972) conducted a comparison of the QWERTY and the Kroemer keyboards, although the latter differed from the standard keyboard in both layout and physical design. Kroemer was only concerned with one particularly highly practised sentence (for which the letters on both keyboards were specifically arranged), so that he could study performance at a high degree of efficiency. His results favoured his modified keyboard in terms of error rate and keystroke frequencies. Subjects were asked to type as long as they could and when asked why they had stopped, those on the standard keyboard blamed 'aches and pains', whereas those on the Kroemer keyboard continued until they could concentrate no more. This tentatively supports the idea that a change in keyboard design might benefit the QWERTY user. After discussing Kroemer's keyboard, Stewart (1973a) reached a similar conclusion and stated that "the value of the split keyboard has yet to be rigorously established but certainly seems to merit further attention".

1.12 Suggested Revision of the QWERTY Layout

The keyboard shown in Figure 3.20 was an attempt to revise the QWERTY layout, but can only be regarded as a basis for development (Ferguson and Duncan, 1974). The proportion of overall load sampled (7,000 keystrokes) on the left hand is 47% and on the right hand is 53%, thus improving upon the QWERTY design.

J U Y I C M H P B Z
F D T A O N S E R G
X Q L . Sh Sh , W V K

Figure 3.20: Revised QWERTY Layout (1974)

Various principles have been used in arranging this layout of the typewriter keyboard:-

(a) The total load on each finger was in descending order of keystroke frequency from the index to the little finger on each hand, but not necessarily on each row.

(b) The load on each hand was roughly equal (any inequality was not intended to give more work to either hand).

(c) The load was distributed so that most fell on the home row of letters, and more work was given to the back row of keys than the front.

The placement of letters has been arbitrary, except that common sequences of two letters which would have resulted in hopping from the back to the front row have been avoided as far as possible (Ferguson and Duncan, 1974).

It is worth noting that the columns of keys on each half of the keyboard are inclined inwards. This was in order to overcome the tendency of the typist to ulnar deviation associated with the present inclination to the left of all the rows of keys on the standard keyboard. For example, ulnar deviation of the left wrist is increased on the QWERTY keyboard, when it is necessary to hit Q at the left end of the back row and even more to hit the shift key to the left of the front row. The design of the recently developed Maltron keyboard also attempts to overcome this problem.

1.13 The P.C.D. - Maltron Keyboard

This electronic keyboard was designed by Lillian Malt in conjunction with P.C.D. Limited around 1975 and it continued the trend of dividing the keyboard into two halves. The design of this keyboard was claimed to be 'entirely ergonomic' and one of its principle features was the key heights, which were designed to fit the unequal lengths of the fingers. Malt (1977) stated that by forcing fingers of unequal lengths to key on a horizontal plane resulted in a reduction of speed, increase in errors and unnecessary discomfort. The Maltron keyboard helped to compensate for the inequality in the relative strengths of the fingers, and also provided immediate tactile feedback should the typists's fingers stray to the wrong row of keys (see Figure 3.21).

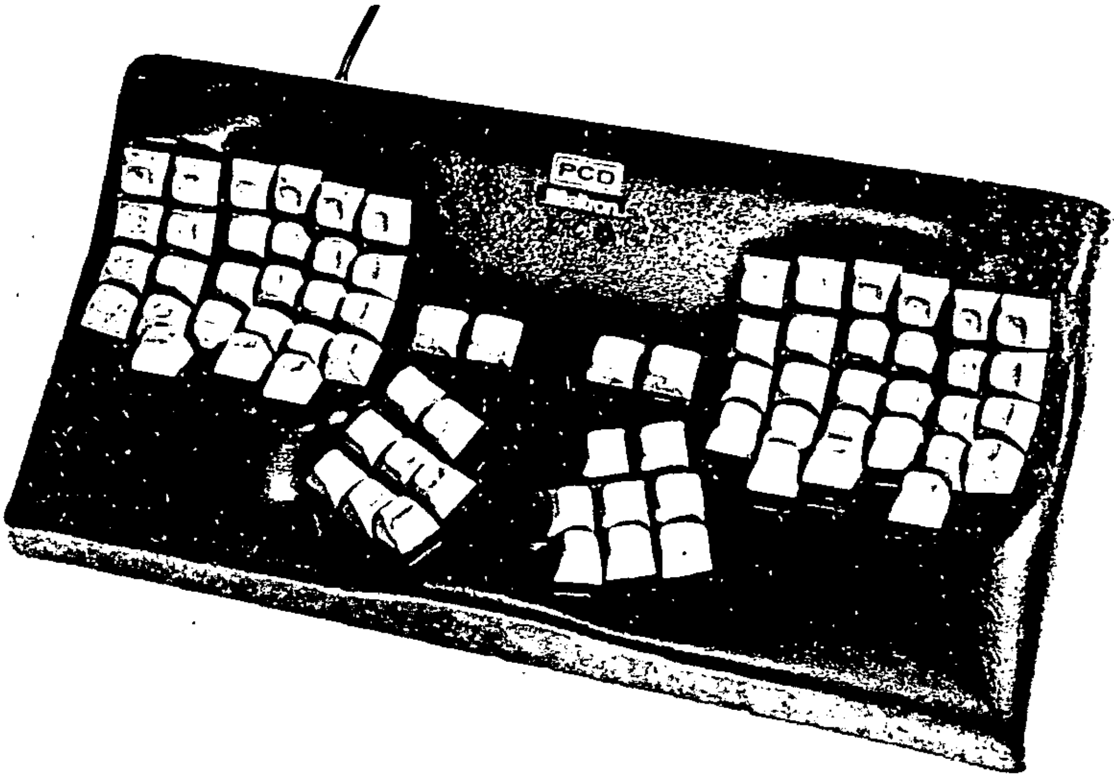


Figure 3.21: The P.C.D. - Maltron Keyboard

There are two keyboard arrangements available for this keyboard; these are the QWERTY layout and the Maltron letter layout. The Maltron layout was based on an analysis of letter frequencies in 1013232 words (Kucera, 1967) and it attempted to avoid some of the limitations laid down by the QWERTY design. Ninety per cent of the letters in the 100 most used words in English were placed on the home row, and similar rates were maintained for six other European languages (see Figure 3.22).

It is predicted that this keyboard will reduce learning time because the fingers will receive more tactile feedback. Accuracy will be induced, because it is anticipated that speed will be almost automatically increased by between 20-40%, and that optimum output will be maintained for longer periods because of the delay in the onset of fatigue (Malt, 1977).

The Maltron keyboard is the latest keyboard to challenge the ubiquitous QWERTY design. It is available with the QWERTY layout, as well as the Maltron arrangement of alphanumerics. Therefore it would be possible to discover if the ergonomic 'claims' of the inventors are appreciated by the user population. No evaluation of this keyboard has ever been carried out and Floyd (1979) was the first to attempt such a task.

1	2	3	4	5	6	7	8	9	0	
Q	P	Y	C	B	V	M	U	Z	X	
A	N	I	S	F	D	T	H	O	R	;
,	?	J	G	"	!	W	K	-	L	
		<	/	E	Sp	"	>			
				./	CR					

Figure 3.22: Diagrammatic Representation of the Letter Layout of the Maltron Keyboard

2. EXPERIMENTAL STUDY OF THE MALTRON KEYBOARD

Since there is a choice of layouts for this keyboard, it would be possible to conduct an experimental investigation into the design of the Maltron QWERTY keyboard and a standard typewriter unit. During the Spring of 1979 the author supervised a final year student's project carrying out such an investigation. The Maltron QWERTY layout was chosen for two reasons. At present, there is no incentive for individuals to learn to type on a new alphanumeric layout because of the dominance of QWERTY. Hence it would be unfair to train subjects on the Maltron and standard keyboards because of the lack of motivation to learn the former. Secondly, results from the questionnaire survey of skilled typists indicated that a modification in keyboard design might be more realistic than a change in letter layout.

A 'repeated measures' statistical design was chosen in preference to an 'independent subject's' study. There was a time limitation on the loan of the Maltron equipment, so it was decided that a balanced repeated measures design was more appropriate as each subject acted as her own control and hence fewer individuals were required. The other advantage of allowing subjects to undergo both treatments was that subjective comparisons of the two keyboards could be obtained. Six female non-typists were selected from a pool of 52 individuals who replied to advertisements. Equal numbers of subjects started training on each keyboard and at a suitable point (the cross-over point) they changed to the other keyboard. Due to the severe time limitations on the piece of work, it was only possible to train subjects for a period of eight hours each.

At the end of their first lesson, the subjects were administered a questionnaire (see Appendix A3-1). This procedure was repeated again at the end of the first keyboard training period, after their first lesson with the second keyboard and on completion of the experiment. The questionnaire was given to the subjects on four occasions to ensure that the wealth of subjective data was recorded.

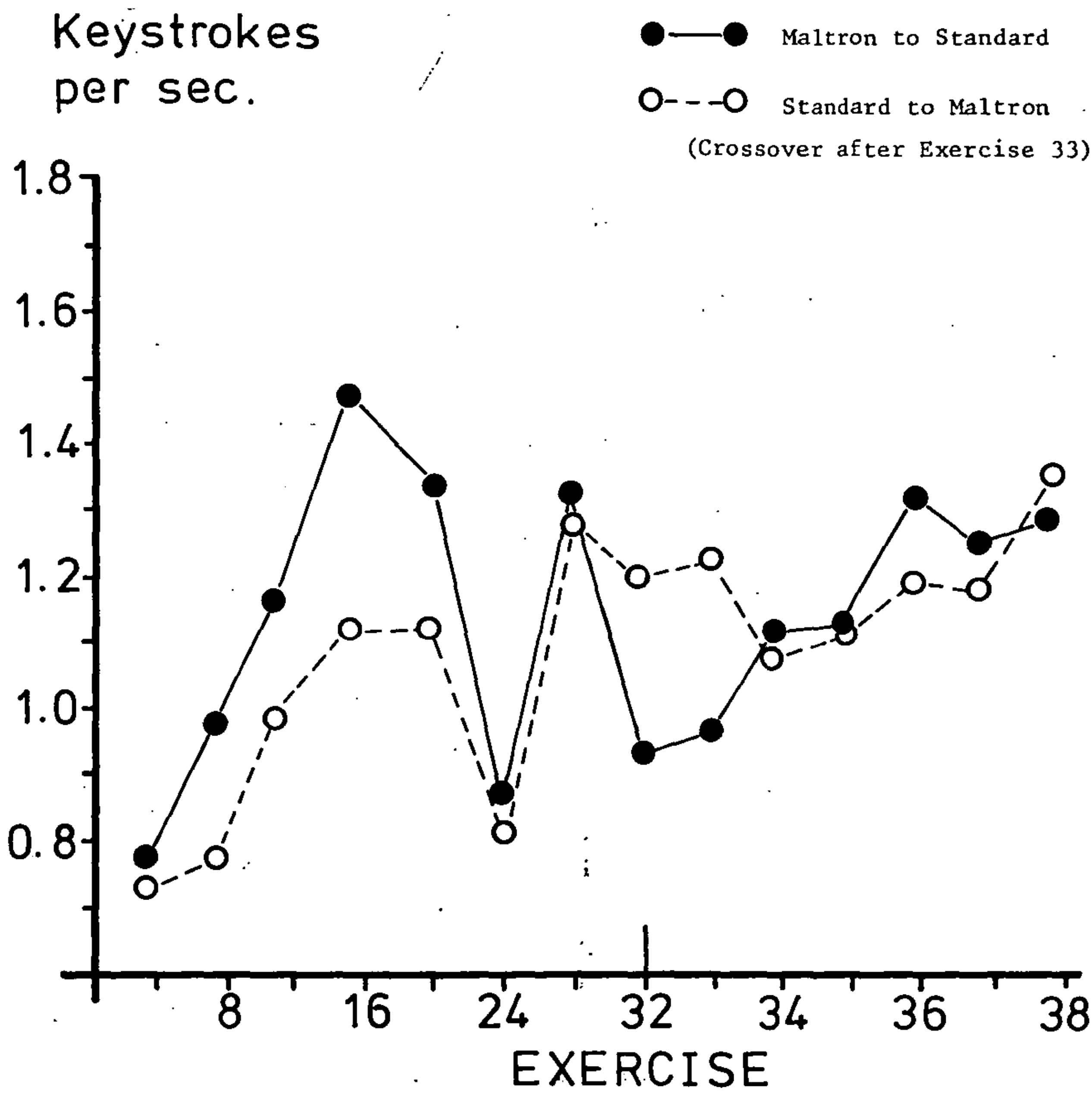


Figure 3.23: Graph of Mean Keying Rate against Exercise Number

2.1 Summary of Results

Statistical analysis (Winer, 1971) of the keying and error rates showed that there was no significant difference between the two keyboards at the 5% level. Visual examination of the graph of mean keystrokes per second plotted against the exercises did show a trend towards faster keying rates on the Maltron keyboard (see Figure 3.23). This trend continued after the cross-over from the standard to the Maltron keyboard. From the graph it could be concluded that it was easier to change from the Maltron to the standard keyboard than vice versa. This can probably be partly explained by the fact that subjects were not surprised by the appearance of the standard keyboard, whereas the more unusual Maltron design might have been quite unexpected. After the decrease in performance caused by the cross-over, the Maltron curve rose at a similar rate to the standard curve and eventually overtook it.

Floyd concluded from the qualitative results that the subjects preferred the Maltron keyboard. Only two individuals favoured the standard design, which appeared to be a result of the difficulties they experienced in adjusting to the Maltron keyboard after the standard. However, they both preferred the split keyboard to the more traditional design of the standard typewriter unit.

2.2 Analysis of Questionnaire Data

At the end of the touch typing programme, all subjects were administered a questionnaire similar to the one developed in the preceding chapter. See Appendix A3-2. This was separate from the experimental work being carried out by Floyd. Since the previous questionnaire study had concentrated on skilled typists, it appeared a natural progression to investigate unskilled typists. The aim of this small study was to find out if the theoretical advantages of the design of the Maltron keyboard were appreciated by the users. As there is no skilled group of keyboard operators using the Maltron, the only individuals available were the six beginner typists of Floyd's experiment.

The results indicated that the subjects were having numerous problems with the positioning of the keys on both keyboards. The letters most frequently cited as being the cause of difficult finger movements and a source of errors were 'C, V, B', and 'I, O, P'. The former are located on the bottom row on the left side of the keyboard, while 'I, O and P' can be found on the right-hand side of the top row. On the standard QWERTY keyboard, the bottom left and top right rows would be difficult to reach because of the diagonal sloping of the columns of keys from left to right. This problem should be alleviated by the design of the Maltron keyboard. One individual stated that she found it difficult to move her middle finger from 'E', to 'C and V'. Another subject brought attention to the fact that the QWERTY layout has resulted in three vowels being placed on the right side of the top row. She suggested that two of these vowels, namely 'O and I', should be exchanged with 'F and V'. Another suggestion was to move 'B and M' nearer to the vowels, because they frequently occurred together.

The location of the letter B created problems for the beginner typist. On the standard keyboard, this key was operated by the index finger of the right hand, whereas on the Maltron keyboard it was typed by the index finger of the left hand. Subjects having learned one position found it difficult to adjust to a different layout. Therefore it could be predicted that more errors would be associated with this letter. One subject stated that she often missed the B key and hit 'V' instead.

It was common for the subjects to complain of 'aches and pains' when learning to type. Two subjects stated that their fingers were aching whilst using the Maltron keyboard, although no similar complaints were received about the standard keyboard. This could be due to the Maltron keyboard having different keying characteristics, for example, greater key displacement, than the standard unit.

The other body aches would stem from the use of unpractised muscles involved in the acquisition of a new skill. Several comments were made concerning the comfort of the Maltron keyboard; this was partly due to the fact that individuals can rest the heel of their hands beneath the rows of keys. The Maltron keyboard also has a possible advantage over the standard unit in that it looks less cluttered, so individuals would expect keying to be easier.

The primary reason for the favourable comments received about the Maltron keyboard was the division of the keys into two halves. When using the standard keyboard, it appeared to be a problem for the subjects to decide which index finger operated the keys clustered in the middle of the keyboard. Such a decision was not necessary with the Maltron; this would imply that it was easier to use. Two subjects complained of the lack of tactile feedback on the standard keyboard since the straight rows made it difficult to know whether one's fingers had returned to the home row of keys. The Maltron keyboard with its curved rows having keys of unequal heights provided more feedback for the subjects, and one subject commented that after the Maltron the keys appeared too close together on the standard. Subjects also preferred the Maltron because it only needed one vertical movement from the home row to strike other keys, whereas the standard keyboard required an up and down motion plus a movement sideways.

Criticisms of the Maltron keyboard included the 'space key' instead of the space bar found on the standard keyboard. Five subjects did not like the positioning of the space key on the Maltron because they had to reach over one key with their right thumb to press it. It was a frequent suggestion that the bottom right thumb key should be the space key. This key due to its frequency of use should be placed in an easily accessible and comfortable position. One subject commented that she kept losing the location of the space key, because it was so small after the space bar. When asked if they would like the thumbs to do more keying (other Maltron keyboard models allocate the thumbs up to eight keys each) the general consensus was no.

Although the split keyboard design with its associated advantages was popular with the subjects, they were not enthusiastic about using the thumbs for keying. This can probably be explained by the anatomical position of the thumb in relation to the other digits. When the four fingertips are depressing keys, the pad of the thumb does not lie flat on a horizontal surface. Hence the thumb keys on the Maltron keyboard are being hit by the edge rather than the pad of the thumb.

3. CONCLUSIONS

As a result of this study the following conclusions were reached.

(a) The division of the keyboard into two halves - each half being a mirror image of the other increases the ease with which the keyboard is operated.

(b) The curved rows of the Maltron keyboard in keeping with the natural arc of the fingertips are more comfortable for the beginner typist.

(c) Different key heights provide the typist with more tactile and kinaesthetic feedback.

(d) The allocation of keys to the thumbs is disliked and this practice should be avoided.

(e) The elimination of the space bar and its subsequent replacement by a space key is unpopular with the beginner typists. Hence the space bar should be retained.

CHAPTER 4

THE 'STATE OF THE ART' ON SEQUENTIAL KEYBOARDS

1. SUMMARY OF RESEARCH ON ALPHANUMERIC KEYBOARD LAYOUTS

The QWERTY keyboard has monopolised the market for alphanumeric sequential keyboards since its conception over a century ago. Within a couple of decades, QWERTY was established and numerous individuals began challenging the supremacy of the QWERTY keyboard with their own arrangements of keys. Between the two world wars, there was a peak of activity by enthusiasm keyboard designers. There were two main trends for reforming the standard keyboard. These involved either placing the most frequently used letters in the centre of the keyboard (Rowell, 1909; Dvorak, 1936; Ward, 1936) or assigning the least common letters to this position (Banaji, 1920; Wolcott, 1920; Gilbert, 1930). It is difficult to justify placing the less frequently used keys under the index fingers, and the apparent reasoning behind this action, namely to reduce the load on these fingers, is suspect. After Dvorak had developed his simplified keyboard, the approach towards designing a new sequential keyboard became more complex and scientific. This is demonstrated by Griffith (1949) and Maxwell (1953). Griffith analysed statistically a representative sample of 100,000 words in order to devise the Minimotion keyboard, while Maxwell studied the 5,000 most frequently used words in the English language to produce the Rhythmic keyboard. When one considers how many keyboard layouts have been invented, it is surprising that some individuals are still producing reformed keyboards in the 1970s: for example, the Alphametric, the Ferguson and Duncan, and the Maltron keyboards. It is also worth noting that the Maltron keyboard design was based on the most sophisticated letter analysis to date, which involved studying the letter frequencies in 1, 013, 232 words (Malt, 1977).

It becomes apparent that there is a wealth of literature concerned with reforming the QWERTY keyboard, which has resulted from an immense amount of thought and work. It is unfortunate that the majority of these keyboards never passed the stage of being patented. Rearranging the letters of the QWERTY layout has been shown to be a fruitless pastime, but it has demonstrated two important points: first, the amount of hostile feeling that the standard keyboard has generated and second, the supremacy of this keyboard in retaining its universal position.

Dissatisfaction with the QWERTY keyboard was further demonstrated by the University typists surveyed in Chapter 2. However they also illustrated clearly the principal reason why QWERTY has remained ubiquitous: unwillingness to change to a new keyboard layout because of the re-training required. When the crucial decision between continuing on the QWERTY keyboard and relearning a completely different layout has to be made, individuals gravitate towards the familiar situation which requires less effort. Hanes (1972) stated that historical precedent should always be followed unless there was a very good reason to change. In 1981, the amount of commercial, financial and skill investment in the QWERTY keyboard is of greater importance than the fact that it is not the most efficiently designed layout. If a change were to be implemented, the problem then would arise of deciding upon the new standard keyboard layout. A glance at the literature review and the numerous permutations which have been advocated demonstrates that this would not be an easy task.

2. PAST RESEARCH ON KEYBOARD DESIGN

The majority of the research on keyboards has concentrated on the letter layout. Several designers however have modified the keyboard itself. Hoke (1924) was the first to suggest that the keyboard should be divided into two and the heaviest keys placed in the centre. In 1934, Biegel echoed Hoke's suggestions and went even further by eliminating the sloping diagonal columns. Klockenberg (1926), Kroemer (1972) and Malt (1977) all continued this trend for logically designing a keyboard in keeping with the shape of the typist's hands. No experimental testing of this revised keyboard design was carried out until Kroemer compared a standard QWERTY unit with the Kroemer keyboard, which differed in both layout and physical design. Due to the problems in an experiment of this nature, the results should be treated with extreme caution.

It was concluded from the experimental study of the Maltron keyboard (described in Chapter 3) that there were certain advantages to be achieved by altering the design of the QWERTY keyboard. The benefit of this type of approach is that it requires comparatively little re-training; hence the increased comfort obtained would probably justify the modest re-learning necessary.

3. THE FUTURE OF THE QWERTY KEYBOARD

3.1 Introduction

In general, keyboard designers have worked in isolation and usually they make no reference to previous research. It could be predicted that unawareness of the history of alphanumeric keyboards (which is not easy to locate) will result in more keyboard layouts surfacing during the 1980s. These will not undermine the position of the QWERTY keyboard, so perhaps the development of a more efficiently arranged layout should remain purely an academic exercise. In 1929, Ostrey at Nebraska University and Riemer at New York University both revised the standard typewriter keyboard for their master's degrees. The future reform of the sequential keyboard layout might perhaps best be conducted at this level.

3.2 The QWERTY Layout

It could be concluded that the QWERTY layout will continue to monopolise the sequential keyboard market, although there might be scope for limited changes in the arrangement of keys. It emerged from the questionnaire survey that the key which created the most problems for the skilled typist was the letter 'A'. This situation might be alleviated if this key could be exchanged with the J key, which is in one of the most prominent positions on the QWERTY keyboard. Stutsman (1959) investigated the effects of reversing only the A and the J keys using a sample of four typists. Unfortunately details of this study are not obtainable, and so the outcome of exchanging the two keys is not known. Gordon, Henry and Massengill (1975) also adopted this approach and carried out a comparison of the standard QWERTY keyboard and six modified keyboard configurations. Keys that were interchanged are shown in Figure 4.1 with their corresponding tapping rates and finger loads.

Letter Interchange	Tapping Rate*	Finger Load (%)
Highload Keys		
J - U	70	19
F - R	66	22
D - E	63	20
Lowload Keys		
K - I	69	8
L - O	62	12
S - W	57	9

* The tapping rate was defined as the number of strokes that a finger was capable of making during a 15-second period, while the load referred to the proportion of typing performed with each finger.

Figure 4.1: Table of Results (Gordon et al. 1975)

The basic finding from this research was that skilled typists tended to maintain their relative level of typing speed and accuracy regardless of the keyboard configuration they were using. It was also found that the recovery of original levels of typing speed and accuracy was a function of the number of key reversals on the modified typewriter. Many researchers regard the changes that occur to typing speeds and error rates as the most prominent aspects of habit interference between different keyboards. This has important implications with regard to the reluctance by manufacturers to experiment with new keyboard layouts. Results also showed that the subject's usual typing speed on QWERTY was more predictive of his/her ability to learn to type on a modified keyboard than it was of his/her ability to make a successful immediate change from one keyboard configuration to another (Massengill, Gordon and Henry, 1975). This research suggests that it might be a feasible proposition to reverse the A and J keys, and perhaps the L and O keys, since the I and O keys also created problems for the typists.

3.3 Keyboard Design

When reviewing the keyboard research over the last 100 years, it becomes apparent that the emphasis for designing keyboards has moved from increasing speed of operation to reducing fatigue. The introduction of word processing equipment will further reduce the emphasis on speed, as it will be met by the use of sophisticated editing facilities provided by the software, for example, the automatic carriage return. Kinkead (1975) measured 7-8% savings in time using the automatic carriage return. Similarly a system which inserts RETURN codes when the space bar is hit at the end of the line will save a minimum of 250 milliseconds per line. The Kroemer, Duncan and Ferguson and Maltron keyboards of the 1970s have been designed to reduce the amount of discomfort experienced by the operator. The results of the questionnaire survey (Chapter 2) reinforce the experimental findings of Osanai (1968), Komoike and Horiguchi (1971), Ferguson (1971) and Ferguson and Duncan (1974) that the QWERTY keyboard is not optimal in design for the user to withstand many hours of typing. This is not surprising, since Sholes, Glidden and Soulé (1868) could not predict the impact their typewriter was going to have, and so did not design it for an individual to use all day.

The basic design of the typewriter has remained unchanged since its developmental stages. Results from the questionnaire survey and the findings of the Maltron keyboard experiment suggest the design of the standard QWERTY should be modified. In 1979, International Business Machines (IBM) proposed a contoured keyboard (see Figure 4.2). This was based on similar principles to previous keyboard designs with the keyboard being split into two, with keys of different heights. Perhaps of more significance than the keyboard design is the fact that it is possible to purchase a separate overlay device to be placed over an existing keyboard and hence create a contoured layout (Conway, 1979).

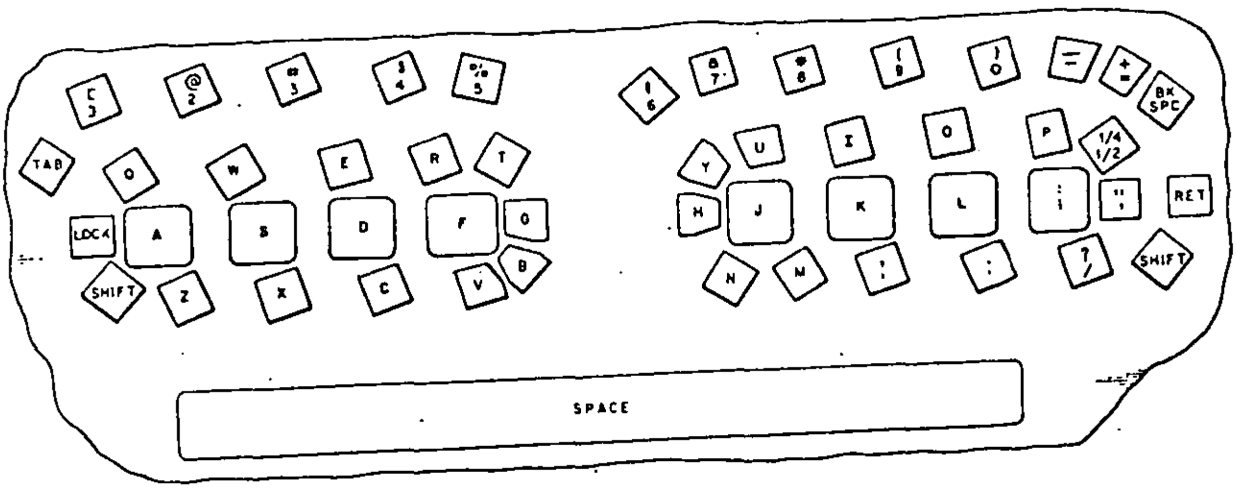


Figure 4.2: The Contoured Keyboard (August 1979)

3.4 Standardisation of Keys

Having discussed the future of the layout and the design of QWERTY, the third area which warrants attention is that of standardization. There were many requests by the skilled typists for more standardization of the punctuation keys. However it is unlikely that any changes of this nature will occur to the standard QWERTY keyboard. An example of the strength of tradition associated with this keyboard was the retention of the semi-colon on the home row of the American National Standard Code for Information Interchange (ASCII) keyboard. This recommendation was made by the U.S. Standards Group despite evidence that the semi-colon has a lower incidence of occurrence than the colon.

4. DIRECTION OF FURTHER RESEARCH

The history of alphanumeric keyboard research is important for three reasons. It places the present QWERTY keyboard into perspective, it demonstrates the lack of experimental work throughout the last century and it indicates the futility of continuing to develop new keyboard layouts. However further research and publicity is needed on keyboard design, and a follow-up study using the Maltron keyboard would be a beneficial exercise. A more elaborate analysis of beginner typists' errors and a study of the re-training of skilled typists on this keyboard could be carried out. Three professional typists attempted to use the Maltron keyboard during the previous study, and it was apparent from the large number of errors they were making that practice was needed.

There is scope for further researching the impact of exchanging keys on the keyboard. Such an exercise would require a thorough evaluation and comparison with other keyboards. However there are several problems associated with comparative keyboard experiments, and these could be listed as follows:-

(a) The length of the training period. Ideally training should be continued until further improvement is negligible, that is, until subjects have reached a plateau of performance. However it is often more realistic, due to the long time scales, to continue to a point where comparison can reasonably be made, and hence comparing improvement rates sometimes overcomes the problem (Conrad and Longman, 1965).

(b) Selection of subjects and the problems of defining non-typists. Hirsch (1970) tried to overcome this by suggesting that non-typists can be selected by taking those individuals who classed themselves as non-typists and who fell below a certain level of skill as measured by a pre-test.

(c) The need to have two groups of subjects with an acceptable justification for regarding them as matched.

(d) The problem of motivation. Keyboard comparisons are usually of long duration and the interest of the subjects needs to be sustained over this period, especially when the individual is learning a new keyboard which will not offer the benefits of training on a QWERTY keyboard.

The main finding from the review of alphanumeric keyboard literature was that all the research had been carried out after the QWERTY keyboard had become established. For example, what did Strong in 1956 hope to achieve from comparing the QWERTY and Dvorak keyboards? The Dvorak Simplified Keyboard had been in existence for over two decades and was still struggling to be recognised; the only justification for such an experiment appears to be curiosity. Because of the large amount of human effort already expended in researching sequential keyboards and because of the supremacy of the QWERTY keyboard, it would appear to be more worthwhile to research a less documented and established area - the chord keyboard.

The chord keyboard is in an embryonic state compared to the century old QWERTY keyboard and merits further attention and research to prevent a repeat of the 'QWERTY episode', where the first keyboard to be developed capable of practical work becomes recognised as the standard. In 1978, the late Dr. Christopher Evans stated that it was important, since we had time for foresight, to start looking at the best way to use chord keyboards. Otherwise they would be made by the billion and sold without any proper research being conducted into whether the product being marketed was a sensible one. There is the danger that chord keyboard development may proceed by a patchwork approach instead of looking ahead over the next couple of decades (Computer Weekly, 5th October, 1978).

5. 'THE KEYPEN CONCEPT'

In 1976, Professor Brian Shackel of Loughborough University made the following proposal. Since the QWERTY keyboard is unlikely to be replaced by a more efficient design, one way to overcome this problem and take a greater leap forward, would be to develop the equivalent keyboard input for general usage into any computer system. This device would have in effect the characteristics and therefore would achieve the ubiquitous acceptance of the pen or pencil. Hence the concept of the need for a 'keypen'. The shape might be very different and could perhaps take the form of a small three-dimensional object with suitable gripping holes for the thumb and touch pads or keys for finger operation.

The success of this concept would depend upon the research achieving a truly optimised layout and general form. If successful, then children would learn to use the device at the same time as learning to use a pencil. Only when the majority of individuals have achieved the same degree of skill as they now have with a pen can complete 'unthinking' Man-computer interaction be expected to develop. It is hypothesised that it would be easier for children to learn to use the keypen than the complexities inherent in learning to write conventional letter characters.

6. CONCLUSIONS

The following conclusions were reached from the literature review and appraisal of the current 'state of the art'.

1. The situation with regard to the QWERTY keyboard is not satisfactory. It could be improved by attention to the following aspects.

   (a) The reversal of some of the keys, for example, the 'A' and 'J' keys.

   (b) Modification of the design of the keyboard.

   (c) Increased standardisation of the punctuation keys.

2. It is intended not to carry out any further research into sequential keyboards, because

   (a) This area has been thoroughly researched in the past.

   (b) The QWERTY keyboard is well established and unlikely to be replaced by another sequential keyboard.

3. (a) The field of chord keyboards is still in its developmental stages and requires much research.

   (b) The concept of the keypen needs to be investigated more fully.

PART II:

THE CHORD KEYBOARDS

CHAPTER 5

A LITERATURE REVIEW OF CHORD KEYBOARDS

1. INTRODUCTION

In order to investigate the concept of the keypen, it is necessary to conduct an extensive review of the literature on chord keyboards. This will enhance the thoroughness and direction of future work. It has been established from the preceding chapters that the standard QWERTY keyboard is usually adopted as the standard Man-computer link. However the chord or 'multipress' keyboard may be a useful alternative for some systems. As the term suggests, one or more fingers are needed to key a single character. In its simplest form, a chord keyboard would consist of five keys, one for each finger and the thumb. Such a device would enable 31 different characters to be transmitted. If a second thumb key is added, this increases the number of alternative chord combinations to 47. It is possible with a two-handed chord keyboard to make available 1023 different combinations.

When considering keyboard systems, the rate of entry of information appears to be highest when using chord keyboard systems (Ratz and Ritchie, 1961). Seibel (1964) discussed this aspect of speed in relation to the 'information theory'. For example, if all N keys of a sequential keyboard are used, an upper limit of log N bits of information per keystroke can be transmitted. Utilising all possible chords of a N-key keyboard ($N \leq 10$) allows an upper limit of just under $N(\log_2(2^N-1))$ bits per chordstroke. If more fingers are used and more than one key is controlled by each finger even larger amounts of information may be entered with each chord keystroke. Therefore a chord keyboard of 10 to 20 keys permits the entry of more than twice as much information per stroke as can be achieved with a 40 key single stroke keyboard such as the typewriter.

A 'very good' typist (100 words per minute) enters approximately 8·3 strokes per second, whereas a stenotypist of equal calibre (200 words per minute) enters approximately three chord strokes per second. Therefore, the information rates are in the ratio 2:1, while the stroke rates are in the ratio 3:8·3.

The stenotypist is entering 5·6 times as much information per stroke as the typist. Hence it can be concluded that chord keyboards allow the entry of larger amounts of information per stroke, although the stroke rate is lower.

2. BRIEF HISTORY OF CHORD KEYING UP TO 1970

2.1 The Printing Industry

Early printing keyboard designers attempted to provide a chord keyboard with the characters in the correct sequence for common digrams and trigrams. In 1879, Wicks arranged the alphanumeric keys in two parallel rows (see Figure 5.1) thus enabling 34 logatypes to be obtained on this keyboard. (Phillips, 1968). The Unitype chord keyboard was a further attempt to devise a keyboard that would be operated by pressing groups of keys. It was not based on a statistical analysis of digrams and trigrams, but on the hypothesised advantages of bringing common logatypes such as 'the' and 'and' together (see Figure 5.2).

However the chord approach was abandoned in favour of a sequential arrangement. Legros and Grant (1916) stated that the problem with chord keyboards was the number of transposition errors produced. The time saved through making chord pressings was lost because of the time required for error correction. It is interesting to note that Legros and Grant did not mention that the keyboard operators found it difficult to generate the chords.

2.2 Early Attempts at Chord Keyboard Design

A patent for a mechanical chord typewriter was requested by Achille Colombo in 1942. This worked on the principle of one left-hand and one right-hand key being pressed simultaneously to type a letter. However no further details of this device are available and it is thought that the machine was never marketed (Conrad and Longman, 1965).

NOTE:

Part of this chapter was published by the author in an Infotech DP Management Report, "Communication Interfaces", Report III - 18 (1981), Infotech Limited, Maidenhead, England.

A S G ; ' b v w q l y x f k ff fi ffi fl ffl :) - ? ! B C D E F H J K L N £ 1 2 3 4 5

, sp M s t p r c h a e i o u m n g d j z . qd I T O P Q R U V W X Y Z - 6 7 8 9 0

Figure 5.1: Wick's Composing Machine Chord Keyboard (1879)*

½) Q W C I O U M F Y 9 6 3 ffl

¼ (J B R A N D S G X 8 5 2 ffi

⅛ V K P Z T H E L $ 0 7 4 1 ff

⅜ ¼ q w c i o u m f y z - fi fl

⅝ & j b r a n d s g x , ' . !

⅞ - k p v t h e i sp qd , , ?

Figure 5.2: The Unitype Chord Keyboard (1898)*

* Both these keyboards are quoted in Phillips (1968).

One of the first chord keyboards to be developed was by Dvorak. During the 1930's, he concentrated his efforts on producing a sequential keyboard, the 'Dvorak Simplified Keyboard' to challenge the ever-increasing popularity of the QWERTY layout. But in 1950, Dvorak reported a keyboard for one-handed operation. Unfortunately no further information concerning the design or application of this keyboard has been located (Seibel, 1972).

2.3 Chord Keyboards in the Post Office

In the formative years of chord keyboards, their development was mainly concerned with systems for the sorting of mail. The Canadian, American and British postal services experimented extensively with the use of chord keyboards. Levy (1955) was one of the first to describe a 10-key 'binary' keyboard consisting of two 5-key keyboards (see Figure 5.3). By pressing the correct combination of keys, each hand coded a letter. Three female subjects were trained for three hours daily over a period of 28 weeks, by which time they had all reached chord pressing speeds of 70 words per minute. The practice material was four letter code lists, and for comparison the same lists were also typed by a good average typist. Her ceiling speed was 95 words per minute. When calculating the speed of the typist, Levy used the criterion of four letters per word, compared to the standard, widely accepted five letters. The skilled typist was therefore typing at a speed of 76 words per minute; this allows direct comparison with the chord keyboard operators. No experimental details or accuracy data were available about this study. It is well-known that there is a trade-off between speed and accuracy, and comparing typing speeds is a fruitless exercise unless error data are available. The main disadvantages of Levy's experiment (apart from the fact that one control subject was totally inadequate) included the introduction of independent variables through having two different keyboards and hence two different training programmes.

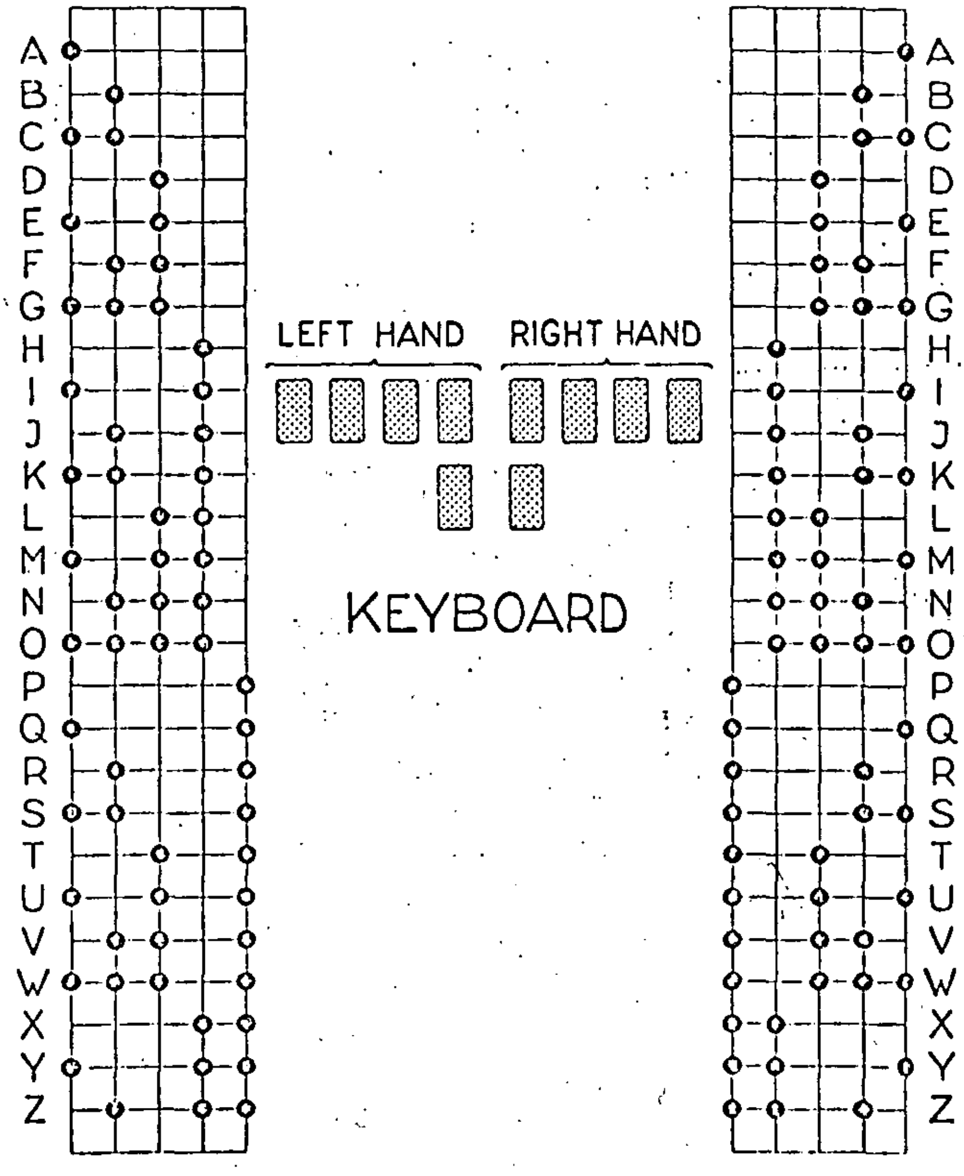


Figure 5.3: The Levy Keyboard (1955)

Five years later in 1960, Conrad reported a letter sorting machine involving simultaneous depression of two keys (one by each hand) in order to sort letters into one of 144 possible destinations. Each hand had one of 12 keys to select, which were arranged in two rows of six keys. Sorting rates improved from approximately 35 sorts per minute to about 60 sorts per minute over the practice period of nine months.

Cornog, Hockman and Craig (1963) reported a study of their 'double-binary' chord keyboard, which was used in America for the sorting of mail (see Figure 5.4). Keying on this keyboard produced a binary code, which was fed into the computer and it has been suggested that the keyboard was inappropriately named 'double-binary'. The keyboard training console consisted of four banks of six keys, an arm-rest bar and a panel of lights. After 36 weeks of practice, the experimental results suggested that the keyboard was a satisfactory proposition for mail sorting, and no significant performance differences were found between different kinds of code, between having or not having speed-reading training, between various age groups, or between the two sexes. It is not clear however what criteria for satisfaction were adopted. Cornog et al. concluded that this keyboard was satisfactory in providing a medium for computer input.

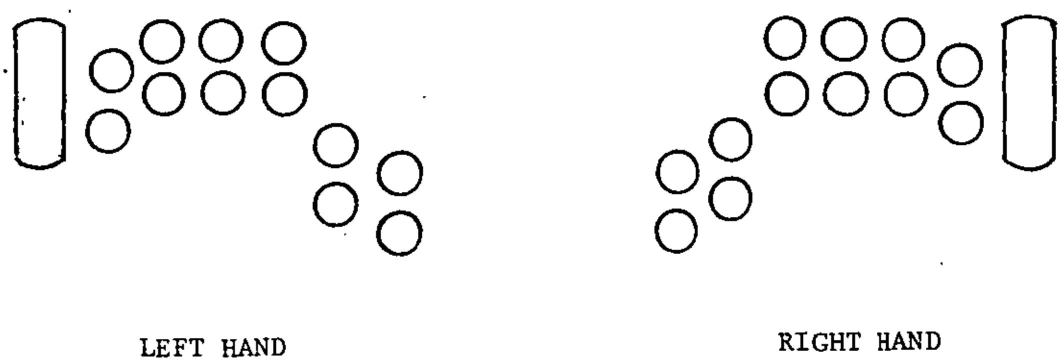


Figure 5.4: The Double-banked Binary Keyboard (1963)

Two years later, Cornog and Craig (1965) described several chord keyboards for use in mail sorting. These included the Burroughs keyboard, the Levy keyboard, the so-called FMC keyboard, and the Sack Sorter keyboard. The Burroughs keyboard consisted of 10 piano-like keys, which enabled mail to be sorted to 3000 destinations. Two hundred and seventy-nine chord combinations were assigned to numbers, which represented the 3000 destinations. The average output was about 45 chords per minute with a 2% error rate.

The Levy keyboard was mounted on a training console, which provided feedback of results. Error rates were low (about 1%). In comparison, the FMC keyboard had two banks of 12 keys, which were in a mirror image to each other. It was found that two-handed operation of this keyboard was about 25% faster than one-handed. The fourth keyboard, the Sack Sorter, was a specialised keyboard with a 10-key adding machine layout. However, comparison with the other three keyboards was not justified since speed of keying was not a critical factor in the sorting of mail sacks. The authors concluded that the FMC was faster than the Levy keyboard for comparable error rates of about 1½% when processing city mail. For outgoing mail, the output was substantially greater for the FMC, that is, 39 words per minute compared with 27 words per minute. The error rate for the former keyboard was more than double that of the Levy at 2.2%. However, due to variations in the training periods (the FMC keyboard operators spent five weeks longer training) it was not possible to draw any firm conclusions from the results.

2.4 IBM Chord Keyboard Developments

There have been other chord keyboards devised besides those involved with mail sorting. As long ago as 1958, IBM produced a 10-key chord keyboard with five keys arranged in a semi-circle for each hand. Klemmer allotted the most frequently occurring letters in the English alphabet (that is, A D E H L N O R S T) to single keys, while other characters were represented by depressing two of the ten keys. Klemmer trained two subjects on his keyboard, one of whom was a skilled touchtypist. He found that after 40 hours of training, the typist had reached a speed of 47 words per minute with a 0.3% error rate, compared with 29 words per minute and 0.7% errors for the naive typist. It was concluded that the learning curves for the acquisition of chord keying were comparable with those expected on a conventional typewriter.

In 1959, IBM carried out an evaluation of an 8-key word writing typewriter. This keyboard consisted of four keys arranged in an arc and allotted to each hand. The thumbs were redundant.

Four subjects trained for 50 sessions lasting 50 minutes each. They were taught to enter 100 common words with a single chord keypress, the 35 alphanumeric chords and two punctuation marks. The 92 most frequently occurring words in the English language were chosen from Thorndike and Lorge's (1952) word list. Eight nouns were added to this list and each word was assigned a pattern using between three and seven fingers (one and two finger patterns and the eight finger pattern being reserved for letters, numerals and punctuation). The 137 chord patterns were learned in less than 30 hours, and word patterns were entered at a rate of between 36 and 45 words per minute. Results obtained with this keyboard were not as good as with the 10-key keyboard, because simultaneous pressing of several keys was required as more chord combinations were involved (Lockhead and Klemmer, 1959).

2.5 Review of Other Chord Keyboards

Webb and Coburn (1959) designed a 'hand-configured' keyboard with three curved rows and five straight columns of keys. The prototype keyboard had the following features:

(a) A keyboard tilted at an angle of 12^{o} from the horizontal.

(b) A compact key arrangement for operation with finger movements only, that is, no gross motor movements.

(c) Four keys grooved to differentiate them from the others and identified as the 'home keys'.

(d) Three dividers to aid the operator to locate the home keys by touch.

The rows were curved to conform to the pattern of finger tip spacing for a relaxed hand. Webb and Coburn intended that this 16-button keyset should be operated with the left hand (the operator's right hand would be needed to operate a track ball), without visual guidance and for long periods of time.

A second keyboard was built with the keys in a 4 x 4 matrix and an experimental comparison carried out. Six subjects were used and results showed superior performance in terms of speed and accuracy, and preference for the hand-configured keyboard.

After an extensive statistical analysis of letter, digram and trigram frequencies, Ayres (1965) patented his word writing machine. This device was designed for chord keying and the keys were so arranged that they could be operated simultaneously. Typing worked on the principle that letters would be selected from each vertical column of five characters from left to right across the keyboard. By selecting these initial consonants, intermediate vowels and final consonants, theoretically whole words could be printed with one stroke of the keys (see Figure 5.5).

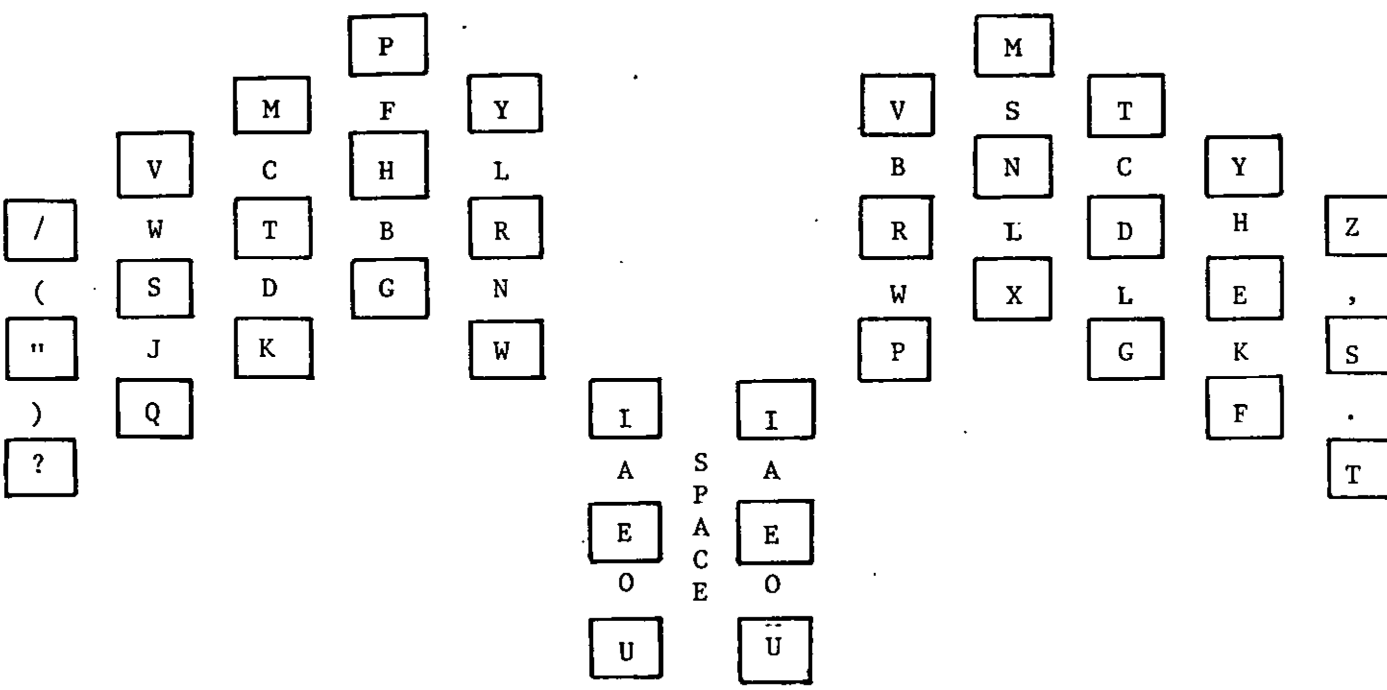


Figure 5.5: Ayres' Word Writing Machine (1965)

However as with most chord keyboard developments, no evaluative work was carried out and apart from the U.S. Patent No. 3,225,883, no other publication of this work has been located.

In April 1966, a five button keyboard was developed for one hand entry of alphabetic information. Data were only reported for one subject (Englebart the designer) who eventually reached 35 words per minute. Little information is available about this keyboard, although it is known that it took 10 hours for Englebart to reach a speed of 10 words per minute.

After training he was able to type at a speed of 35 words per minute with his right hand and 25 words per minute with his left (Barmack and Sinaiko, 1966).

Englebart and English (1968) reported a system which used the 5-key handset for entry of control codes. They concluded that one-handed typing with the keyboard was slower than two-handed typing with the standard keyboard, but that enough skill could be acquired within five hours of practice to make using the keyboard a worthwhile exercise.

Amann and Klerer (1967) described an 8-button keyboard, which they developed at Columbia University. Depressing one of the eight buttons caused the device to emit a serial string of parallel eight-bit codes. This resulted in a set of typing actions in an input/output typewriter terminal. No evidence of any research has been found concerning this keyboard.

One of the most comprehensive studies of chord keyboard design was carried out by Hillix and Coburn (1961) at the Navy Electronics Laboratory (NEL). They compared seven different designs of keyset and used time and error measures combined in a single performance index to indicate the number of bits of information that were being transmitted per second. The keyset units are shown in Figure 5.6. No significant differences were found between the 8, 16 and 32 patterns per hand and Hillix and Coburn found that "practised subjects took no longer to 'encode' octal or decimal stimuli on binary keys than to enter binary digits on binary keys or decimal digits on decimal keys". This indicated that keysets relying on position are not always superior to those based on patterns.

General conclusions made by Hillix and Coburn were as follows:-

(a) "The design of keysets for high information transmission rates must be based on a thorough analysis of the human keysetting processes involved in the particular situation for which the keyset is intended".

(b) "Within fairly wide limits, the physical features of keyset design, for example, key sizes and pressures, are less important than those features that relate to continuity of the process".

(c) "Speed and error properties of keysets are related through operating curves: keyset operators can trade speed for errors".

(d) "Patterned pressing in some situations yields transmission rates as good as the traditional sequential pressing".

(e) "Simple encoding tasks may be carried as part of keyset entry without slowing the overall process".

Hillix and Coburn recommended that:-

(a) "Keyset designers should consider a wider range of entry devices including those using patterns of presses which may result in a saving of time and money".

(b) "Experience with a keyset in one situation should not result in the design being labelled 'good' or 'bad' - the keyset should always be judged with respect to that particular situation".

(c) "Keysets should also be designed for trained operations, as those designed for the naive users are likely to be inefficient and rigid".

(d) "The maximum potential of the keyset as well as its simplicity and initial ease of operation should be evaluated".

Hillix and Coburn (1961) concluded that the aims of the chord keyset were to be flexible, efficient, cheap and to transmit information at a comparatively high rate. They suggested that the ideal keyset should have the following optional features incorporated into the design. These included a touch operation facility, a hand-configured layout, provision for two-handed operation with maximum alteration facility, provision for individual character error correction and an easy-to-learn operating procedure. A typical chord keyboard does not have many of these features and, for the occasional user, operating instructions and extensive feedback mechanisms would have to be provided for such a keyset to be successful.

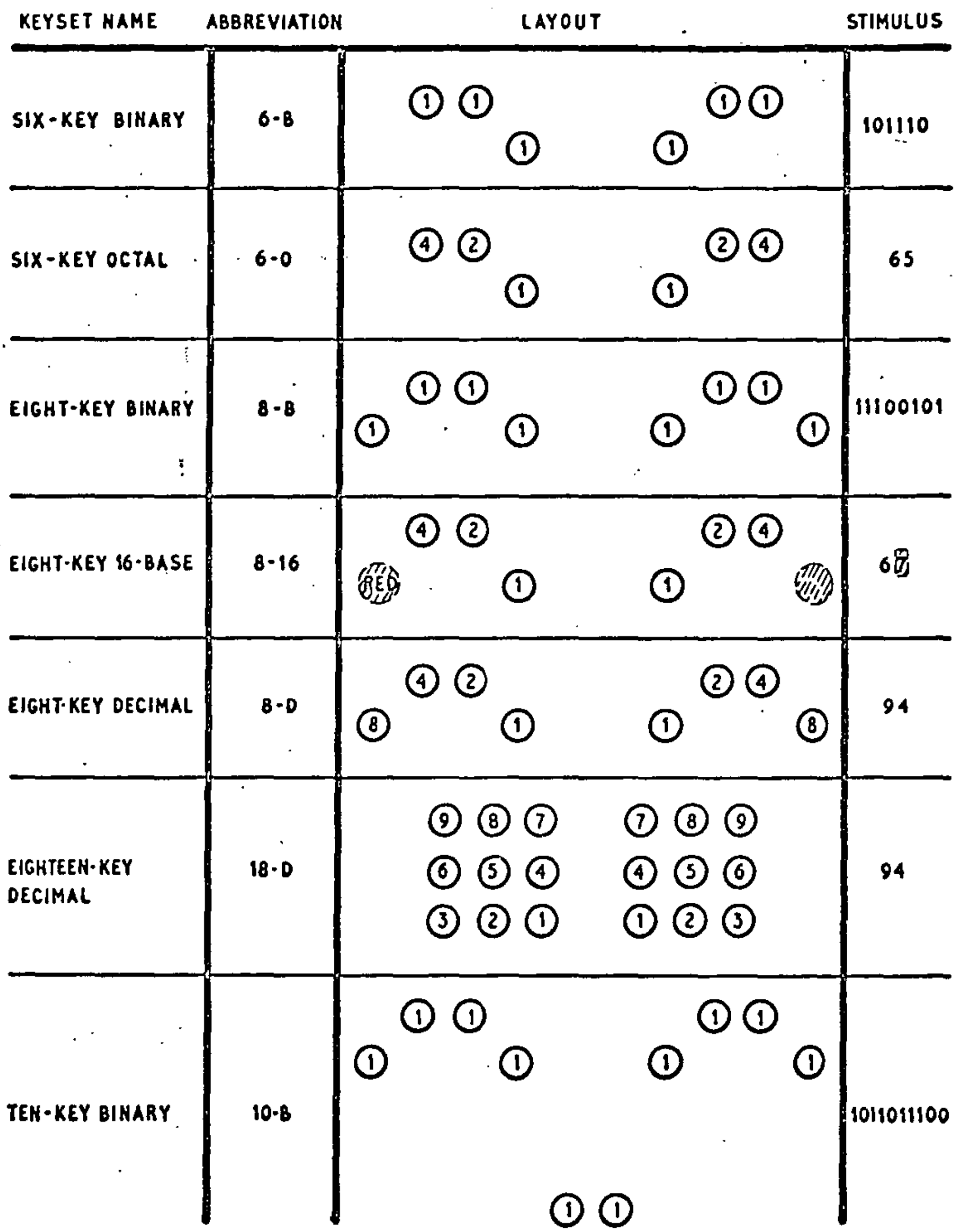


Figure 5.6: Keyset Units used by Hillix and Coburn (1961)

3. EXPERIMENTAL COMPARISONS OF SEQUENTIAL AND CHORD KEYBOARDS

3.1 Discussion of Methodology

There are several methodology problems to be cons[illegible] when designing an experiment to compare a sequential and a [illegible] keyboard. One of the most important aspects is motivation: sub[illegible]ts learning to operate a chord keyboard are unlikely to be as h[illegible] motivated as individuals learning to type on, for example, a [illegible] keyboard. At the present time, reducing the imbalance between the incentives of learning to key appears to be an insurmountable problem. Other aspects include the nature, content and length of the training programme and the instructor. These could be listed as follows:-

(a) The two groups of subjects must be matched with regard to the qualities considered to be relevant to the study. Since naive sequential keyboard users, unlike naive chord keyboard beginners, are likely to be familiar to some extent with their keyboard layout (especially if QWERTY is being compared), some experimenters have administered a typing pre-test and discarded those individuals who attained a certain level of skill (Hirsch, 1970).

(b) The groups should be trained either by the same instructor or 'matched' instructors.

(c) All subjects must receive the same amount of practice, and whenever possible the training material for the two groups should be kept constant. Conrad (1961) has shown that the nature of the practice material can be a major factor in determining keying speed. This latter requirement provides a major drawback when comparing sequential and chord keyboards, because it is not possible to standardise the training programme.

(d) Improvement on keyboard tasks has been shown to continue for a year or more (Conrad, 1960; Klemmer and Lockhead, 1962), so the problem arises of when to cease training. Ideally, training should be continued until further performance improvement is negligible, that is, until subjects have reached a plateau of performance on each keyboard being compared.

However, if performance is compared at the nth week, besides there being problems deciding the nth week, the subjects will register an improvement by the (n + 1)th week. Thus it can be shown that there are many experimental difficulties associated with keyboard training experiments comparing sequential and chord keyboards.

3.2 Brief Review of Experimental Work

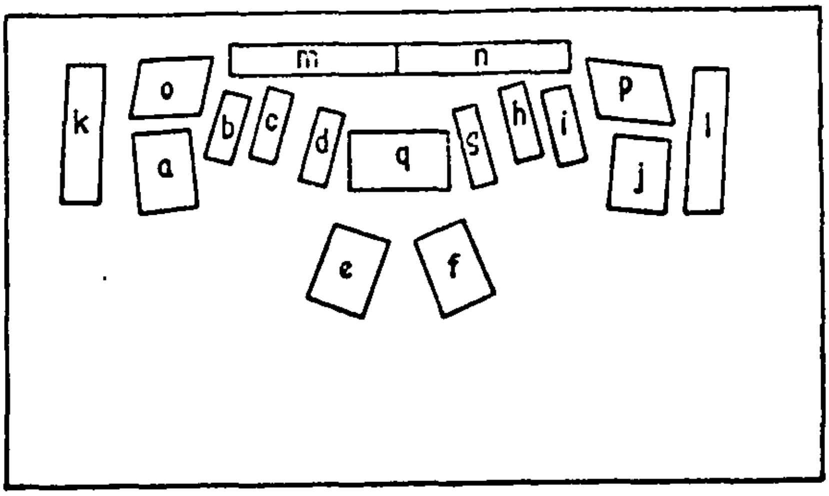
In 1955, Levy carried out an experiment comparing the performance of three chord keyboard operators and a standard keyboard typist. However due to the small number of subjects, and lack of performance data, this study warrants little merit and minimal interest.

Ten years later in 1965, two studies both concerned with the coding of mail for electronic sorting at the Post Office were carried out. Conrad and Longman compared the performance of two groups of postmen on a chord and a sequential keyboard. The chord keyboard is shown in Figure 5.7.

The keyboard has ten 'home' keys, which are depressed in pairs using the left and right hands. Fifty milliseconds was the time allowed to depress the two keys, and if more keys were depressed or the 50 milliseconds time ran out, an error was registered. Both these situations did not arise with the standard keyboard.

Postmen in the 30-40 years age group were subjects for the experiment and 24 were randomly allocated to the typewriter group and 22 to the chord group. No subjects had prior typing experience. They received training for three and a half hours daily, five days a week for seven weeks. This seven week course took place on four occasions making the total length of the experiment about ten months.

Conrad and Longman discovered that the group using the chord keyboard became 'operational' about two weeks earlier than the standard typewriter group, that is, in two weeks instead of four (31 hours instead of 73) and after that their improvement rates could be regarded as parallel.



a + f = A	l + a = 1
a + g = B	l + b = 2
a + h = C	l + c = 3
a + i = D	etc.
a + j = E	k + f = 6
b + f = F	k + g = 7
b + g = G	k + h = 8
etc.	k + i = 9
	k + j = 0

Figure 5.7: Conrad and Longmans' Chord Keyboard Layout (1965)

While Conrad and Longman were experimenting at the British Post Office, Bowen and Guinness (1965) were investigating chord keying with the aim of designing the optimal keyboard for sorting mail in the United States. They reported some pilot experiments comparing the chord keyboard with a standard sequential keyboard for two types of encoding - 'memory' coding (learning a large list of paired associates) and 'extraction' coding (applying basic rules of extraction to provide a different code for each address).

A chord keyboard with few keys generally demands many keys per stroke. For both sequential and chord keyboards, there is a trade-off between the number of keys required to be struck in order to type a given amount of information and the total number of keys on the keyboard. Smaller keyboards require fewer lateral movements of the hands and fingers than large keyboards. A small keyboard usually entails making more difficult finger movements which could result in increasing the keying error rate. Bowen and Guinness experimented with two chord keyboards having 12 and 24 keys each, and a standard typewriter keyboard (see Figure 5.8).

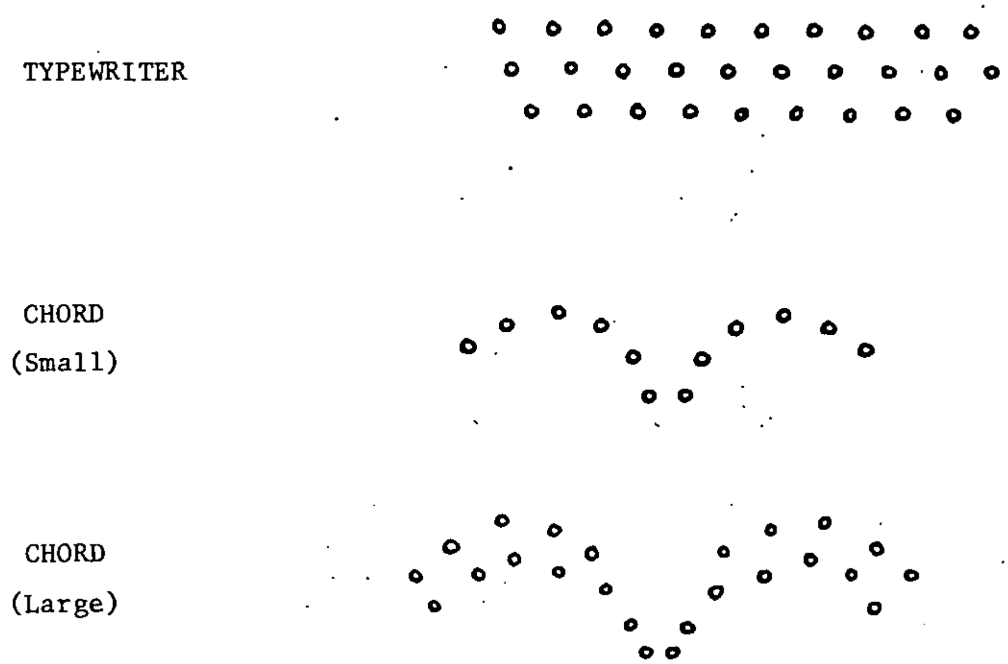


Figure 5.8: The Three Keyboards used by Bowen and Guinness (1965)

The material that the subjects typed consisted of three digit numbers. Bowen and Guinness experimented with the three keyboards for both types of encoding. The first study used encoding as follows: for the typewriter, two keys depressed sequentially; for the small chord keyboard, 1, 2, 3 or 4 keys depressed simultaneously; for the large chord keyboard, 1, 2 or 3 keys depressed simultaneously. It was concluded that the large keyboard was preferable although it was slower than the small chord keyboard by 6·3 encodings per minute, it was more accurate by 4-5 encodings per minute. This finding can be explained by the trade-off that exists between speed and accuracy of keying.

The higher speeds obtained with the smaller keyboard produced more errors. In general, large keyboards also have advantages in that they do not require such difficult finger patterns.

The second study was concerned with 'extraction' coding and only the standard typewriter and the large keyboard were used. It was found that there were no significant differences with regard to speed and accuracy of sorting between the keyboards. Bowen and Guinness concluded that the chord keyboard was preferable to the sequential keyboard for mail sorting in the Post Office.

4. CHORD KEYBOARD DEVELOPMENTS WITHIN THE LAST DECADE

4.1 Introduction

Between the years of 1950 and 1970, the majority of chord keyboards developed were for specific tasks such as mail sorting. Only IBM explored the possibility of using a chord keyboard in place of a sequential layout, and hence they called their inventions - the 10-key typewriter and the 8-key word writing typewriter. Throughout the last decade, rapid electronic advances have been made and a trend towards personal computing has begun to develop. This manifested itself in part by the pocket calculator, which soon became ubiquitous amongst school children. Hence it is not surprising that the chord keyboard has come under review and been developed with the view to being a personal connection to the computer for general use.

4.2 The ANTEL Chord Keyboard

One of the first researchers to recognise the potential of the chord keyboard was Tom Stewart, who in 1973 patented the ANTEL chord keyboard. This device was basically a 12-key keyboard (see Figure 5.9), which was operated like a sequential keyboard, when one of the 12 keys was depressed and as a chord keyboard, when an appropriate chord or group of keys was depressed simultaneously. The letter A is obtained by pressing the key labelled A, while B is obtained by pressing the keys A and C. It is possible to press up to four keys with one finger, due to the compactness of the keyboard. The letters G and I would be obtained in this way.

The advantages of this keyboard include the following:-

(a) Only 12 keys are necessary to provide a full alphanumeric keyboard generating up to 39 characters.

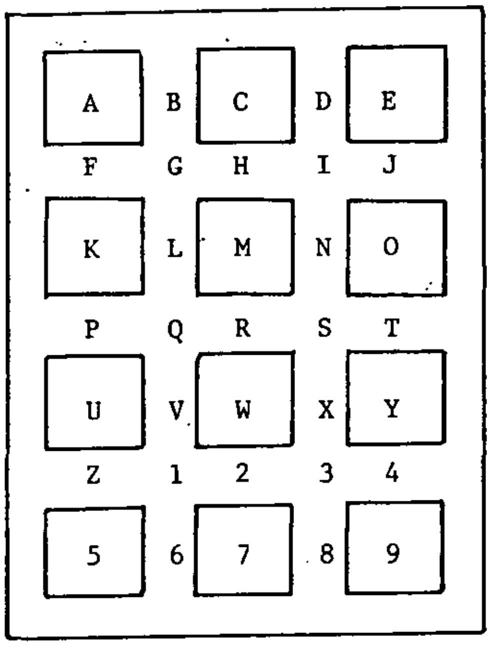
(b) One handed operation is possible.

(c) The compactness of the design results in a reduction of the number of hand movements without incurring higher mis-keying rates.

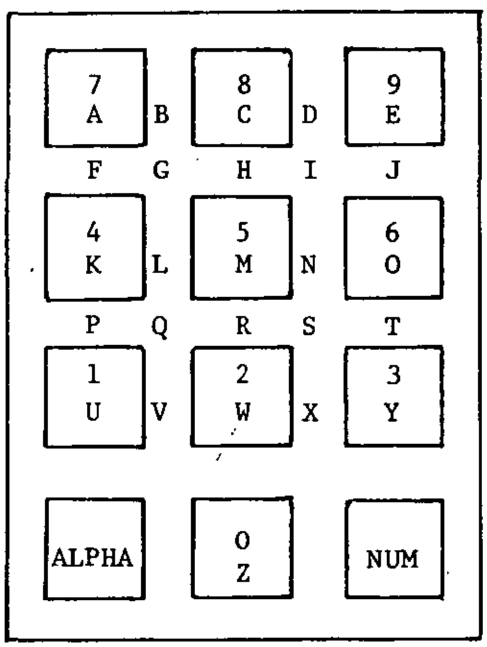
(d) No previous training is required.

(e) The simplicity of the chords avoids overloading the user's short term memory.

(f) The design facilitates clear graphic labelling which is likely to assist understanding and acceptability for new users.



35 clearly labelled functions.



Possible calculator or computer version.

Figure 5.9: The ANTEL Chord Keyboard (1973b)

4.3 The Writehander

Within the last three years, three chord keyboards have been developed. In January 1978, details of a chord keyboard called the 'Writehander' were published in Interface Age (Owen, 1978). The Writehander was originally conceived and developed for physically handicapped people.

It is operated by one hand, leaving the other one free perhaps for some other function. The hand chosen to carry out the keying rests on the half sphere with the four fingers resting on their own keys; the thumb has eight keys (see Figure 5.10). As each finger only operates one key, this reduces the likelihood of mis-keying. Unlike the conventional typewriter keyboard, the thumb is used extensively. This is logical since the thumb has a greater range of movement, and a larger part of the brain controlling its use (Haaland, 1962).

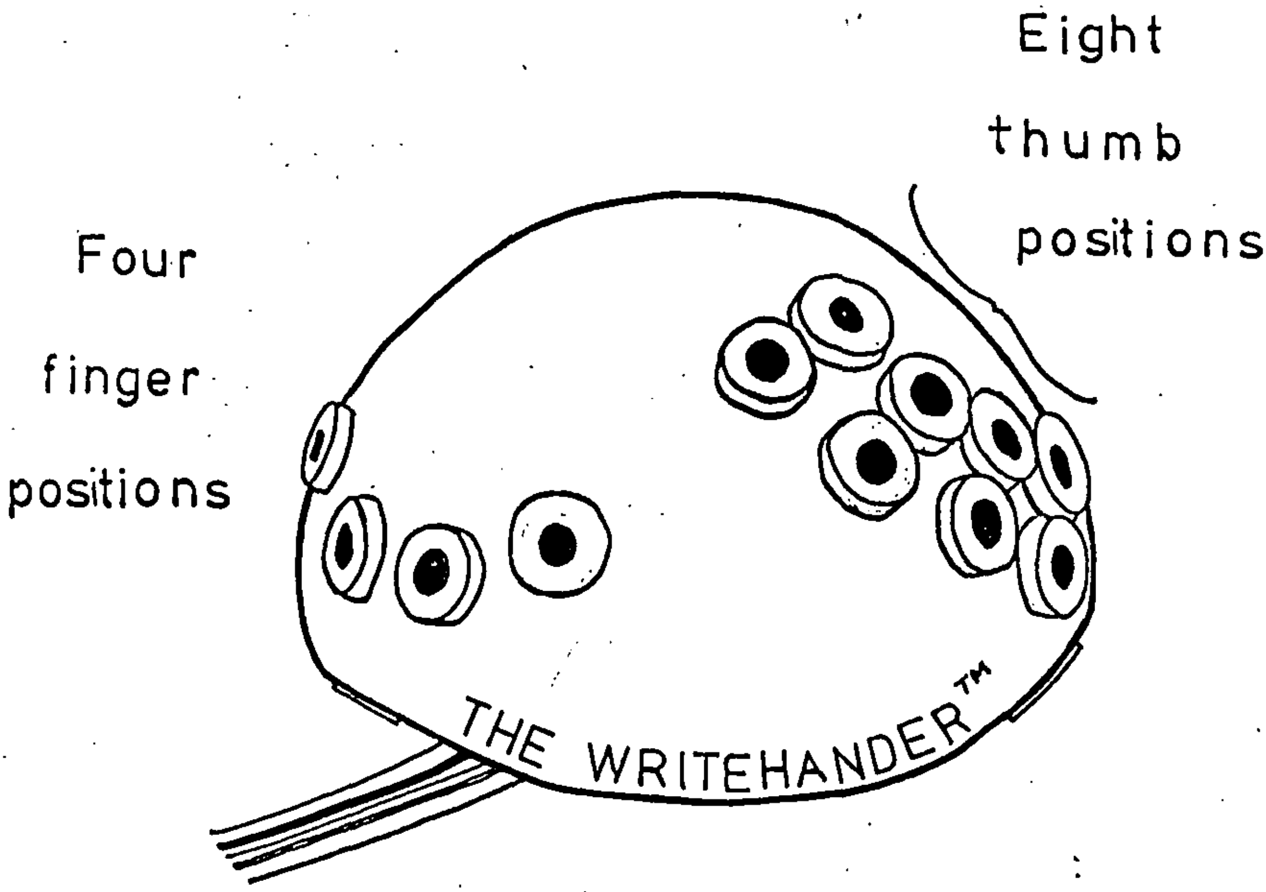


Figure 5.10: The Writehander (1978)

The thumb is the only digit to change position and hence it controls the selection of control characters, numbers and symbols, lower case letters and capital letters. During keying, the fingers never move from their single keys - they simply press or relax the keys, while the thumb rocks forwards and backwards to close one of two switches. By using various combinations of fingers and thumb the Writehander generates the entire 128 characters of the ASCII code. Although the Writehander has been evaluated by the Post Office, no details of this investigation are available.

4.4 The Microwriter

The Microwriter is a portable, battery operated, chord keyboard about the size of a medium-sized electronic calculator. There are five basic keys (one for each finger and thumb), plus a key which controls functions, enters figures, punctuation marks and editing control, and a key for entering capital letters (see Figure 5.11). There are 16 editing functions including back-space, insert, delete, etc.

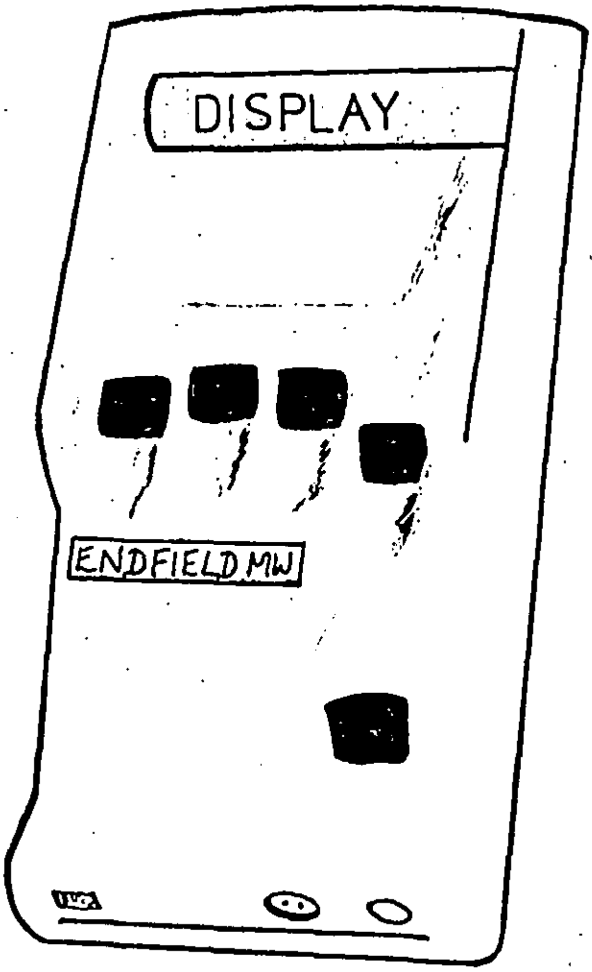


Figure 5.11: The Microwriter (1978)

The Microwriter has a single line 16-segment LED display of up to 12 characters. The text is recorded in the machine's 8K byte memory, which is able to store up to 8000 characters. Extra storage can be provided on cassettes. The Microwriter does not itself produce words on paper, but plugs into an electronic typewriter, or television set, or computer system. No published evaluation of this keyboard is available.

However, Endfield (the inventor) claims that learning to use the Microwriter takes about 30 minutes, and after one to two days useful work could be carried out on it, and after three to four weeks a reasonable level of skill could be attained. Endfield also claims that after using the device for a period of seven months, he was keying at a speed of about 40 words per minute (Sunday Observer, June 18, 1978).

4.5 The IBM Chord Keyboard

For the last five years, IBM have been developing a chord keyboard for one-handed operation (Rochester, Bequaert and Sharp, 1978). The right-handed chord keyboard is shown in Figure 5.12. It has a five by two array of square keys operated by the fingers and a row of four rectangular keys operated by the thumb. The finger keys have rounded depressions, called 'dimples'. The IBM chord keyboard works on similar principles to the ANTEL keyboard (Stewart, 1973b). If the B dimple is pressed, two keys go down and a B is typed, while depressing the W dimple results in four keys being pressed and a W being typed. The keyboard consists of 27 dimples, which allows the full alphabet to be typed.

The IBM keyboard differs from the Writehander and Microwriter in that a three finger chord would produce a string of three letters. The dimples have been arranged so that the fingers can produce common trigrams such as 'the' in one key-pressing. The little finger is redundant since it does not function well independently from the ring finger.

The thumb has a separate keyboard consisting of seven troughs, and as 'no response' from the thumb is a valid action, the thumb has eight possible positions. The following example of a typical sentence demonstrates the chords to be formed.

/l/n/ thi/s/ se/g/me/nt/ of/ te/xt/ the/ cho/rd/ bo/und/ar/i/es/ ha/ve/ be/en/ s/ho/wn/ by/ li/ne/s.

The Writehander and Microwriter are traditional chord keyboards where patterned pressing of keys results in single characters being emitted. The IBM chord keyboard, on the other hand, has many of the features of a stenographic keyboard. Therefore, higher keying speeds would expect to be reached. A good stenotypist can reach typing speeds of 3·3–5·0 words per second (Turn, 1974).

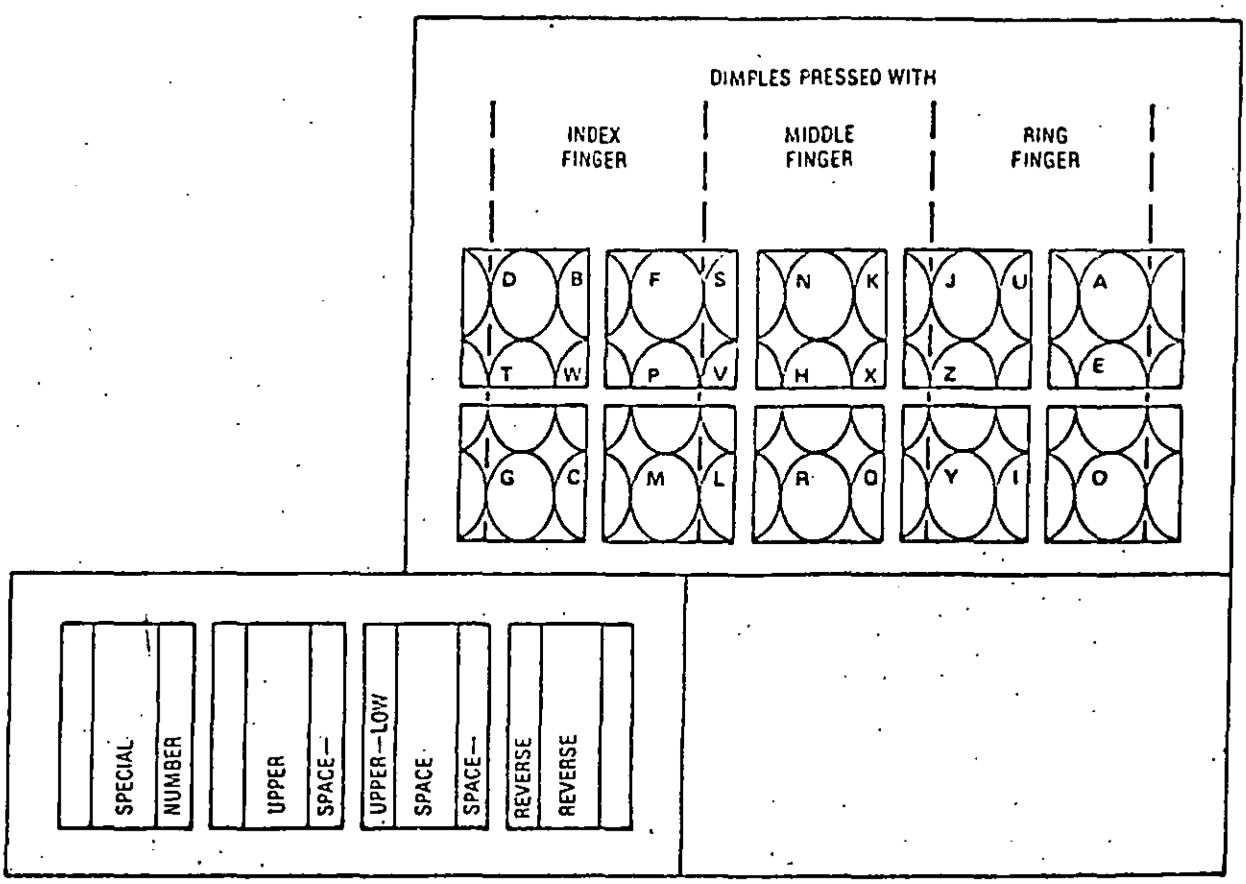


Figure 5.12: The IBM Chord Keyboard (1978)

5. CHORD KEYBOARDS - AN APPRAISAL

The feasibility of using a chord keyboard as a data entry input device was first seriously investigated in the mid-fifties. The trend towards research into chord keying reached a peak around 1960, and it is interesting to note that at the end of the sixties there were no commercially available chord keyboards. Following the impact of the micro-processor revolution and the technical ability to reduce the size of the electronic components of keyboards, the chord keyboards returned to the market place in the mid-seventies. Although four chord keyboards have been developed within the last decade, it is apparent that there is a lack of fundamental research into chord keying. Ratz and Ritchie (1961) and Seibel (1962) have been the only individuals to lay the foundations for some basic fact-finding research into chord keyboards. Other keyboard designers have continued a similar trend to that developed by sequential keyboard inventors. Namely, the only preliminary investigation into their chord keyboards has taken the form of an evaluative study after they have been developed. The lack of experimental work in this field coupled with the minimal amount of research by chord keyboard inventors suggests that more effort should be concentrated in this area. As long ago as 1963, Pollock and Gildner suggested research into chord keying, before enthusiasm for a new and novel input technique led to improper incorporation into a computer system. A repeat of the QWERTY keyboard situation should if possible be avoided.

One of the primary characteristics of the chord keyboard is that the individual has to learn and to remember the various chords in order to be able to operate the device. It is immediately obvious with a sequential keyboard how to type any word, which has advantages for the naive or occasional user. Once this initial hurdle of learning has been overcome, the chord keyboard should allow much faster speeds to be attained. Since there is no group of skilled operators other than those trained for specialised tasks, it has not been possible to carry out a controlled study to support this hypothesised increase in speed.

A second requirement of a chord keyboard concerns the allocation of the alphanumerics to the various chord combinations. This task is equivalent to arranging the letters in a sequential keyboard layout. The optimum way of choosing the alphanumeric-chord combinations has yet to be decided. This area warrants further investigation.

There are several theoretical advantages associated with a chord keyboard. The relatively small number of keys necessary to produce a full alphanumeric set allows the device to be very compact and hence easy to transport. For example, the Microwriter could be used whilst travelling, when writing or dictation would not be feasible. As with many other writing devices, a chord keyboard provides several opportunities for disabled individuals. A recently televised case study was suggested to demonstrate the benefits that the Microwriter could provide for the handicapped. A haemophiliac boy had learned to use the device because it was stated to reduce the likelihood of injury when compared to a typewriter. Endfield (1978) suggested that it was easier to learn to type fast on his device than to learn touchtyping, because the fingers never have to move between the keys.

Chord keyboards are still a novelty and whereas executives and office staff would not want to learn to touchtype, chord keying might appeal to them. This might have certain advantages in that it could perhaps eliminate the typing pool, thus making the conversion of thoughts into type faster and highly confidential. The Department of Health bought four Microwriters in 1978. They found then to be successful for specialised uses involving technical language (for example, the names of drugs), when dictation to a secretary was difficult (article by Peter Large in the Guardian on Thursday May 15th, 1980).

6. PROPOSED EXPERIMENTAL WORK

The chord keyboard, unlike the sequential, is a relatively recent innovation. A review of the literature demonstrates a trend away from specialised tasks (for example, mail sorting) to a more general application for chord keyboards. The increase in computer technology and the flexibility of the chord keyboard indicate that this device has much potential. A lack of fundamental research pertinent to chord keyboards has resulted in there being no standards or recommended keying parameters. It would appear imperative to carry out some basic research into chord keying for the following reasons:-

(a) The foundations need to be laid for a chord keyboard standard.

(b) Some basic research on chord keyboards will be of value for future keyboard designers.

(c) A repeat of the QWERTY episode should be avoided where the first keyboard to be developed and marketed monopolises the keyboard sales.

There are a number of alternate ways of designing a chord keyboard and hence a decision has to be made concerning the basic parameters of the chord keyboard to be investigated. It was decided to study a one-handed, 5-key chord keyboard for the following reasons:-

(a) The sequential keyboards are all two-handed, therefore a one-handed chord keyboard is in direct contrast.

(b) A 5-key keyboard provides the most basic form a chord keyboard can take, and hence it appears a suitable point from which to start.

(c) It was predicted that some recommendations could be produced from this basic chord keyboard which could be applied to more complex multi-key chord keyboards.

Between the two concepts of sequential and chord keyboards, there lies a group of keyboards which show characteristics of both sequential and chord keyboards. The Ayres word writing machine, and the ANTEL and IBM chord keyboards could be said to fall into this category. However the author decided to investigate the 'true' chord keyboards in direct contrast to the sequential keyboards.

It was decided to investigate the following aspects of chord keying:-

(a) The general form and design of a chord keyboard (Chapters 6 and 7).
(b) The speed of execution of the various chord patterns (Chapter 7), as a possible means of allocating chords to alphanumerics.
(c) The ease of learning the chord patterns as a possible means of allocating chords to alphanumerics, and the use of memory aids to help the retention of these chords (Chapter 8).
(d) User attitudes towards chord keying and the chord keyboard system (Chapter 9).

7. CONCLUSIONS

The following conclusions were reached from a review of the literature concerned with chord keyboards:-

(a) There is a lack of experimental work associated with chord keying.

(b) The trend in the seventies was towards one-handed chord keyboards for general use as writing devices. The use of the chord keyboard for specialised tasks is declining.

(c) The need for some fundamental research into the motor and cognitive aspects of chord keying is warranted. This would lead to the eventual production of a Standard for chord keyboards.

(d) It was decided to investigate several keying parameters working from the base of a 5-key chord keyboard.

(e) These parameters included the following:-

(i) the general form and design of a chord keyboard;

(ii) the motor aspects of chord keying, in particular the problem of allocating chords to alphanumerics;

(iii) the cognitive aspects of chord keying, in particular the allocation of chord patterns to alphanumerics and the use of memory aids to help the retention of these codes.

CHAPTER 6

A PRELIMINARY INVESTIGATION INTO VARIOUS SHAPES FOR A SMALL CHORD KEYBOARD

1. INTRODUCTION

It was apparent from the literature review of sequential keyboards that the design and general form of the keyboard, unlike the layout of keys had received relatively little attention. When considering sequential and chord keyboards, the problems surrounding the arrangement of keys are different. On the layout of a sequential keyboard, a decision has to be made concerning the positioning of the alphanumeric keys. This issue does not arise with a chord keyboard, since the alphanumeric characters are generated by patterned pressing of keys. However, the problem does arise of allocating the alphanumerics to the chord patterns.

It is evident when reviewing the literature on chord keyboards that there is a lack of reference to the general form of the keyboards being developed. Webb and Coburn (1959), Hillix and Coburn (1961) and Endfield (1978) were the only researchers to discuss the design of the keyboard shape. The few references to keyboard design could be a function of the fact that chord keyboards are still in their developmental stages and attention to the design will follow at a later date. For example, IBM investigated a 10-key keyboard (Klemmer, 1958) and an 8-key keyboard (Lockhead and Klemmer, 1959), but did not follow up these developments. Hence in 1960 IBM not knowing the trends in keyboard design over the next 20 years would have been foolish to devote a large amount of time to researching this area. However the state of the art in 1981 results in the design of the keyboard being of paramount importance. This was one of the reasons why an investigation into the general form of the 5-key keyboard was initiated.

2. BRIEF REVIEW OF THE RELEVANT LITERATURE

In 1959, Webb and Coburn developed and tested a hand-configured keyset. They examined the various keysets available and found they all had straight rows and most had straight columns. As a result of this study, Webb and Coburn produced a prototype keyboard with the rows curved to conform to the pattern of the fingertips in a relaxed hand. See Figure 6.1.

Endfield, the inventor of the Microwriter experimented with plasticine models of his keyboard based on the position of the hand in a horizontal posture. Although no written account of the developmental work has been documented, the two prototypes of the Microwriter are in the Science Museum, London.

Owens (1980) discussed the biomechanical considerations of chord keyboard design. He evaluated a hemispherical keyboard and suggested a keyboard shape which should avoid the need for unsatisfactory joint/limb positions. This shape was a modification of the hemispherical design (R.D. Owens - Personal Communication).

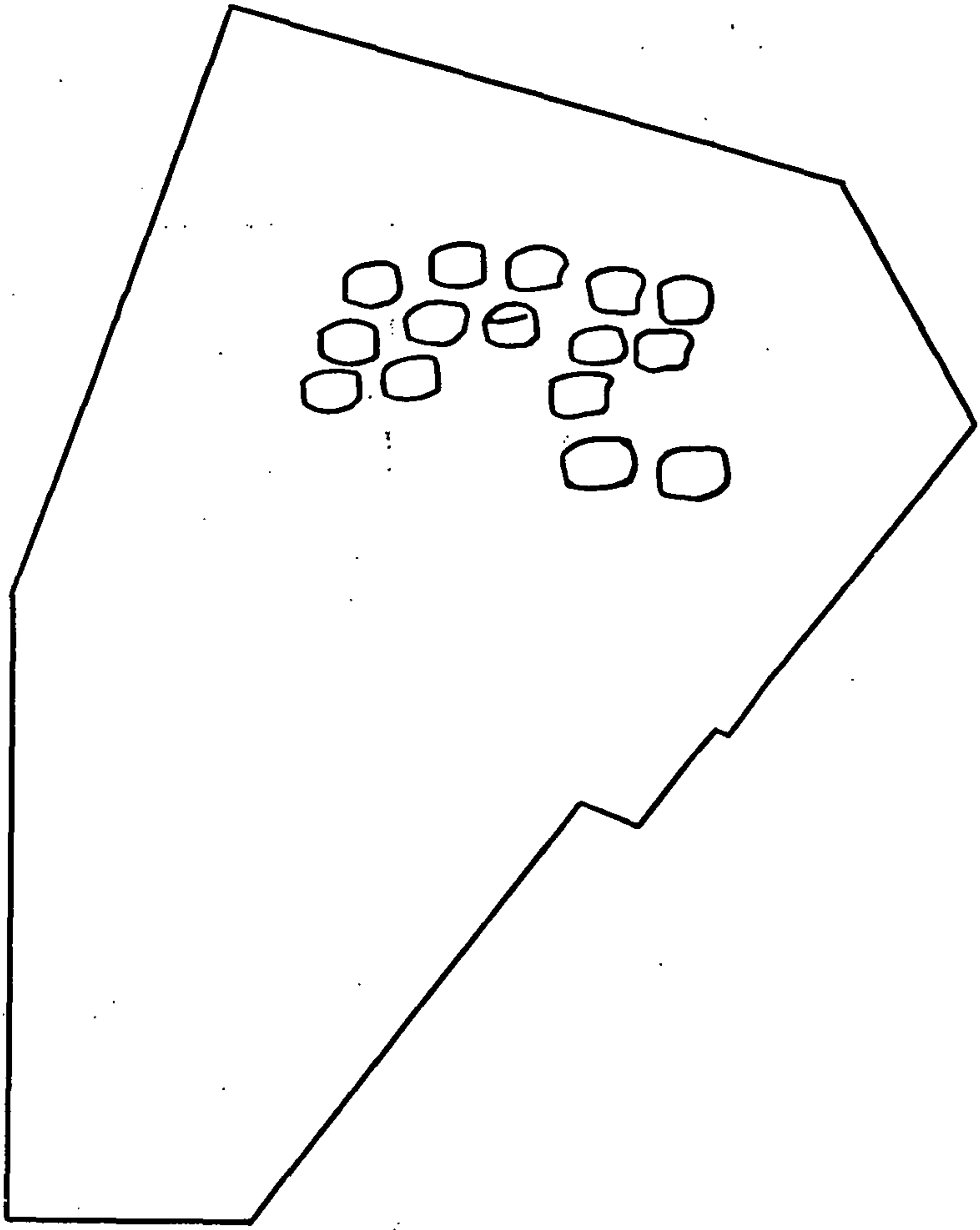


Figure 6.1: The Outline of Webb and Coburn's Keyboard (1959)

NOTE: This is the most detailed pictorial description of this keyboard available.

3. METHODOLOGY

Three basic shapes were selected for study; these were a hemisphere, a cylinder with sealed ends and a rectangular box. The first, a hemisphere was an example of a rounded, curved, shape and was partly chosen because of its similarity to the Writehander chord keyboard (Owen, 1978). The cylinder was chosen by the author, because such a shape fits the anatomy of the human hand, that is, the plane in which the four fingertips lie is at right angles to the plane in which the thumb lies. It was discovered after this experiment had been conducted that Mamerow (1916) patented a cylindrical 5-key chord keyboard identical to the one used in this study. Similarly, Jarmann (1952) patented a typewriter keyboard which consisted of two cylinders each having six keys. The third design, a thin rectangular box represented an angular shape with no curvatures and was the basic model behind the Microwriter (Endfield, 1978) and many alphanumeric 'calculators'. Three cardboard prototypes with the use of hard plastic for the curved part of the hemisphere were built. The exterior of each model was made as neutral as possible, so as not to influence the subjects' reactions to it. The size of the models was governed by anthropometric hand data (Churchill, Kuby and Daniels, 1957; Jones, Kobrick and Gaydos, 1958; Garrett, 1971). See Figure 6.2.

At the start of the experiment, the subjects were given a standard introductory explanation about the purpose of the study and what was expected of them. Emphasis was placed on the fact that it was an exploratory pilot study and subjects were encouraged to 'brainstorm' and do most of the talking.

The shapes were presented one at a time in a random order. The author placed the model on the table and subjects were expected to handle and explore the prototypes. The following questions were then asked:

Question 1 : If you were given this object, how would you operate it?
Question 2 : What do you feel about the size for your own use?

Question 3 : Do you think such a device would be comfortable to operate for long periods of time?

Question 4 : What modifications would you make to the basic shape to improve it?

Question 5 : Have you any other comments?

This procedure was repeated for all three prototypes. At the end of the experiment the subjects were asked to rank the shapes in order of preference and to suggest alternative shapes, which they believed would make good keying devices. A paper trace of subjects' hand sizes was taken, in order to discover whether the size of the subject's hand was instrumental in affecting his/her views on the various shapes. The experiment concluded with a question asking the subjects for any comments or suggestions that they might have.

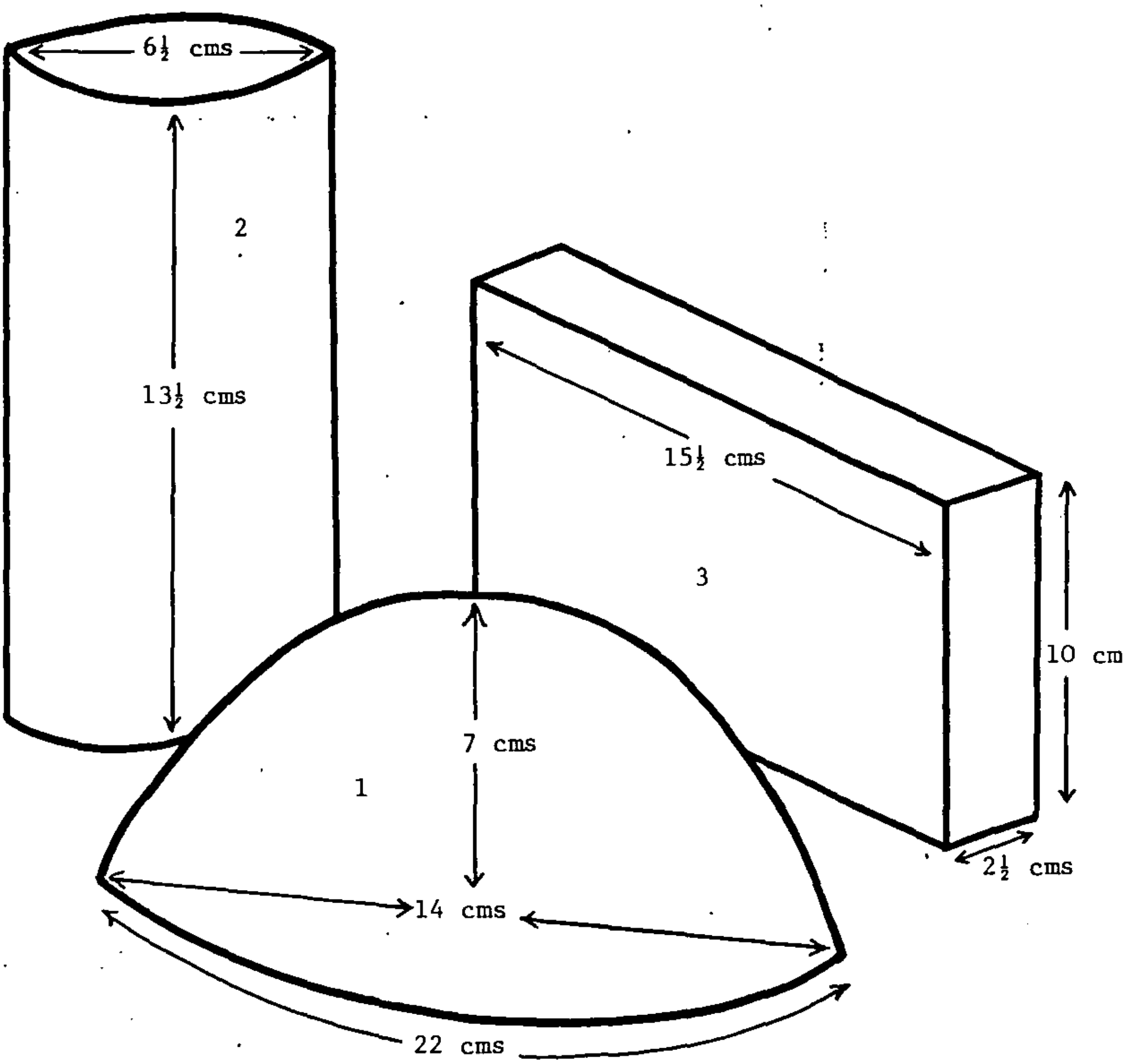


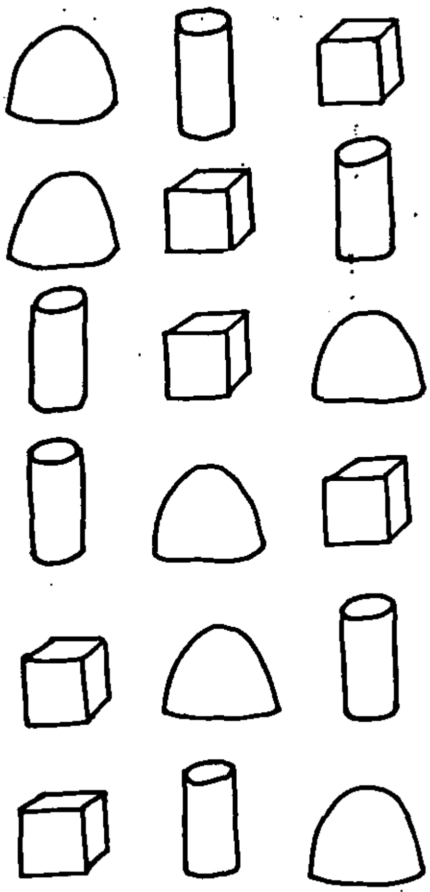
Figure 6.2: The Three Models used in this Study

(not drawn to scale)

4. RESULTS

Order in which the shapes were ranked — Number of subjects (n=20)

1 2 3



2)
7) 9 subjects selected the hemisphere as the best design.

1)
3) 4 subjects chose the cylinder.

6)
1) 7 subjects chose the rectangular design.

As the experiment was a preliminary study, elaborate statistical analysis was not thought necessary at this stage. It was apparent however that of the three prototypes, the hemisphere was the most popular, with the cylinder being the least preferred.

5. DISCUSSION

5.1 Shape 1 : The Hemisphere

The most common way to operate such a keying device was to place the model on the desk and to rest one's hand over the top of the hemisphere - this position was selected by 14 subjects. Other suggestions included holding in the left hand and keying with the right, and secondly, resting the arm on the work-top so that the fingertips only covered a quarter of the sphere. Only one subject suggested holding the curved part of the sphere in the palm of the hand and keying on the base.

Seven subjects felt that the size of the hemisphere was satisfactory as a keying device, whereas the other 13 believed that the model was too large. Suggestions included a reduction in the diameter and height to make the shape less rounded.

Eleven of the 20 subjects were satisfied that a keying device of this shape would be comfortable to operate for long periods of time. The other individuals cited the thumb and the muscles of the lower arm as possible targets for chronic fatigue. The problem with the thumb was that its range of movement and the angle at which it would hit the keys was different from the fingertips.

The hemisphere was found to be an aesthetically pleasing shape to work with. However, there was a demand for more flexibility in the device; for example, grooves for the fingers were requested to provide more tactile feedback and a more comfortable operating position. One idea involved elevating the hemisphere at an angle; this overcomes the problem of being unable to see the keys on the other side of the model, which could hinder the beginner. A further elaboration of this was to place the device on a ball and socket type apparatus, which could stand at the edge of the desk. Two subjects thought that elevated keys would be necessary on the basis that it is easier to key with arched fingers. When learning to type, beginner typists are always encouraged to hold their wrists up high and to arch their fingers. This idea could stem from there.

5.2 Shape 2. : The Cylinder

The majority of the subjects (that is, 12) operated the cylindrical shaped device using the power grip. The two other popular suggestions were to place the thumb key at the end and the finger keys down one side, and to place three fingers on the sealed end with a thumb and digit key either side on the rounded surface. Two subjects suggested operating the device in a horizontal plane. In order to do this, the object would have to be attached to a static fixture, similar to a kitchen roll holder or would have to be flattened on one side, to prevent rolling.

Although seven individuals thought the size of the shape was appropriate, the rest felt that it was too bulky and large in both diameter and length. Suggestions included reducing the shape by 50%, and increasing the diameter.

There were doubts as to the comfort of operating such a device. Problems arose from the fact that it was impossible to hold and operate such a device using the power grip, and the resulting small movements of the fingers placed pressure on the joints. Only one individual thought that the shape would be comfortable to operate for long periods of time.

Modifications to the model centred around making the ends more rounded and the basic shape elliptical. Again, indentations for the digits were requested, and it was thought that the power grip could result in excessively sweaty palms. The addition of some sort of strap or attachment to a stand was felt to be vital. The cylindrical shape does not inspire confidence in the user, because of the likelihood of dropping it. One subject pointed out the problems of carrying cylindrical shapes about the person as opposed to flat, rectangular shapes.

5.3 Shape 3 : The Rectangular Box

This shape was treated by the majority of the subjects as being analogous to a numeric calculator. They suggested placing the five keys on the largest surface area which would lie flat on a horizontal work-top. Other variations included placing the thumb on the narrow edge and the four fingers on the largest face of the shape, or alternatively placing the little finger on the opposite narrow edge. Both these latter cases would have to be operated with the longest side of the model in the vertical plane.

There were mixed feelings about the size of the device: several individuals felt the shape was too large and cumbersome, while others suggested that the dimensions could be increased in some directions. The feelings of the group could be summarised in that they felt the size of the rectangular box was too large to be handheld, but too small for a keyboard. However subjects were reasonably happy that the device would be comfortable to operate.

One of the most frequent modification requests was for a wedge shaped attachment to the back of the keyboard in order to be able to vary the angle of the device for keying. Again, the request for rounding off the edges and corners was made; and a strap to attach the device to one's hand was suggested. It would be necessary to have a 45^{o} piece cut out for the thumb, if the thumb key was placed on the narrow edge. Sone subjects suggested a slimline version of the model, which would enable individuals to carry the device quite comfortably.

5.4 Suggestions of Alternative Shapes for Future Development

The various shapes that were suggested can be divided into two categories; namely, those that were handheld, that is, in the palm of the hand, and those which were operated on a desk-top, or while held in the other hand.

Shapes for one-handed operation included a small sphere, which would fit comfortably into the palm of the hand known as the 'Collet enclosure' (Roebuck, Kroemer and Thomson, 1975), and a shape based on the 'handle-bar rubber grips' of a bicycle.

This latter shape was also described as the 'gear-stick knob' device used to operate model racing cars. A reduction in the length and diameter of the cylinder would result in the latter shapes. A further modification was to make the hand sized spherical shape pear-shaped, with provision for a thumb key at the narrow end of the pear. Another popular suggestion was for an ovoid shape with a hole in the middle, through which one placed one's hand.

There were several ideas which kept recurring when considering shapes for two-handed or desk-top operation. One was a horse-shoe shape with the keys arranged in an arc, in keeping with the natural positioning of the fingertips. Another was a wedge shape - an extension of the rectangular box model. A small cylinder with a flattened side to prevent movement on the work-top, and elevated finger keys (the thumb key being at the end) was also suggested.

It was interesting to note that the majority of the subjects found it very difficult to think of appropriate hand sized keying devices and some individuals could offer no suggestions.

6. SUMMARY OF RESULTS

It has emerged from the pilot study that some basic decisions concerning the nature and form of the keying device will have to be made. The first of these is to decide whether the device will be developed for one-handed desk-top operation or handheld use. There are certain advantages connected to the former, since portability is increased and the other hand is freed, perhaps to perform some other task such as answering the phone or turning the pages of a book. The main disadvantage, which far outweighs the advantages, is that the hand is under tension when in the disc grip necessary to grasp small objects. When considering the question of fatigue, the optimum position for the muscles of the hand is relaxed, that is, when they are at their longest. Hands that have fingers curled around a small object are under stress, since the lumbrical and interosseus muscles are contracted. A further drawback concerns the close proximity of the fingers in the disc grip. When the hand is relaxed the fingertips are spaced out, but as soon as the hand is flexed the fingertips are brought into close contact with each other. In this position, movement of the fingers is restricted, and it is hypothesised that keying for long periods of time would be uncomfortable.

It was very apparent from the subjects' comments that the models were a lot larger than expected, hence a reduction in size is warranted. The subjects repeatedly stressed the need for hand-configured keyboards contoured to the anatomy of the hand. The experiment was interested in the basic shapes of the keying devices and not at this stage in the attractiveness and colour of the finished product. Although unfortunately the hemisphere was in white plastic, compared to the wood finish of the other two models, several subjects expressed the view that the hemisphere was more 'exciting' as a keying device. This and the fact that it was a curved design probably partly account for this shape being the most popular.

7. CONCLUSIONS

It has already been stated that the aim of this preliminary investigation was to study various hand sized shapes for a future experiment. From the findings of this work, it was decided to concentrate on the development of a small chord keyboard for one-handed desk-top operation, in preference to a handheld chord keyboard. Reasons have already been given for this choice, but this area of work requires further investigation.

After having analysed both the subjective and the objective data, it was decided to continue working with the three basic designs, but greatly modified. The new modified shapes are shown in Figure 6.3 on the next page.

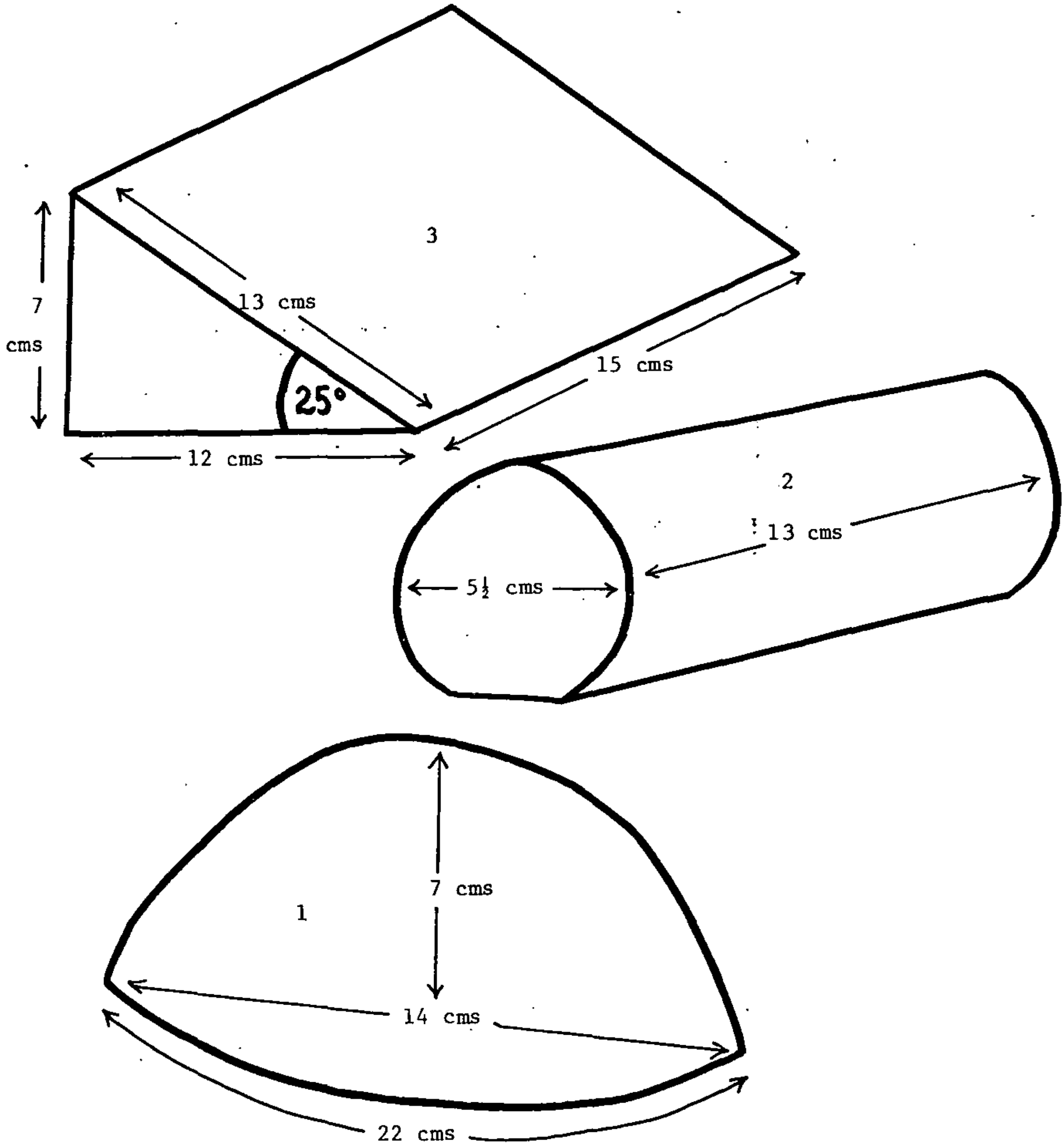


Figure 6.3: The Three Modified Shapes
(not drawn to scale)

CHAPTER 7

A STUDY OF THE MOTOR ASPECTS OF CHORD KEYING

1. INTRODUCTION

After the rash of enthusiasm towards chord keyboards in the fifties, there followed a series of experiments on chord keying in the early 1960's. It was concluded from the literature review of chord keyboards that in general there was a lack of experimental work in the field, although Ratz and Ritchie (1961) and Seibel (1962 - 1964) tried to rectify this situation. Both these researchers studied information rates and investigated the problem of deciding which message units should be assigned to the combinations of chords.

2. TWO STUDIES OF PERFORMANCE ON CHORD KEYBOARDS

2.1 Ratz and Ritchie's Experimental Work on a Chord Keyboard

Ratz and Ritchie suggested that the relative difficulty of the various chords could be measured in terms of the reaction time in responding on the keyboard to a visual presentation of the chord pattern. When the lights, fingers and keys are in direct correspondence, the stimulus-response codes are highly compatible and hence mental recoding of the information is avoided. This would enable the more frequently used message units to be allocated to the easier responses.

As a result of this hypothesis Ratz and Ritchie experimented with six subjects who practised for ten minutes a day on random sequences of thirty-one chords. Recordings were made for the first and last one hundred seconds of each ten-minute interval. As with any keying experiment, there was a learning period and surprisingly Ratz and Ritchie found little performance improvement after the second day. The average ranking of chords by increasing reaction times is shown in Figure 7.1, where the right hand is used. It was found that the average correlation coefficient among operators for all thirty-one chords was 0·91.

It can be seen from the chord rank chart that chords involving one finger were keyed fastest, as might be expected. However, it was surprising to find that the weakest finger (the little finger) was in first position. The chords requiring the longest time all have patterns using three or four fingers.

Rank	Chord pattern	Rank	Chord pattern
1	- - - - *	17	* - * - -
2	* - - - -	18	* - - * -
3	- - * - -	19	- - * * *
4	- - - * -	20	* - - * *
5	- * - - -	21	* * - - *
6	* * - - -	22	* - * - *
7	* - - - *	23	- * - - *
8	- * * - -	24	* - * * *
9	* * * - -	25	- - * - *
10	- * * * -	26	* - * * -
11	- - * * -	27	* * - * -
12	- - - * *	28	* * * - *
13	* * * * *	29	* * - * *
14	- * * * *	30	- * * - *
15	* * * * -	31	- * - * *
16	- * - * -		

Figure 7.1: The Chord Rank Chart (Ratz and Ritchie, 1961)

NOTE: The digits of the right hand are indicated, that is, the thumb being on the left.

The second part of the experiment was concerned with information rates. The information rate (measured in bits per second) was obtained from the product of 'H' and the average number of responses per second measured over a three minute period for five fingers and six minutes for ten fingers.

Hence

$$H = \log_2 \text{(number of choices)}$$

The following results table was formulated.

TABLE 7.1

EXPERIMENT	STIMULUS CHORDS	PATTERNS H (bits/ stimulus)	OBSERVED RESPONSE TIME T (secs/response)	OBSERVED DATA RATE H/T (bits/sec.)
ONE HAND				
A	1-finger	2.32	0.94	2.4
B	1-,2-,finger	3.91	1.07	3.7
C	1-,2-,3-,finger	4.64	1.15	4.1
D	All chords	4.95	1.20	4.1
TWO HANDS				
E	1 finger per hand	4.64	2.08	2.3
F	All chords	9.91	2.63	3.8

It can be shown from the data (that is, comparing A and E, and D and F) that an operator using only one hand performed at least twice as fast as an operator using both. Hence the increase in choice obtained from ten keys was offset by the slower reaction times.

Ratz and Ritchie ranked the thirty-one chords according to the time taken to respond to each chord combination. They based their experiment on the assumption that the motor system predominated over choice reaction time. In order to help to achieve this they used a highly compatible stimulus (display) and response (keyboard). They concluded that for one hand the information rate increases with the complexity of choice of patterns, but with two hands a loss of speed in the response occurred with the increased choice of stimuli.

2.2 Seibel's Experimental Work

A year later in 1962, Seibel carried out a similar experiment measuring Discrimination Reaction Times (DRTs) for the thirty-one chords possible with a five finger chord keyboard. Seibel's prime reason was to demonstrate that Ratz and Ritchies' claim that "little improvement took place after the second day" was erroneous. Four undergraduate students reported daily for a thirty-minute experimental session over a period of either thirty or forty-eight days. Each subject showed performance improvements over 4000 to 11,000 DRTs on the chord keyboard despite prior practice. The thirty-one chords were ranked according to speed and accuracy (see Figure 7.2).

Seibel's study only used four subjects, who did not provide statistically reliable data. For example, from Figure 7.2 it can be seen that 'Pattern 4' yielded the fastest DRT for the four subjects, but this was primarily due to the performance of one subject. The other three subjects showed 'Pattern 3' to be the fastest. It was also of interest to note that the correlation between average DRT and percentage errors was high (0.836), which would imply that the longer DRTs also have more errors.

Whereas Ratz and Ritchie had carried out an experiment to determine the relative speeds at which the thirty-one chords could be executed, Seibel's prime objective was to carry out a similar study to disprove some of Ratz and Ritchies' findings. Hence he showed that improvement in performance continued at least up to 11,000 response times. Seibel's DRTs were also less than one-third of the values reported by Ratz and Ritchie. It was found, however, that the order for the thirty-one chords in both experiments was highly correlated (0.896). Ratz and Ritchie applied the 'coding theory' (Mandlebrot, 1954) to the thirty-one chords. This involved working out the average response time (the cost) for each chord and applying this to the relative frequencies of the use of the chords.

From this optimum distribution, Ratz and Ritchie deduced that improvements in the order of 5% in the net information rate were to be expected. Seibel suggested that a gain in information rate of between 200% and 300% might have been achieved. He supported this hypothesis by referring to a study which Klemmer and Muller (1953) carried out. Using an almost identical experimental situation they reported information rates twice those found by Ratz and Ritchie.

In 1963, Seibel carried out a second study of DRT using a 10-key keyboard which gave 1023 alternative chord combinations. He was primarily interested in researching aspects of information transmission rather than chord keyboard design, which simply provided the task to enable his ideas to be developed. Hicks (1952) and Fitts and Switzer (1962) summarised the controversy over DRT by stating that it was generally accepted that DRT increased linearly with the information contained in the stimulus. Other investigators (Klemmer and Muller, 1953; Leonard, 1954; Mowbray and Rhoades, 1959) concluded DRT and the information transmission rates were independent of each other. Seibel trained three subjects for more than 75,000 DRTs and found that DRT did not increase linearly with information transmitted.

A year later in 1964, Seibel moved his attention towards comparing the sequential and chord keyboard in terms of information per stroke, stroke rate, motor difficulty of chord strokes, motor learning for chord keying, memorization of code, and characteristics of use and users of the device in terms of skill level and trainability.

Seibel concluded that in general chord keyboards resulted in larger amounts of information per stroke, but the stroke rate was lower. This was due to the difficulties of producing chord strokes compared with striking single keys on a sequential keyboard.

Chord Pattern	DRT (Milliseconds)	Error (percentage)
4	281	5.9
3	285	2.4
1	289	1.8
2	292	5.0
5	294	5.6
1 4	306	3.8
2 3	306	8.8
3 4	306	10.3
1 2	310	6.2
2 3 4	311	9.1
1 3	312	5.0
1 2 3 4	314	4.1
1 2 3	315	5.3
1 5	315	5.6
4 5	316	11.5
2 4	316	12.1
2 3 4 5	317	4.4
1 3 4	320	10.6
3 4 5	321	7.6
1 2 3 4 5	325	7.4
2 5	326	12.4
1 4 5	328	8.2
1 2 4	328	13.2
1 3 4 5	330	12.4
1 2 5	335	11.8
3 5	343	13.2
1 2 3 5	345	18.8
1 3 5	349	15.0
2 4 5	349	20.9
1 2 4 5	351	25.9
2 3 5	352	22.1

NOTE: The above data were obtained from the last five sessions of practice for each subject. The digits of the right hand are indicated.

Figure 7.2: The Chord Rank Chart showing Average DRTs and Percentage Errors (Seibel, 1962)

He suggested that the choice of a single-stroke keyboard, chord keyboard or some combination depended on several considerations, but that for skilled typists a compromise keyboard with characteristics of both sequential and chord keyboard appeared most promising.

2.3 Conclusion

In 1964 there were no commercial chord keyboards available, and hence it is not surprising that Ratz, Ritchie and Seibel never applied their findings to a chord keyboard system. Robert Seibel at this time was primarily interested in learning curves and the problems associated with the training period for keyboard operators. Both studies ranked the thirty-one chords according to speed of response, but this was a by-product of the experiment and not the objective. There is a slight discrepancy between these results, which could be explained by the fact that Ratz and Ritchie used a 10-key keyboard and Seibel a 5-key keyboard. Both studies employed small numbers of subjects (n=6 and 4 respectively), which would not enhance the reliability of the results.

The problem of allocating chord patterns to alphanumerics still exists today, although recent chord keyboard designers (Owen, 1978; Endfield, 1978) appear to have paid little attention to this feature of chord keyboards. It was therefore decided that a response time experiment should be conducted based upon the findings of the preliminary pilot study in Chapter 6. The aims of this study were:-

(a) To investigate various chord keyboard designs by means of a reaction time test and subjective preferences.
(b) To test the hypothesis that chords are keyboard shape specific.
(c) To rank the chord combinations according to speed of execution, and locate trends in the pattern of responses.
(d) To work towards producing a standard for chord keyboards.

3. METHODOLOGY

3.1 Pilot Study I

3.1.1 Experimental Design

It was decided that a 'repeated measures' design similar to that used in the Maltron keyboard experiment (see Chapter 3) was the most appropriate since it allowed subjective comparisons to be made. The preliminary pilot study provided the basis for the design of the three response keyboards. Eight subjects (six females and two males) were presented with the keyboards in a random order.

3.1.2 Description of Equipment

The following experimental apparatus was set up.

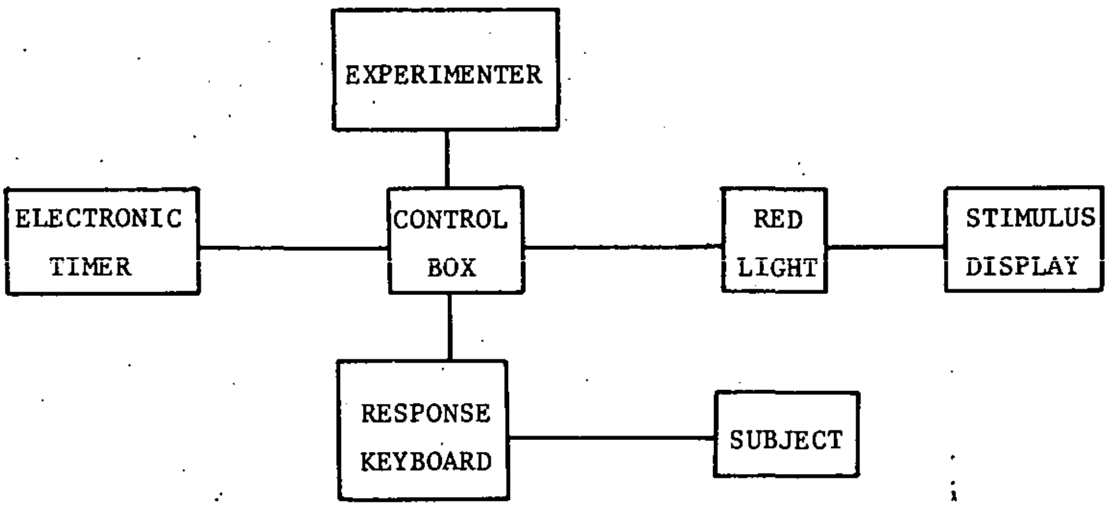


Figure 7.3: Diagrammatic Representation of the Apparatus

3.1.3 Experimental Procedure

Initially, subjects were given instructions explaining that they had to respond as quickly and as accurately as possible by pressing the identical combination of keys on their keyboard to the pattern of lights on the display. The stimulus display consisted of a rectangular box with a horizontal row of five green lights.

The experimental procedure was as follows. After the start key had been pressed by the author, a red light acting as a warning signal appeared telling the subject that he/she had x number of seconds* until the pattern of green lights flashed up. The subject was expected to respond as quickly as possible to this array of stimulus lights, by pressing the identical combination of keys on his/her keyboard. All chord patterns were generated randomly and an electronic timer provided the response times, that is, from the appearance of the green lights until the subjects had pressed the keys. Errors were noted by the author, since the subject's response was observed on the control box.

It has already been established that there are thirty-one chords (2^5-1) possible with one hand. All three keyboards were 5-key devices for right handed operation only, hence a total of ninety-three experimental trials were carried out for each keyboard. Data were collected for all 279 trials, but it was intended to use in calculations, only the third set for each keyboard. As with all keyboard experiments, there is a learning period that has to be taken into consideration.

3.1.4 Analysis of Data

Each subject generated a large quantity of experimental data, which was suitable for statistical scrutiny by analysis of variance (2-way block design test - M.A. Sinclair, Personal Communication).

* This time lag was under the control of the author who could set it as a constant up to approximately four seconds.

Since the primary objective of Pilot Study I was to test the experimental apparatus, no formal subjective data were collected, although the subjects were questioned about the keyboards and the experiment. However, it was intended to administer a questionnaire as a part of the main study, in order to investigate various aspects of comfort and fatigue, and subjective preferences, which would be piloted in Pilot Study II.

Due to the number of problems experienced with the apparatus (for example, two electronic timers were used and both proved unsuitable, which resulted in lost data), it was decided not to indulge in any elaborate statistical analysis. The results showing total keying times can be seen in the Appendices.

3.1.5 Discussion of Pilot Study I

3.1.5.1 The Physical Design of the Keyboards

The results from the preliminary study combined with the anthropometric data determined the design of the three keyboards. However, all three were built with standard typewriter keys. These keys increased the effective size of the models making simultaneous key-pressing impossible. They were also very cumbersome in appearance. After several subjects had attempted to use the keyboards, low profile rectangular keys with green tops to match the stimulus lights were substituted. The sensitivity of these keys and the tactile feedback that they provided fitted the requirements of the experiment, but not a commercially viable keyboard. Due to the increased comfort achieved with these keys, subjects found it easier to carry out simultaneous key-pressing.

After the new keys had been installed, slight alterations to the positioning of the little finger keys on the cylinder and hemisphere were made on the recommendation of the subjects. The wooden support on the cylinder was also moved to increase the ease of operation of this device. The rectangular box had been built at the recommended angle of 25^{o} (Cooper, 1976) but subjects complained that this angle was too steep. However due to the length of the new keys, it was not possible to reduce the slope of the box without removing the keys.

The three keyboards had been constructed from wood, white plastic and aluminium. To ensure that the subjects were commenting on the physical shape of the keyboard, and not the appearance of the material of construction, all three keyboards were sprayed with black gloss paint.

3.1.5.2 Stimulus-Response Compatibility

The three response keyboards have already been described in detail. The stimulus display was a rectangular box with a row of five green lights. In a reaction time experiment, the amount of thinking that the subject has to do must be reduced to a minimum so that the response time is essentially measuring the motor reaction. The experimental set-up for the pilot study demanded that the subjects remembered the position of the green lights with respect to the five digits. Therefore the construction of a more compatible stimulus display was recommended. This display would show a hand with green lights placed at the fingertips, and would be applicable for all three keyboards. The construction of three stimuli for the different keyboards was considered; each stimulus being a replica of a keyboard. However the difficulty arose of placing a three-dimensional keyboard display on a two-dimensional surface, so that the subjects can see all the lights; the revised presentation device is described later in Section 3.3.3.

3.1.5.3 The Experimental Environment

It is imperative with a reaction time study to ensure that the subjects have a quiet, non-distracting setting for the experiment. Suggestions included placing a screen between the experimenter and subject to minimize the distraction. The subjects' ability to concentrate also affects the length of the experiment. It was concluded that three trials for each keyboard with a break after the second keyboard provided a satisfactory length for the experiment of approximately 45-50 minutes.

Due to the amount of work generated by the study it was found necessary to have two experimenters, one controlling the experiment and the other collecting the results.

3.1.5.4 Problem Areas

In this experiment, the appearance of the stimulus was controlled by the author. Previous reaction time studies have been self-paced, that is, when the subjects have released the keys, the next stimulus pattern has appeared. It is important therefore to try and maintain a constant period of time between each key-pressing. The pilot study determined the time that was suitable between the appearance of the warning light and the stimulus lights. This time must be suitably short to prevent the subject becoming bored and his/her attention wandering.

The other potential problem area was concerned with simultaneous pressing of keys. Seibel (1962) allowed 0.1 seconds in which to press all the keys, otherwise an error was registered. It would be useful to incorporate such a system into the present apparatus and this was done (see later description).

A group of subjects having a wide variation in their ages was deliberately chosen for this pilot study. Five subjects were over thirty-five years, and it was noted that reaction times increased with age as the flexibility of the joints decreases. Therefore, consideration should be given to the age-group of subjects selected for the main study.

It was evident from the pilot data that there was a considerable learning effect between the first and third trials. This coupled with the effects of transfer between keyboards suggests that 'repeated measures' might not be the optimum experimental design.

3.1.6 Conclusions

The following conclusions were reached after the first pilot study:

(a) The three keyboards should be further modified and more appropriate keys should be found.

(b) Due to the learning effect present when using the keyboards, the experimental model for the main study should be reconsidered.

(c) Data generated from this study were not analysed statistically, because of problems experienced with the equipment resulting in missing data.

(d) An upper age limit for subjects (for example, thirty-five years) should be defined.

(e) It would be more appropriate to computerise the system. This would eliminate the need for two experimenters, standardise the time between the stimulus patterns, and overcome the problem of non-simultaneous pressing of keys.

3.2 Pilot Study II

The changes which resulted from the first pilot study were implemented. The manual system was replaced by a PDP-11 computer and the experimental design of the experiment was altered. Pilot Study II employed four individuals, who essentially tested out the equipment and experimental procedure for the author. The aims of this second pilot study were:

(a) To ensure the smooth running of the computer and associated apparatus.

(b) To allow the author practice in giving verbal instructions and running the experiment.

(c) To make any necessary final changes before the main study began.

(d) To study the learning effect by providing some dummy data for statistical analysis.

(e) To certify that the electronic problems experienced with keyboard 2 in Pilot Study I had been rectified.

Pilot Study II was successfully conducted and allowed the author practice in setting up and running the experiment. No major changes were made and it was concluded that the main study could begin.

3.3 The Main Study

3.3.1 Experimental Design

Pilot Study I employed a 2-way block design, which resulted in every subject being tested on each keyboard. It was decided that an 'independent subjects design' should be used for the main study in preference to 'repeated measures'. Poulton (1969, 1973) suggested if the same individuals work with all the pieces of equipment in a balanced order, the results may be biased by hidden asymmetrical transfer effects. Therefore performance in the second trial benefits or suffers from what was learned during the first trial. This is overcome by only testing subjects on one keyboard. Therefore it was decided to test ten different individuals on each keyboard.

Subjects can be allocated to the three keyboard groups in two ways. This can be carried out by a pre-test on a 'neutral' keyboard with high and low scorers being evenly distributed across the three groups, or by random allocation. The use of a pre-test in this situation might also introduce transfer effects, and because the subject pool is being artificially created, this might affect the sensitivity of the findings. It was decided therefore to assign each of the thirty subjects at random to one of the three keyboards. This was carried out using random number tables (Snedecor and Cochran, 1967).

3.3.2 Selection of Subjects

Reaction times are known to be influenced by experience, sex and age (Andreas, 1972). Thus it was decided that thirty naive individuals (fifteen females and fifteen males) who had not participated in the pilot studies, and were between the ages of twenty and thirty-five years of age, should be selected for the experiment.

Potential subjects were questioned about their background, because piano-players and typists would be at an advantage in an experiment of this nature and hence were not selected (Klemmer, 1958). These pre-test questions are shown in Appendix A7-3.

3.3.3 Description of Equipment

One of the conclusions from Pilot Study I was to utilise the facilities provided by the Department's PDP-11 computer. The following experimental set-up was implemented.

A display board was constructed showing the outline of a white hand on a matt black background. Green lights were present on the fingertips and the red warning light * was positioned three centimetres above this display.

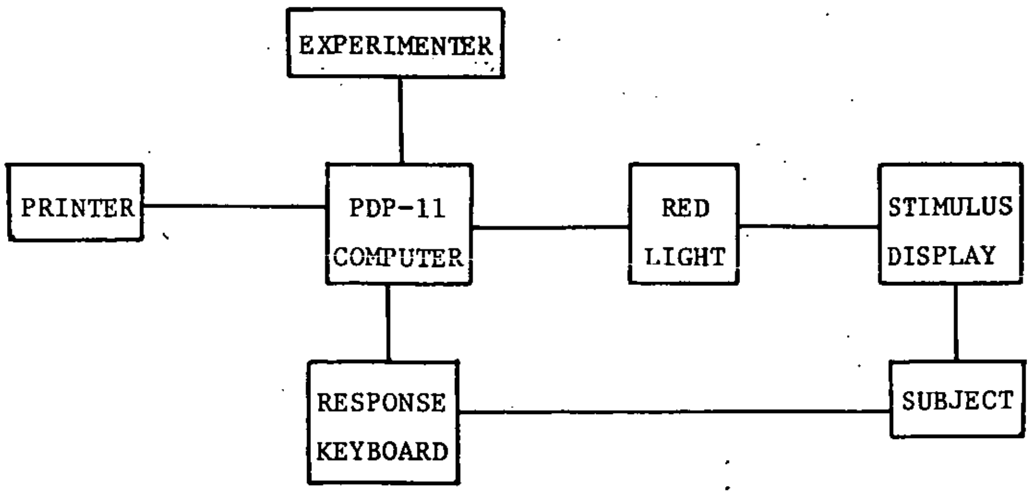


Figure 7.4: Diagrammatic Representation of the Apparatus

The stimulus display, the red warning light and the response keyboard were located in a small experimental psychology cubicle away from the computer room. This windowless cubicle was quiet, had few distractions, and little extraneous noise. The author controlled the experiment from the computer room and was concealed from the subjects. The level of lighting in this cubicle was kept constant since environmental illumination conditions have been shown to influence response times (Andreas, 1972).

---

* A red cue light has been recommended by John (1969) and Green, Sime and Guest (1972) for use as a warning signal in reaction time experiments.

The three response keyboards used in Pilot Study II and the Main Study are shown in Appendix A7-4.

3.3.4 Experimental Procedure

Upon arrival at the psychology cubicle, subjects were presented with the keyboard which they were to use. This choice was pre-determined by the random number tables. Subjects were told that they could operate the keyboard either on the desk-top (height = 70 cms.) or held in the hand. The emphasis was always placed on a relaxed, comfortable sitting and keying position. A padded chair with wooden arms (height of seat of chair = 46 cms.) was provided for this purpose.

It was then explained to the subject that a pattern of green lights on the stimulus display would be illuminated and he/she should respond as quickly and accurately as possible by pressing the identical combination of keys on his/her keyboard. Subjects were told to watch the red light positioned directly above the stimulus display as this indicated that there would be two seconds until the green lights appeared. The author later found out that this time lag was recommended by Fitts and Pearson (1964). The green lights faded as soon as the subjects responded and the signal for the next chord combination to be generated was provided by releasing the green keys on the response keyboard. A printed set of instructions (which the author memorised) was used in order to standardise this procedure (see Appendix A 7-5).

The emphasis was placed on both speed and accuracy. Howell and Kreidler (1963) studied the trade-off between speed and accuracy and found that reaction time results were influenced by the experimental instructions. They investigated three conditions: conditions one and two stressed speed and accuracy respectively while the third condition placed emphasis on both.

They found that the data generated by the three groups of individuals corresponded to the type of instructions provided.

Thirty-one chords are available on a 5-key chord keyboard and the subjects worked through nine trials of thirty-one key pressings. The order of presentation of the chords was determined at random, and differed for every trial and every subject. No feedback (other than self-detection of errors) was provided. There were two main reasons for this. It was found from the pilot studies that individuals make very few incorrect keypressings. Errors were in the region of one to two per trial of thirty-one chords, and hence it was surmised that an elaborate feedback mechanism was unnecessary. It was also anticipated that showing the correct combination of lights either on the stimulus display or a second display would merely add confusion to an experiment which relied on alertness and simplicity.

Two hundred and seventy-nine responses per subject constituted an experiment which was suitably short to avoid the subjects becoming bored. It was intended to provide a short break of a few minutes after the first trial in order to sort out any problems and again after the third and sixth trials. It was anticipated that the last three trials would be used in the statistical analysis. However when the learning curve of the group means was plotted for the nine trials, it was decided to use trials 4, 5, 7, 8 and 9 in the statistical analysis.

Data from trial 6 were omitted because of the relatively high response times, which were probably due to fatigue. See Figure 7.5 in Section 4.

At the end of the experiment subjects were questioned about the keyboard (see Appendix A.7-6).

3.3.5 Data Analysis

Response times and keying errors were stored on a floppy disc in the PDP-11 and then transferred to the University's 1900 computer for analysis (Dixon, 1970). A hard copy printout allowed visual inspection of the results. The data were suitable for a 'three way analysis of variance with replications' statistical test (Winer, 1971). This was performed using the GENSTAT analysis of variance (ANOVA) statistical package. Error scores for the three keyboards were analysed using the OMNIBUS computer program (Meddis, 1980). This unique package was developed by Dr. Ray Meddis of the Department of Human Sciences, Loughborough University, and consists of an ANOVA by ranks procedure dealing with non-parametric data from a very wide range of experimental designs. For a fuller explanation see Appendix A7-10.

A secondary aim of the experiment was to rank the thirty-one chords according to speed of execution for each keyboard. It was anticipated that this could be done using a simple computer program. However, due to time limitations, the author carried out this part of the data analysis herself. In order to control for undetected errors, an independent observer checked a random sample of the data and found no errors in the author's work.

4. RESULTS

The objective results are shown by a graph (indicating the learning curve for the 279 trials) and two tables. These tables arise from the GENSTAT and OMNIBUS statistical packages, and indicate the results of the speed and error analysis, respectively. There was no statistically significant difference between the three keyboards with regard to reaction times, although there was a significant difference between the error scores for the three keyboard groups.

The ranking of the thirty-one chords are shown in Table 7.4 at the end of this section.

The subjective data obtained from this experiment are discussed in Section 5 of this Chapter.

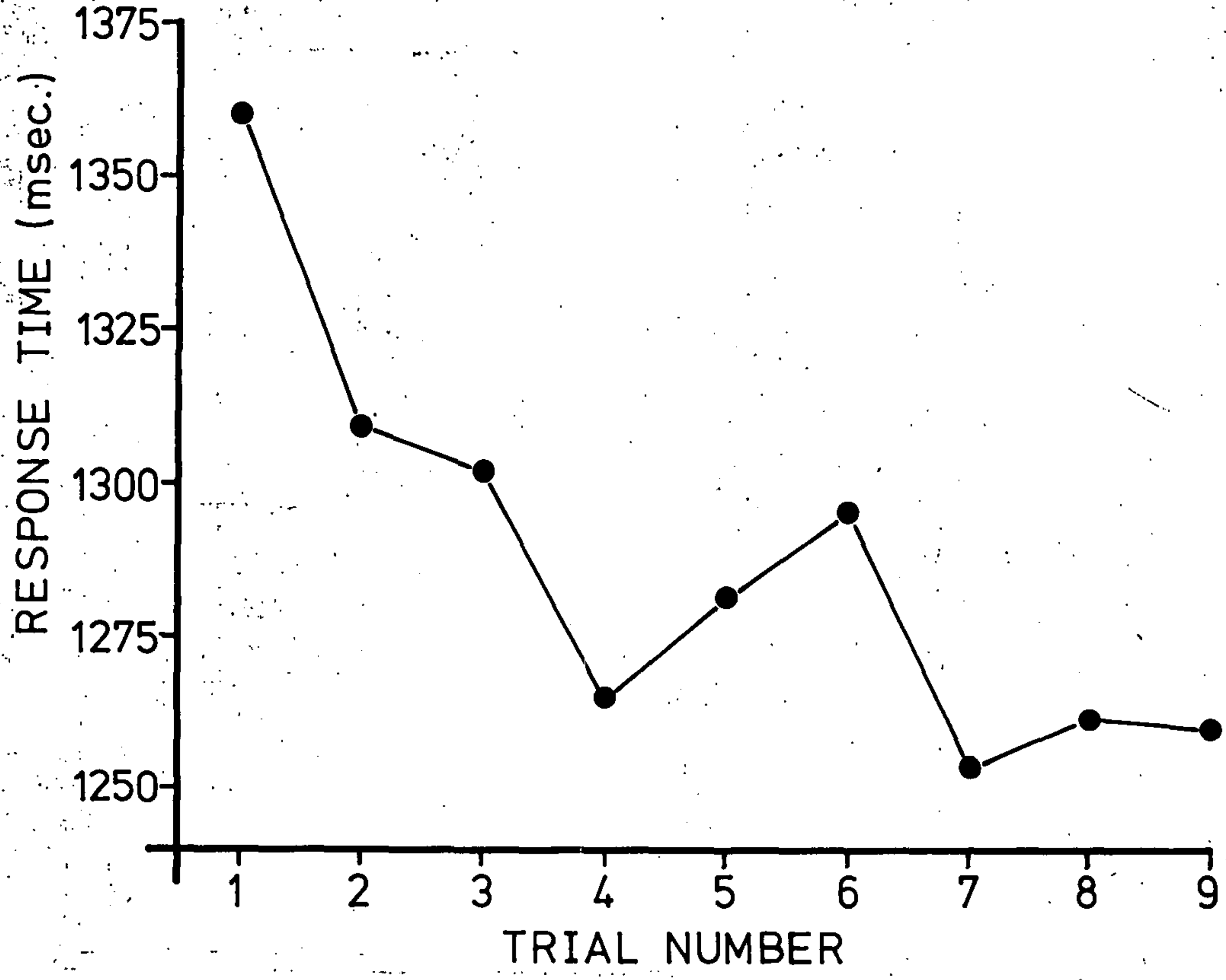


Figure 7.5: Group Means for Response Times Plotted against Trial Number

TABLE 7.2: The GENSTAT ANOVA Results

ANALYSIS OF VARIANCE

VARIATE TIME

SOURCE OF VARIATION	DF(MV)	55	55%	MS	VR	
* UNITS * STRATUM						
KEYBD	2	80579	0.07	40289	0.460	n.s.
CHORD	30	5E 7	38.76	1539300	17.577	sig.
KEYBD * CHORD	60	718118	0.60	11969	0.137	n.s.
RESIDUAL	830(7)	7E 7	61.01	87572		
TOTAL	922	1E 8	100.44	129786		
GRAND TOTAL	922	1E 8	100.44			

NOTE: The data from trials 4, 5, 7, 8, 9 were used in this analysis.

TABLE 7.3: The OMNIBUS Test Results on the Error Scores

Keyboard	Frequency	Rank Mean
1 (Hemisphere)	50	68.25
2 (Cylinder)	50	80.03
3 (Box)	50	78.22

** Overall test for finding any effect among group means
$H = 232.684$ $p < 0.001$

Conclusion : There is a significant difference between the error scores for the three keyboard groups.

NOTE:

The data from trials 4, 5, 7, 8, 9 were used in this analysis.

TABLE 7.4: The Ranking of the 31 Chords

Chord Pattern					Response Time (M.Secs)	Error Score
				5	1004.97	0.66%
	2				1005.20	0.66%
1					1008.90	0
		3			1074.53	2.0%
			4		1076.63	1.33%
1	2				1077.87	4.0%
1				5	1080.43	2.0%
1	2	3	4	5	1091.58	22.0%
	2	3			1099.40	4.66%
	2	3	4		1142.30	12.66%
		3	4		1154.40	4.66%
			4	5	1157.83	7.33%
	2	3	4	5	1162.23	21.33%
1	2	3			1177.40	8.0%
1	2	3	4		1204.74	14.0%
1			4		1223.77	2.66%
	2		4		1230.00	6.0%
		3	4	5	1253.30	16.66%
	2			5	1270.37	3.33%
1		3			1276.13	7.33%
1	2			5	1373.03	4.66%
1			4	5	1393.47	7.33%
1		3	4		1424.37	14.0%
1		3	4	5	1454.27	18.66%
1	2		4		1512.40	20.66%
1	2		4	5	1612.30	31.33%
1	2	3		5	1655.30	21.33%
	2		4	5	1656.50	41.33%
		3		5	1673.63	16.0%
	2	3		5	1679.50	30.0%
1		3		5	1682.97	19.33%

5. DISCUSSION

5.1 Summary of Keyboard Results

The difference between the mean keying times for each keyboard was small and not statistically significant. However the difference between the error scores was significant. Hence the subjective data were closely examined in order to find if the subjects favoured one keyboard.

5.1.1 First Impressions of the Keyboards

The general concensus was that the three keyboards when first seen were larger than expected. Some individuals found the designs satisfactory, others were indifferent, while others complained about minor points such as the key surfaces being slippery. A myriad of answers were emitted in response to the question "What do you think of the keyboard?". Often these responses were more appropriate to the other questions and hence will be dealt with accordingly.

5.1.2 Enjoyment of Keyboard Operation

Several individuals enjoyed the experience of using a chord keyboard. The expressions 'good fun' and 'very novel' were used to describe the keyboards. Fourteen of the thirty subjects declared that they did enjoy using the keyboard, and nine responded negatively to this question ("Did you like using it?"). It was noticeable that more negative responses emanated from the group using the cylindrical keyboard.

5.1.3 Ease of Operation

All the subjects apart from one using the hemispherical chord keyboard found operation of the devices easy. Several individuals commented that it was difficult at the start of the experiment to make the appropriate key pressings, but this phase soon passed. Other comments included the fact that the keys were heavy and some of the chords difficult to form. Responses to this question showed little variation across the three keyboard groups.

5.1.4 The Size and Shape of the Keyboards

Few comments were received about the size of the hemispherical chord keyboard; these all requested a reduction in size. It was concluded if the keyboard was to be used for handheld operation, the diameter would have to be considerably reduced. More feedback was provided from the subjects concerning the shape of the keyboard. It was suggested by four of the ten subjects that the shape was deceptive because it implied that the user could rest his/her hand over the top of the keyboard. In practice it was not possible to maintain this position when keying. However it was anticipated a flattened hemisphere would permit this. This new shape would also allow the subjects to rest their hands and hit the keys with their finger-tips and not the length of their fingers.

The cylindrical shape did not generate as much criticism as the hemisphere. The general concensus was that the shape was good but the size could be reduced. Other suggestions included providing some support for the hand and grooves for the fingers. This would be particularly advantageous for the little finger.

Although six of the ten subjects were pleased with the size and shape of the rectangular box, there was one major criticism. Originally it was intended that this design should be based on a model of the hand in a relaxed position. However due to the slope of the keyboard and the thumb key positioned on the edge, which pulled the whole hand to the left, this design was deemed not to be satisfactory.

5.1.5 The Position of the Keys

There were three requests to move the thumb key nearer the finger keys on the hemisphere. It was also suggested that the little finger key should be higher: varying the key heights to be compatible with the length of the four fingers is a characteristic of the Maltron keyboard.

It was also the thumb key which attracted many comments from the users of the cylindrical keyboard. Two subjects suggested moving the thumb key onto the same surface as the four finger keys. However unless a special purpose thumb key was built this would entail hitting the key with the side of the thumb. This could become uncomfortable after a period of time.

Comments about the rectangular box shape also focussed around the position of the thumb key. These ranged from stating that the thumb key was the "most comfortable", the "most awkward" and "a bit peculiar". The position of the little finger key also came under attack: it was suggested that this key should be moved closer to the three finger keys to avoid stretching.

5.1.6 The Weight of the Keyboards

There was a general concensus across the three keyboard groups that the weight of the chord keyboards was acceptable*. All the suggestions involved increasing the weight in order to help solve the problem of the keyboard moving around on the desk-top. However rubber feet would help to alleviate this occurrence.

5.1.7 Mode of Operation

There were two main ways of positioning the keyboards. These could be summarised as follows:-

	On the desk-top	Resting in the lap and supported by the hand.
Hemisphere	2 subjects	8 subjects
Cylinder	1 subject	9 subjects
Rectangular Box	4 subjects	6 subjects

* Total weight of the hemisphere chord keyboard = 175 grams.
Total weight of the cylinder chord keyboard = 225 grams
Total weight of the rectangular chord keyboard = 300 grams.

It could be concluded that when given the choice, individuals preferred to operate the keyboard resting in their laps and supported by the other hand. The summary of results indicated that the rectangular box was least likely to be positioned in the lap. This was probably due to the bulky size of the keyboard.

5.1.8 Comfort of Operation

Nine out of the ten individuals using the hemispherical chord keyboard found it comfortable to operate. The tenth subject said that the diameter of the hemisphere was too wide. This could have been a purely individual comment, since this subject could have had small hands. If this was the case, provision will have to be made for the various hand sizes across the population.

Similarly nine out of ten subjects in the cylindrical chord keyboard group made positive comments about the comfort of operation of this keyboard.

In comparison, only five individuals answered positively when questioned about the rectangular keyboard. It could be concluded from these results that the latter keyboard was not comfortable to operate.

5.1.9 Aspects of Fatigue

Seven out of the ten individuals using the hemisphere declared that, by the end of the experiment, no part of their body ached. The other three subjects were suffering from an assortment of aching forearms, wrists and fingers.

Approximately 50% of the cylindrical keyboard group suffered from body fatigue. This included aching wrists, the upper part of the arm and the back of the hand.

It could be predicted from the previous answers concerning the rectangular keyboard that this design would result in more fatigue.

This prediction was correct since only two individuals stated outright that they did not suffer from any aching. Complaints of aching covered the forearm, the wrist and the back of the hand.

5.1.10 The Stimulus Display

Favourable comments were received about the stimulus display. One individual felt that the thumb light was too distant from the other lights which resulted in it being on the periphery of the visual field. Another subject commented that by the end of the experiment he became mesmorised by the lights flashing off and on. This suggests that the number of trials executed by the subjects was appropriate and could not be increased.

5.1.11 Conclusions from the Subjective Data

It becomes apparent when studying the comments about the three keyboards that the rectangular box was the least preferred. This is particularly noticeable from the answers concerning comfort of operation and fatigue. Therefore it is concluded there would be little advantage in pursuing this keyboard design, and it was decided that this shape should be abandoned. There was little difference between the results concerning the hemispherical and cylindrical keyboards, although the former might have fared slightly better in receiving favourable comments. The cylindrical chord keyboard was more liked during this experiment than in the preliminary pilot study described in Chapter 6.

The subjective data suggested many viable modifications for the keyboards. For example, the weight of the devices should be increased and rubber feet attached. The size of all three keyboards should be reduced, and the shape of the hemispherical keyboard altered by flattening the dome.

It could be deduced from the remarks concerning this keyboard that individuals like to rest the palm of their hands when pressing keys. The Maltron keyboard might have an advantage over the standard typewriter unit for this reason, since it provides for the heel of the hand to rest on the edge of the keyboard. Users of the cylindrical keyboard requested a hand-configured layout with grooves for the various fingers. There was an assortment of answers concerning the position of the keys from all three keyboard groups. This can probably be accounted for because of the difference in hand sizes. It was evident that there was a severe lack of appropriate anthropometric data on this topic. But common sense suggests that more than one keyboard for the user population would be necessary.

5.2 Summary of Chord Results

The GENSTAT statistical package showed that there was a significant difference between the times taken to form each of the thirty-one chord patterns. Analysis of variance tests also demonstrated that the pattern of the chord responses did not relate specifically to the keyboards. For this reason and the fact that using the data from all thirty subjects strengthened the validity of the ranking, the thirty-one chords were ranked using the results from all three keyboard groups.

The ranking of the thirty-one chords showed that the single digit chords were the fastest to execute. Individuals also made less errors on these chords, and surprisingly no subject in the three groups made any errors using the thumb key on its own. This result suggests that previous research (Haäland, 1962; Malt, 1977) implying the superiority of the thumb over the fingers may be correct. These single digit results are in keeping with those found by Ratz and Ritchie (1961) and Seibel (1962). It should be noted that direct comparison of the results was not possible since there was an unknown but constant system delay due to the PDP-11 computer.

The Department Programmer estimated that this unavoidable time lag would be in the region of 550 milliseconds.

Two and three digit chords were bunched in the middle of the rank of thirty-one chords, while the four digit chords were at the end. It should be noted that the last four chords were identical for Ratz and Ritchies', Seibel's and the present study. The last six from this experimental work corresponded exactly to the last six in Ratz and Ritchies' study. The little finger featured in all six chords, while the middle finger appeared in four of these and the ring finger in the other two chords. This suggests that the execution of a chord involving the middle and little fingers (that is, chord 3 5) is one of the most difficult. It should be noted that chord 3 5 is among this end group of chords. The other difficult move is to place the index, ring and little fingers (that is, chord 23 5) down at the same time. Again, this chord (23 5) appears in the penultimate position in the chord rank table. Similarly it could be predicted that the chord 1 3 5 would create problems for the user. A study of the experimental findings demonstrates that this was the most difficult chord to execute. Seibel's four subjects also supported this conclusion by placing chord 1 3 5 in the penultimate position.

A strong correlation was found between the time and error scores (Spearman's Rank Correlation - 0·74). The chord pattern that was conducive to most errors was 2 45, with a 41·33% error rate. The problem appears to emanate from the index and the ring fingers which are difficult to use without the intervention of the middle digit. Hence chords 2 45, and 12 45 appeared in the last six on the chord rank table. Chords 2 4 and 12 4 were found to be easier to execute although they appeared in the latter half of the ranking.

5.3 Criticisms of the Experiment

Several of the subjects commented at the end of the experiment that the task became tedious and slow as they became more skilled at pressing the combinations of keys. In retrospect, it would probably have been a worthwhile exercise to modify the computer program so that the presentation of 'light' chords was faster towards the end of the nine trials. A more extensive pilot study would have determined by how much the two second interval would have to be reduced. Another area which warrants consideration is that of feedback. The provision of 'knowledge of results' for the subjects might have relieved the tedium of the experiment besides encouraging greater speeds. However the actual mechanism for providing the feedback would have to be determined by pilot studies. A further modification to this experiment would be to change the spacing of the breaks throughout the nine trials. It emerged during the experimental period that two individuals were predicting the single digit chords in the groups of thirty-one. This problem could very easily be solved by grouping the chords across two or three trials.

It was apparent from the subjective comments that the keys on the chord keyboards were far from ideal, although Galanter and Owens (1974) had concluded that modest changes in the design of a response key are an irrelevant variable in reaction time experiments. However the author was aware of this problem before the models were built and was unable to improve the choice of key-switch within the limits of availability, finance and time. The major criticism was that the switches were too heavy, although they were adequate for the purposes of this experiment. The location of appropriate switches is a problem experienced by other keyboard designers and it is becoming evident that keys will have to be specifically designed and built.

The final criticism of this experiment concerned the questions asked at the end of the nine trials. In retrospect, it might have been more advantageous to structure these questions in the form of 'attitudes' scales: this would have resulted in more accurate subjective data being obtained.

5.4 Implications of the Experimental Findings

Several minor criticisms of this experimental study have been discussed. However the original hypotheses were successfully investigated, which resulted in the following findings. It was apparent from the objective and subjective data that the hemispherical and cylindrical chord keyboards were superior to the rectangular box design. Small modifications such as the addition of rubber feet would be a beneficial exercise. An interesting finding was that more subjects from the cylindrical keyboard group enjoyed using the device than the other two groups. There is no apparent explanation for this. It could be concluded from this experimental study that the hemispherical and cylindrical designs warrant further investigation and that the rectangular box shape has little potential as a chord keying device. However if a choice has to be made between the hemisphere and the cylinder, the former would be selected. The overall impression gained by the author from the subjective data favoured the hemisphere, especially the replies to the questions on fatigue. The error data also clearly supported the choice of the hemisphere.

6. CONCLUSIONS

The following conclusions were reached from this experimental study:

(a) Objective performance measures showed no significant differences for the response times. The error scores showed a significant difference between the three keyboards, which favoured the hemisphere.

(b) The subjective data demonstrated a preference for the hemispherical chord keyboard. Therefore it is recommended that the cylindrical and rectangular box designs should be discarded.

(c) Statistical analysis revealed that the chords did not relate specifically to the design of the keyboard.

(d) Single digit chords had the fastest response times, while four digit chords were positioned at the end of the chord rank chart. These results corresponded to Ratz and Ritchies' and Seibel's findings.

(e) A good correlation was calculated between response times and error scores, namely those chords which were fastest to execute had the lowest error scores.

CHAPTER 8

A STUDY OF THE COGNITIVE ASPECTS OF CHORD KEYING

1. INTRODUCTION

It has already been discussed in Chapter 5 Section 5 that, when designing a chord keyboard for general use, there are two main problem areas to be resolved: namely, the fact that the individual has to learn and to remember the various chords in order to be able to operate the device, and the determination of the allocation of chords to alphanumerics.

The first area is concerned with learning the chord patterns in relation to the alphanumeric symbols to be keyed. This is where the chord keyboard might have its greatest disadvantage for general use. It is important therefore to discover how individuals learn the different chords in order to incorporate these findings into an optimal system.

Chapter 7 described an investigation into the motor aspects of chord keying, and one of the findings from this study was the ranking of the thirty-one chord patterns according to speed of execution. If only motor aspects are to be considered when allocating chord patterns to alphanumerics, the more frequently occurring letters of the alphabet would be given to the 'faster' chord patterns. However there is an alternative method for determining the allocation of chords to alphanumerics. This would be to allocate those chord patterns which are easiest to learn to the most frequent letters in English text.

The merits of these two bases for allocating chords to alphanumerics has yet to be determined and a combination of both might prove the most suitable. This problem is discussed in Section 3.2.4 of Chapter 10. It was concluded to be worthwhile to rank the thirty-one chords according to ease of learning. The experimental work on this topic is described in this Chapter.

2. BRIEF REVIEW OF THE RELEVANT LITERATURE

Since several chord keyboards have been developed, the problems already discussed must have arisen and attempts been made to overcome them by keyboard designers. One of the first individuals to create a 'working' chord keyboard was Levy in 1955. He apparently seemed unaware of the human factors problems and not illogically used the binary code as the basis for his keyboard (see Figure 8.1).

For example:-

A	1 0 0 0 0	N	0 1 1 1 0
B	0 1 0 0 0	O	1 1 1 1 0
C	1 1 0 0 0	P	0 0 0 0 1
D	0 0 1 0 0	Q	1 0 0 0 1
E	1 0 1 0 0	R	0 1 0 0 1
F	0 1 1 0 0	S	1 1 0 0 1
G	1 1 1 0 0	T	0 0 1 0 1
H	0 0 0 1 0	U	1 0 1 0 1
I	1 0 0 1 0	V	0 1 1 0 1
J	0 1 0 1 0	W	1 1 1 0 1
K	1 1 0 1 0	X	0 0 0 1 1
L	0 0 1 1 0	Y	1 0 0 1 1
M	1 0 1 1 0	Z	0 1 0 1 1

Figure 8.1: Levy's Allocation of Chords to Letters

NOTE:

The digits of the left hand are indicated. If the right hand had to type the letters, the equivalent fingers would be used (that is, thumb for thumb). For further clarification, see Page 96.

Klemmer (1958) considering a 10-key chord keyboard allotted the most frequently occurring letters to single keys, while the other characters were represented by depressing two of the ten keys.

However he does not justify this approach and presumably it was based on his own instinctual logic. A year later, Lockhead and Klemmer experimented with a different chord keyboard which allowed the entry of 100 common words with a single chord keypress. This keyboard was probably the precursor for the IBM chord keyboard developed in the seventies. Neither the 1959 nor the 1978 IBM chord keyboards have been developed by individuals who have justified their designs with practical research. Rochester et al. (1978) stated that the letters were arranged on the dimples in order to optimise the average number of characters produced per chord for English text. No further support or reason was provided. A similar situation exists with the recently marketed Writehander and Microwriter chord keyboards.

It has already been established that some chords are physically more difficult to execute than others. Therefore it is logical to give easier chords to the more common letters of the English alphabet. The designers of the Writehander tried to strike a balance between this and laying out the chords and their combinations in a systematic way in order to facilitate remembering them (R.D. Owens - Personal Communication). This is demonstrated in their chart showing the ASCII code and the corresponding position requirements of the digits. See Figure 8.2. The Writehander has eight keys for the thumb to operate and one key for each finger. Hence there are eight possible positions for the thumb and only two for each finger, namely, when the key is depressed and when it is not. The chart shown in Figure 8.2 shows the thumb key and the corresponding finger keys, which need to be pressed in order to generate the ASCII code, alphanumeric characters, etc.

It becomes apparent when studying this chart that the designers of the Writehander placed more emphasis on the cognitive aspects of chord keying than the physical difficulties of making the various chord patterns.

THUMB KEYS								FINGER POSITIONS			
1	2	3	4	5	6	7	8	1	2	3	4
NUL	DLE	0	SP	\	p	@	P				
SOH	DCI	1	!	a	q	A	Q	●			
STX	DC2	2	"	b	r	B	R		●		
ETX	DC3	3	Y	c	s	C	S	●	●		
EOT	DC4	4	$	d	t	D	T			●	
ENQ	NAK	5	%	e	u	E	U	●		●	
ACK	SYN	6	&	f	v	F	V		●	●	
BEL	ETB	7	.	g	w	G	W	●	●	●	
BS	CAN	8	(	h	x	H	X				●
HT	EM	9	)	i	y	I	Y	●			●
LF	SUB	'	*	j	z	J	Z		●		●
VT	ESC	:	+	k	(	K	[	●	●		●
FF	FS	<	.	l	;	L	\			●	●
CR	GS	=	.	m	)	M	]	●		●	●
SO	RS	>	.	n	~	N	V		●	●	●
SI	US	?	/	o	DEL	O	-	●	●	●	●

● indicates the key is depressed.

Figure 8.2: Chart of ASCII Code and Corresponding Finger and Thumb Positions for the Writehander

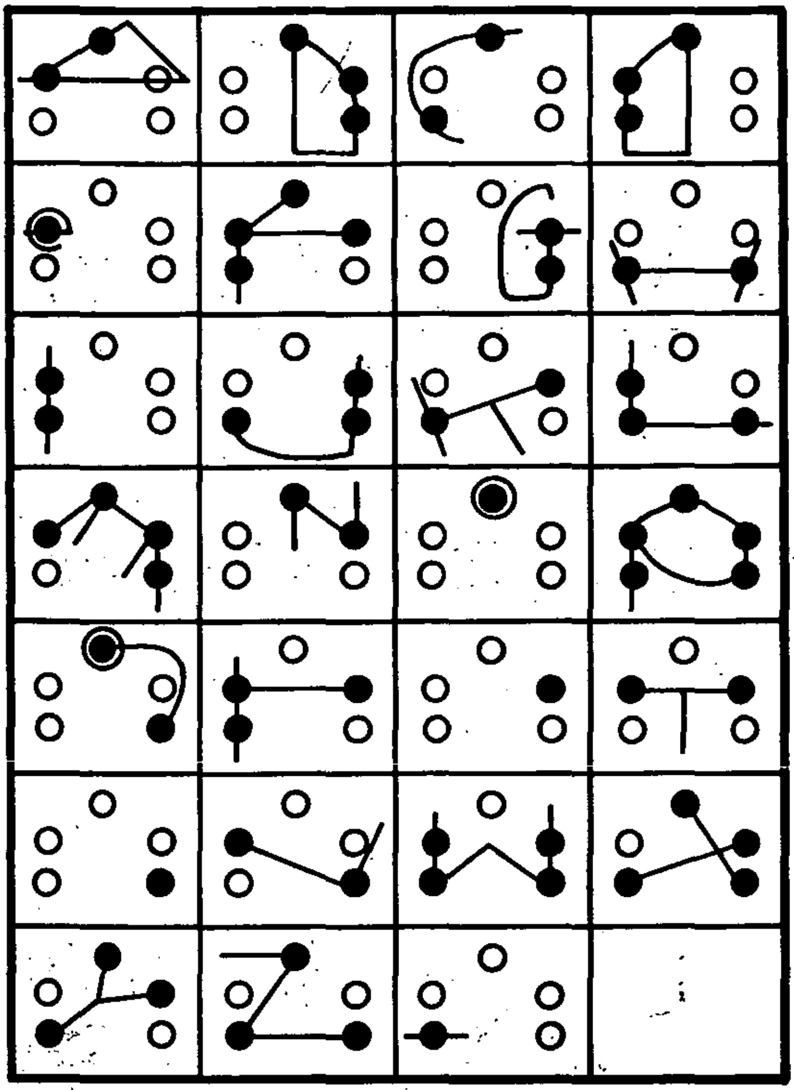


Figure 8.3: Endfield's Mnemonic Chart

Unfortunately the only evaluation of this keyboard has been carried out by the Post Office who are unwilling to disclose the results. It could be hypothesised that individuals would learn the alphanumeric chord combinations relatively easily when laid out in this way.

The inventor of the Microwriter selected a different approach to the learning problem by trying to design mnemonics. Endfield (1978) has chosen combinations of keys that he claims are easy to remember making the shape of the letters out of the five keys (see Figure 8.3). Like the Writehander, the more common letters are allocated easier chords, but some mnemonics, for example, F, M and Q are not particularly representative of their letters.

2.1 Experimental Proposals

It was concluded from the review of the literature that this area of chord keying is little researched and no substantiated plan for allocating chords has been proved. Therefore, an experiment was planned to find the chords which were easiest to learn, so that they could be assigned to the most frequently used letters of the English alphabet. The subjects' task was to learn abstract associations between alphanumerics and their randomly allocated chord combinations. At the end of the experiment, subjects were closely questioned on how they had learned the chords and what memory aids (if any) they had used. It was envisaged that this basic research into chord keying would help to overcome the two problem areas already mentioned. Surprisingly, no research of this nature has been carried out, but this could be interpreted as merely reflecting the embryonic state of the art concerning chord keyboards.

The reasons for carrying out the proposed experimental work could be summarised as follows:-

(a) The cognitive aspects of chord keying should not be overlooked, because they play an important part in the operation of a chord keyboard.

(b) The optimal system for assigning chords to alphanumerics needs to be located.

(c) To study some of the approaches that have already been taken, for example, Endfield's mnemonics chart.

(d) There is a need to find out if flexible memory retention aids decrease the learning time of chord codes, so that they can be incorporated into the system if found to be beneficial.

3. METHODOLOGY

3.1 Pilot Study

3.1.1 Introduction

There are thirty-one possible chords that can be executed by one hand, that is, five digits, see Figure 8.4. In order to keep this variable of thirty-one chords constant, it was proposed to teach subjects a chord for each of the twenty-six letters of the alphabet and five numerals. The chord combinations were randomly assigned to the alphanumerics so that each subject received a different set; this reduced the effect of some chords being learned more quickly because the chord combinations had a special association with the letter, for example, the letter 'A' and the ring finger - A4 (paper), or 'P' and the ring and little fingers - P45 (a form). The ten subjects (five females and five males, having a wide variation in ages from twenty to sixty years) were presented with the chords via a tachistoscope and in a random order. All alphanumeric combinations appeared for a fixed amount of time (that is, six seconds). See Appendix A8-1 for an example of a tachistoscope card.

After the subject had been shown the alphanumerics and the corresponding codes, the procedure was repeated but with only the alphanumeric appearing. The subject was asked to complete the associated code verbally; he/she was then shown the correct chord combination. This experimental procedure continued until all the chord codes had been successfully identified. Each time the subject worked through the list of alphanumerics, this constituted one trial. A random order of presentation of the list was used for each successive trial to prevent the influence of order effects on learning.

It was hoped that repeated randomization (that is, of alphanumerics to chords, and to subjects) minimised the effects of bias in the experiment. The Prime computer was used to generate random numbers for the study.

By combining the group results, it was possible to rank the chord codes according to the number of trials that were needed until the subjects had successfully learned all the chord combinations.

Assignment of Codes to Chords

0	0 0 0 0 0	16	0 0 0 0 1
1	1 0 0 0 0	17	1 0 0 0 1
2	0 1 0 0 0	18	0 1 0 0 1
3	1 1 0 0 0	19	1 1 0 0 1
4	0 0 1 0 0	20	0 0 1 0 1
5	1 0 1 0 0	21	1 0 1 0 1
6	0 1 1 0 0	22	0 1 1 0 1
7	1 1 1 0 0	23	1 1 1 0 1
8	0 0 0 1 0	24	0 0 0 1 1
9	1 0 0 1 0	25	1 0 0 1 1
10	0 1 0 1 0	26	0 1 0 1 1
11	1 1 0 1 0	27	1 1 0 1 1
12	0 0 1 1 0	28	0 0 1 1 1
13	1 0 1 1 0	29	1 0 1 1 1
14	0 1 1 1 0	30	0 1 1 1 1
15	1 1 1 1 0	31	1 1 1 1 1

Figure 8.4: Chord Combinations Available with a 5-key Chord Keyboard

3.1.2 Results

It was realised before the start of the experiment that it would not be possible for the majority of the general population to learn thirty-one chord combinations without a great deal of hardship. So the pilot study used groups of ten, fifteen and sixteen chord combinations (some individuals learned fifteen and some sixteen because fifteen and sixteen total thirty-one).

It was found that there was little difference between the times taken to learn the group of ten chords and the group of sixteen. All subjects completed the learning session in nine trials. It was not felt necessary at this stage to carry out a closer analysis of the results data.

3.1.3 Discussion

3.1.3.1 The Aims of the Pilot Study

One of the main reasons for running the pilot study was to locate any problems in the experimental procedure. At the start of the experiment, the subjects were given the background to the study and instructions about what they had to do. Two points arose from this: it was not emphasised enough that subjects had to make a conscious effort to learn the code assignments - this was probably due to the fact that the author was trying to avoid discouraging the subjects, and secondly, it was not made clear that there was no logical association between the alphanumerics and the chords. Some subjects throughout the first few trials were desperately looking for an association. A pattern began to emerge of the subjects' reactions to the experiment. After the first trial, subjects were thoroughly confused but still willing to continue. By the second and third trials, they were becoming despondent and would start making excuses to justify why they could not remember the chord combinations. A trial was then reached whereby they remembered several chord combinations, and quite quickly after this, they would learn the complete list. At the end of the experiment, the subjects were pleased with their performance and satisfied with the experiment. It was decided that the criterion for completing the experiment was to identify successfully all the chord combinations on two successive occasions.

It could be concluded from the pilot study that the experimental procedure was a feasible proposition and would achieve what the study aimed to discover.

3.1.3.2 Length of the Experiment

It has already been stated that it is not realistic to expect subjects to learn thirty-one chord combinations. Therefore, it was anticipated that the pilot study would help to determine the length of the experiment. When subjects were given sixteen chord combinations to learn, they did this in thirty to forty minutes. In view of the subjects' attitudes and feelings of despondency during the experiment, it was felt sixteen chords were the maximum that could be used. The author was very reluctant to increase the average time span of thirty to forty minutes, because the concentration needed for a learning experiment cannot be sustained for much longer than half an hour. There was the added problem of low motivation; subjects volunteering for this study had little incentive to complete the task. However, this could partly be overcome by financial encouragement.

3.1.3.3 Selection of Subjects

It was necessary for this experiment to obtain individuals who were neither brilliant nor inept at learning tasks. The subject who could learn the associations in one trial would be useless with regard to this experiment and likewise the individual who dould never learn the list of chord combinations. However, the information provided by the latter subject might indicate some trends. A population of individuals who learned the task in a similar time was required for this experiment. A person who spent an abnormally long period of time learning the associations would distort the average results for the whole group.

It was relatively easy to locate variables that affected learning time, but this experiment was particularly interested in the pattern of learning and hence it was more difficult to decide upon influencing experimental variables. A random sample of the general population was tested. Age and sex variables were taken into account in order to avoid using a biased sample of subjects.

3.1.4 Conclusions

The following conclusions were reached from the pilot study:-

(a) Sixteen chord-code alphanumeric associations should be presented to each subject.
(b) It was decided to modify the diagrammatic representation of the chord pattern as shown on the tachistoscope card (Appendix A8-1). The chord was to be shown solely by the numbers, thus reducing the amount of unnecessary 'cognitive clutter' introduced by the hand and shaded fingertips.
(c) If a subject cannot complete the learning of the list of codes, his/her results will be discarded. Although this implies that the allocation of chord codes may be determined by the more skilled members of the population, it was hoped that such an event would not occur.
(d) A financial incentive should be offered to the subjects due to the relatively boring, taxing and unrewarding nature of the task.
(e) Subjects would be randomly selected from the general population taking into account sex and age variables. An upper age limit of fifty years was applied to subjects because of the decrease in the power of the memory with old age.
(f) The problem of deciding upon other variables that affect the pattern of learning remains unsolved.
(g) Subjects would be verbally examined on how they learned the chord combinations - this was for future reference on a follow-up experiment.

3.2 The Main Study

3.2.1 Experimental Design

It was concluded from the pilot study to present sixteen tachistoscope cards showing randomly associated alphanumerics and chords to the subjects. Each subject had a unique set of associations to learn and no repetitions of these combinations occurred. This was to reduce the effect of 'special associations'.

An alternative experimental design was to let subjects return on a second occasion and learn the remaining fifteen associations. This design was not chosen because of the learning effect and the practical difficulties of experimenting with subjects on two different occasions.

3.2.2 Selection of Subjects

Thirty subjects (fifteen females and fifteen males) participated in this experiment. The age of the subjects ranged from twenty to forty-seven years, and they were located by advertising in a monthly University publication. Subjects who volunteered for the study came from a variety of semi-professional and professional backgrounds ranging from teachers and computer programmers to technicians and nurses. Although the group was diverse in this respect, the common factor that linked the subjects was that the majority had undergone specialised training. No undergraduates were used and a minimum number of graduates. It was intended that the subject pool should emulate the predicted user population of the chord keyboard as fully as possible. A description of the thirty subjects is given in Appendix A8-5.

3.2.3 Description of Equipment

Plain white cards showing the alphanumeric and its associated chord pattern (see example in Appendix A8-2) were presented to the subjects. The reasons behind expressing the pictorial concept of the chord patterns in this way are described in the pilot study.

A tachistoscope was chosen to present the chords for two main reasons. It directed attention towards the learning task and away from the author, and it allowed the cards to be exposed to the subjects for a constant fixed amount of time.

3.2.4 Experimental Procedure

At the start of the experiment, subjects were briefed about what was required of them. The procedure was standardised (see Appendix A8-4 'Verbal Instructions to Subjects'). The objectives of the study were explained and it was stressed that they should try and learn the associations as quickly as possible, but not to be concerned if they were slow at learning, because it was the pattern of learning and not the speed that the experimenter was interested in. From the pilot study, it had been concluded that sixteen cards could not be learned immediately, but most individuals had learned them after eight experimental trials. Subjects were constantly encouraged throughout the experiment, regardless of their ability.

Initially, tachistoscopic cards showing the alphanumeric and chord pattern were presented singly to the subjects. Subjects had been instructed to concentrate on the association, and were told that the general feeling after viewing all sixteen would be of total confusion and lack of confidence that they would ever complete the experiment. The next time through the list, subjects were asked if they knew the corresponding chord. This constituted the first trial. The experiment continued until all sixteen alphanumeric chord associations had been correctly identified on two consecutive trials.

At the end of the experiment, the subjects were closely questioned about how they had learned the pairs of alphanumeric and chord patterns. They received a nominal payment to compensate for the low level of motivation associated with an experiment of this nature.

Eight subjects were unaware that they would be approached approximately a week later and asked to recall as many of the chord patterns as possible. They were provided with a list of alphanumerics to help them do this. This 'long term memory' study was essentially an exploratory exercise to find out how many of the chord patterns could be recalled.

3.2.5 Data Analysis

One of the objectives of the experiment was to rank the thirty-one chord patterns according to ease of learning. Therefore extensive statistical analysis was not appropriate for the data generated.

The chords were ranked according to ease of learning and the OMNIBUS computer program (Meddis, 1980) was used to detect any significant differences between the times taken to learn the various chord patterns (that is, the one, two, three, four and five digit chords).

The results of the second part of the experiment on how individuals learned the alphanumeric chord combinations were examined by content analysis.

4. RESULTS

The results are shown by a series of tables. Tables 8.1 and 8.2 demonstrate the thirty-one chords ranked according to ease of learning for the first five trials and all the trials, respectively. The correlation between these two chord rank charts was 0·93.

Table 8.3 shows the results of the OMNIBUS test on the times taken to learn one, two, three, four and five digit chords. It was concluded that there was a statistically significant difference in the times taken to learn these various chord patterns.

The final table in this Section indicates the results obtained from the 'long term memory' study. The subjective data collected during the experiment are discussed in Section 5 of this Chapter.

TABLE 8.1

The Chord Rank Chart

CHORD PATTERN					MEAN NUMBER OF TRIALS*
1					1.80
	2				1.89
			4		2.06
1	2	3	4	5	2.06
				5	2.21
		3	4	5	2.64
1		3			2.69
		3			2.75
1	2				2.78
1	2	3			3.00
1			4		3.07
		3	4		3.53
	2	3	4		3.66
	2		4		3.71
	2	3	4	5	3.71
1	2		4	5	3.72
1				5	3.73
		3		5	3.77
	2	3			3.82
1		3		5	3.86
			4	5	3.87
	2			5	3.94
1		3	4	5	4.00
1	2			5	4.00
	2	3		5	4.06
1	2	3	4		4.12
1		3	4		4.25
1	2		4		4.26
1	2	3		5	4.27
1			4	5	4.50
	2		4	5	4.53

* using first five trials.

TABLE 8.2

The Chord Rank Chart

CHORD PATTERN					MEAN NUMBER OF TRIALS*
1					1.80
	2				1.89
1	2	3	4	5	2.06
				5	2.21
			4		2.24
		3	4	5	2.64
1		3			2.71
		3			2.75
1	2				2.85
1			4		3.06
1	2	3			3.07
		3	4		3.53
1				5	3.80
	2		4		3.82
		3		5	3.94
1	2		4	5	4.00
	2	3	4	5	4.07
1	2			5	4.11
			4	5	4.12
1		3		5	4.14
1		3	4	5	4.18
	2			5	4.23
1		3	4		4.23
	2	3		5	4.25
	2	3	4		4.26
1	2	3	4		4.35
	2	3			4.36
1	2		4		5.00
	2		4	5	5.14
1			4	5	5.33
1	2	3		5	5.35

* using all trials.

NOTE:

The correlation between the two chord rank charts was 0·93 (Spearman's Rank Correlation test - Siegel, 1956)

TABLE 8.3: The OMNIBUS Test Results
on the Time Taken to Learn One, Two, Three, Four & Five Digit Chords

Chord Pattern	Frequency	Rank Mean
1 digit	5	4
2 digits	10	14.85
3 digits	10	21.35
4 digits	5	22.20
5 digits	1	3

** Overall test for finding any effect among the group means
$H = 16.705$ $p = 0.003$

Conclusion: There is a significant difference between the times taken to learn one, two, three, four and five digit chords.

TABLE 8.4

Long Term Memory Results

SUBJECT 6		SUBJECT 7		SUBJECT 8		SUBJECT 9	
CODE	RESPONSE	CODE	RESPONSE	CODE	RESPONSE	CODE	RESPONSE
1 34	12 4	2 45	23 5	2	✓	4	✓
345	✓	12 45	123 5	2 4	–	23 5	✓
2 45	✓	123 5	–	3	✓	1 3	✓
1 4	✓	4	✓	3 5	32	5	✓
2 4	34	12345	–	12 45	✓	1 3 5	✓
23 5	✓	23 5	–	12	–	1	✓
2	✓	12 4	–	1 34	2 4	345	✓
5	✓	2 5	–	1 45	1 3 5	1 34	✓
12 5	✓	2345	–	4	✓	1 4	✓
1 45	1 34	1234	–	1	✓	2345	✓
3 5	✓	34	–	1 5	✓	123	✓
2 5	1 5	234	–	2 5	2	12 45	✓
45	✓	45	✓	12345	✓	12345	✓
123	✓	23	–	34	3 5	2 45	✓
1 3	✓	1 5	✓	12 4	✓	123 5	1 345
234	✓	345	1 3 5	1234	1 34	1 345	123 5

KEY:

✓ represents a 'correct response'

– represents 'no response'.

TABLE 8.4 (Contd.)

SUBJECT 11		SUBJECT 13		SUBJECT 14		SUBJECT 15	
CODE	RESPONSE	CODE	RESPONSE	CODE	RESPONSE	CODE	RESPONSE
12 4	✓	1 3 5	✓	12 5	✓	1 45	✓
1 345	-	12345	✓	1 34	1 3 5	3	✓
1234	-	2 45	-	3	✓	3 5	✓
3 5	✓	12 4	✓	12 4	-	5	✓
4	-	3 5	✓	5	✓	12 5	✓
34	-	2	✓	45	✓	12345	✓
12 5	2 5	1 34	-	345	✓	123 5	✓
1 45	-	123 5	✓	2345	-	234	✓
1 5	-	1	✓	1 3	✓	1234	✓
3	✓	12 45	123 5	2 4	✓	1 345	✓
2 45	-	4	✓	23	2 7	123	✓
2 4	-	45	✓	1 4	✓	34	✓
12	123	12	-	34	2 4	1 3 5	✓
23 5	-	12 5	✓	2	✓	2 45	✓
1 34	✓	234	2345	3 5	✓	12	✓
1	✓	345	-	12345	✓	345	✓

5. DISCUSSION

5.1 Implications of the Chord Rank Chart

All subjects completed the task of learning sixteen alphanumeric chord combinations. The mean number of trials for the group was 7·5, with a range of five to ten trials. There appeared to be little difference (0·3 trials) between the performance of males and females.

The data were analysed and ranked according to two different methods. Since three subjects had successfully identified the chord patterns twice by the fifth trial, it was decided to use this as a cut-off point and only study the data generated in the first six trials. It was anticipated that this method would avoid biasing some chord patterns which by chance had been allocated to slow learners. One of the drawbacks of this method was that even if a chord had not been successfully identified by the ninth trial, it would still be counted as if it had been learned by the sixth trial. The results using this method are shown in Table 8.1

The second method of analysis was to take all the data generated into account and Table 8.2 shows these results. It should be noted that it is the chords towards the bottom of the rank chart which change position, namely those which took longer than four trials to learn. Nevertheless there was a strong correlation (0·93) between the two sets of data derived using different methods.

Several generalisations can be made from the results tables. The single digit chords and the five finger chord were the easiest to learn as would be expected. The simplest of the thirty-one chords, namely '1' and '2' were remembered in the shortest number of trials. The chords 1 3 and 345 were also quickly learned. The remembering of the former chord was probably explained by the associations that the number thirteen has in our Society.

It remains a mystery why chord 345 should be learned so quickly, particularly since chord 2345 falls so low down the list. The chords 12, 14, 34 and 123 were the next to be remembered. Therefore it would appear that two-digit chords are the next most easily retained. The simplicity of the chord 123 probably placed this pattern so high on the list. The last third of the list consists almost entirely of three and four digit chords. The only unexpected results are finding the chords 23 and 25 among this group. The far most difficult chords to remember are 124, 245, 145 and 1235. It is perhaps of interest to note that the number 3 only appears once in these four chords.

5.2 Application of these Findings

Much research has been carried out into single letter, digram and trigram frequencies (Hardy, 1978). Examples of these single letter frequencies can be found in Appendix A8-7. Although it has been a common occurrence to design sequential keyboards based upon a statistical analysis of English words (Nelson, 1920; Dvorak, 1936; Malt, 1977) this trend has not been demonstrated with chord keyboards. This important area of research has been neglected, so this experiment was designed to provide one basis for the allocation of chords to alphanumerics. The proposed allocation is given in Table 8.5. An alternative method would be to use the results obtained from Chapter 7 (see Figure 7.6). The merits of these two approaches are discussed in Section 3.2.4 of Chapter 10.

It can be seen from the four lists of letter frequencies derived from continuous English text that there is a slight disagreement between them. This is similar to the results shown in Tables 8.1 and 8.2 and is useful in that it allows a certain amount of flexibility to be built into the alphanumeric chord allocation system. The material from which the letter frequencies were calculated is not specified and the six lists shown in the Appendix A8-7 were constructed over a forty-year period, so these letter frequencies provide only a crude guide to which letters have the most common occurrence.

TABLE 8.5: Proposed Allocation of Alphabet Letters to Right Hand Finger - Chords

E	1	U	2 4
T	2	P	3 5
A	12345	M	12 45
O	5	W	2345
N	4	G	12 5
I	345	Y	45
R	1 3	B	1 3 5
S	3	V	1 345
H	12	K	2 5
D	1 4	X	1 34
L	123	J	23 5
C	34	Q	234
F	1 5	Z	1234

5.3 Long Term Memory Study

A week after eight of the subjects had participated in the experiment they were presented with a list of the alphanumerics and asked to complete the corresponding code. Subjects were not aware at the time of the main experiment that this would occur, so that no conscious effort was made to remember the alphanumeric code combinations. This part of the experiment was considered to be of minor importance and for the purpose of this study little attention should be paid to the results.

The main discovery to emerge from this study was the variability in individuals' long term memory. Two of the subjects were able to complete the sixteen code list, whereas two could only remember six and seven codes out of the sixteen. As would be expected single digit codes were the easiest to remember and on only one occasion a single digit chord could not be recalled. From a cursory visual inspection of the results, the chord combinations 34, 134, 145 and 12345 proved to be the most difficult to remember. This finding could provide useful information when allocating the alphanumerics to the chord combinations, since the chords 134 and 145 were at the lower end of the chord rank chart (Tables 8.1 and 8.2).

5.4 Methods used to Remember Chord Patterns

It was stated in the introduction that one of the objectives of the experiment was to discover how individuals learned the various chord combinations. To attain this, subjects were asked to describe how they remembered the chord patterns. It is of interest to note that 'fast' learners (that is, subjects who completed the task in five trials), were not as fruitful at providing information as 'slow' learners. The former group could often not explain why or how they had learned a pattern.

It emerged from this study that individuals were learning the chord combinations using several different methods. These could be broadly classified into five groups. The least common way of memorising the chords was by rote learning. Thirteen examples of rote learning were given: seven of these involved the chords 134, 235 and 245. It is a significant finding that there were no single, four and five digit codes amongst this group. Thus it could be concluded that the three combinations stated above were the most difficult to learn. This is supported by the chord rank chart, which showed these chords to be amongst the slowest to be learned.

The second method of learning was based upon a simple association. For example, the chords C/23, E/23, G/3 and P/3 were all associated because the letter and the number rhyme. Other more self evident examples included P/2 (P^2), 5/14 ($5 = 1 + 4$), 2/4 ($2^2 = 4$), N/123, G/1234, 2/12345, and 2/34.

A more frequently used means of learning the chords was to depend on an abstract association between the alphanumeric and the chord pattern. On several occasions the chord 13 was learned because of the connotations of the number 13 being unlucky in our Society.

Some individuals learned a chord because it had special meaning and personal significance. For example, some chords corresponded to bus routes, chronological ages and house numbers and, although there was no obvious association between this number and the alphanumeric, subjects used this mechanism in order to be able to remember the chord. Although this method of abstract association concentrated on the chord pattern, the alphanumeric was also treated in this manner. Examples included remembering that the chord pattern was associated with one's own, husband or wife's, or boss' initial. Another example included the Q which was remembered as 'question' and then associated with 24. Thus the individual learned 'question 24', which had apparently no special meaning to them. Perhaps one of the most bizarre associations occurred with E/1245, which the subject learned as 'Egg and the 3 missing'. He was unable to explain his reasons for choosing this abstract association, but it did enable him to remember the chord pattern. Another interesting memory aid was provided by the subject who learned L/125; he learned this chord by remembering that there was no association between them. It is apparent that individuals rely on any small indicators to enable better retention of the alphanumeric chord combinations.

Although some chords were learned using an abstract association, it was more common for individuals to create a logical association. Several of these logical associations would be universally recognised. For example, the letters A and M were often associated with roads and motorways. Other examples included U/14 (a battery), K/2 (the mountain), K/4 (a chess move), B/1345 (a chord on a guitar), X/45 (a plane) and K/145 (the music chord K). Some subjects made a phonetic phrase from the alphanumeric and chord combination. U/4 was learned as the word 'euphoria', T/4 as 'tea for...', Y/2 as 'why two?', G/13 as 'gradient one in three', and R/124 as 'R one to four'. Other chord patterns resulted in quite complex manoeuvres being made in order to remember them. For example, D/345 was remembered as 'Decline 345', H/12 as 'H_2O with the two replacing the one', C/123 as 'ABC123', E/124 as 'E1234 with the three missing because it was a similar shape to the E', Z/2345 as '12345 with the one being associated with A and then Z', Q/1234 as 'QE234 with the E being replaced by the one' and 0/235 as '2 + 3 + 5 = 10'. Other frequent logical associations included making a word from the letter of the alphabet which was related to the chord. T/12345 was learned as 'Total = 12345' and P/12345 was similarly remembered as 'Perfect = 12345'. T/125 was identified as a '125 Train' and Q/134 was remembered as 'Queue for a 134 bus'. It became apparent during the experiment that subjects were overcoming the problem of non-association between the alphanumerics and the chords by inventing their own, sometimes very imaginative, relationships. Therefore, it could be hypothesised that given a novel situation such as using a chord keyboard, individuals would attempt to overcome the problems of learning the chord patterns by applying their own retention aid.

The fifth and most popular method employed to learn the chord patterns was based on the shape of the alphanumeric. Subjects learned the chord by arranging it spatially on the letter of the alphabet.

For example:

```
T/345     =     3 4 5
                  T

Y/1235    =     2 3
                 Y
                1 5

W/135     =     1 3 5
                  W

V/234     =     2 4
                 V
                 3

E/24      =      1    (the three horizontal strokes
                E3     of the 'E' represented 1 3 5 -
                 5     the gaps being 2 4).
```

Points on the letter were frequently used to locate the numbers of the chord, although on some occasions the curved part of the letter was employed.

For example:

```
    B/234     =     2
                   B3
                    4

    U/345     =    U
                  3 5
                   4

    0/123     =    2
                  103

    Q/1245    =   2 4
                   Q
                  1 5
```

Some individuals concentrated on the shape of the letter and found similarities between this and the chord. An obvious example is S/5, although H/4, K/4, S/2 and Z/2 were also treated in this way. An extension of this method was to relate the number of strokes in a letter to the numbers in the chord pattern. For example, X (2 strokes) and the chord '12'. F/234, E/1234, X/14, N/345, L/14, V/24, L/15 etc. The use of symmetry was also encountered and in particular with the letters H, T and X. On three occasions, a more complex memory aid was used. V/1245 was learned as '12V45 where the V had knocked out the three', 5/1235 was interpreted as 'jumping into five', and M/134 and W/25 were learned because 'the shapes of the letters and the chords were opposite'.

It is of interest to note that this method of learning the chord combinations was used more with the three and four digit chords, whereas the first and second methods described (that is, rote learning and simple association) were employed more extensively with the 2 and 3 digit chords and with 1 and 2 digit chords respectively. In this experiment, 26 letters of the alphabet and five numbers were presented as stimuli. Due to the lack of feedback from the numbers concerning the methods used to learn their associated chords, it might have been wiser in retrospect to eliminate the five number tachistoscope cards.

The ways in which individuals learned the chord patterns were broadly classified into five categories. It would appear from the results that the method employing the shape of the alphanumeric and/or chord pattern has the most potential for incorporation into a chord keyboard system for general use. Unlike the abstract and logical associations, this method did not depend upon personalised, specific connections, although there was scope for this. The rote learning and simple association methods have obvious disadvantages in their application to a task of this nature. Rote learning provides an arduous and tedious approach to the learning of the chord patterns and their associated alphanumerics, while the simple association method has limitations when applied to the three, four and five digit chords.

6. CONCLUSIONS

One of the objectives of this study was to rank the thirty-one chords according to ease of learning. If the chord-code allocation was to be based solely on the cognitive aspects of chord keying, the following recommendations should be taken into account:-

(a) Single digit and five digit chords should be allocated to the most frequent letters of the alphabet.

(b) There was a significant difference in the time taken to learn two, three and four digit chords.

(c) The chords 12 4, 2 45, 1 45, and 123 5, were the most difficult to learn and should be allocated to the least frequent letters of the alphabet.

The second part of the study investigated the ways in which individuals learned the chord patterns. Although the effects of meaningfulness of some associations could never be eradicated across a group of individuals, it was concluded that a system based on the shape of the chord had the greatest potential. Therefore, it was decided that a further experiment to support and clarify the findings of this study should be undertaken.

7. THE FOLLOW-UP STUDY - AN INVESTIGATION INTO THE USE OF MNEMONICS FOR LEARNING THE CHORD COMBINATIONS

7.1 Introduction

The experiment described in the previous section distinguished the various approaches individuals used in order to learn the chord patterns. It was concluded that a mnemonics system based on the shape of the letter would be the most appropriate across a population of individuals. It was hypothesised that the incorporation of such a system would increase the rate of learning. An experiment was executed in order to test this hypothesis.

7.2 Methodology

The experimental design, equipment and procedure were identical to the previous study. Ten subjects (five females and five males) were selected on a similar basis, as it was important to maintain constancy and avoid bias*. The only change to be implemented concerned the tachistoscope cards. The chord patterns were replaced with the shape of the letter. See Figure 8.5. The most frequent letters of the alphabet were allotted to the chord patterns which were easiest to learn and the author arranged the digits of the chord around the shape of the letter. Whenever possible the five numbers of the chord pattern were arranged spatially in keeping with the arc shape previously used on the tachistoscope cards. The numbers 1 to 5 were not assigned to chords, since without a specific application it was not possible to determine their frequency of use. Hence in this study only 26 chord patterns were used.

---

* No subject was used on more than one occasion throughout the 'Cognitive Aspects of Chord Keying' pilot, main and follow-up studies. Therefore the total number of subjects tested was 50.

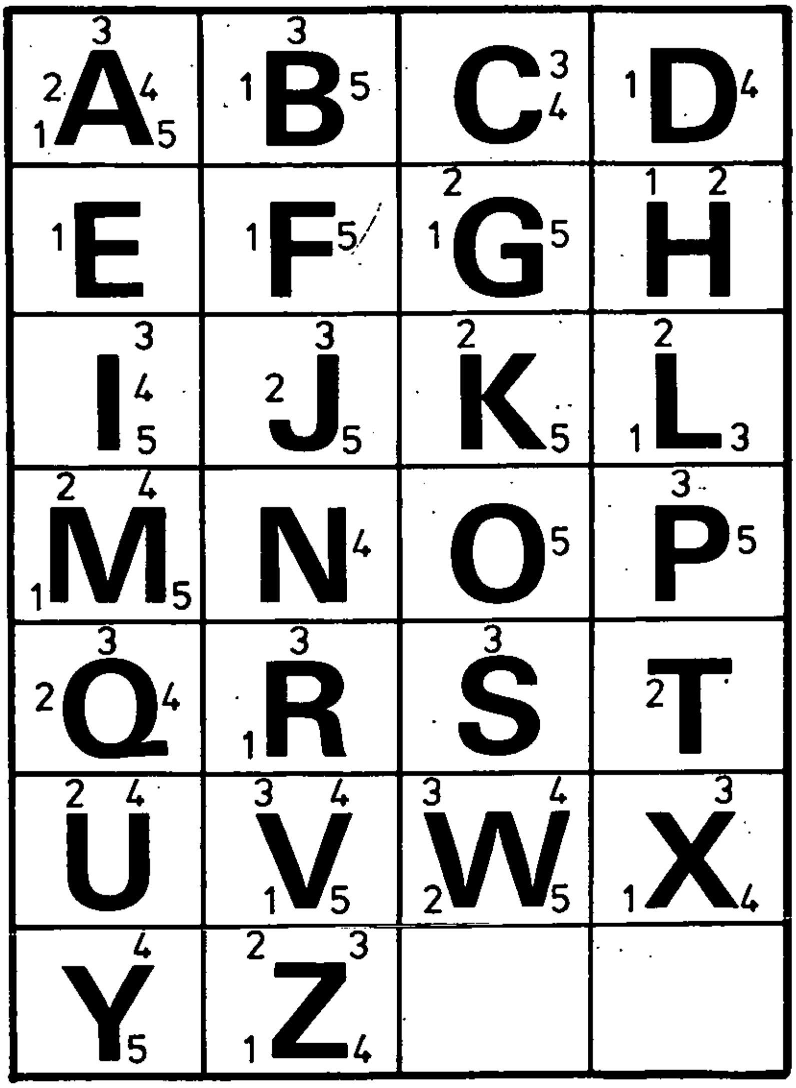


Figure 8.5: Chord Pattern plus Letter Shape Integrations Proposed and Tested

Sixteen randomly generated tachistoscope cards were presented to each subject in a similar manner to the previous experiment. At the end of this follow-up experiment, subjects were asked how they had remembered the various chords. No mention was made by the author about the arrangement of the chord around the letter, in order to find out if this mechanism was being used by the subjects to aid learning.

7.3 Results

Table 8.6 shows the mean number of trials taken to learn the chord patterns. Each chord related specifically to one letter of the alphabet throughout this study.

TABLE 8.6

LETTER	CHORD PATTERN					MEAN NUMBER OF TRIALS*
T		2				1.14
S			3			1.28
A	1	2	3	4	5	1.50
E	1					1.57
H	1	2				1.75
U		2		4		1.75
O				4		2.33
Z	1	2	3	4		2.50
M	1	2		4	5	2.60
P			3		5	2.83
Q		2	3	4		2.86
F	1				5	3.00
L	1	2	3			3.00
N				4		3.17
W		2	3	4	5	3.17
V	1		3	4	5	3.25
B	1		3		5	3.33
I			3	4	5	3.33
R	1		3			3.33
G	1	2			5	3.57
D	1			4		3.75
X	1		3	4		3.87
K		2			5	4.00
Y				4	5	4.00
C			3	4		4.14
J		2	3		5	5.17

* Using all trials.

7.4 Discussion

Visual inspection of the data suggested that the new method had reduced the learning time. The t-test for independent samples was applied to the data (Snedecor and Cochran (1967)) which showed that there was a significant difference between the two sets of data shown in Tables 8.1 and 8.6 (t=2.745, significant at the 1% level). However these results should be treated cautiously. Although an effort was made to maintain the constancy of the experimental conditions for the main and follow-up studies, there was one fundamental difference, namely, the removal of the five numerics from the pack of thirty-one chords. It was not possible to quantify the effects of this change but it was hypothesised that this variable might affect the experimental results. In the previous study described in Section 5.4, it was found that there was a lack of feedback from the numbers concerning the methods used to learn their associated chords. This could be interpretated as indicating that the number chords were more difficult to learn. Hence, it was concluded that the significant difference should be viewed with caution, although it was probable that a trend towards faster learning was demonstrated in the follow-up study.

Content analysis of the results indicated that individuals were relying on the shape of the letter to aid retention. Eight of the ten subjects declared that it was the arrangement of the digits around the letter which helped them to learn the chord. Often the placement of the chord pattern resulted in a pictorial representation of some object which the subjects remembered. For example, H/12 represented rugby posts and B/135 was a road.

The most common methods used for learning the letters could be summarised as follows:-

A/12345	'A' represents the word 'all' which is directly related to the chord.
B/135	Shape of the letter/road number.
C/34	Shape of the letter/C3PO - robot in 'Star Wars'.
D/14	14D is similar to chemical '13D'/shape of the letter.

E/1	Learned because of its simplicity/that is, (i.e.).
F/15	Flying 15 was a boat.
G/125	Shape of the letter/G chord on a guitar - 125 is the position of the fingers.
H/12	Shape of the letter/rugby posts.
1/345	No explanation provided.
J/235	Rote learning.
K/25	Two subjects related '25' to the shape of 'K', while a third individual found this confusing.
L/123	Shape of the letter/L = 'learner' 123.
M/1245	Shape of the letter.
N/4	N = 4, a term often used in statistics.
O/5	'Hawaii 5-O'
P/35	Shape of the letter/form P35.
Q/234	Remembered as a sequence /Q.9 (2+3+4=9) from Spike Milligan.
R/13	Shape of the letter/similar to B/135/unlucky number.
S/3	Similarity of shape.
T/2	Shape of letter 'T' that is, two strokes/ 'tea for two'.
U/24	Shape of the letter.
V/1345	Shape of the letter.
W/2345	Shape of the letter/similarity to 'V'/the missing '1'.
X/134	Position of the numbers on the X/rote learning, because the shape is misleading.
Y/45	Why 45?
Z/1234	Shape of the letter.

It becomes apparent from these results that, for 17 out of the 26 letters, the integration of the chord pattern into the shape of the letter was being used by the subjects to help them learn the chords. Letters which were doubtful in this respect included the 'F, I, J, X and Y'. Others which were not cited were probably learned because of their simplicity, namely 'E, N, and O'. Surprisingly the letter N in this experiment appeared quite low down the list for a single digit chord. No explanation for this can be provided.

It could be concluded from the decrease in the learning times and the subjective data that the method used for presenting the chord patterns was successful. This coupled with the fact that individuals were inclined to make up their own personal associations and would not normally learn chords separately (and hence would gain the advantage of sequence effects) suggested that even faster learning times could be attained.

7.5 Conclusions

On the basis of these experimental findings it is recommended that a 'memory aid' be incorporated into any chord keyboard system. The major requirement is that the memory aid should be applicable to a large proportion of the population. The method of using the shape of the letter to aid retention was found to be successful. It is anticipated that the system of mnemonics used in this follow-up study, which was similar in principle to Endfield's approach, would make learning the chord patterns easier, faster and more enjoyable.

CHAPTER 9

A SURVEY OF USERS' ATTITUDES TOWARDS CHORD KEYBOARDS

1. INTRODUCTION

This research has focused upon the development of the sequential keyboard, the introduction of the chord keyboard and the concept of the keypen. A natural conclusion to a piece of work of this kind would be to try and assess the reactions of the eventual user population to this chord keyboard. Although there are many foreseeable problems in such an exercise, the author decided to instigate a study in order to gain individuals' first impressions of the concept of a chord keyboard system. It was hoped that this work would indicate whether there is any potential advantage in developing the chord keyboard, as attitudes towards such a device are going to be an important factor in determining the success of the concept.

There are a great many ways of assessing peoples' attitudes and feelings to an object or new device. One approach would be to adminster 10 to 20 questions covering different aspects of the object and calculate the number of respondents giving various answers. A slightly more elaborate approach would involve the use of rating scales. Rating scales usually result from intense pilot work and are administered to a sample of the individuals whose attitudes are being assessed. The end-result of such a scale is to place people on a continuum in relation to one another in relative and not absolute terms. Such an exercise would provide useful information concerning the attitude in question.

1.1 Problems of Attitude Testing

Research on the measurement of attitudes is plentiful and this area of Psychology has been well documented. However problems arise when measuring attitudes, because like other components of behaviour they are abstract. Most definitions agree that an attitude could be interpreted as acting in a certain manner when presented with a particular stimulus. The intensity of the attitude is an important consideration, and Social Psychologists make a rough distinction between the different levels of an attitude. These levels range from the most superficial attitudes which could be termed beliefs through to the deepest levels which could be interpreted as the personality of the individual.

However the concept is not as straightforward as this since there are interrelations and patterns of connection apart from the logic of feelings and emotions. It is important to realise that attitudes are not always the product of a balanced conclusion after a review of the evidence (Oppenheim, 1966). They can be highly emotional, both in the sense of irrational or illogical and in the sense of arousing powerful needs and ego defences.

It is usual practice to measure attitudes by administering a series of questions (Moser and Kalton, 1977), as it is not possible to determine accurately an attitude from the answer to a single specific question. A solitary belief is a poor indicator of a person's general attitude, which in order to be measured more precisely needs to be based upon a range of questions covering the various aspects of the attitude. This approach also avoids weighting the sample of questions towards one particular facet of the attitude. Besides this, it will reduce the effects of idiosyncracies of particular respondents with regard to some questions. Again the problem arises of determining the nature of the attitude and its subsequent aspects, due to its abstract form.

There are also problems associated with the rating scale itself. For example, the more extreme attitudes are usually held with more vehemence, whereas the more neutral position may be defended with far less intensity. Another factor to be taken into consideration is that subjects tend to avoid the two extremes. This effectively reduces the length of the rating scale, and results in the 'error of central tendency'. Another difficulty associated with such rating scales is the 'halo effect': subjects classify the object on each scale according to their general impression rather than the meaning of the scale. If an individual likes the object, he/she will score it favourably on all the scales.

1.2 Compilation of the Attitudes Questionnaire

One of the major problems associated with the attitudes questionnaire concerned the extensive pilot work that would be required. For example, Thurstone rating scales provide one of the best known approaches, but this method relies heavily upon the pilot procedure (Summers, 1970). This laborious procedure employs 50 - 100 judges who assess about a hundred statements along a continuum. From these statements a sample is selected to form a questionnaire, which is administered to the subjects. Subjects are asked to agree or disagree with the statements, and from these results a score for each individual is calculated (Moser and Kalton, 1977). Due to the unfamiliarity of the chord keyboard among the general population, it would be difficult (if not impossible) to locate a large number of individuals qualified to partake in a pilot study.

A second well known approach is to use the semantic differential scale (Osgood, Suci and Tannenbaum, 1957). This rating scale has six divisions between the two end points which are described by adjectives opposed to each other. The seven positions along the scale are allocated scores one to seven, and the data are then analysed by calculating mean scores for each item. Osgood et al. have developed and tested many adjective pairs to provide the basis for semantic differential scales. However due to the unsuitability of the majority of these adjectives (because of their apparent irrelevance), the semantic differential was not considered appropriate for this study.

The actual format of the rating scale provided one of the most difficult decisions connected with this research. None of the scales briefly reviewed was considered wholly suitable. However it was decided to utilise some of the material collected from a previous experimental study, by following a method suggested by Edwards (1957). After subjects had participated in the reaction time experiment (Chapter 7), they were closely questioned about the chord keyboard.

From their comments, which were readily expressed on the basis of the keyboard they had used, it was possible to compile a list of statements describing the keyboards. By contrast, in the questionnaire survey of skilled typists (Chapter 2) a modest attempt was made to obtain skilled typists' opinions about chord keyboards without giving them one to use. This approach was deemed totally unsuccessful, because it asked individuals to comment upon a device which they had probably never seen.

Based upon the subjects' statements (from Chapter 7), a questionnaire (see Appendix A9-1) was composed. It was divided into two parts, sections A and B. Section A consisted of 16 rating scales; each statement was followed by a five point scale ranging from 'agree to disagree'. This technique is similar to that used by Likert (Oppenheim, 1966). Likert Scales normally have five response categories with the middle of the scale providing the neutral response, for example, 'undecided'. Some Likert rating scales use three or seven categories. Each category is assigned a score, so that results can be calculated for each subject: factor analysis is widely used with Likert scales. When constructing the 16 rating scales, recommendations laid down by Edwards (1957) were followed. For example, all statements which could be regarded as factual were eliminated, and ambiguities, double negatives, the use of certain words (all, always, never, none) and references to the past were avoided. Section B of the questionnaire consisted of seven questions. The reason for this part of the questionnaire was to explore more fully some of the areas covered by the 16 rating scales.

1.3 Objectives of the Experimental Investigation

The primary reason for conducting this study was to try to gain an impression of individuals' reactions to the chord keyboard concept. There were also several secondary objectives for the work. These could be listed as follows:-

(a) The experiment incorporated the findings of the previous studies described in Chapters 6, 7 and 8.

(b) It was anticipated that this simulation would provide useful information concerning the physical design of the chord keyboard and the mnemonics chart. Although these areas had already been investigated, this had occurred in isolation. Therefore it was a more valid exercise to consider the keyboard and the mnemonics chart in an applied situation.

2. METHODOLOGY

2.1 The Pilot Study

2.1.1 Selection of Subjects

Six individuals (three females and three males) participated in the pilot study. They were all qualified researchers and chosen deliberately by the author in order to draw on their professional knowledge and gain criticisms concerning the questionnaire and the experiment.

2.1.2 Description of Equipment

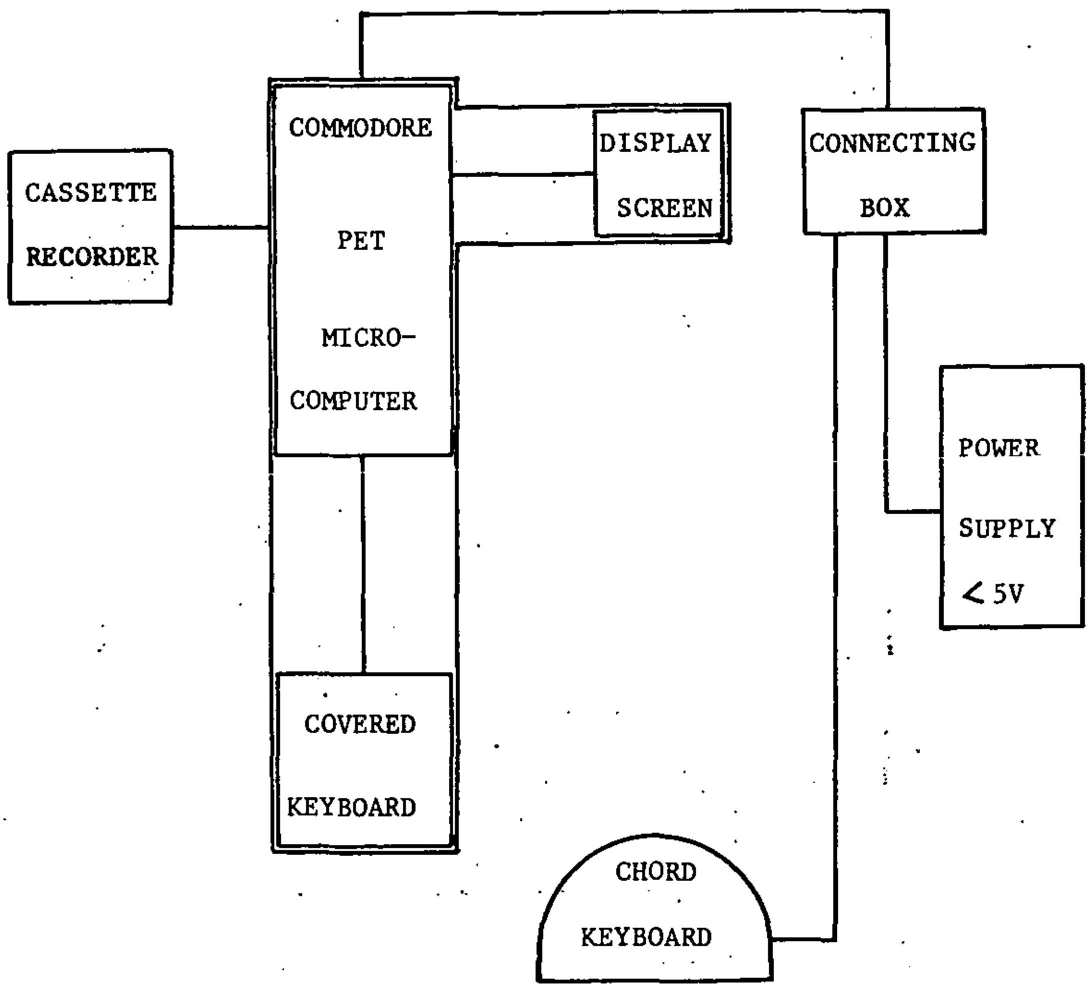


Figure 9.1: Diagrammatic Representation of the Chord Keyboard System

2.1.2.1 The Chord Keyboard

The hemispherical chord keyboard was used in this experiment. It had been concluded from the experimental investigations into the physical design and motor aspects of chord keying that the hemispherical shape was more suitable as a keying device than the cylindrical or boxshaped keyboard. Hence the decision to incorporate this keyboard into the final study.

2.1.2.2 The Role of the Commodore PET Computer

The hemispherical chord keyboard was interfaced to a Commodore PET computer. This enabled the screen of the PET to be used as an output medium for the chord keying device. The keyboard of the PET computer was not operated by the subjects, although the author used it to locate the keying exercises on the computer programs. A specially constructed wooden box completely concealed the PET's keyboard from the subjects. The mnemonics chart conveniently fitted the top of the box.

The computer programs for the experiment were stored on cassette and 'floppy diskette'. The latter method allowed much faster retrieval of the keying programs, so the author employed the use of the diskette. The cassette tape acted as a back up copy, in case the disc system crashed.

2.1.2.3 The Mnemonics Chart

The problem of allocating chords to alphanumerics, which has been discussed in previous chapters, was also present in this study. It was decided to use the 31 chord patterns suggested in Chapter 8. Reasons for this choice were as follows:-

(a) This allocation of chord patterns to alphanumerics had been successfully investigated during the follow-up work to the 'Cognitive Aspects of Chord Keying' study.

(b) There was a good correlation (0·64) between the ranking of the 31 chords using the 'reaction time' data (from the Motor Aspects study - Chapter 7) and the 'learning time' results. Hence it was hypothesised that the latter could be used without major modification.

Some amendments had to be made to these 31 chord-alphanumeric combinations, namely, changing the use of four chords from numerics to punctuation. These chords were 23 for 'space', the chord 123 5 for the period (full stop), the chord 1 45 for carriage return and the chord 12 4 for delete (which included automatic backspace). The mnemonics chart was letra-set on plain white A4 sized card and positioned on the box covering the PET's keyboard.

2.1.3 Experimental Procedure

The experiment was divided into three parts. Subjects upon arrival at the Computer room were seated in a comfortable chair facing the screen of the micro-computer with the chord keyboard resting in their laps or on the worksurface to the right of the PET. They were given the set of verbal instructions as outlined in Appendix A9-3.

The first part of the study involved working through the letters of the alphabet three times. Subjects were instructed to make the appropriate chord pressing when a letter appeared. If they were correct, the word 'CORRECT' appeared in the middle of the screen and the program moved to the next letter of the alphabet. If the subject had made a wrong keypressing or had not pressed the keys simultaneously, the word 'INCORRECT' appeared, and the subject would have to attempt to make the chord again. This procedure continued until subjects had worked through the 26 letters on three occasions. Due to time limitations, the computer program was very basic and did not have an elaborate feedback mechanism written into it.

The second part of the experiment required the subjects to key in lines of prose. In order to be able to do this, the additional chords for space, full stop, carriage return and delete had to be supplied. The prose (an extract from a Pitman's Teach Yourself Typing book) appeared one line at a time. The characters that the subjects keyed in appeared immediately beneath each line of text (see Figure 9.2).

GOODS MAY BE TRANSPORTED BY LAND SEA OR AIR. IN THIS COUNTRY THE GREATEST TRANSPORTATION OF COMMODITIES IN LARGE BULK IS BY RAILWAY ALTHOUGH A VERY CONSIDERABLE QUANTITY OF GOODS IS NOW TRANSPORTED BY FLEETS OF LARGE MOTOR LORRIES FOR WHICH TRUNK SYSTEMS COVER THE WHOLE COUNTRY.

Figure 9.2: The Text Used in this Part of the Experiment

It was stressed to the subjects that no speed of accuracy measures were being taken. However all individuals were asked to correct errors using the delete key (which included automatic backspacing). The only chord which could not be deleted was carriage return, so if the chord 1 45 was inadvertently pressed, the next line of text would appear. However this only occurred on a couple of occasions and subjects were instructed to continue on the next line (that is, from the position of the cursor).

Performance measures were not collected during the experiment for a variety of reasons, as follows:

(a) Learning curves for the very naive user are atypical of later performance, and the slow 'speed' of keying and high error rates can greatly distort the group means.

(b) This study was primarily concerned with attitudes towards the chord keyboard system. Therefore the emphasis was placed on the questionnaire administered at the end of the experiment.

(c) Due to time limitations, the computer programs were made as simple as possible for the Departmental Computer Programmer.

The third and final part of the experiment involved filling in the questionnaire. Subjects were required to complete this questionnaire in the experimental room, while the chord keyboard system was still 'fresh' in their minds. Throughout the experiment, the author remained outside of the computer room, but within earshot. It was felt that the presence of another individual within close proximity of the subject could be distracting and unsettling for the individual, especially if he/she was making a lot of errors.

A formal data analysis was not carried out on the pilot study results, since the group of subjects were biased as they were all researchers.

2.1.4 Discussion of the Pilot Study

There were two main objectives for running the pilot study. These were to improve the questionnaire by seeking comments from individuals skilled in compiling questionnaires and to allow the author practice in conducting the experiment and operating the micro-computer.

The results of the pilot study indicated that several minor adjustments had to be made to the wording of the questionnaire. These included the addition of question 7 "Have you any further comments to make concerning the chord keyboard system or this experiment?".

The only other change concerned the cursor on the computer screen. The computer program was adjusted so that the underscore cursor was replaced by a hyphen. It was concluded that the latter had greater clarity.

2.1.5 Conclusions

Several valid observations emerged from the pilot study and the necessary adjustments were made to the questionnaire and the computer program. After these changes had been implemented, it was concluded that the main study should be initiated.

2.2 The Main Study

2.2.1 Selection of Subjects

Twenty subjects (ten females and ten males) constituted the experimental group. Individuals were selected on the basis of representing a variety of backgrounds. A profile of the subjects is provided in Appendix A9-2. It was intended that the pool of subjects should not be biased towards one group of individuals (for example, students) and that it should attempt to represent the potential user population of chord keyboards.

Subjects who had participated in the response time experiment (Chapter 7) were not considered eligible for this study, and were not used.

There were no specific personal requirements needed for the experiment. Individuals under the age of 45 years were selected, because with the approach of old age, the flexibility and agility of the fingers decreases. Hence the middle-aged and the elderly might have problems operating the keyboard which may result in their attitudes towards it being affected by their inability to use it. Although the chord keyboard was intended for right-handed individuals, two left-handed subjects participated in the study and did not have any problems using the device with their right hands.

2.2.2 Description of Equipment/Experimental Procedure

The experimental equipment and procedure were identical in the main study to that used in the pilot study. See Sections 2.1.2 and 2.1.3.

2.2.3 Data Analysis

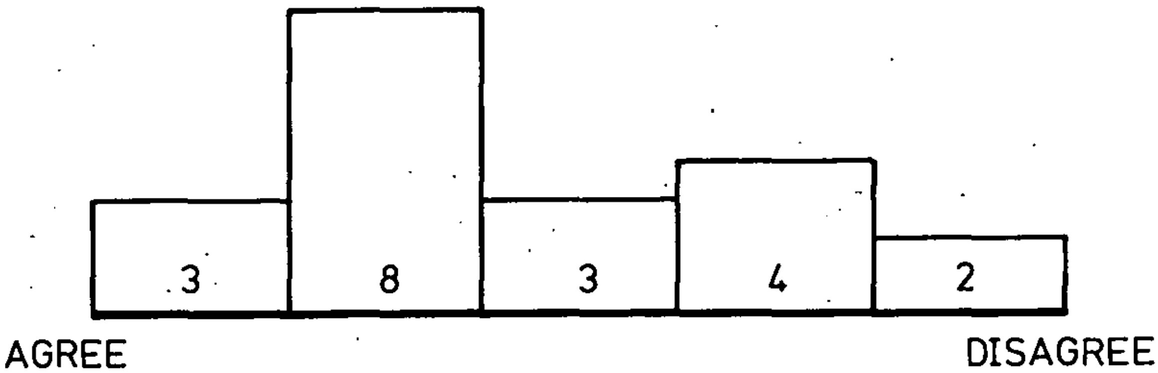
The questionnaires were analysed manually and frequency tables constructed to demonstrate the results. Content analysis was carried out on the answers to Section B of the questionnaire.

3. RESULTS

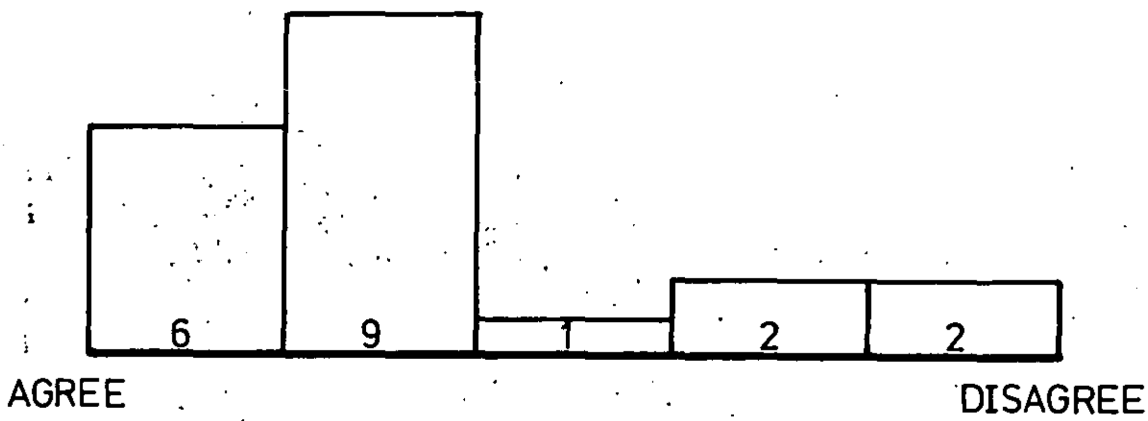
3.1 Section A of the Questionnaire

These results are shown by a series of histograms, which indicate the number of responses to each of the 16 rating scales.

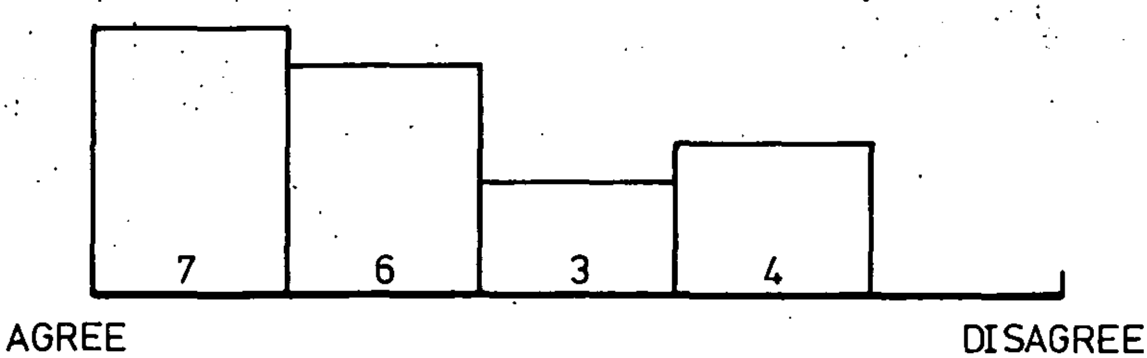
1. I FOUND THE CHORD KEYBOARD AWKWARD TO USE.



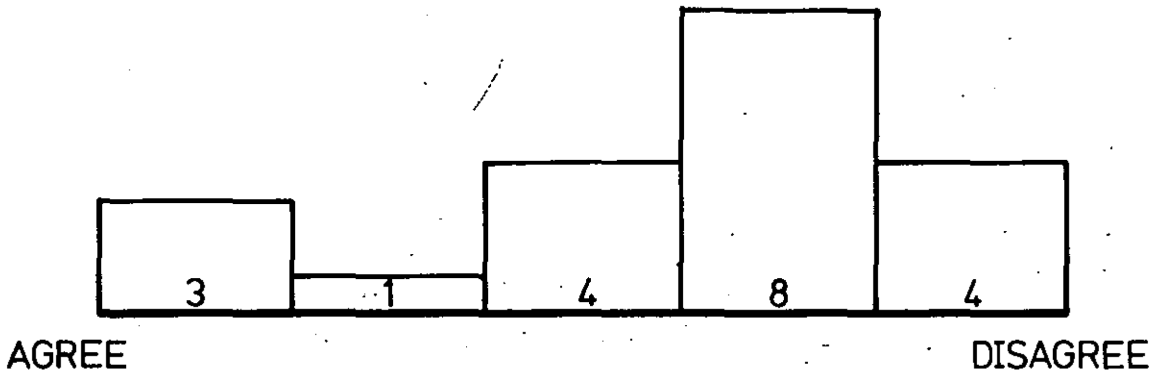
2. I THINK MY ARM WOULD ACHE AFTER KEYING FOR LONG PERIODS OF TIME.



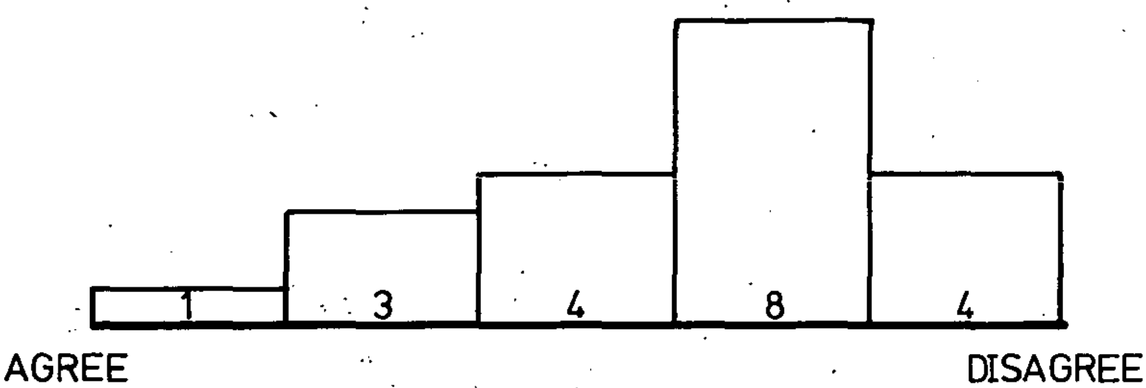
3. I THOUGHT THE MAJORITY OF THE CHORDS WERE EASY TO MAKE.



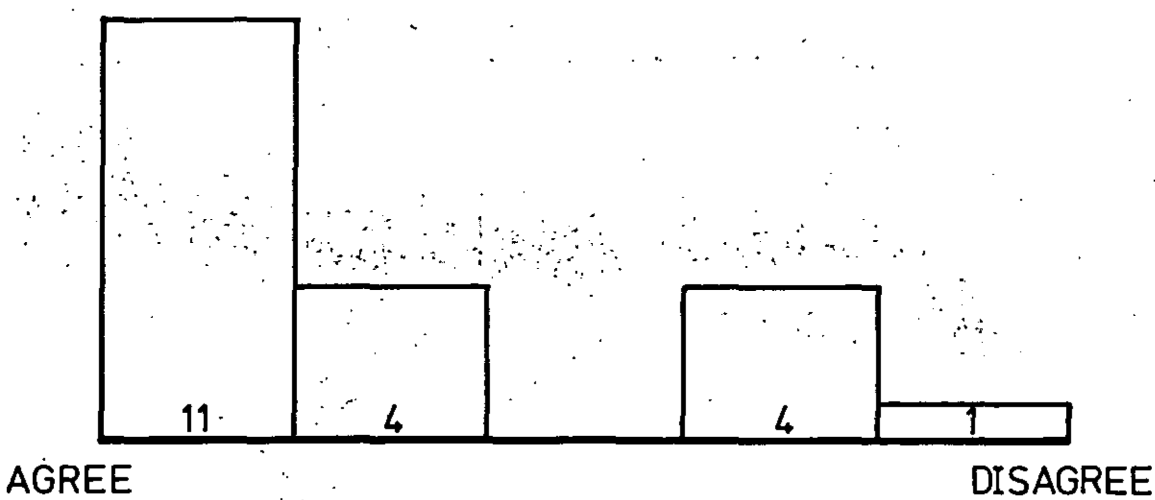
4. I WOULD ALTER THE POSITION OF THE KEYS.



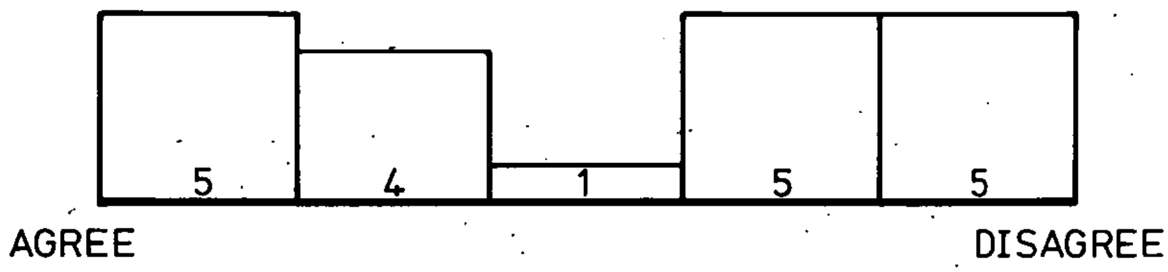
5. THE CHORD KEYBOARD WAS COMFORTABLE TO OPERATE.



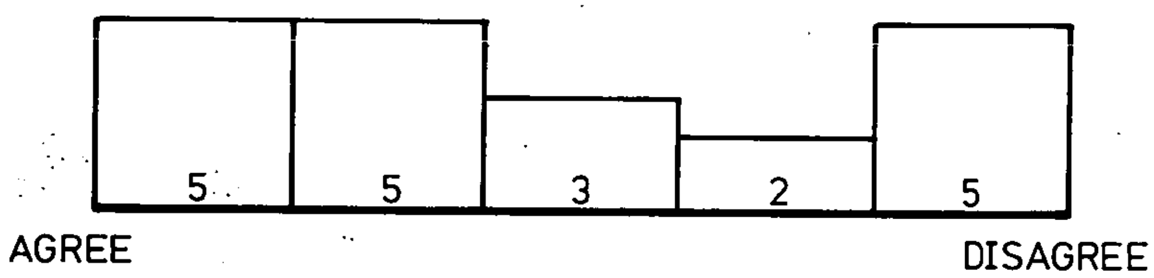
6. THE MNEMONICS CHART WAS CLEAR.



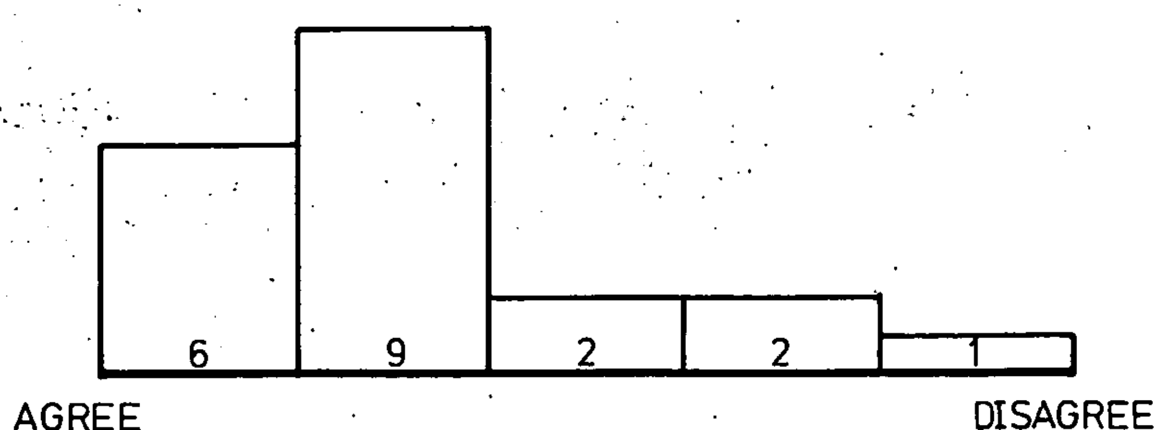
7. I WAS UNSURE WHEN I HAD DEPRESSED THE KEYS.



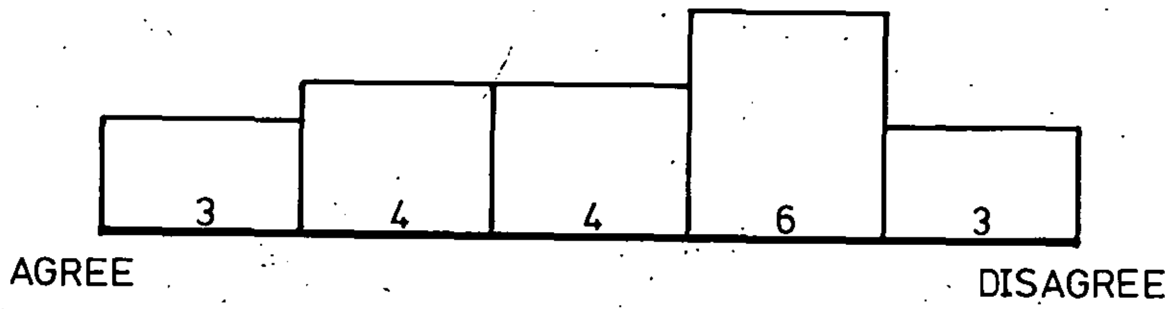
8. I WOULD ALTER THE SHAPE OF THE KEYBOARD.



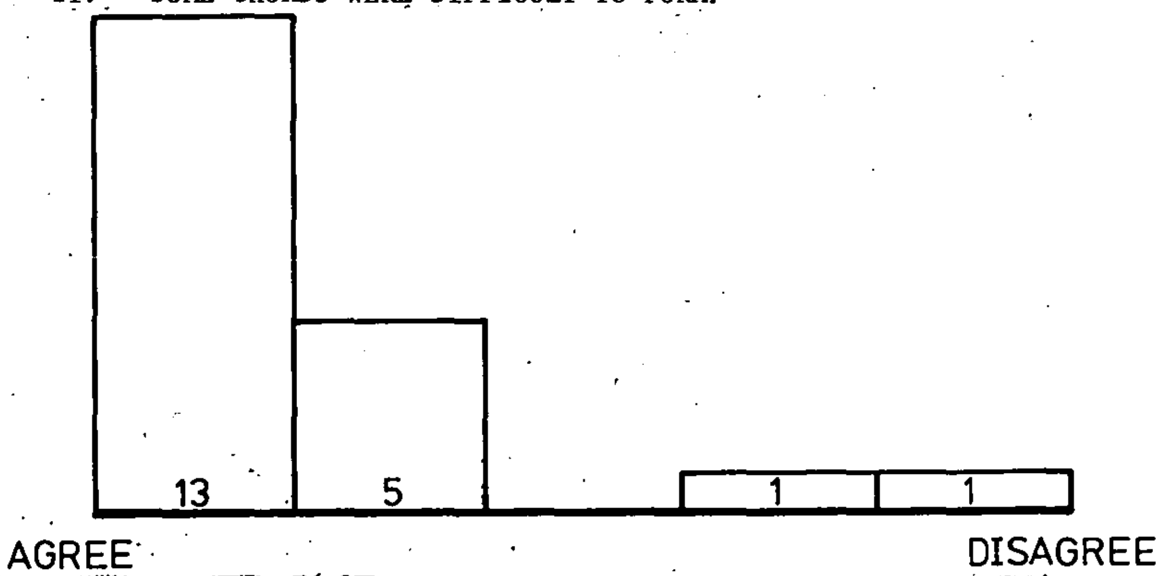
9. THE CHORD KEYBOARD WAS GOOD FUN TO USE.



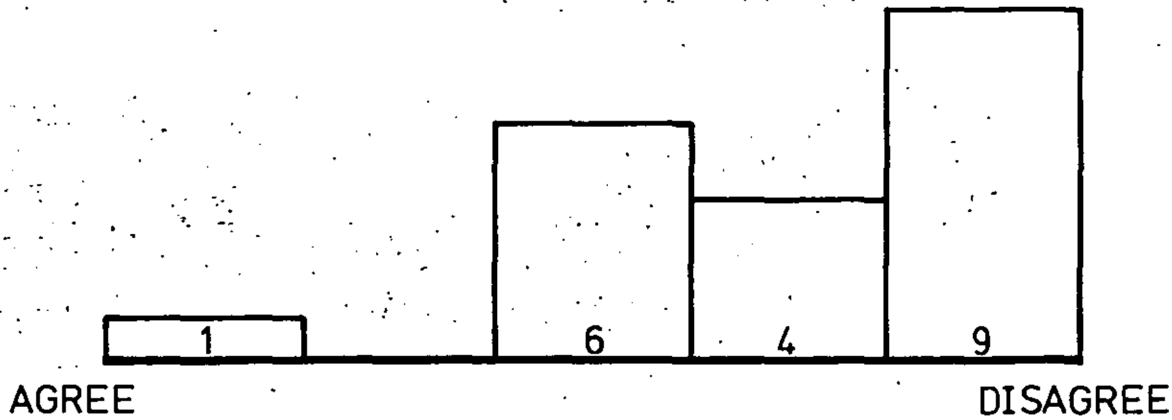
10. I THINK THAT I WOULD HAVE PROBLEMS REMEMBERING THE VARIOUS CHORD COMBINATIONS.



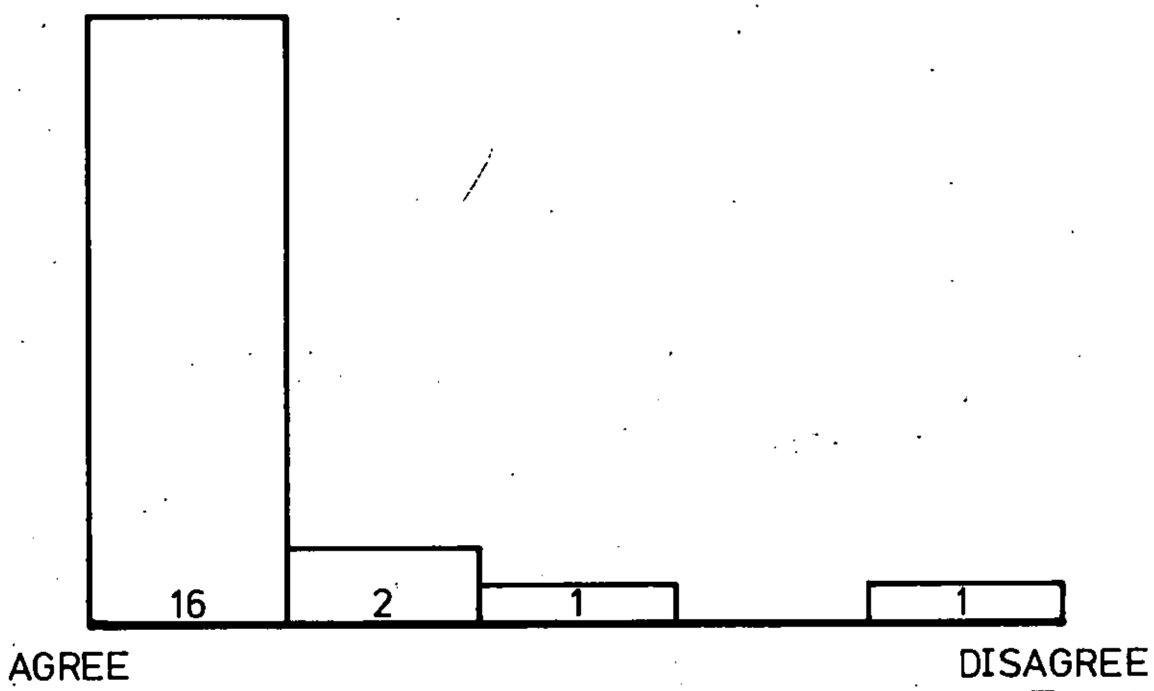
11. SOME CHORDS WERE DIFFICULT TO FORM.



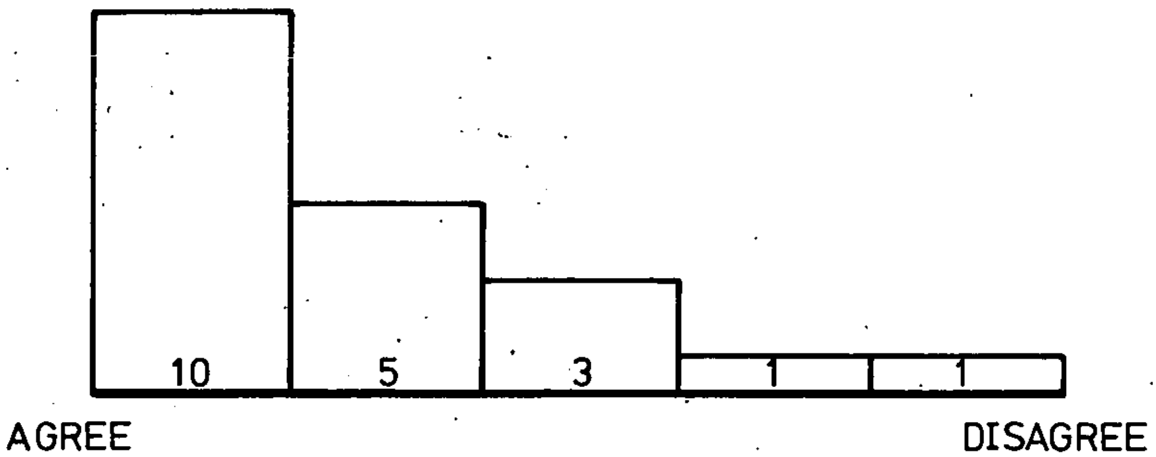
12. I WOULD LIKE TO USE THE KEYBOARD FOR LONG PERIODS OF TIME.



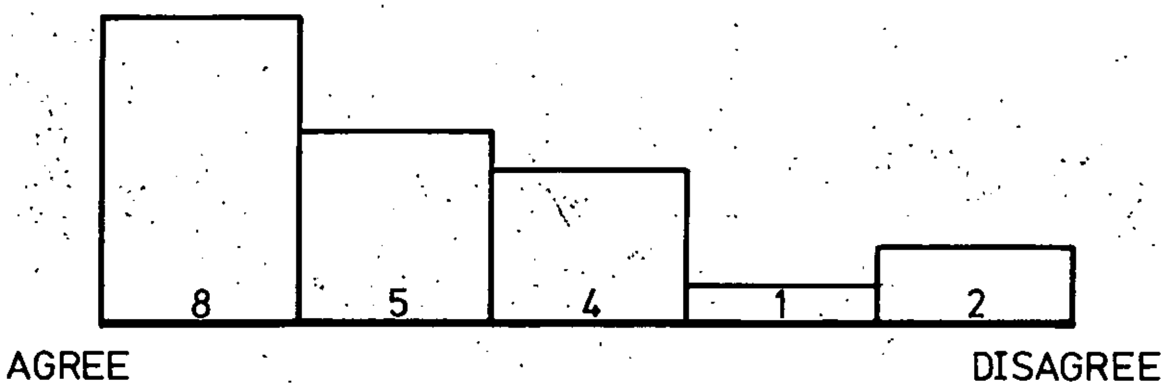
13. I FOUND THE DEVICE INTERESTING TO USE.



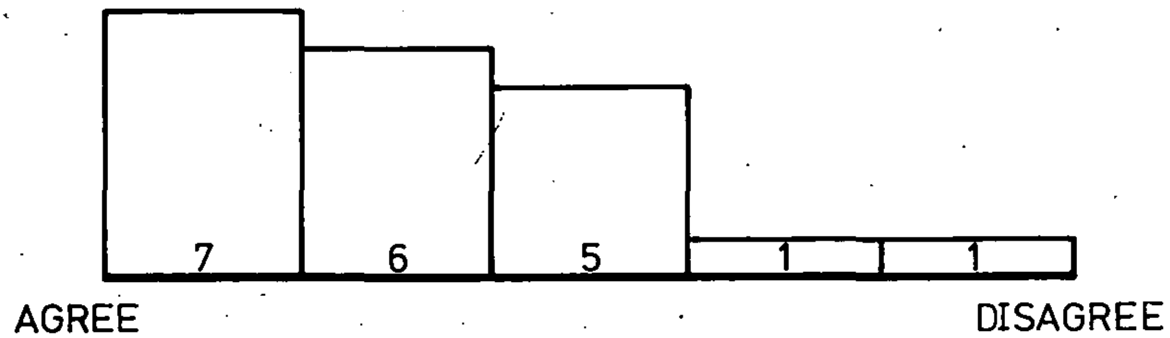
14. I THINK MY HAND WOULD ACHE IF I USED THE KEYBOARD FOR LONG PERIODS OF TIME.



15. OPERATION OF THE DEVICE WAS STRAIGHTFORWARD.



16. I THINK THE CHORD KEYBOARD IS A NOVEL IDEA.



3.2 Section B of the Questionnaire

These results are summarised in a tabular form. The responses to each of the seven questions have been classified according to the number of subjects who responded with each comment.

1. How would you modify the size of the keyboard to suit your particular needs?

Number of Subjects	12	6	1	1
Comment:	"Reduce the size"	"The size is O.K."	"Increase the size"	No Comment

2. How would you modify the shape of the keyboard to suit your particular needs?

Number of Subjects	7	6	1	2	4
Comment:	"Make the shape less rounded"	"The shape is O.K."	"Increase the height of the keyboard"	"Prefer a rectangular shape"	No Comment

3. How would you alter the position of the keys for your handsize?

	Number of Subjects		
	12	3	5
Comment:	"Move the keys closer together"	"The positioning of the keys is O.K."	Miscellaneous comments, see 4.1.3.

4. Do you think that the 'mnemonics chart' was the best way of representing the chords? Can you suggest a better alternative?

	Number of Subjects			
	10	5	4	1
Comment:	"Satisfied with the mnemonics chart as it is"	"Keep the arc of numbers around the letters in the same position"*	"Gave alternative suggestions"	No Comment

* This alternative is discussed more fully in Section 4.1.4.

5. Which chords were easy?

4 subjects said "all the chords".
7 subjects said "single chords".
6 subjects said "chords involving two digits".
2 subjects said "chords involving the first three fingers".
1 subject said "the chords 1 4 and 1 5".
4 subjects said "the chord 12345".

6. Which chords were difficult?

12 subjects said "the chord 1 3 5".

7 subjects said "the chord 23 5".

4 subjects said "the chord 3 5".

4 subjects said "the chord 12 45".

8 subjects said "the chords which required the use of finger 4, and not 3 and 5, for example, 12 4".

7 subjects said "chords involving the digits 4 and 5".

4. DISCUSSION

4.1 General Form and Physical Design Aspects of the Keyboard

The reaction time experiment described in Chapter 7 was intended to lay the foundations for the optimum chord keyboard design. However the use of the keyboard in a rigidly controlled laboratory experiment cannot generate reliable comments and criticisms compared to a 'real-life' simulation. Several guidelines concerned with the development of the design of the hemispherical chord keyboard emerged from the reaction time study and it was anticipated that further evidence would be collected in order to optimise the shape of the chord keyboard.

4.1.1 The Size of the Keyboard

The first question in Section B of the questionnaire was concerned with the size of the keyboard. Answers ranged from stating that the hemisphere was 'too large' to 'just right'. Twelve subjects thought that the keyboard was too large, six stated that the size was acceptable and one individual said that the size should be increased (plus one questionnaire which was left blank). The general concensus was therefore, that the hemisphere was too large and the dimensions described in Chapter 6, should be reduced.

4.1.2 The Shape of the Keyboard

This design aspect was probed in Sections A and B of the questionnaire. When asked if they would change the shape of the keyboard, a range of replies were made by the subjects, which were 'evenly' spaced along the five-point continuum. Content analysis of question 2 gave more insight into the subjects' feelings about the shape of the keyboard. Seven individuals requested a less rounded, more flattened out design while six subjects were content with the present shape. Only one of the remaining seven individuals stated that the keyboard was too small and suggested increasing its height. The conclusion from the subjective results of question 2 was that the chord keyboard shape should be modified. Firstly, the human hand is not symmetrical; therefore, it does not follow that the design of the keying device should be symmetrical.

The second point concerns the gripping action of the hand. When all five digits depressed the keys, the inward motion created by the fingertips would result in an ovoid-shaped keying device. Anatomically, there is a trend for the thumb and little fingers to gravitate towards each other when making chord keypressings. Hence it is suggested that the design of the chord keyboard should be approached from first principles.

The most 'natural' position of the hand occurs when the fingers are relaxed, and the heads of the metacarpals are approximately two centimetres above the surface of the desk, table, etc. It would appear necessary to design a keyboard around this position. Hence the suggestion by a third of the subjects for a 'flattened' hemisphere. Two individuals requested a rectangular shaped keyboard, and retrospectively the similarity between this shape and the proposed revision of the existing design is apparent. The modified shape of the keyboard is difficult to describe. It would be based on the contours made by the hand when resting on a work surface in a relaxed position. The tips of the fingertips (and thumb) and the carpus of the hand making contact with the keyboard. See Figure 9.2.

4.1.3 The Keys

A spin-off from this question concerned the shape of the keys. The keys described in Chapter 7 and used in this experiment were far from satisfactory. A review of electrical component brochures revealed no wholly appropriate keyswitch mechanisms. This is not really surprising since chord keyboards are a new innovation and there would be no demand for specially designed chord keyboard keys. Due to the financial resources and time limitations on the research, it was not possible to have special keys constructed. However the study did result in various guidelines and recommendations being collected from the subjects about the keys. These data would be of value to future chord keyboard designers and manufacturers.

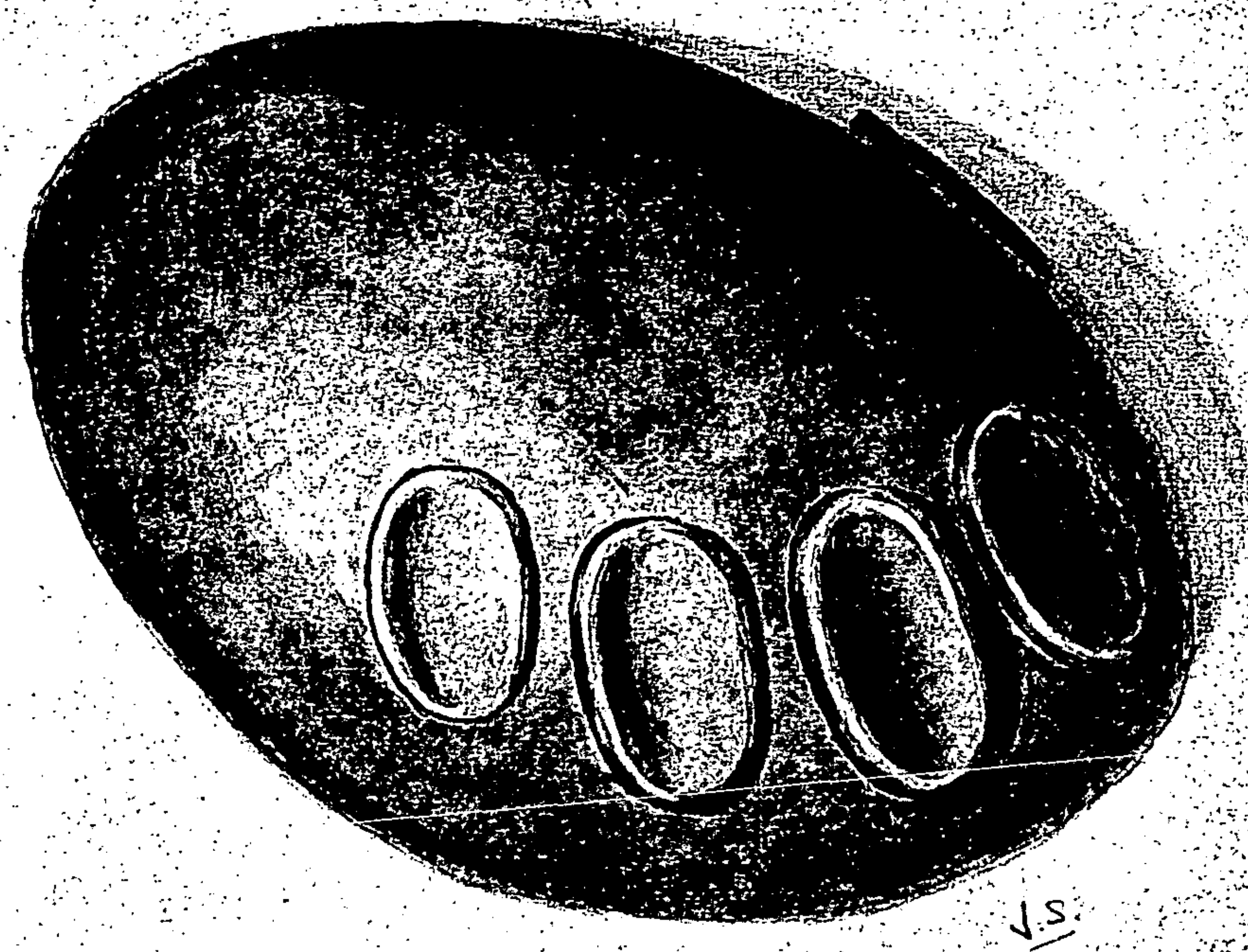


Figure 9.2: Artist's Impression of the Proposed Chord Keyboard

The following suggestions were made by the subjects when asked the question, "How would you modify the shape of the key-board to suit your particular needs?"

(a) Place the keys in slots on the device, which the operators could push into the correct position for their hand-size and lock with a lever under the keyboard base.

(b) Reduce the size of the keys (three subjects).

(c) Make the keys concave rather than flat.

(d) Provide recesses for the fingers and micro-touch switches at the pad points.

(e) Have more rounded keys flush to the casing with a larger thumb key.

The first suggestion highlights the problem of designing one keyboard for a population having various hand-sizes. Solutions are not easy and the most likely would appear to be individually moulded keyboards, or larger key buttons to allow the fingers to control them in different places, or some form of adjustment. The American-produced Writehander is available in two different sizes, whereas the Microwriter makes no allowance for different hand-sizes. This problem of varying hand-sizes stresses the importance of experimental evaluation. When the dimensions of a chord keyboard are based on mean anthropometric data, it would appear imperative to test this design on the user population.

Other suggestions from the subjects involved modifying the shape of the keys.

Parameter		The Chord Keyboard	Recommended Value for Sequential Keyboards*
Size of the keys	=	1·90 by 1·40 cms	1·27 by 1·27 cms
Displacement (travel)	=	0·3 cms	0·13 - 0·63 cms
Force to displace key	=	250 grams**	25 - 150 grams.

Figure 9.3: Characteristics of the Keys on the Hemispherical Keyboard

* From Cakir, Hart and Stewart (1980).

** This measurement was made in the Department of Physical Education and Sports Science, Loughborough University of Technology.

The size, shape, force and displacement characteristics of keys for sequential keyboards has been thoroughly researched and there are many sets of human factors recommendations available (Cakir et al., 1980). However it is not known whether these are appropriate for chord keyboards. It could be hypothesised that the dimensions of the finger keys could be based on these recommendations, but since the thumb key is largely redundant operating sequential keyboards, these values will not apply. Further research might indicate that the thumb key warrants a different design from the other keys.

From a human factors point of view the keys should be compatible with the size and shape of the digits which will strike them. Typewriter research has shown that skilled typists hit the keys with an elliptical shape at the end of their fingertips (Chambers and Stockbridge, 1970). Therefore the keys should be circular and if possible, pertaining towards an elliptical shape with a concave surface. It is concluded that the optimal force and displacement characteristics for the keys on chord keyboards will have to be determined through experimentation.

Rating scale 4 of Section A and question 3 of Section B were both concerned with the positioning of the keys. Results from Section A showed a tendency (12 individuals) towards subjects altering the position of the keys. However the answers to Section B reflected conflicting results. Twelve subjects stated that they would move the keys closer together, and of these twelve, four individuals specifically requested the thumb key to be located closer to the finger keys. Three individuals declared that they would not change the position of the keys, while the other five made the suggestions as listed below.

(a) Lower the 'touch' position of the keys, so that they are only just proud of the hemisphere.

(b) Alter the position of the little finger key (the other four finger keys are O.K.).

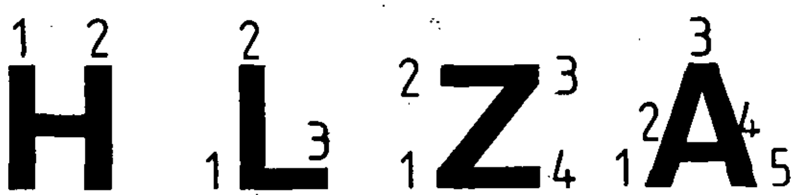
(c) Help locate the fingers by providing dimpled keys.

(d) Lower the height of the little finger key (requested by two subjects).

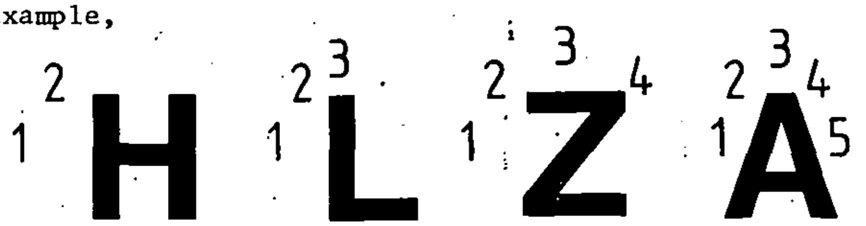
The positions of the keys are intrinsically linked with the size and shape of the keyboard. Since these latter aspects have been shown to require modification, there is perhaps little to be gained by placing emphasis upon these criticisms of the key locations on the existing keyboard.

4.1.4 The Mnemonics Chart

Fifteen subjects agreed that the mnemonics chart was clear (rating scale 6), and this finding was supported by analysis of question 4 (Section B), which asked the subjects if they thought that the chart was the best way of representing the chords. Four individuals commented on the arrangement of numbers around the letter. As a result of the follow-up study described in Chapter 8, the numbers had been arranged symmetrically around the letters. For example,



These four subjects suggested that in order to avoid confusion, the numbers should be arranged in an arc always keeping the same location. The arc would represent the four fingertips and the thumb. For example,



Other suggestions for representing the chords were made by the subjects. These are listed as follows:

(a) Place the numbers under the letters in a straight line.

(b) Lay out the alphabet in the QWERTY arrangement, so letters are easier to find for skilled typists.

(c) Place the numbers over the letters in a straight heading.

(d) Explain the origins of the chart to facilitate ease of use.

Rating scale 10 was also concerned with the Mnemonics Chart. The statement "I THINK THAT I WOULD HAVE PROBLEMS REMEMBERING THE VARIOUS CHORD COMBINATIONS" was closely linked with the Cognitive Aspects of Chord Keying study which had been executed. The range of answers given to this statement was evenly spaced along the five-point continuum, although there was a slight trend towards more subjects disagreeing with this statement.

4.1.5 Physical Formation of the Chords

The statement "I THOUGHT THE MAJORITY OF THE CHORDS WERE EASY TO MAKE" received a favourable response from 13 of the 20 subjects who agreed with it. It is significant that no one disagreed completely with this statement. Content analysis of question 5 (Section B) revealed that the single, two-digit chords, the chord 123, and the five digit chord were cited as being the easiest key patterns to form.

Eighteen subjects agreed with the statement "SOME CHORDS WERE DIFFICULT TO FORM". From question 7 (Section B) it was possible to determine which chords these were. Chords which required the use of the third and fifth fingers and not the fourth (the ring finger) were cited as being difficult to make. A second group mentioned were those chords which required the use of the fourth finger and not the third and fifth. Finally, a general comment, which covered seven of the 20 responses, included those chords which involved the use of the fourth and fifth digits.

4.1.6 Aspects of Fatigue

The topic of fatigue is a thread which runs throughout the thesis. After the reaction time experiment, comments were collected describing the subjects' aches and pains. It was therefore thought to be a worthwhile exercise to incorporate some statements and associated rating scales into Section A of the questionnaire. These statements were actually made by the participants of the 'Motor Aspects of Chord Keying' study.

Fifteen individuals anticipated that their arm and/or hand would ache if they keyed for long periods of time. This result may not be a reflection of the design of the keyboard, but merely represents the learning of a sensori-motor task. Twelve subjects did not think the chord keyboard was comfortable to operate, which might explain why they thought their upper limbs would suffer.

In retrospect, statements 2 and 14 were not pertinent to this study on users' attitudes. Statement 5 ("THE CHORD KEYBOARD WAS COMFORTABLE TO OPERATE") supported the earlier finding which has already been discussed; that the design of the chord keyboard needed modifying. It is hypothesised that it would be a valid exercise to administer the same questionnaire to the identical experimental group using the proposed modified chord keyboard. Comparisons could then be made between the questionnaire results which would show whether the new design was more appropriate.

4.1.7 The Chord Keyboard Concept

Throughout the questionnaire, there were statements incorporating adjectives to describe the chord keyboard. For example, statement 9 ("THE CHORD KEYBOARD WAS GOOD FUN TO USE"). It was envisaged that these statements would allow an overall picture of the chord keyboard to be obtained. Fifteen subjects agreed that the chord keyboard was good fun to use, which was compatible with the results from statement 16 ("I THINK THE CHORD KEYBOARD IS A NOVEL IDEA"). Thirteen individuals agreed with this latter statement, and five were unsure. It could therefore be concluded that the majority of the individuals used in this study found the chord keyboard entertaining to use. This conclusion is supported by the results of statement 13 ("I FOUND THE DEVICE INTERESTING TO USE"). Eighteen subjects agreed with this comment.

Statement 15 ("OPERATION OF THE DEVICE WAS STRAIGHTFORWARD") was asked because of the increased complexity of using a chord keyboard compared to a sequential keyboard. Thirteen of the 20 subjects found the device straightforward to use. Although 13 individuals found operating the keyboard was straightforward, the same number did not like the thought of using the chord keyboard for long periods of time. No explanations were given for the answers to this statement ("I WOULD LIKE TO USE THE KEYBOARD FOR LONG PERIODS OF TIME"). Retrospectively, it might have been advantageous to incorporate a question seeking an explanation into Section B of the questionnaire.

The final question in Section B asking for further comments from the subjects generated much information concerning the chord keyboard concept. Subjects wrote about the mnemonics chart and the logic behind the letter construction, and the problems of learning the chord patterns. Some individuals thought that learning the various chords would not pose a problem. One subject succinctly said, "Some of the chords are difficult to form, but easy to learn". Another commented that he preferred the chord keyboard to a typewriter.

Other issues that were raised included the slowness of the system. One subject stated that patterned pressing of keys would have limited applications, due to the slowness of operation. Another individual declared that simultaneous pressing of the keys was a problem, due to the fact that he made the mistake of not pressing hard enough. However this could be alleviated by providing light touch keys. Three subjects made this suggestion. A fourth commented that it was probably more the shape of the hand than the keyswitches. She suggested altering the shape of the keyboard. A further suggestion included having buttons on the production model with a range of stiffness values for individual tastes.

Two subjects commented that a one-handed keyboard leaves the other free for some other activity, such as turning the pages in a book. A left-handed keyboard was requested by a right-handed individual so that he could leave his writing hand free. It would seem logical to produce right and left-handed chord keyboards; a fact that has been overlooked by the manufacturers of the Microwriter.

5. CONCLUSIONS

1. The initial reaction to the chord keyboard concept was favourable. The majority of individuals found the keying device novel, interesting and good fun to use.

2. The classification of the other responses to the keyboard was not as distinct, and because of the interrelations between the design of the chord keyboard and aspects of fatigue, it was not possible to draw any clear-cut conclusions.

3. This study also provided an opportunity to investigate other aspects of the chord keyboards, and the following conclusions were reached. The prototype for the chord keyboard requires modification. This would include the following:-

(a) A reduction in overall size (present dimensions - height of hemisphere = 7 cms, diameter of hemisphere = 14 cms).

(b) A change in shape. It is recommended that the modified design of the keyboard should be based on the shape of the hand when in a relaxed position. The resultant shape would probably resemble that of a flattened ovoid.

(c) The keys on a chord keyboard will have to be specifically designed. The following recommendations emerged from this research concerning the design of the keyswitch mechanisms

- the keys should be circular, tending towards an elliptical shape,
- they should have a force of less than 250 grams,
- a travel of 0·2 centimetres is satisfactory.

(d) The layout of the mnemonics chart is not wholly satisfactory and needs amending.

PART III:

GENERAL DISCUSSION

CHAPTER 10

A DISCUSSION OF SEQUENTIAL AND CHORD KEYBOARDS

1. OVERVIEW - SEQUENTIAL KEYBOARDS

1.1 The QWERTY Keyboard

There is a wealth of research concerned with sequential keyboards. Hale (1970) summised that over a thousand references had been published in this area, but unfortunately he does not cite them. The literature review of keyboard research in Chapter 3 indicated the aspects of sequential keyboards which have attracted the interest of individuals from a diverse variety of backgrounds. It could be concluded from the review of the literature that the layout of the alphabet keys has been the cause of most discussion and debate, in view of the dissatisfaction of the user population with the QWERTY arrangement of keys. Further evidence of this is shown by the results of the questionnaire survey in Chapter 2. From a recent article entitled "QWERTYUIOP - dinosaur in a computer age" (Litterick, 1981) it can be hypothesised that feelings about the standard keyboard remain unchanged in 1981. However, although it is over a century since the advent of the QWERTY keyboard, it still resists change and the challenges made by a multitude of keyboard designers (Evans and Martin, 1970).

The mystery of the origins of the standard QWERTY still remains. It would appear to be based on the layout of the alphabet, although no details concerning the reasoning behind the QWERTY keyboard were provided by the inventors, Sholes, Glidden and Soulé. It is of interest to note that Sholes et al. were between the 54th and 112th inventors of 'writing machines', depending on how you count (Beeching, 1974). The success of the QWERTY keyboard appears to rely on the fact that it was the first writing machine to go into production for marketing. The ergonomic approach of user evaluation was not practiced in the nineteenth century and Sholes and his associates were primarily concerned with the engineering aspects of the typewriter. Today, it is feasible to predict that the shortcomings of the QWERTY keyboard would never have existed if the original device had been subject to intense investigation by human factors specialists. However such comment is not constructive since it is retrospective and hypothetical.

The QWERTY keyboard, complete with its inadequacies, monopolises the sales of alphanumeric sequential keyboards. The questionnaire of skilled typists described in Chapter 2 concluded that, although the QWERTY keyboard was not satisfactory, the users did not relish the prospect of exchanging the standard for another keyboard. The foreseeable problems in such an exercise are immense. Michaels (1971) estimated that there were 45 million typewriters in the United States, with 2·3 million being sold every year (Note: these are 1971 figures). Therefore the physical difficulties alone of converting existing manufacturing equipment would discourage any change. The population of the Western world is familiar with the QWERTY keyboard. Although such a statement is hard to quantify, Barmack and Sinaiko (1966) carried out an informal survey of professional scientists and engineers, which showed that 75% had a working familiarity with the QWERTY keyboard.

In Chapter 3, the distinction between alphabet-key layout and keyboard design was made. The Maltron keyboard is probably the first sequential keyboard to be marketed incorporating a modified design. Conclusions reached from the preliminary exploratory study evaluating the Maltron were positive towards the adoption of the design of this keyboard, although there were minor grievances over the use of thumb keys. The critical appraisal of the 'state of the art' of sequential keyboards as outlined in Chapter 4 concluded that the QWERTY keyboard was invincible, but there was scope for modifying the design of the keyboard. Since there is no experimental evidence it is hypothesised that skilled keyboard operators would find it more difficult to type on a new layout of keys than adjust to a modified design of keyboard (like the Maltron QWERTY). It is ironic therefore that it would be easier for manufacturers to change the layout than alter the design of the keyboard. However a compromise can be reached. Conway (1979) and Computers and Automation (1971) proposed a contoured keyboard design more suited to the anatomy of the hands (apart from the fact that the diagonal slant of the key columns was retained). Conway's contoured keyboard can either be built into the design of the keying device or be a separate overlay to be positioned over an existing keyboard.

An overlay device would have the advantage of providing an effective but low cost means of achieving the improved layout while using conventional keyboards. The height of the overlay is adjustable. Therefore the device could be raised or lowered by approximately 0·64 to 0·95 centimetres to change the angle and height of the key switches to suit the personal preferences of the user.

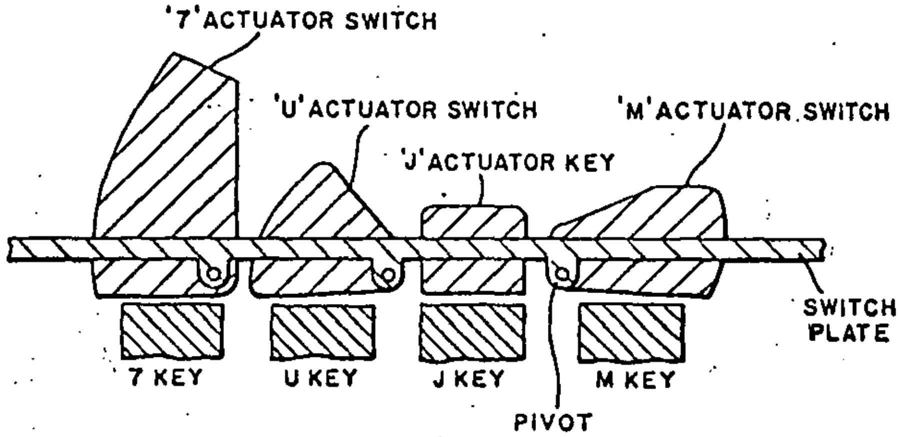


Figure 10.1: Profile of a Key Column

1.2 The Question of Fatigue

Anecdotal and research evidence (for example, Kroemer, 1972) and the findings of the questionnaire survey (Chapter 2) have shown that the posture, which keyboard operators have to maintain, leads to muscular fatigue and strain. Therefore, it might be suggested that the QWERTY keyboard is detrimental to the health of the user. A trend towards considering aspects of fatigue has developed in the last twenty years, while the topic of speed of operation has warranted less interest (Dunn, 1971). Since the invention of the QWERTY keyboard, the majority of challenges to the standard have ultimately been made on the basis of increasing the speed of operation. It could be argued that this latter approach is irrelevant since the QWERTY keyboard has been shown to be operated at near maximum speeds (Kinkead, 1975). Therefore the emphasis for keyboard reform should be placed on alleviating the amount of fatigue experienced when keying.

The 'aches and pains', which skilled and naive keyboard users suffer, result from the inefficient organisation of the immediate workplace environment and the design of the keyboard. This statement is based on the assumption that keyboard design rather than layout is a major contributor to fatigue (Kroemer, 1972; Malt, 1977). For example, in Chapter 2, it was established that adjustable chairs and desks, and document holders would improve the work situation for keyboard operators. And in Chapter 3, the attributes of the design of the Maltron keyboard (namely, a split keyboard, arched rows of keys and varying key heights) were deemed to improve the comfort of keyboard operation. This and other research (Osanai, 1968; Komoike and Horiguchi, 1971; Kroemer, 1972; Duncan and Ferguson, 1974; Malt, 1977) have demonstrated that discomfort and fatigue result from periods of keying, and the findings from this experimental work suggest various solutions to alleviate the situation. The question then arises of why previous research has not made any impact on the design of the keyboard. Various explanations to answer this could be suggested.

(a) The first is concerned with cost. If keyboards are being produced and purchased, from the manufacturers' point of view there is little to be achieved in spending money to develop a new design. This attitude is supported by the fact that individuals are renowned for being 'resistant to change' and so probably would not adopt the revised keyboard for many years (if at all). The marketing of the Dvorak Simplified Keyboard (D.S.K.) provides a classic example. Although there was a 35 year hiatus between development and production, the D.S.K. was given much publicity and support, for example, by the U.S. Navy (1944), TIME Magazine (1939), the Australian Post Office (1953), Phillips (1968), Computers and Automation (1971), Martin (1972), Harnett (1972), plus Dvorak's own publications. However the adoption of this keyboard by even a small percentage of the market never occurred. In 1981, there are still enthusiasts; a speed typing competition to promote the D.S.K. has been organised by an American (Computing, April 30th, 1981).

(b) It has been established that the QWERTY keyboard is being operated at near maximal speeds. Some individuals might interpret this as indicating that the QWERTY keyboard is optimal in design. Therefore they might not see a need to modify the standard keyboard.

(c) The advantages to be gained from the reformed keyboard would have to outweigh greatly the re-training problems which would result from its adoption. Since keyboard operators are usually female (with the resultant implication that they will marry and have children) and have low status within the hierarchy of their working environment, the costs and inconvenience of re-training are not justified. This is supported by task analysis of secretarial work. Typically, a secretary will only spend a quarter of her time at the typewriter, which would account for approximately 2½% of office labour costs (Computer Weekly, February 15th, 1979). Wohl (1980) quoted similar figures and stated that 20% of an 'average' secretary's total time was spent typing. If these statistics are accurate, this specific example of an office secretary demonstrates that the low usage of her typewriter would not justify a change in the design of the keyboard.

1.3 The Future of the QWERTY Keyboard

This research has demonstrated that the design and layout of the QWERTY keyboard are not optimal for efficient operation. However it is not feasible to modify the standard keyboard and hence improve it, because of confounding factors pertinent to QWERTY's situation.

The QWERTY arrangement of keys has become a historical precedent. Any change in this layout would have to be initiated by the Standards committees. Such a change (unless it was minor, for example, changing the positions of the A and J keys) would throw keyboard operators into chaos: the cost and extent of re-training would be immense. Problems would also arise because there would be two groups of keyboard users, namely QWERTY users and those trained on the new keyboard.

Potential operators would have difficulties learning to use the reformed keyboards because of lack of training facilities since all the typing schools would have to convert to the new arrangement of keys. Secondly, employers would be reluctant to employ individuals trained on the new keyboards because they would have to work on existing equipment. In order to avoid these problem areas, individuals would take the course of least risk and learn to type on the QWERTY keyboard layout.

It is hypothesised that modification in the design of the QWERTY keyboard would require less re-training for the user than a change in layout. This, supported by the fact that keyboard operators will benefit in terms of comfort from a revised keyboard design, suggests that modifications should be implemented. However as outlined in Section 1.2 of this chapter, there are reasons why manufacturers would not adopt a new design for alphanumeric keyboards.

It could be concluded that in an ideal situation the QWERTY keyboard should be reformed. However in 1981 it is not a viable proposition to modify the design and it is even less realistic and feasible to consider making changes to the arrangement of the alphanumeric keys. Therefore the QWERTY sequential keyboard will in all probability persist in its present form.

1.4 Alternative Sequential Keyboards

Having established the supremacy of the QWERTY keyboard, the question then arises of whether this is the most appropriate device for all keying applications. From the many keyboards which have challenged the QWERTY keyboard over the years, the D.S.K. and the alphabetical arrangement of keys emerge as the most likely contenders for other uses. However the adoption of the D.S.K. does not offer any advantages over the QWERTY keyboard. The alphabetical layout, on the other hand, does.

An alphabetically arranged keyboard has advantages for the occasional unskilled user, who only has a small amount of keying to perform. Stockbrokers and airline reservation clerks are two groups of individuals who use an alphabetically arranged keyboard (Avakian, 1968; Bodenseher, 1970). However within the last five years, manufacturers have begun producing small, pocket-sized, keyboards. Many designers have placed the alpha keys on a calculator keyboard (Pocket TTY - G.R. Electronics Limited, the Memo Note 30 - Toshiba, MINNIE - the National Physical Laboratory). Alphanumeric 'calculators' may be useful and fufil a need but it is recommended that manufacturers keep to an alpha layout and not QWERTY. The standard QWERTY keyboard allows rapid touch typing and hence meets speed needs; however, the small 'calculator' keyboard does not permit fast data entry, and the claims of some manufacturers (for example, G.R. Electronics Limited) that it is a substitute for conventional teletypewriters is erroneous. It is only possible to 'hunt and peck' on a small, calculator-shaped keyboard and hence the author recommends that the alphabetical arrangement of keys is the most suitable layout for a small keyboard. Nevertheless, research is warranted in this area to test this recommendation.

1.5 Summary

The goals of sequential keyboard designers up until the 1970's were speed, accuracy and comfort (in that order). The seventies entered an era during which individuals were more concerned with aspects of fatigue during operation of the keyboard. The conclusions to be drawn from keyboard research may be summarised as follows:

(a) The search for speed is fairly pointless, since the average typist spends only about 20% of the time typing and the standard keyboard has been shown to be operated at maximum speeds.

(b) The QWERTY keyboard is extremely well established.

(c) Past experience has demonstrated that trying to replace the standard keyboard will lead to a lifetime of labour likely to end in frustration.

Therefore, it could be concluded that there are three categories of chord keyboards.

Group I: <u>Hybrid Chord Keyboards</u>
Having characteristics of sequential and chord keyboards, for example, ANTEL (Figure 5.9).

Group II: <u>'True' Chord Keyboards</u>
Operated by patterned pressing of keys, for example, the Microwriter (Figure 5.11).

Group III: <u>Shorthand Chord Keyboards</u>
Involves coding the text into a form of shorthand, for example, the palantype.

The trend towards developing chord keyboards has escalated over the last three decades. There are no standards available for chord keyboards, which is probably a function of the embryonic stage of their development. Beeching (1974) pointed out that the state of the chord keyboard was analogous to the Sholes' typewriter a century ago. For example, Sholes and his comrades initially developed a machine which only printed the letter 'W'. They then worked to perfect the mechanism with the result that the machine wrote in capitals. After a further six years of mechanical problems, they developed a four bank keyboard. The development of the typewriter keyboard like the chord keyboard was a slow process plagued by many difficulties and set-backs. Although Beeching's analogy is not wholly appropriate, since he was comparing one typewriter keyboard and an indeterminate number of unspecified chord keyboards, it has certain implications. A study of the development of sequential keyboards suggests that it will be several years before a chord keyboard emerges as a standard, or plans for an international standard are initiated.

2.2 The Development of a Chord Keyboard

Three categories of chord keyboards have been outlined. Group III includes the palantype and stenograph machines which, it could be hypothesised, were specifically developed for the task of taking shorthand dictation. This situation is reversed for groups I and II. The majority of keyboards in these two groups have been developed with no specific task in mind. The exceptions are of course the Post Office mail sorting keyboards. Since there are many other chord keyboards, as shown by the literature review in Chapter 5, it appears a mystery why these keyboards were developed, as they have no specific task to perform. It is hypothesised that there are three steps towards the manufacture of a chord keyboard.

Stage 1: The formation of the concept, for example, Stewart's idea of the ANTEL keyboard.

Stage 2: The development of the keying device to assess whether the concept is feasible in terms of electronics, size, costs, etc. In the case of the ANTEL keyboard there was a time span of six to seven years until a production model was built by Cossor Electronics Limited.

Stage 3: The manufacture of the keyboard and the subsequent need to find an application for the device in order to market it. A classic example is provided by Endfield, who uses the soubriquet "a personal word processor" to describe the Microwriter. It is highly unlikely that Endfield set out to develop a hand-held word processor.

The end-result is the production of a chord keyboard, which has been marketed with no specific use in mind other than general purpose applications. The advertising attached to these keying devices is usually concerned with the fact that they are superior to the QWERTY keyboard (for example, "QWERTY is obsolete" to advertise the Writehander, "A Typewriter in your Pocket" for the Microwriter). To give these inventors the benefit of the doubt, it would be a worthwhile exercise to consider the advantages to be attained from using a chord keying device.

2.3 Hypothesised Advantages of Chord Keying

Several of the benefits to be gained from the use of a chord keyboard have been briefly mentioned in Chapter 5. These could be summarised as follows:-

(a) The option of one or two handed use. Unlike a sequential keyboard, a chord keyboard can be operated by one hand. The advantages of a one handed keyboard are:

- the device does not take up space immediately in front of the operator.
- the user does not have to sustain an unnatural keying posture.
- the keyboard can be moved around freely over a wide area.
- the other hand is free to perform a second task such as answering the 'phone, turning the pages in a book, etc.

(b) The comparative small size and compactness of a chord keyboard enhances its portability and potential usability in hostile environments, for example, on trains.

(c) In terms of the information theory, chord keyboard users enter more bits of data per second than sequential keyboard operators. However this is misleading, because in real terms, less characters per minute are being emitted. An accurate picture of the potential of chord keyboards cannot be realised, because there are few skilled chord keyboarders on which to collect speed measurements. However it is known that stenotyping is one of the fastest modes of data entry. See Table 10.1.

TABLE 10.1

Data Rates for Man-Computer Communication (Turn, 1974)

Silent reading	2·5-9·8 words/second
Spontaneous speaking	2·0-3·6 words/second
Handwriting	0·38-0·42 words/second
Handprinting	0·22-0·53 words/second
Skilled typing	1·6-2·5 words/second
Inexperienced typing	0·2-0·4 words/second
Stenotyping	3·3-5·0 words/second
(Typically, 1/3 of the number of strokes of sequential keying)	
Touchtone 'phone	1·2-1·5 digits/second
Rotary dialling 'phone	1·54 digits/second.

(d) It has been suggested by Endfield (1978) that chord keyboards are easier to learn than sequential keyboards, because the fingers never have to move between the keys. However there is no definitive research evidence to support or disprove this claim.

(e) Chord keyboards have a novelty aspect as demonstrated by the findings from Chapter 9. This may result in these keying devices appealing to sections of the population who would not normally learn to touch type, for example, executives and office staff.

Many of the advantages of chord keyboards stem from their size, and one-handed operation, which increases their flexibility. It would appear unlikely that speed and ease of learning would be classed as aspects favouring a chord compared to a sequential keyboard. In the preceding chapters, it has already been stated that chord keyboards require initial guidance before they can be used, followed by intensive learning of the chord patterns. Findings from the questionnaire survey in Chapter 2 also supported this. Comments were received from the skilled typists such as "a chord keyboard is an interesting idea, but surely it would be complex to operate and to learn to use", and "no - sounds complicated". It could be hypothesised that the complexity associated with the learning and operation of a chord keyboard might outweigh the novelty aspects. The suggestion that the chord keyboard was a novel idea was clearly demonstrated by the results of Chapter 9. Thirteen of the twenty subjects agreed that the concept was novel, while five were unsure and two individuals disagreed. However, is the novelty of a chord keyboard sufficient basis to guarantee its commercial success? The overriding problem with devices which are purchased because of their 'fun to use' and novelty values, is that with time these factors fade in significance.

2.4 Summary

It becomes apparent from a review of the state of the art of chord keyboards, that the concept of chord keyboards can be approached from two levels. Firstly from a macroscopic viewpoint, the justification of a need for chord keyboards has to be established. In the case of special purpose keyboards (such as the Levy keyboard) and specifically designed keyboards (the palantypes and stenographs) there is no doubt about their application and usefulness. However the situation is entirely different when considering keyboards such as ANTEL, the Writehander, the Microwriter, and the Mode keyboard (Litterick, 1981)*. Designers and inventors have tunnel vision with regard to the development of their keyboards, and their main objectives are patents and manufacture. The need for many of the recently developed chord keyboards has yet to be clarified.

The second level from which to approach chord keyboards is to study the minute details of their design and application. In order to do this, the assumption that there is a need for chord keyboards has to be made. This research was based on the assumption that there was an implicit need for special purpose chord keyboards as outlined in the 'keypen concept' in Chapter 4. The model of a chord keyboard which was elected for study was one having five keys. The choice of a 5-key chord keyboard is open for discussion. It has already been explained (Chapter 5) that five keys provide the most basic form of a chord keyboard and hence its selection. The 5-key chord keyboard was intended to be used as a vehicle to locate a series of basic findings that could be applied to the design of chord keyboards in general.

---

* Litterick is in the process of patenting a one-handed desk-top keyboard with a limited number of keys. A large number of characters (total not determined as yet) are obtained by rocking the keyboard into different modes (shifts).

3. APPLICATIONS OF THIS RESEARCH

3.1 Sequential Keyboards

The implications and results of this work on sequential keyboards have been discussed in Chapter 4 and again at the start of this chapter (Section 1). Therefore it is not intended that the application of this research on sequential keyboards should be covered in this section.

3.2 Chord Keyboards

3.2.1 The Design of Chord Keying Devices

A search for the optimum design of a chord keyboard was a thread which ran through Part II of this research (Chapters 6, 7 and 9). It was concluded that when developing a chord keyboard from first principles, the hand in a relaxed posture should provide the basis of the design. The general form of the hemisphere was the closest to this position. However due to the limitations of the research, the author did not have the resources to build a keyboard based on this flattened ovoid shape. The need for a hand-configured layout was also frequently suggested by the subjects. If this proposed design could be plastic moulded, these two issues would be solved. The Microwriter is probably the only keyboard which fits these requirements, although it has a disadvantage in its size. The dimensions of the Microwriter are 10·16 cms. wide, 21·59 cms. long and 5·72 cms. deep. Throughout the experimental programme, individuals expressed their surprise at the large size of the keyboard prototypes. Therefore it is suggested that future designers aim to produce smaller chord keyboards than those which are at present on the market.

Further experimentation will have to be carried out in order to determine the optimum force-displacement characteristics for keyswitches on a chord keyboard. The author searched radio spares catalogues for appropriate chord keyswitches, but found nothing suitable. It might arise that specially designed keys have to be built for chord keyboards.

Consideration of the design of a chord keyboard raises the issue of the optimum number of keys. There is no statement in the open literature concerning this problem. The full alphanumeric set on a sequential keyboard requires 44 keys, but if the production of the ASCII code is needed, the keyboard must have the ability to generate 128 characters. It is unlikely that special-purpose chord keyboards will need to produce a full set of alphanumerics, and that only general purpose keyboards will require to generate the ASCII code. Five keys produce 31 chord patterns (2^5-1), while the addition of a second thumb key increases this to 47 ($(2^4 x 3^1)-1$). It is apparent that a 6-key chord key board would cover the production of a full alphanumeric set. This logic does not take into account a shift key; this allows the 44 keys on a sequential keyboard to produce 88 characters. Hence the addition of a seventh (shift) key on the proposed chord keyboard would be needed. It could be concluded that the minimum number of keys needed on a one-handed keyboard is seven. Other possibilities for the design of a chord keyboard are discussed in the next section.

3.2.2 The Motor Aspects of Chord Keying

The 31 chord patterns available with a 5-key chord keyboard were investigated by means of a reaction time test. Three different response keyboards were used and it was found that the pattern of the reaction times did not relate specifically to the chord keyboards. Hence it may be suggested that the findings apply within reason to chord keyboards in general, regardless of their design.

The 31 chords were ranked according to speed of execution across the three keyboard groups. If the author had been specifically interested in developing one keyboard, this would not have been appropriate. Since one of the objectives of the study was to produce general guidelines, it was in order to take this approach.

The speeds of execution of the chords were found to be as one would predict. Single digit 'chords' were the fastest to perform, and four digit patterns the slowest. The two and three digit chords were bunched in the middle of the chord rank chart. These findings corresponded to previous research. It is the chords which were slowest to execute which exhibit the most interest (namely, 1 3 5, 23 5, 3 5, 2 45, 123 5, 12 45, 12 4, in that order). It can be noticed that none of these chords contain the combination 34 (the middle and ring fingers). These fingers do not function well independently, and hence more errors arose from making these chords.

One possible way to solve this problem and enhance the ease of operation of a chord keyboard might be to provide a single large key for the middle and ring fingers. This would have the effect of reducing the number of chord combinations from 31 to 15 (2^4-1). In order to restore the number of chords, three thumb keys would have to be present making a total of 71 possible combinations ((2^3 x 3^3) -1). It could be concluded from this work that the middle and ring fingers should share the same key, and be treated as a single unit in the execution of the chord combinations. No previous research has suggested or investigated this concept, and therefore further experimentation would have to be conducted in order to substantiate the validity of this suggestion.

Other possibilities involve the omission of the five slowest chords (1 3 5, 23 5, 3 5, 2 45, and 123 5). If a shift key was added to the standard five keys, the total number of combinations would be 52. The shift could perhaps be operated by the other hand. An extension of this proposal is to add a second row of five keys to the device. The numbers and punctuation characters would be designated to this row. This would increase the total number of chord combinations to 104. The merits and disadvantages of these various chord/key designs will be discussed after the cognitive aspects of keying have been considered.

3.2.3 The Cognitive Aspects of Chord Keying

The allocation of chords to alphanumerics based on the cognitive factors involved in the keying process is an area which has warranted minimal research (if any). Endfield is one of the few designers who "has deliberately chosen combinations that are easy to remember" (Mussín, 1980), and hence he placed the emphasis on cognition ignoring the motor aspects. The end-result is Endfield's allocation of chords to letters (see Table 10.2). It is interesting to note that he discarded the following chords: 1 34, 1 345, 234, 5, 12 4.

TABLE 10.2

Endfield's Allocation of Chords to Letters

A			3	4		N		2	3		
B	1	2	3			O			3		
C			3		5	P	1	2	3	4	5
D			3	4	5	Q	1		3		
E				4		R		2		4	5
F		2	3	4	5	S		2			
G	1	2				T		2		4	
H	1				5	U	1				
I				4	5	V	1			4	
J	1	2			5	W	1	2		4	5
K		2			5	X	1	2	3		5
L	1			4	5	Y		2	3		5
M	1	2	3	4		X	1		3		5

The main experimental study, described in Chapter 8, ranked the 31 chords according to ease of learning. Results showed the single digit chords to be the easiest to learn and the chords 12 4, 2 45, 1 45, and 123 5 to be the most difficult, since they took the longest times. On the basis of these cognitive findings, it is recommended that the single digit 'chords' should be allocated to the most frequent alphanumerics, followed by the two digit chords, and the three and four digit chords, respectively. The most difficult chords should if possible not be used in practical allocations.

A further objective of this work on the cognitive aspects of chord keying was to locate a 'general' method which could be applied to the learning of the chord patterns. There is a pressing need to develop retention aids for a chord keyboard system, if the device is intended for general use among the population. It was concluded that a system based on the shape of the letter was the most appropriate. Endfield uses a variation of this method in his mnemonics chart. He contrives to draw the letter around five spots which represent the digits. The end result is that some letters are misleading and not immediately obvious (for example, F and Q) while others are fanciful (for example, u, which in more recent charts than that shown in Section 2. of Chapter 8, has been indicated by a crooked little finger holding a cup. Since the letter u is generated by the little finger alone, the apparent connection is concerned with the idea that it is 'u' to crook your little finger drinking tea, as opposed to non-u.) Endfield claimed to have chosen combinations that were easy to remember. It is unclear from this statement whether he was referring to the actual chords or the mnemonics chart as a whole. Consideration of the former point demonstrates that Endfield's claim is untrue, since a comparison of his chord-letter allocations with the experimental findings shows that he did not use the chord patterns which were easy to remember. On the other hand, if he was referring to the mnemonics, this research has also shown that his approach (although a better attempt than most chord keyboard designers) was not wholly appropriate.

3.2.4 Motor Versus Cognitive Aspects

These two studies, described in Chapters 7 and 8 respectively provided different approaches to the problem of allocating chords to alphanumerics. The question then arises of whether motor or cognitive findings should provide the basis for the design of the chord keyboard system.

Seibel (1972) considered this problem, but did not draw any conclusions, other than the recommendations that chord keyboard systems should be explored more fully.

Seibel hypothesised that the motor action of keying was slower than the encoding activity; hence a system which required less motor activity per unit of information would allow the operator to increase the information rate. Seibel appeared to place more emphasis on the motor aspects, possibly because motor times were easier to measure than cognitive aspects. He stated that motor difficulties with some chords led to slower and more variable response times and suggested that the motor difficulty of some responses could not be ignored when designing data entry devices (Seibel, 1972). He continued by stating that on the other hand the act of encoding need not slow down the rate of data entry if simple encoding schemes are used and difficult chords avoided. Although Seibel's work is 20 years old, he raised some valid points. His interpretation of the cognitive aspects of chord keying is slightly different from the context in which it was used in this research. Seibel referred to the encoding of the chord immediately before execution, rather than the committing of the chord pattern to short term (or long term) memory.

From the two studies of this research the 31 chords were ranked according to speed of execution and speed of learning. There was a good statistical agreement between these two rank orders (0·64). Closer inspection of the results revealed that the single digit 'chords' were the fastest to execute and to learn, followed by the two and three digit chords. The chord patterns 2 45 and 123 5 appeared in the bottom five of both rank charts (see Tables 7.4 and 8.2) and hence because of their associated motor and cognitive difficulties should not be used when designing a chord keyboard. Suggestions concerning a single key for the middle and ring fingers have already been made. It is concluded that the allocation of chords to alphanumerics should be made on the basis of motor and cognitive parameters together and that the occasional disagreement between these two aspects should be resolved by applying the motor study findings, since the physical execution of a difficult chord poses a problem not so easily solved as learning a complex chord pattern.

3.2.5 Attitudes towards Chord Keyboards

User and population attitudes towards chord keying devices will play a major role in the ultimate success of the concept. Mussin (1980) stated that the needs and attitudes of the users of chord keyboards had yet to be defined in any great depth. Although there were several unavoidable methodological problems in this part of the research (for example, subjects responding in favour of the chord keyboard believing that they would thus please the author), the reaction of the majority of the subjects was favourable. Individuals found the chord keyboard system novel, interesting and good fun to use. It was noticeable that the subjects generated characters on the screen at a slow pace, but it was unfair to ask them about the speed of their key-pressings, since naive keyboard operators show atypical performance.

The evidence collected from this experiment concerning user attitudes to chord keyboards is tenuous. The prediction of a population response to any new device poses a difficult problem. This situation is further exaggerated when the device provides a new concept for the potential users. For example, the evaluation of a new make of car allows a comparison of existing models to be carried out, since the user population are all familiar with motor vehicles. The nearest communications device to the chord keyboard (ignoring the palantype and stenograph which are not familiar objects) is probably the typewriter followed by the pen. However due to the large differences in these devices, it was not feasible to employ a comparative psychometric technique to assess user attitudes towards the chord keyboard system. Retrospectively, the objectives of this final study on attitudes were ambitious and the conclusions reached indicate this. However the experiment fufilled a valid and useful exercise from the point of view of substantiating various findings from the previous experimental work.

3.2.6 Summary

Several suggestions concerning the optimum number of keys for a chord keyboard emerged from this work. The following proposals were put forward:-

(a) Four finger keys plus three thumb keys (total number of possible chord combinations = 94).

(b) Three finger keys (the middle and ring fingers sharing the same key) plus three thumb keys (total number of possible chord combinations = 71).

(c) Omission of the five slowest chords (namely, 1 3 5, 23 5, 3 5, 2 45, and 123 5). Four finger keys plus a thumb key and a shift key operated by the other hand (total number of possible chord combinations = 52).

(d) Omission of the five slowest chords. Two rows of five keys plus a shift key (total number of possible chord combinations = 104).

The disadvantage of the first proposal is that the problem chord patterns are not omitted. However this could be partly overcome by discarding the chords 2 45 and 123 5. It was recommended in the previous section that these two chords should not be used when designing a chord keyboard. The main shortcoming of the third and fourth proposed designs is that they introduce the use of the other hand. It was concluded from Chapter 6 that individuals preferred a chord keyboard for desk-top operation rather than handheld use. Hence the introduction of a key for the other hand may not be liked by the users. No research on the optimum number of thumb keys or the use of single row versus multi-row chord keyboards has been conducted. It can be hypothesised that the use of two rows as suggested in the fourth proposal (d) would slow down the speed of keying, because the fingers would have to move between the rows. Again, this is an area which requires further research.

Although each of the proposed keyboard designs has associated disadvantages and there is a pressing need for some further experimental work on chord keyboards before firm conclusions can be drawn, it is hypothesised that the second proposal may have the most potential. The use of a single key for the middle and ring fingers does in effect eliminate many difficult chords. However a total of 71 characters may be inadequate for some users.

From the work on the motor and cognitive aspects of chord keying, the following recommendations can be made concerning the allocation of characters to chord combinations.

Working from the basis of a 5-key chord keyboard, the order in which the characters should be allocated is as follows:-

Frequently used characters

↓

Least frequently used characters

Single digit chords
(1, 2, 3, 4, 5)

Five digit chord
(12345)

Two digit chords
(12, 1 3, 1 4, 1   5,
23, 2 4, 2 5, 34, 3 5, 45)

Three digit chords
(123, 234, 345,
12 5, 1 45, 1 34, 12 4)

Four digit chords
(1234, 2345,
1 345, 12 45)

** The chords 2 45 and 123 5 should be omitted completely, and the chords 23 5 and 1 3 5 if possible.

4. THE PRACTICAL IMPLEMENTATION OF THESE RESEARCH FINDINGS

It has already been established that the area of chord keyboards is little researched. This thesis has studied sequential and chord keyboards in depth and after a series of experiments has drawn various conclusions about alphanumeric keyboards. Having reached this point, the problem arises of disseminating this knowledge and applying the information to practical situations. It is debatable whether research of this nature is justified if it is destined for a dusty library shelf. Grandjean and Vigliani (1980) stated "therapies are useful only if they are applied". The problem of implementing research findings has no easy solution. Two classic examples from the literature on keyboards illustrate this.

Several experimental educational studies have been carried out into the effects of using a typewriter on children. Wood and Freeman (1932) investigated these effects by studying 15,000 children during one year and 4,000 children during two years. The children were divided into two groups; one group acted as a control while the experimental group used the typewriter as part of their regular classroom equipment. It was found after seven months that the children using the typewriters were progressing faster in their academic studies than the control group. A second study was conducted by Haefner (1937), who carried out a series of experiments with children who were taught to operate typewriters. He concluded that children, regardless of age, enjoyed using the typewriter and the total volume of 'writing' they produced was greatly increased. Although this article contained no data to support these conclusions, Haefner stated that children made requests for spelling longer words, they produced longer sentences and typed as much as 50% more words.

A similar experiment was reported by Kobler in 1967. He studied the results on 350 children of using a typewriter daily. Twenty 'talking typewriters' were installed in soundproof booths, upon which the children practised for an hour a day.

They were tested four and a half months later for improvements in the extent of their word knowledge and discrimination. Results showed that these children were equal to those individuals who had completed a year at school. McCauley (1970) found that children as young as seven years could learn the Dvorak Simplified Keyboard in less than two weeks. However McCauley does not present any experimental data to substantiate this finding.

There have been three studies (Fisher, 1971; Bridgman, 1972; Edwards, 1972) carried out on dyslexic and remedial children. These experiments all employed the Sight and Sound Education Limited fully-automated basic course of keyboard instruction, and the results were optimistic towards the use of typewriters for these groups of children. For example, Bridgman (1972) found that after 12 days of lessons, every pupil had learned the keyboard and was able to touch type.

It becomes evident, from experimental work on children and on other keying skills, that the introduction of typewriting into schools would be a beneficial exercise. Why then is there not a typewriter in every classroom?

As long ago as 1961, Professor J.C. Stanley suggested that "perhaps the typewriter and similar devices should largely replace handwriting for everything except brief notes and such things as bank cheques". He commented that the usual objection to typewriters in the classroom is cost, but that this is completely unfounded when considering the cost of existing educational hardware such as televisions, radios, video systems, tape recorders. Perhaps individuals fear that the introduction of keying devices will result in pencils, pens, chalk, etc. becoming obsolescent. However, this is unlikely since an increase in the use of typewriters might improve the sales of these objects because of the added interest in writing, etc. The introduction of the television did not inhibit the development of the radio and its popularity.

The second example of research findings, that were never implemented, concerns the arrangement of numeric push-buttons. There are two standards for the layout of numerics, in contrary versions (see Figure 10.2).

1	2	3		7	8	9
4	5	6		4	5	6
7	8	9		1	2	3

The Pushbutton Telephone Layout — The Adding Machine/ Calculator Layout

Figure 10.2: The Two Numeric Layout Standards

Deininger (1960) carried out a series of experiments at the Bell Systems Laboratories and rejected the adding machine/ calculator layout since it violated a firmly established psychological principle of equipment design, namely, that the equipment should be compatible with individuals' expectations. Lutz and Chapanis (1955) reported that when they had asked 100 people who had not used a keyset to indicate which key should be labelled '1', 55 pointed to the top left-hand corner. Only eight individuals indicated the bottom left-hand corner. Conrad (1967) supported this finding that the pushbutton layout was superior to the adding machine/ calculator design. Although research has unanimously shown the 1,2,3, top row layout to be more suitable than 7,8,9, calculator design, manufacturers persist in using the latter. There appears to be no solution to this problem, since the 7,8,9, layout has become a familiar feature of calculators, and with its accompanying financial and skill investment, the situation is becoming constantly more difficult to amend.

The application of the two research findings described here probably did not occur for different reasons. The expense for the schools of installing typewriters could well have been thought to outweigh the benefits the children might have gained.

These costs, coupled with the fact that educationalists and teachers were likely to be unaware of the advantages to be reaped from the use of typewriters, would explain why these devices were not adopted. However, these reasons would not apply to the numeric keyset layouts. It is apparent that the research on the 1,2,3, and 7,8,9, pushbutton designs was carried out after the calculator/adding machine layout was in existence. This last example is a similar situation to that found when trying to introduce new key layouts, on sequential keyboards, different from the ubiquitous QWERTY. Further, the attempt to introduce chord keyboards for typing, with sequential keyboards already in existence, faces similar problems.

The development of general purpose chord keying devices (for example, the Writehander and the Microwriter) is in its early stages. This research has laid down the foundations for the design of these keyboards, and made other recommendations concerning the motor and cognitive aspects of chord keying. In order for other individuals to benefit from these findings, it would appear imperative to publicise this research. It was evident from the literature reviews on alphanumeric keyboards that there was a lack of ergonomic pre-thought and subsequent evaluation of these devices. Unfortunately it is becoming increasingly common for inventors and designers to attach the words 'ergonomically designed' to their products (Hobday, 1981), which is misleading and usually untrue. Part of the solution appears to lie in increasing the amount of human factors research and publications, to make the population more aware of the advantages of ergonomics.

5. PROBLEMS ASSOCIATED WITH KEYBOARD RESEARCH

5.1 General Difficulties

The paucity of evaluative keyboard research can probably be explained by the immense methodological problems which are associated with such work. These difficulties are outlined in Section 3.1 of Chapter 5: they result in experimental keyboard evaluations being time-consuming and costly. These reasons coupled with inadequate ergonomic skills and resources could explain why inventors and designers neglect this stage in the development of their keying devices.

The difficulties associated with this type of research do not diminish after a lengthy keyboard training programme has been set up and the subjects have reached asymptotic performance levels. There has been some controversy over the techniques used for the analysis of the speed and accuracy data collected from such experiments. It is well known that there is a speed-accuracy trade-off for sensori-motor tasks, and problems arise because the two parameters, speed and accuracy, are tested in isolation.

Due to the trade-off effects, it would be a more valid exercise to consider a single performance score. Several attempts to generate such a formula have been made. For example, the IBM typing guide (Hirsch, 1970) describes a method to calculate performance levels in terms of 'net words per minute'. The total number of strokes, which subjects key in a 15 minute test, is divided by five. Ten words for each error are deducted from this total to obtain the net words per minute value. If an operator is slow or prone to making errors, a negative score may be attained. Hirsch (1958, 1970) in his experiment comparing an alphabetical and a QWERTY keyboard used a more elaborate formula on his data.

Hirsch's formula was:-

$$\text{Input Rate (strokes/second)} = \frac{S}{T_t(1 + \frac{KE}{S-E})}$$

T_t = time taken to type the test material

S = the number of strokes actually typed during the test

E = the number of errors found in the typed material

K = a constant.

E characters must be corrected, and the correcting of the errors will take K times the original input time; or, stated in the above symbols, the correction time = $\frac{KT_T}{S}$

Hirsch placed the value of K at 10 and 100, and it is this part of Hirsch's formula which is most suspect, and difficult to apply to other research. There would appear to be no satisfactory combined speed and accuracy performance index for measuring typing performance, and hence these two parameters must continue to be treated separately.

5.2 Specific Problem Areas Relating to this Work

Eason (1976) stated "too often, the designer uses himself as the model of the computer user." This research attempted to avoid this by selecting a pool of subjects from a diverse variety of backgrounds, who were chosen to represent the potential user population. However, this was not always possible since there were certain conflicts between the nature of the experiment and the type of users. For example, in the reaction time and learning studies, the age of the subjects was limited to under 45 years, because of the decrease in the flexibility of the joints and in the learning rate and memory with the onset of old age. Similarly in the reaction time study, only right-handed individuals were used. Hence, it could be argued that the chord keyboard was being designed for young, right-handed people. There is no obvious solution to this problem. The selection of subjects will inevitably be a compromise taking into account the skills of the users and the demands of the experiment.

This research also highlighted a further difficulty experienced when designing keyboards. The preliminary pilot study (Chapter 6) was concerned with the hand at rest. However the situation changes when the hand moves from being static to dynamic and operates the key-switches. This demonstrates the importance of ergonomic evaluations, which study the keyboard in its working environment.

Questionnaires were extensively used in this work (Chapters 2 and 9), and there are many difficulties associated with the use of this technique. The main shortcoming when analysing questionnaire data and attitude rating scales concerns the interpretation made by the author. The classic example encountered in this work was connected with the question of fatigue. For example, the results of the questionnaire survey showed that 52% of skilled typists suffered from back-ache. The problem arises of relating the percentages of positive replies to the gravity of the situation, that is, at what percentage do you declare that operating the QWERTY keyboard is causing back-ache among typists.

This example demonstrates a fundamental difficulty in the use of questionnaire and interview techniques. However Kroemer (1972) found a solution for comparative keyboard experiments. He asked each subject her reasons for terminating the experiment (a comparison of the Kroemer and the QWERTY keyboards). Each reply was later classified into groups (see Figure 10.3).

Primary Reasons	Frequency	
	Kroemer Keyboard	QWERTY Keyboard
Cannot sit any longer	2	1
Aches and pains in the region of:		
back	5	9
neck	4	4
shoulders	17	11
arms	27	48
wrists	9	24
fingers	10	14
Subtotal	(72)	(110)
Can no longer concentrate on the task:		
together with aches and pains	9	10
without mentioning aches or pains	41	22
explicitly without aches or pains	8	5
Subtotal	(55)	(37)
Total	132	148

Figure 10.3: Reasons given by 12 Subjects for Terminating the Experimental Trials

Finally, the standard procedures with questionnaires require piloting and the application of reliability and validity testing. Although the methodology for the latter was investigated, it was not practised. The primary reason for not conducting reliability and validity tests was time, and the fact that the research was using the questionnaire as an experimental measurement tool and not as a vehicle to produce a 'tried and tested' questionnaire for widespread usage.

Moreover, Likert-type rating scales were used as the main instrument for the attitude study of Chapter 9, and the recommendations of Edwards (1957) were closely followed. Elsewhere, apart from the initial exploratory survey reported in Chapter 2, the questionnaires were essentially used for comparisons between keyboards being tested by subjects under similar circumstances, and not for 'absolute' results. For this purpose it was considered satisfactory to develop the questionnaires through the pilot trials as described.

6. THE FUTURE OF THE ALPHANUMERIC KEYBOARD

The increase of computer technology over the last two decades has resulted in the emergence of many advanced data entry devices, for example, voice recognition input, and optical character recognition systems. The question then arises of how secure the future of the alphanumeric keyboard is.

It has already been concluded from this research that the QWERTY standard sequential keyboard will remain in its dominant role for many years to come. Skilled typists enjoy typing and 78% prefer this mode of communication to handwriting. One of the advantages of keying compared to voice recognition systems is that it is less tiring. Skilled personnel are able to type all day, whereas it is tedious (and perhaps impossible in a crowded environment) to input data by voice for long periods of time (Braunstein and Anderson, 1959). Hence the medium of keying may well be preferred to speaking for quite a proportion of work situations.

6.1 Input by Speech Recognition

Intuitively, speech would appear to be the most natural method for communicating with the computer. However, research in this field has not progressed very far due to the technical difficulties resulting from individual differences, and wide variations in sound patterns produced by people for the same word. For example, IBM researchers with the use of a large computer take 3½ hours to decode one minute of dictation. This is with a vocabulary restricted to 1000 words and after an hour of 'training' the computer to understand the particular user. However the system is still subject to a 10% error rate (Litterick, 1981). There are advantages of such a system, these could be listed as follows:-

(a) The user's eyes and hands are free to operate other equipment.

(b) Voice input as a data entry technique speeds up the over-all system and hence it would be possible to reduce the number of individuals involved in one job.

(c) The system requires a relatively short training period.
(d) There are many benefits to be gained for the physically handicapped.
(e) Security - only authorised personnel would be allowed to enter data.

In 1981, the use of voice recognition systems instead of alphanumeric keyboards does not appear to be a feasible proposition. Litterick (1981) echoed this viewpoint by giving his opinion that it will be the end of the century before voice recognition systems will start to have a significant impact on the market for keyboards. It is quite likely that speech recognition devices will enhance the sales of some keyboards, since they will be needed for editing and correcting the output from the voice recognition systems.

6.2 Input by Character Recognition

The method of inputting data into a system via a handwriting medium has much potential for the unskilled and occasional user. One of the problems of such a system (like the voice recognition system) is the individual variation in handwriting patterns. One of the ways of overcoming this is to standardise working by block printing letters and several commercial devices are on the market. However, writing speed is considerably reduced; printing rate is about 12½ words per minute instead of the average of 25-30 for handwriting. Nevertheless, the adoption of even the printing recognition devices would appear to suggest that character recognition systems have advantages over the keyboard for certain applications.

At the moment, the still-developing technology and cost of character recognition systems hinders their adoption. Since speed needs can be met by sequential keyboards, it would seem likely that character recognition systems would have a useful application for the occasional user who is a non-typist. The outcome of this suggestion will be substantiated over the next decade.

6.3 Summary

A comparison of the sequential keyboard and other input media demonstrates the advantages and potential of the former. The standard QWERTY keyboard is firmly entrenched in our offices, homes and factories, and will remain there because of the financial, commercial and skill investment, and the attitudes of the user population to this keyboard. In 1981, it is not necessary to justify a need for this keyboard, unlike the chord keyboards.

Chord keyboards have a valuable contribution to make, when specifically designed for a task. Unfortunately, some inventors and keyboard designers have a complete disregard for the application of their keying devices. It is likely that within the next few years, more keyboards (for example, the Mode keyboard) will flood onto the market, with sensational advertising such as "this machine will revolutionise typing" (Endfield, 1978). Unless a need other than to rival the QWERTY keyboard is present, it is questionable whether the development of these chord keyboards can be justified. However, if there is a need for such keyboards, then the results of this research, as summarised in Section 3.2.6 of this chapter, may prove a useful basis for further development.

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The findings of Part I of this research supported the results of previous studies, namely,

* The QWERTY keyboard is not optimal in terms of layout and design for touch typing.

* The QWERTY arrangement of keys hinders keyboard operation for naive and skilled keyboard users.

* The design of the QWERTY keyboard needs modification.

Literature reviews and experimental work on sequential keyboards reached the following conclusions:

* The QWERTY keyboard will continue to monopolise the sales of alphanumeric sequential keyboards.

* The reasons for the predicted permanence of the QWERTY keyboard are summarised as follows:

  strength of tradition

  the recognition of QWERTY as the International, British and American standards

  the financial, skill and commercial investment in this keyboard

  the attitudes of the user population, who are unwilling to change to a new layout and/or design

  the fact that manufacturers do not recognise a need to discard the QWERTY keyboard

  the problems of locating a replacement keyboard

  the inconvenience and costs of retraining.

* An alphabetically arranged keyboard has advantages for the occasional unskilled user with a small work-load.

* The development of sequential keyboards with new layouts is a fruitless task, because of the establishment and predicted continuing dominance of QWERTY.

* There is some evidence from the work of others that the keyboard and key heights and positions may help to reduce aches and pains.

Conclusions from Part II of this research on chord keyboards were as follows:

* Chord keyboards can be classified into three groups, namely,

  hybrid chord keyboards (for example, ANTEL)
  'true' chord keyboards (for example, the Post Office chord keyboards)
  shorthand chord keyboards (for example, the Palantype).

* Many chord keyboards have been developed before a need or an application has been located.

* Three chord keyboard designs were investigated and it was concluded that none of these was optimum for a one-handed desk-top chord keying device (although the hemisphere was the most appropriate).

* The speed of execution of chords does not relate specifically to the design of the keyboard.

* The allocation of chord patterns to alphanumerics should be made on the basis of motor and cognitive parameters. Any disagreement between these two aspects should be resolved by applying the motor study findings, since the physical execution of difficult chords poses more of a problem than learning a complex chord pattern.

* Retention aids, such as mnemonics, are an important consideration when designing a chord keyboard.

* Different methods of learning the chord patterns were investigated: a 'general' memory aid based on the shape of the letter was concluded to be the most satisfactory, for example, an arc of numbers arranged around the character.

* The introduction of a mnemonics memory aid increased the speed of learning of the chord pattern.

* Initial reactions towards the chord keyboard concept were favourable.

2. RECOMMENDATIONS

* Manufacturers should study the benefits to be gained from modifying the design of sequential keyboards. Modifications should be based on designing a keyboard layout in keeping with the anthropometry of the hands, for example, curved rows of keys, varying key heights, and palm rests.

* The optimum design for a chord keyboard should be based on the position of the hand in a relaxed posture. In the case of a 5-key chord keying device, this would be a flattened ovoid shape.

* Further experimentation will have to be carried out in order to work towards a standard for chord keyboards.

* The minimum number of keys needed for a general purpose one-handed chord keyboard is six.

* Further research will have to be conducted on the use of a single shared key for the middle and ring fingers.

* The optimum force-displacement characteristics of key switches on a chord keyboard need to be studied.

* Single digit 'chords' should be allocated to the most frequent alphanumerics, followed by two digit, three and then four digit chords, respectively.

* There is a need to develop a single performance index for the measurement of speed and accuracy scores in keying regimes.

* The hybrid group of chord keyboards has many of the advantages of both sequential and chord keying devices and may be most suitable for general use.

3. EPILOGUE

This research has demonstrated the abundance of work on sequential keyboards and the paucity of information on chord keyboards. It is hoped that this research will reduce the imbalance between these two areas. There are two themes which emerge throughout the work: these are the strength of the QWERTY keyboard and the lack of application associated with the development of several chord keying devices. This second point raises the issue of whether there is a need for chord keyboards other than those which are designed for specific applications. Rightly or wrongly, part II of this research was based on the assumption that there was a need for general purpose chord keyboards. Although the author would favour the argument that there is no justification for developing these chord keyboards, since the sequential keyboards available fulfill the majority of the requirements of the general population, it is inevitable that inventors and enterprising individuals will continue to develop chord keyboards. It could also be argued that although there appears to be no immediate need for a general purpose chord keyboard, the rapid development of personal computers might create the need. A lack of communication among keyboard designers (coupled with inadequate research in the case of chord keyboards) explains why new sequential and chord keyboards continue to be produced. It is hoped that this work, and subsequent publications which emanate from it, have served to clarify somewhat the 'state of the art' of sequential and chord keyboards.

REFERENCES

ALDEN, D.G., DANIELS, R.W., and KANARICK, A.F., (1972)
Keyboard design and operation: A review of the major issues.
Human Factors, 14(4), 275-293.

AMANN, C., and KLERER, M., (1967)
Hardware documentation of an 8-button keyboard.
University Technical Report No. 127, ASTIA document 650 841,
Dobbs Ferry, New York: Hudson Laboratory of Columbia.

ANDREAS, B.G., (1972)
Experimental Psychology.
New York: John Wiley and Sons, Inc.

AUSTRALIAN POST OFFICE., (1953)
Dvorak keyboard experiment - follow up investigation.
Melbourne: Australian Post Office.

AVAKIAN, E.A., (1968)
Applications and utility of alphabetic clusters, the non-QWERTY keyboards.
Paper presented at the Workshop on Keysets and Keyboards of the IEEE Man-machine Systems Group NBS, Gaithersburg, Maryland.

AYRES, A., (1965)
Word writing machine producing closed-up printing in response to simultaneous actuation of keys.
U.S. Patent No. 3,225,883

BADDELEY, A.D., CONRAD, R., HULL, A.J., LONGMAN, D.J.A., RABBITT, P.M., SKOULDING, B.A., and STEWART, G.A., (1958 - 1962)
Code design and the design of keyboards.
Report of work carried out on behalf of the Post Office, Applied Psychology Research Unit of M.R.C., Cambridge.

BANAJI, F.M.M., (1920)
Keyboard for typewriters.
Specification of Letters Patent, U.S. Patent No. 1,336,122

BARMACK, J.E., and SINAIKO, H.W., (1966)
Human factors problems in computer-generated graphic displays.
Study S-234, Report No. IDA/HQ 66-4820, Institute for Defence Analysis, Research and Engineering Support Division, 400 Army Navy Drive, Arlington, Va.

BEECHING, W.A., (1974)
Century of the Typewriter.
London: Heinemann.

BEQUAERT, F.C., and ROCHESTER, N., (1977)
One-handed keyboard and its control means.
U.S. Patent No. 4,042,777

BIEGEL, R.A., (1934)
An improved typewriter keyboard.
The Human Factor, 8, 280-285.

BODENSEHER, H., (1970)
A console keyboard for improved man-machine interaction.
IEE, MCI.

BOWEN, H.M., and GUINNESS, G.V., (1965)
Preliminary experiments on keyboard design for semi-automatic mail sorting.
Journal of Applied Psychology, 49(3), 194-198.

BRAUNSTEIN, M., and ANDERSON, N.S., (1959)
A comparison of reading digits aloud and keypunching.
IBM Research Memo No. RC-185, Yorktown Heights, New York.

BRIDGMAN, D., (1972)
Sight and Sound typewriting programmes: 1. Typewriting in remedial education at the secondary stage.
Remedial Education, 7(2), 27-31.

CAKIR, A., HART, D,J., and STEWART, T.F.M., (1980)
Visual Display Terminals.
Chichester: John Wiley and Sons, Inc.

CAMPBELL, D.D., (1973)
Typewriting contrasted with handwriting: A circumvention study of learning - disabled children.
Journal of Special Education, 7(2), 155-168.

CHAMBERS, J.B., and STOCKBRIDGE, H.C.W., (1970)
Comparison of indicator components and pushbutton recommendations.
Ergonomics, 13(4), 401-420.

CHURCHILL, E., KUBY, A., and DANIELS, G.S., (1957)
Nomograph of the hand and its related dimensions.
Wright Air Force Development Centre, Technical Report 57-198, ASTIA document AD 118 162.

COCKING, R.W., (1970)
In place of QWERTY.
Daily Telegraph Supplement, No. 301, 24/7/70.

COMPUTERS and AUTOMATION., (1971)
The Dvorak Simplified Typing Keyboard - Comment.
February 1971, p. 8-9.

COMPUTER WEEKLY, (1978)
Calculators will 'converse' with the users.
October 5th, page 13.

COMPUTER WEEKLY, (1979)
Key requirement for office automation.
February 15th, page 22.

COMPUTING, (1981)
Reader's Digest inspires keyboard quest.
April 30th, page 60.

CONRAD, R., (1960)
Letter sorting machine-paced, 'lagged' or unpaced?
Ergonomics, 3, 149-157.

CONRAD, R., (1961)
Ergonomics in Industry.
London: H.M.S.O.

CONRAD, R., (1967)
Performance with different pushbutton arrangements.
HET PTT-BEDRIJF DEEL, Netherlands, May 1967, 15, 110-113.

CONRAD, R., and LONGMAN, D.J.A., (1965)
A standard typewriter versus chord keyboard - an experimental comparison.
Ergonomics, 8, 77-88.

CONWAY, D.L., (1979)
Contoured keyboard.
IBM Technical Disclosure Bulletin, 22(3), 1276-1277.

COOPER, M.B., (1976)
The effect of a keypad angle of a table keyphone on keying performance.
Applied Ergonomics, 7(4), 205-211.

CORNOG, J.R., and CRAIG, J.C., (1965)
Keyboards and coding systems under consideration for use in the sorting of United States mail.
Paper to VI Annual Symposium of Human Factors in Electronics IEEE on Man and Computers, May 6-8th.

CORNOG, J.R., HOCKMAN, J.F., and CRAIG, J.C., (1963)
Address encoding - a study of the double-binary keyboard as a link in the machine sorting of mail.
A.S.M.E. Paper No. 63-WA-338, presented to the Winter Annual Meeting of the American Society of Mechanical Engineers.

DATASAAB., (1976)
Ergonomics - the third factor.
Sweden: Skandia Insurance Company.

DEININGER, R.L., (1960)
Desirable push-button characteristics.
IRE Transactions Human Factors in Electronics, HFE-1(1), 24-30.

DIXON, W.J., (1970)
BMD Biomedical Computer Program.
Berkeley: University of California.

DUNCAN, J., and FERGUSON, D., (1974)
Keyboard operating posture and symptoms in operating.
Ergonomics, 17(5), 651-662.

DUNN, A.G., (1971)
Engineering of the typing keyboard from the human factors viewpoint.
Computers and Automation, 20, 32-33.

DVORAK, A., (1936)
Typewriter keyboard.
U.S. Patent No. 2,040,248

DVORAK, A., (1943)
There is a better typewriter keyboard.
National Business Education Quarterly, 12-2,51-88, 66.

DVORAK, A., (1950)
A one-handed keyboard for one-handers.
Handicap, April 1950.

DVORAK, A., MERRICK, N.I., DEALEY, W.L., and FORD, G.C., (1936)
Typewriting Behaviour.
New York: American Book Company.

EASON, K.D., (1976)
Understanding the naive computer user.
Computer Journal, 19(1), 3-7.

EDWARDS, A.L., (1957)
Techniques of Attitude Scale Construction.
New York: Appleton-Century-Crofts.

EDWARDS, R., (1972)
Sight and Sound typewriting programmes: 2. A summary of experiments with handicapped pupils.
Remedial Education, 7(2), 31-33.

ENDFIELD, C., (1978)
A typewriter in your pocket.
Computer Weekly, May 11th, page 4.

ENGLEBART, D.C., and ENGLISH, W.K., (1968)
A research centre for augmenting human intellect.
AFIPS Conference Proceedings, Volume 33, FJCC, 395-410.

EVANS, R.A., and MARTIN, W.L., (1970)
A proposal for simple conversion of QWERT keyboard typewriters to write in S.I. units.
Report SPG TR8, Central Electricity Generating Board Generation Development and Construction Division Southern Project Group: London.

FERGUSON, D., (1971)
An Australian study of telegraphists' cramp.
British Journal of Industrial Medicine, 28, 280-285.

FERGUSON, D., and DUNCAN, J., (1974)
Keyboard design and operating posture.
Ergonomics, 17(6), 731-744.

FISHER, V.W., (1971)
Dyslexic Review.
Winter 1971, No. 6.

FITTS, P.M., and PEARSON, J.R., (1964)
Information capacity of discrete motor responses.
Journal of Experimental Psychology, 67, 103-112.

FITTS, P.M., and SWITZER, G., (1962)
Cognitive aspects of information processing: 1. The familiarity of S-R sets and subsets.
Journal of Experimental Psychology, 63, 321-329.

FLOYD, S.J.H., (1979)
Standard QWERTY Versus Maltron QWERTY - An Experimental Comparison.
Final Year Project Report, Department of Human Sciences.
Loughborough University of Technology.

FOX, J.G., and STANSFIELD, R.G., (1964)
Digram keying times for typists.
Ergonomics, 7(3), 317-320.

GALANTER, E., and OWENS, J.A., (1974)
The independence of the simple reaction time on key force.
Abstract in Government Reports Announcements (Report No. AD-783123/3GA, 15 pages).

GARRETT, J.W., (1971)
The adult human hand: Some anthropometric and biomechanical considerations.
Human Factors, 13, 117-131.

GILBERT, W.A., (1930)
The Orthographic Keyboards.
Spokane, Washington: Shaw and Borden Company.

GORDAN, M.E., Henry, H.G., and MASSENGILL, D.P., (1975)
Studies in typewriter keyboard modification: 1. Effects of amount of change, finger load and copy content on accuracy and speed.
Journal of Applied Psychology, 60(2), 220-226.

GRANDJEAN, E., and VIGLIANI, E., (1980)
Ergonomic Aspects of Visual Display Terminals.
In: Proceedings of International Workshop, Milan, 17-19 March,
London: Taylor and Francis Ltd.

GREEN, T.R.G., SIME, M.E., and GUEST, D.J., (1972)
Some types of error in a choice response task.
Quarterly Journal of Experimental Psychology, 24, 149-158.

GRIFFITH, R.T., (1949)
The minimotion typewriter keyboard.
Journal of the Franklin Institute, 248, 399-436.

HAALAND, J., (1962)
Anatomic and physiological consideration of the use of the thumb for manual control in space flight.
Honeywell Memorandum, July 11th.

HAEFNER, R., (1937)
Typewriter, the three R's.
American School Board Journal, 95(3), 28-30.

HALE, D., (1970)
Speed/Accuracy Interaction in Human Performance.
Report to the Social Science Research Council, London.

HANES, L.F., (1972)
Human Factors in International Keyboard Arrangement.
In: Ethnic Variables in Human Factors Engineering, (pages 189-207). Edited by A. Chapanis, Baltimore and London: The John Hopkins University Press.

HARDY, R., (1978)
A Study of the Feasibility of Accessing Information on PRESTEL by Numeric Representation of Keyboards.
Unpublished M.Sc. Thesis, Loughborough University of Technology.

HARNETT, J., (1972)
QWERTY lives another day.
Office Equipment News, 15, 16, 57.

HICK, W.E., (1952)
On the rate of gain of information.
Quarterly Journal of Experimental Psychology, 4, 11-26.

HILLIX, W.A., and COBURN, R., (1961)
Human Factors in Keyset Design.
NEL/Report 1023, U.S. Navy Electronics Laboratory.

HIRSCH, R.S., (1958)
A human factors comparison of two keyboards, proposed for special purpose and limited application.
IBM Research Memo No. RJ-151, San Jose, California.

HIRSCH, R.S., (1970)
Effects of standard versus alphabetic keyboard formats on typing performance.
Journal of Applied Psychology, 54(6), 484-490.

HOBDAY, S.W., (1981)
The quick brown fox ..... or keyboard alternative.
Inventor, January, pages 16-20.

HOKE, R.E., (1924)
Typewriter keyboard arrangement.
Specification of Letters Patent, U.S. Patent No. 568,792

HOWELL, C., and KREIDLER, L., (1963)
Information processing under contradictory instructional sets.
Journal of Experimental Psychology, 65, 30-46.

HÜNTING, W., LÄUBLI, Th., and GRANDJEAN, E., (1980)
Constrained postures of VDU operators.
In: Ergonomic Aspects of Visual Display Terminals,
Grandjean, E., and Vigliani, E., (Eds.), 1980, op cit.

JARMANN, H., (1952)
Electromagnetic operating mechanisms for typewriters.
U.S. Patent No. 2,581,665

JOHN, I.D., (1969)
Mediating Processes in Choice Reaction Tasks.
In: Attention and Performance II, Proceedings of the Donders Centenary Symposium on Reaction Time, W.G. Koster (Ed.),
Amsterdam: North Holland Publishing Company.

JONES, C.E., KOBRICK, J.L., and GAYDOS, H.F., (1958)
Anthropometric and biomechanical characteristics of the hand.
Technical Report No. EP-100, U.S. Army, Natick, Massachusetts, Environmental Protection Research Division Psychology Branch, Project 7-83-01-005.

KINKEAD, R., (1975)
Typing speed, keying rates and optimal keyboard layouts.
In: Human Factors in our Expanding Technology, Proceedings of the Human Factors Society Nineteenth Annual Meeting, Dallas, Texas, U.S.A., 14-16 October, pages 159-161.

KLEMMER, E.T., (1958)
A ten-key typewriter.
IBM Research Memo No. RC-65, Yorktown Heights, New York.

KLEMMER, E.T., and LOCKHEAD, G.R., (1962)
Productivity and errors in two keying tasks.
Journal of Applied Psychology, 46(6), 401-408.

KLEMMER, E.T., and MULLER, P.F. Jr., (1953)
The rate of handling information. Key pressing responses to light patterns.
U.S.A.F. Human Factors Operation Research Laboratory, Report No. 34.

KLOCKENBERG, E.A., (1926)
Rationalisierung der Schreibmaschine und ihrer Bedienung.
Berlin: Springer.

KOBLER, R., (1967)
The talking typewriter - and the learning of reading in a disadvantaged community.
Computers and Automation, November, page 37.

KOMOIKE, Y., and HORIGUCHI, S., (1971)
Fatigue assessment of key punch operators, typists and others.
Ergonomics, 14(1), 101-109.

KROEMER, K.H.E., (1972)
Human engineering the keyboard.
Human Factors, 14, 51-63.

KUCERA, H., (1967)
Computational analysis of present-day American English.
Providence, Rhode Island: Brown University Press.

LEGROS, L.A., and GRANT, J.C., (1916)
Typographical Printing Surfaces.
London: Longmans Green.

LEONARD, J.A., (1954)
The Effect of Partial Advance Information.
Report No. 217/54, Medical Research Council, Applied Psychology Unit, Cambridge, U.K.

LEVY, M., (1955)
The electronic aspects of the Canadian sorting of mail systems.
Proceedings of the National Electronic Conference, 10, 1-14.

LITTERICK, I., (1981)
QWERTYUIOP - dinosaur in a computer age.
New Scientist, January 8th, pages 66-68.

LOCKHEAD, G.R., and KLEMMER, E.T., (1959)
An evaluation of an 8-key word-writing typewriter.
IBM Research Memo No. RC-180. Yorktown Heights, New York.

LUTZ, M.C., and CHAPANIS, A., (1955)
Expected locations of digits and letters on ten-button keysets.
Journal of Applied Psychology, 39(5), 314-317.

MALDE, B., HELLER, L.F., and STEWART, T.F.M., (1978)
Mirror Study I - A Preliminary Ergonomics Survey of the Photocomposing and Hot Metal Methods of Newspaper Production.
HUSAT Memo No. 166, Department of Human Sciences, Loughborough University of Technology.

MALT, L.G., (1977)
Keyboard design in the electronics era.
Paper presented at PIRA symposium - Developments in Data Capture and Photocomposition, London.

MAMEROW, W., (1916)
Elektrische Tastatur.
German Patent No. 308048

MANDLEBROT, B., (1954)
Simple games of strategy occurring in communication through natural languages.
IRE Transactions, IT-3, 124-137.

MARES, G.C., (1909)
The History of the Typewriter.
London: Pitman.

MARTIN, A., (1972)
A new keyboard layout.
Applied Ergonomics, 3(1), 48-51.

MASSENGILL, D.P., GORDAN, M.E., and HENRY, H.G., (1975)
Studies in typewriter keyboard modification: II. Effects of amount of change, finger load, and copy content on accuracy and speed.
Journal of Applied Psychology, 60(2), 227-230.

MAXWELL, W.C., (1953)
The rhythmic keyboard.
Journal of Business Education, 27, 327-330.

McCAULEY, B., (1970)
The Dvorak Simplified Typing Keyboard.
Computers and Automation, December, page 8.

MEDDIS, R., (1980)
Unified analysis of variance by ranks.
British Journal of Mathematical and Statistical Psychology. In Press.

MICHAELS, S.E., (1971)
QWERTY versus alphabetic keyboards as a function of typing skill.
Human Factors, 13, 419-426.

MOSER, C.A., and KALTON, G., (1977)
Survey Methods in Social Investigation.
London: Heinemann Educational Books.

MOWBRAY, G.H., and RHOADES, M.U., (1959)
On the reduction of choice-reaction times with practice.
Quarterly Journal of Experimental Psychology, 11, 16-23.

MUSSIN, E.H., (1980)
The Microwriter.
Excerpt from IERE Electronic Office Conference Proceedings, April.

NELSON, W.W., (1920)
The improvements in connection with keyboards for typewriters.
British Patent No. 155,446

NIE, N., BENT, D.H., and HULL, C.H., (1970)
SPSS Statistical Package for the Social Sciences.
U.S.A.: McGraw-Hill Book Company.

OPPENHEIM, A.N., (1966)
Questionnaire Design and Attitude Measurement.
London: Heinemann Educational Books.

OSANAI, H., (1968)
Ill health of key punchers.
Journal of Science and Labour, July, 367-371.

OSGOOD, C.E., SUCI, G.J., and TANNENBAUM, P.H., (1957)
The Measurement of Meaning.
Urbana: University of Illinois Press.

OSTREY, J.M., (1929)
A Critical Analysis of Letter Sequences in Typewriting.
Unpublished Master's Thesis, University of Nebraska, U.S.A.

OWEN, S., (1978)
QWERTY is obsolete.
Interface Age, 3(1), 56-59.

PHILLIPS, A., (1968)
Computer Peripherals and Typesetting.
London: H.M.S.O.

PHILLIPS, S.A., and KINCAID, J.P., (1971)
The human engineering of the typewriter keyboard: A case in point.
Human Factors Society Bulletin, 14, 7-8.

POLLOCK, W.T., and GILDNER, G.G., (1963)
Study of computer manual input devices.
Technical Document Report No. ESD-TDR-63-545: Contract AF.19 (628) 435, Project 9678, BSC Report 40138.

POULTON, E.C., (1969)
Bias in experimental comparisons between equipments due to the order of testing.
Ergonomics, 12(4), 675-687.

POULTON, E.C., (1973)
Unwanted range effects within subject experimental designs.
Psychology Bulletin, 30, 113-121.

RATZ, H.C., and RITCHIE, D.K., (1961)
Operator performance on a chord keyboard.
Journal of Applied Psychology, 45, 303-308.

RICHARDS, G.T., (1964)
The History and Development of Typewriters: Science Museum.
London: H.M.S.O.

RICHARDS, M., (1978)
Britain tackles illiteracy.
Change, 10, 16-19.

RIEMER, E., (1929)
A Revised Keyboard For the Typewriter.
Unpublished Master's Thesis, New York University.

ROCHESTER, N., BEQUAERT, F.C., and SHARP, E.M., (1978)
The chord keyboard.
Computer, 11(12), 57-63.

ROEBUCK, J.A., KROEMER, K.H.E., and THOMSON, W.G., (1975)
Engineering Anthropometry Methods.
New York: John Wiley and Sons, Inc.

ROWELL, S.W., (1909)
Typewriter keyboard.
Specification of Letters Patent, U.S. Patent No. 943,466

SEIBEL, R., (1962)
Performance on a five-finger chord keyboard.
Journal of Applied Psychology, 46(3), 165-169.

SEIBEL, R., (1963)
Discrimination reaction time for a 1023 alternative task.
Journal of Experimental Psychology, 66(3), 215-226.

SEIBEL, R., (1964)
Data entry through chord, parallel entry devices.
Human Factors, 6, 189-192.

SEIBEL, R., (1972)
Data Entry Devices and Procedures.
In: Human Engineering Guide to Equipment Design,
Van Cott, H., and Kinkade, R., (Eds.), American Institute for Research: Washington DC, Chapter 7 (pages 311-345).

SHACKEL, B., (1980)
Man-Computer Interaction (MCI) - Reality and Problems.
Introductory Paper to NATO Advanced Study Institute, 1976.
In: Proceedings of A.S.I. 'Man-Computer Interaction', Sijthoff and Noordhoff.

SHOLES, C.L., GLIDDEN, C., and SOULÉ, S.W., (1868)
Improvements in type writing machines.
U.S. Patent No. 79,868

SIEGEL, S., (1956)
Non-parametric Statistics for the Behavioural Sciences.
London: McGraw-Hill Book Company.

SNEDECOR, G.W., and COCHRAN, W.G., (1967)
Statistical Methods (Sixth Edition).
Ames, Iowa: Iowa State University Press.

STANLEY, J.C., (1961)
Cited in New Horizons for Research in Handwriting.
Herrick, V.E., (Ed.), Madison, Wisconsin: University of Wisconsin Press

STEWART, T.F.M., (1973a)
Data Entry and Keyboards: A Review.
HUSAT Memo No. 60, Department of Human Sciences, Loughborough
University of Technology.

STEWART, T.F.M., (1973b)
Improvements in or relating to keyboards: concerned with
marking and use of chord keyboards.
British Patent No. 1,492,538

STRONG, E.P., (1956)
A Comparative Experiment in Simplified Keyboard Retraining and
Standard Keyboard Supplementary Training.
Washington DC, U.S.A.: General Services Administration.

STUTSMAN, G., (1959)
Reverse the 'A' and 'J' keys?
Journal of Business Education, 6, 249-250.

SUMMERS, G.F., (Ed.), (1970)
Attitude Measurement.
Chicago: Rand McNally and Company.

SWEDISH NATIONAL BOARD OF OCCUPATIONAL SAFETY AND HEALTH., (1979)
Wordprocessors - the health debate.

THOMAS, M.P., (1972)
Human Coding Performance: A Review.
LUTERG 66, Loughborough University of Technology Internal Report.

THORNDIKE, E.L., and LORGE, I., (1952)
The Teacher's Wordbook of 30,000 Words.
New York: Columbia University Press.

TIME Magazine., (1939)
Faster typewriter.
March 20th, page 39.

TURN, R., (1974)
The Use of Speech for Man-Computer Communication.
Report R-1386-ARPA, Rand Corporation, Santa Monica, California, 90406, U.S.A.

UNITED STATES NAVY., (1944)
A Comparison of Typist Improvement from Training on Standard Keyboard and Retraining on Simplified Keyboard.
Washington: United States Navy, Division of Shore Establishments and Civilian Personnel.

WARD, J.L., (1936)
A study of typewriter keyboards.
Educational Research Bulletin, 15, 243-246.

WEBB, S., and COBURN, R., (1959)
Development and Testing of a Hand-configured Keyset.
Technical Memo No. TM-357, San Diego, California: U.S. Navy Electronics Laboratory.

WINER, B., (1971)
Statistical Principles in Experimental Design.
London: McGraw-Hill Book Company.

WOHL, A.D., (1980)
Replacing the pad and pencil.
Datamation, June 1980, 169-176.

WOLCOTT, C., (1920)
Keyboard.
Specification of Letters Patent, U.S. Patent No. 1,342,244

WOOD, B.D., and FREEMAN, F.N., (1932)
An Experimental Study of the Educational Influence of the Typewriter in the Elementary School Classroom.
London: MacMillan.

APPENDICES

APPENDICES ARE NUMBERED SERIALLY
BY CHAPTERS FOR CONVENIENT REFERENCE

The Questionnaire

Section A

1. Job title.
2. Age of subject.
3. How did you learn to type?
4. How long did this training last?
5. At what speed were you typing at the end of this training?
6. In your opinion, how long was it after this training period, before you became proficicent and reasonably confident using the typewriter?

Section B

7. Are you satisfied with the arrangement of keys on the typewriter keyboard? If no, please specify.
8. Are there some finger movements between keys which are more difficult to do than others? If yes, please specify.
9. Are there any keys or sequences of keys with which you seem to make more errors than others? Please specify.
10. If you could move the typewriter keys around, are there any keys that you would change the position of? Please specify.
11. Would you prefer it if the thumbs were given more work to do?
12. Imagine that you were designing a typewriter keyboard. You have the letters of the alphabet, the numbers and punctuation symbols - where would you place the various keys?

Section C

13. Do you find it a problem having to move your head so much when working?
14. When typing, does your neck sometimes ache?
15. Does your back sometimes feel strained when typing?
16. Do your shoulders sometimes ache?
17. Do your arms become tired?
18. Do your fingers sometimes become tired and start to ache?
19. Can you remember if parts of your body ever used to ache when you first began to learn to type? Please specify.
20. Do you have any other problems of fatigue?
21. Can you think of any improvements that would make operation of the typewriter more comfortable?

Section D

22. Do you enjoy typing?
23. Do you prefer typing to handwriting?
24. What aspects of the typewriter and typing do you like?
25. What aspects of the typewriter and typing do you dislike?
26. Do you think that the typewriter is equally suited to both left and right handed people? If no, please specify.
27. Do you know of any other devices like the typewriter which produce typewritten words? If yes, please specify.
28. Do you think that a smaller, lighter, more compact version of the typewriter would be useful?
29. Do you think that you would like to use a hand-sized, typing device with only five keys - typing would be carried out by pressing combinations of these keys?
20. Are there any comments, that you would like to make about typewriting or this questionnaire?

The Questionnaire before piloting:-

1. Job title.
*2. Sex of subject.
3. Age of subject.
*4. How long have you been using the typewriter?
5. How did you learn to type?
6. How long did this training last?
7. At what speed were you typing at the end of this training?
8. In your opinion, how long was it until you became proficient and reasonably confident using the typewriter?
*9. Were you satisfied with the method that was used to teach you to type?
*10. If not, what improvements could you suggest?
*11. If you were teaching someone to type, where would you place the emphasis - on speed or accuracy?
*12. Why?
*13. How much time during the day do you actually spend typing?
*14. Do you normally use the same typewriter?
*15. (If yes) is it electric of manual?
*16. Which do you prefer?
*17. Why?
18. Are you satisfied with the arrangement of keys on the typewriter keyboard?
19. Are there some finger movements between keys which are more difficult to do than others? If yes, please specify.
20. Are there any keys or sequence of keys that you seem to make more errors on than others? Please specify.
21. If you could move the typewriter keys around, are there any keys that you would change?
*22. Are you satisfied with the position of the punctuation keys?
*23. Do you think the numbers are well positioned on the top row?
*24. Are there any keys on the keyboard which you think need not be there? Please specify.
*25. Are there any keys that are not there, that you think should be on the keyboard? Please specify.
26. Would you prefer it if the thumbs were given more work to do?

*27. Do you think the spaces between the keys are satisfactory?

*28. Are you satisfied with the feel of the keys?

*29. Are you satisfied with the distance that the keys travel when you press them?

*30. Several researchers and designers have produced keyboards with different key arrangements. Do you know of any keyboards other than the one you use? If yes, please name.

31. If you were designing a typewriter keyboard, have you any suggestions as to where you would place the various keys?

*32. When using the typewriter, are there any parts of your body that become tired more quickly than others? Please specify.

33. Do you find it a problem having to move your head so much when working?

34. When typing, does your neck sometimes ache?

35. Does your back sometimes feel strained when typing?

36. Do your shoulders sometimes ache?

37. Do your arms become tired?

38. Do your fingers sometimed become tired and start to ache?

39. Can you remember if parts of your body ever used to ache when you first began to learn to type?

40. Do you have any other problems of fatigue?

*41. How do your fingertips and fingernails stand up to a lot of typing?

42. Can you think of any improvements that would make operation of the typewriter more comfortable?

43. Do you enjoy typing?

44. Do you prefer typing to handwriting?

45. What aspects of the typewriter and typing do you like?

46. What aspects of the typewriter and typing do you dislike?

47. Do you think that the typewriter is equally suited to both left and right handed people?

48. Do you know of any other devices like the typewriter which produce typewritten words?

49. Do you think that a smaller, lighter, more compact version of the typewriter would be useful?

50. Do you think that you would like to use a hand-sized, typing device with only five keys - typing would be carried out by pressing combinations of these keys?

51. Are there any other comments you would like to make about typewriting or this questionnaire?

* denotes those questions that were deleted.

University of Technology

LOUGHBOROUGH LEICESTERSHIRE LE11 3TU Tel: 0509 63171 Telex 34319 Telegrams Technology Loughborough

DEPARTMENT OF HUMAN SCIENCES

Beginner Typists
Questionnaire Survey

The standard arrangement of keys on the typewriter, nicknamed QWERTY after the top six letters, has come under much criticism during the last 100 years. This questionnaire is aimed at individuals learning to type, in order to find out what they feel about the positioning of the letters on the QWERTY keyboard. Please tick the appropriate boxes.

---

1. Age of subject

   Up to 20 years ☐ 21 - 30 ☐ 31 - 40 ☐ 41 - 50 ☐ 51 - 60 ☐ 61 upwards ☐

2. Are you satisfied with the arrangement of keys on the typewriter keyboard?

   Yes ☐ No ☐ Don't know ☐

   Please give reasons for your answer:

   ____

   ____

   ____

3. Are there some finger movements between keys which are more difficult to do than others?

   Yes ☐ No ☐ Don't know ☐

   If yes, please specify:

   ____

   ____

4. Are there any keys or sequences of keys that you seem to make more errors on than others?

Yes ☐ No ☐ Don't know ☐

If yes, please specify:

____

____

____

5. If you could move the typewriter keys around, would you change the position of any keys?

Yes ☐ No ☐ Don't know ☐

If yes, please specify:

____

____

____

6. Do you enjoy typing?

Yes ☐ No ☐ Indifferent ☐ Don't know ☐

7. Which do you prefer - typing or handwriting?

Typing	Handwriting	Indifferent	Don't know
☐	☐	☐	☐

8. Are there any comments that you would like to make about typewriting or this questionnaire?

Many thanks.

Questionnaire Used by Floyd (1979)

Name:

1. What are your first impressions of the keyboard?

Lesson:

Date:

Time:

Keyboard:

2. Do any parts of your body ache? (Prompt, fingers, wrists, arms, shoulders, neck, back).

3. Any problems with the keyboard?

4. Any problems using the display screen?

5. Any points that you would like to make about anything?

Questionnaire for the QWERTY and Maltron Keyboard Users

1. Job title.
2. Sex of subject.
3. Age of subject.
4. Were you satisfied with the method that has been used to teach you to type?
5. If not, what improvements could you suggest?
6. Are you satisfied with the arrangement of keys on the two keyboards?
7. Do you find that there are some finger movements between keys which are more difficult to carry out than others? If yes, please specify.
8. Were there any keys or sequences of keys with which you seemed to make more errors than others? Please specify.
9. If you could move the keys around, are there any keys which you would change?
10. Do you think that you would prefer it if the thumbs were given more work to do?
11. Which do you prefer - the space bar found on the standard QWERTY keyboard or the space key found on the Maltron keyboard?
12. When typing, does your neck sometimes ache?
13. Did your back sometimes feel strained when typing?
14. Did your shoulders sometimes ache?
15. Did your arms become tired?
16. Did you have any other problems of fatigue?
17. Can you think of any improvements that would make operation of the keyboards more comfortable?
18. Did you enjoy typing?
19. Do you think you would prefer typing to handwriting?
20. Are there any other comments you would like to make about the experiment or this questionnaire?

Results from Pilot Study I

Subject	Mean Keying Times (Milliseconds)*			
	Cylinder	Box	Hemisphere	
1	116 (2)	139 (1)	117 (1)	(Trial 1)
(♀ - 53yrs)	150 (1)	127 (0)	108 (3)	(Trial 3)
	Box	Hemisphere	Cylinder	
2	144 (2)	63 (3)	76 (3)	(Trial 1)
(♀ - 26yrs)	53 (2)	49 (3)	56 (2)	(Trial 3)
	Cylinder	Hemisphere	Box	
3	140 (1)	100 (1)	83 (1)	(Trial 1)
(♀ - 22yrs)	95 (0)	79 (2)	64 (2)	(Trial 3)
	Box	Hemisphere	Cylinder	
4	106 (4)	87 (5)	Not working	(Trial 1)
(♂ - 56yrs)	86 (1)	82 (4)	Not working	(Trial 3)
	Hemisphere	Box	Cylinder	
5	166 (5)	118 (7)	Not working	(Trial 1)
(♀ - 38yrs)	85 (4)	105 (4)	Not working	(Trial 3)
	Box	Hemisphere	Cylinder	
6	105 (5)	84 (5)	Not working	(Trial 1)
(♂ - 39yrs)	100 (7)	86 (7)	Not working	(Trial 3)
	Hemisphere	Box	Cylinder	
7	99 (3)	91 (3)	Not working	(Trial 1)
(♀ - 43yrs)	103 (5)	74 (0)	Not working	(Trial 3)
8	No results -	electronic timer kept sticking		
(♀ - 24yrs)		at 0·016 seconds.		

* The figures in brackets represent the number of errors per 31 chords.

Results from Pilot Study II

Mean Keying Times (Milliseconds)

Subject	Trials 1	2	3	4	5	6	7	8	9	Keybd*
1(♂)	1415	1200	1267	1187	1186	1291	1219	1255	1271	1
1	1160	1168	1188	1193	1149	1119	1159	1225	1180	2
1	1497	1351	1320	1365	1306	1268	1196	1277	1267	3
2(♂)	1197	1166	1160	1160	1185	1135	1175	1130	1220	2
3(♀)	1426	1501	1484	1446	1611	1901	1547	1710	1848	2
4(♀)	1398	1329	1417	1373	1355	1361	1401	1394	1464	2

Error Scores

Subject	Trials 1	2	3	4	5	6	7	8	9	Keybd*
1(♂)	1	2	2	2	3	6	5	5	2	1
1	3	5	3	4	3	3	1	1	3	2
1	1	2	2	2	2	3	1	3	1	3
2(♂)	2	3	4	4	2	2	4	5	1	2
3(♀)	11	7	9	6	3	10	3	5	1	2
4(♀)	3	1	3	3	3	1	2	3	0	2
Percentage Errors	11·3	10·7	12·4	11·3	8·6	13·4	8·6	11·8	4·3	

* Keyboard 1 = the hemisphere,
Keyboard 2 = the cylinder,
Keyboard 3 = the box.

Questionnaire for Selection of Subjects

NAME: ______________________________

ADDRESS: ______________________________

____

AGE: ☐ 20-35 years ☐ 35-40 years ☐ over 40 years

Are you left-handed?

☐ Yes ☐ No

Are you a skilled typist?

☐ Yes ☐ No

Are you a regular player of any musical instrument that requires chords to be made?

☐ Yes ☐ No

Do you suffer from any form of colour blindness?

☐ Yes ☐ No

Do you suffer from any limb disabilities which restrict arm or hand movement?

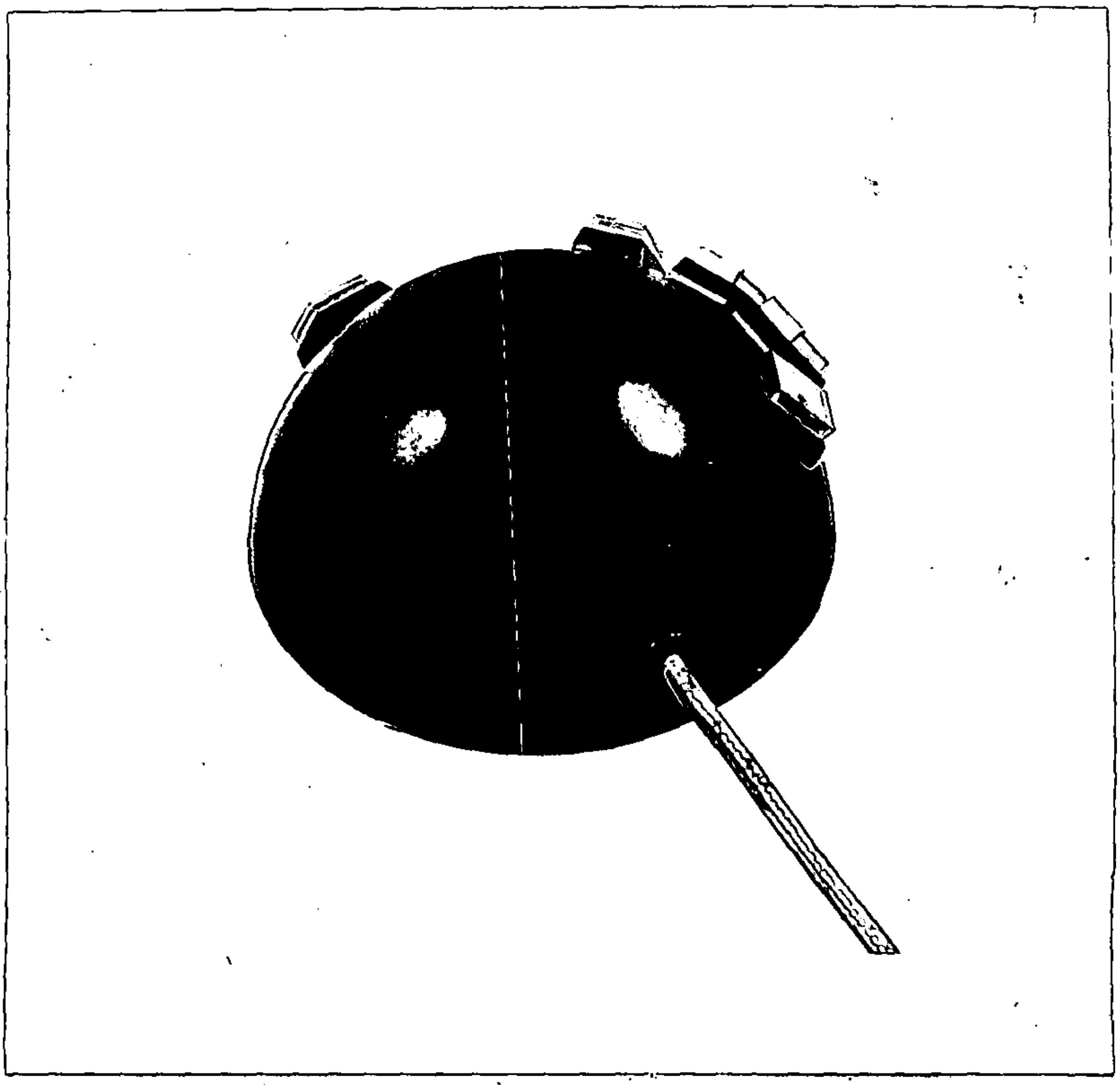
☐ Yes ☐ No

Have you participated in a reaction time experiment before?

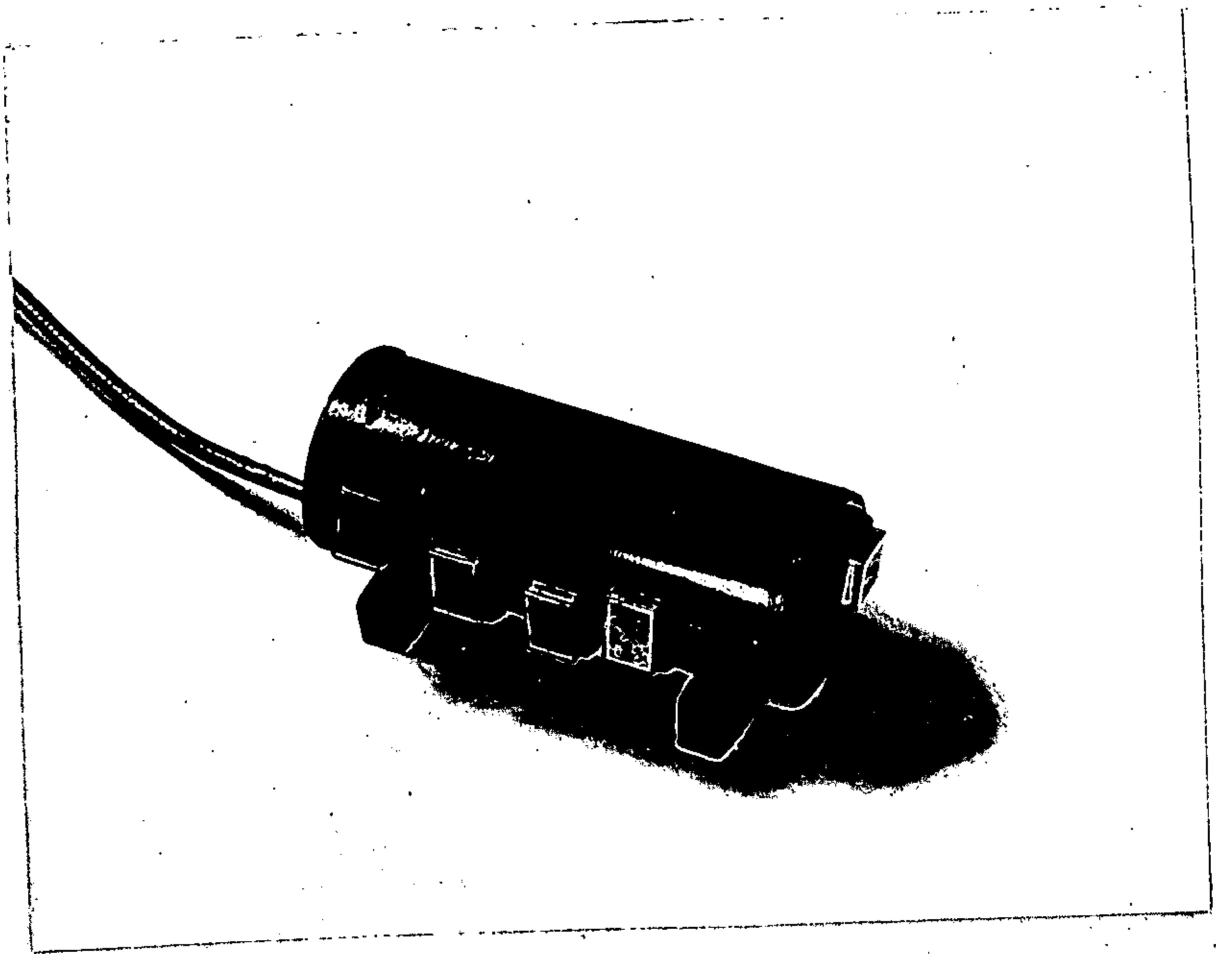
☐ Yes ☐ No

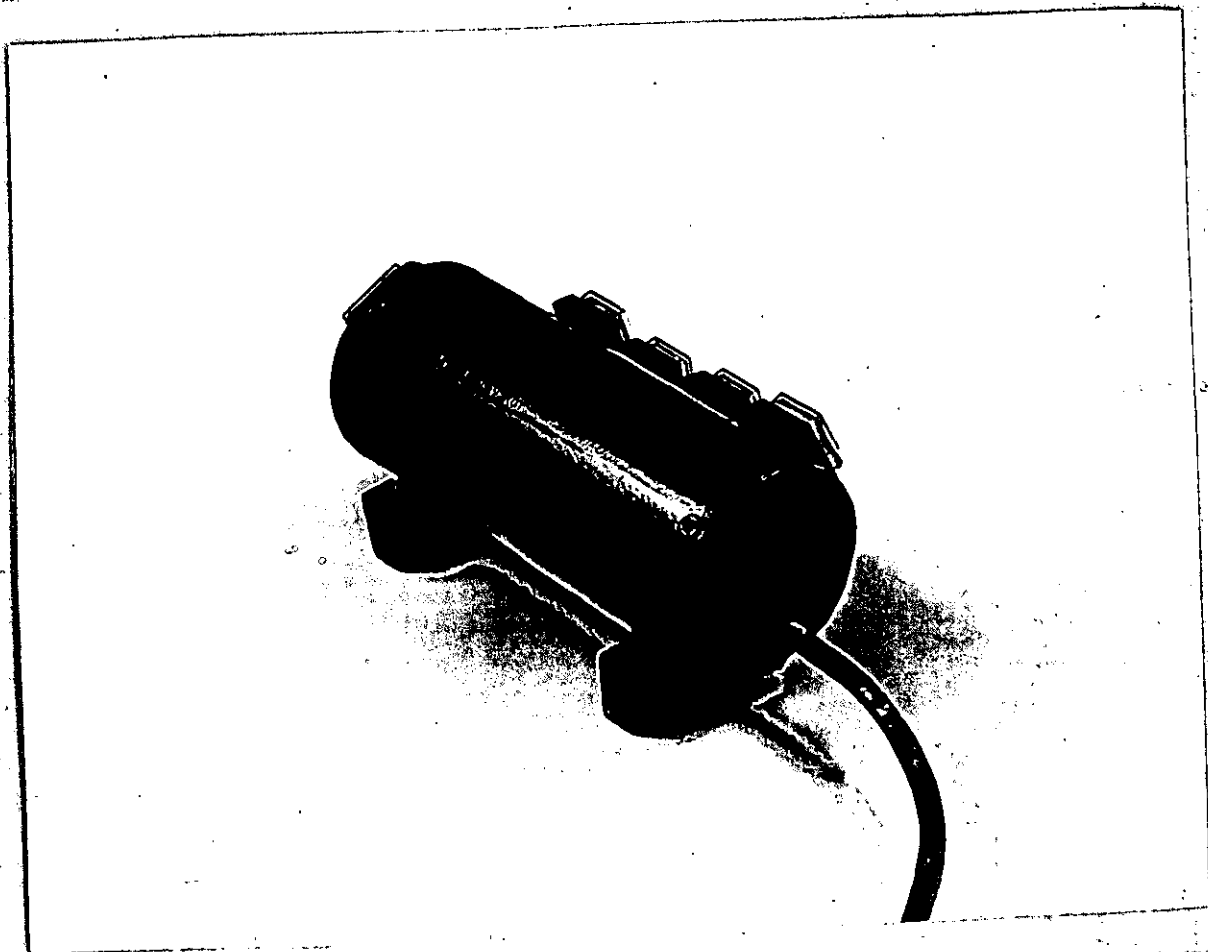
If yes, please give details:

Photograph of Hemispherical Chord Keyboard

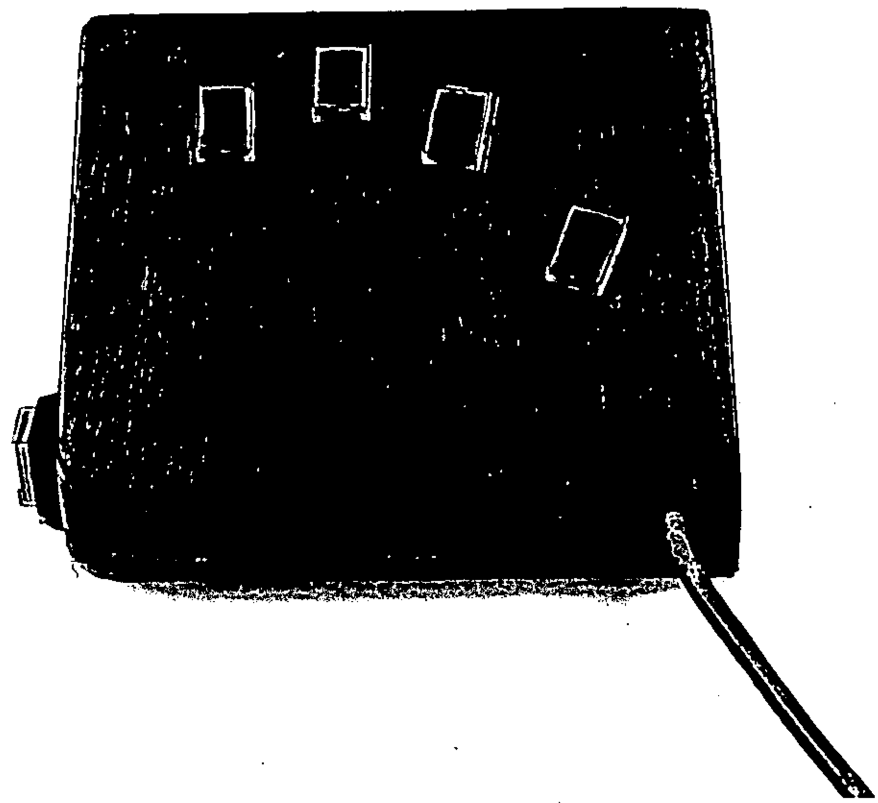


Photographs of Cylindrical Chord Keyboard





Photograph of Box-shaped Chord Keyboard



Operating the Hemispherical Chord Keyboard

Operating the Box-shaped Chord Keyboard

Operating the Cylindrical Chord Keyboard

Verbal Instructions Given to Subjects

Please adjust the position of the seat until you are comfortable. The keyboard can be operated either on the desk-top or held in the hand. It is up to you to find a satisfactory keying position.

Directly in front of you is the stimulus display. The red light acts as a warning light and tells you that you have two seconds until a pattern of green lights appear. This pattern could be any combination between one and five green lights. As soon as the red light fades, these green lights flash, and you respond as quickly and as accurately as possible by pressing the identical pattern of keys on your keyboard.

Please try and press all the keys at the same time and then release them. The computer stops the clock when you make a key-pressing and then allows a short period of time until it reads the key depressions again and records this as the response. You will probably find it convenient to rest your fingers lightly on the keys between key pressings.

The first part of the experiment ts a practice trial and consists of working through 31 different combinations of key pressings. After this I will return and sort out any problem areas. I will then explain the rest of the experiment.

Please feel free to try out sitting and keying positions throughout the experiment until you have reached an optimum.

Have you any questions or perhaps there is something which I have not explained very well?

Format of Questions Asked at End of Experiment

Question 1 is open-ended in order to gain your first impressions of the keyboard.

1. What do you think of the keyboard?
2. Did you like using it?
3. Was it easy to operate?
4. What do you feel about the size? The shape?
5. What do you feel about the positioning of the keys?
6. What do you feel about the weight? Were you aware of the weight of the keyboard?
7. Did you prefer to leave it on the desk-top or to support it in one hand?

   Demonstrate your operating position, please?
8. Was this position comfortable?
9. Did your arm ache? Where? At what point in the experiment?
10. Did your hand ache? Where? At what point in the experiment?
11. Have you any comments to make about the stimulus display?
12. Would you like to make any other comments about the experiment?

Table of Mean Keying Times (Milliseconds)
Per Trial for Keyboard I (the Hemisphere)

Subject*	Trials								
	1	2	3	4	5	6	7	8	9
1	1192	1128	1177	1256	1251	1307	1193	1231	1392
2	1164	1071	1147	1179	1159	1180	1154	1169	1192
3	1413	1377	1609	1444	1379	1502	1352	1319	1344
4	1701	1570	1705	1509	1627	1652	1638	1713	1746
5	1833	1998	1822	1562	1786	1715	1705	1762	1854
6	1282	1241	1111	1093	1087	1075	1071	1169	1070
7	1214	1216	1276	1231	1273	1250	1242	1301	1268
8	1135	1061	1051	1052	1037	1074	1029	1016	1007
9	1042	1122	1047	987	982	1015	1019	1174	1062
10	1152	1131	1119	1157	1222	1105	1154	1140	1208
Mean	1313	1292	1306	1247	1280	1288	1256	1299	1314

Table of Mean Keying Times (Milliseconds)
Per Trial for Keyboard II (the Cylinder)

Subject	Trials								
	1	2	3	4	5	6	7	8	9
11	1354	1334	1360	1332	1379	1440	1372	1307	1258
12	1805	1715	1548	1671	1632	1565	1586	1487	1540
13	1269	1218	1275	1222	1287	1293	1212	1173	1236
14	1514	1512	1474	1406	1345	1386	1283	1381	1319
15	1258	1179	1158	1066	1098	1102	1107	1041	997
16	1570	1346	1264	1076	1134	1170	1023	1072	1087
17	1251	1130	1401	1207	1268	1339	1266	1324	1335
18	1474	1560	1518	1481	1624	1540	1407	1405	1424
19	1503	1285	1296	1220	1199	1195	1160	1189	1189
20	1024	1080	1030	972	990	983	925	925	906
Mean	1402	1336	1332	1265	1296	1301	1234	1230	1229

* For the tabulation of the results the three keyboard groups consisted of subjects 1 - 10, 11 - 20, and 21 - 30, although in fact the keyboards were presented randomly throughout the experiment.

Table of Mean Keying Times (Milliseconds)
Per Trial for Keyboard III (the Box)

Subject	Trials								
	1	2	3	4	5	6	7	8	9
21	1330	1298	1218	1211	1167	1161	1213	1159	1178
22	1252	1248	1278	1215	1230	1177	1115	1137	1134
23	1644	1474	1347	1424	1377	1502	1511	1594	1514
24	1568	1625	1488	1502	1456	1474	1476	1625	1451
25	1147	1070	1052	1118	1092	1090	1030	1063	1028
26	1470	1352	1260	1326	1389	1309	1216	1139	1232
27	1274	1249	1386	1385	1347	1445	1347	1394	1364
28	1604	1402	1432	1474	1483	1577	1597	1555	1553
29	1254	1175	1185	1152	1141	1150	1091	1103	1075
30	1119	1089	1077	1032	1055	1101	1169	1104	1139
Mean	1366	1298	1272	1284	1274	1299	1276	1287	1267

Table Showing Error Scores

Subject	Trial Number 1	2	3	4	5	6	7	8	9
1	3	1	3	3	1	3	2	3	3
2	2	4	2	5	4	0	2	2	3
3	7	9	13	12	5	7	9	5	3
4	3	6	4	3	5	3	3	5	3
5	2	0	2	2	1	1	1	1	1
6	2	0	1	0	0	0	1	0	1
7	6	3	2	0	2	1	3	1	1
8	2	0	1	4	0	2	2	1	1
9	11	8	8	10	4	3	5	8	1
10	7	8	6	5	6	7	2	8	5
11	13	7	5	6	6	4	5	4	8
12	5	2	2	1	1	2	1	2	0
13	8	5	6	5	3	2	2	2	2
14	4	2	4	6	5	2	6	1	5
15	2	2	2	1	2	1	0	3	2
16	14	14	15	11	8	10	8	9	10
17	6	8	1	5	2	1	3	2	1
18	4	4	1	2	0	1	0	1	2
19	1	5	4	4	4	6	8	5	5
20	17	6	3	5	2	3	5	5	5
21	9	9	7	10	7	6	8	4	5
22	3	2	1	1	2	2	1	0	0
23	6	7	8	4	4	4	1	3	2
24	2	1	1	6	5	5	5	1	2
25	1	2	2	7	0	2	4	1	2
26	9	6	13	8	9	10	12	7	6
27	4	5	2	4	6	1	4	0	0
28	3	4	3	4	2	0	5	2	0
29	6	6	4	5	3	1	4	0	2
30	10	1	2	7	6	4	2	2	3
Total Percentage Errors	18·5	14·7	13·8	15·7	11·3	9·7	12·2	9·5	9·0

```
C             PROG IN FILE JAN.FOR
C             WRITTEN FOR J MARTIN PROJ
C             THIS IS _MAIN_ WHICH HANDLES USER I/O AND THE DATA FILE JANDAT.DAT.
C             TWO FORT SUBROUTINES ARE CALLED, FROM _MAIN_, THEY ARE UNIQRD & RAND.
C             ALSO TWO MACRO-11 ROUTINES ARE CALLED THEY ARE DOTEST & CLEARS.
C                     AS THE TWO FORT ROUTINES EXIST IN _MAIN_ THEN LINK AS ...
C             JAN,DOTEST,CLEARS
C
              INTEGER TEMP(128),TX,RX,TIME
              INTEGER CHOICE,SUBNUM,TCOUNT,CORDNO
              INIT=1
              CALL ASSIGN (4,'DX1:JANDAT.DAT','O','OLD')
              DEFINE FILE 4(270,128,U,IREC)
              CALL DOTEST(INIT,,,)
C             OUTPUT MENUE
90            CALL CLEARS
              TYPE 100
100           FORMAT(//' PRINT ENTIRE FILE (1)',
            1 //' PRINT RESULTS FOR SINGLE SUBJECT (2)',
            1 //' CARRY OUT A TEST (3)',
            1 //' QUIT (4)'//)
              ACCEPT 110,CHOICE
110           FORMAT(I4)
              IF(CHOICE.GT.4.OR.CHOICE.LT.1)GO TO 90
              GO TO (1000,2000,3000,4000)CHOICE
C
1000          IREC=1
C             DUMP FILE HERE
1005          READ(4'IREC,ERR=5000) (TEMP(I),I=1,128)
              WRITE(7,1010) (TEMP(I),I=1,128)
1010          FORMAT(//6(I7,4X))
              IF(IREC.GT.270)GO TO 90
              GO TO 1005
              GO TO 90
C
2000          CALL CLEARS
              TYPE 2010
2010          FORMAT(//' INPUT SUBJECT NUMBER'//)
              ACCEPT 110,SUBNUM
              IF(SUBNUM.GT.30)GO TO 90
C             SKIP APPROPRIATE NO OF RECORDS
              IREC=1+(SUBNUM-1)*9
              DO 2040 J=1,9
              READ(4'IREC,ERR=5000) (TEMP(I),I=1,128)
              WRITE(6,497)
497           FORMAT(1H1)
              WRITE(6,498)
498           FORMAT(41X,' ...........................................')
              WRITE(6,499)
499           FORMAT(41X,' : Printed in the Department of Human Sciences :')
              WRITE(6,498)
              WRITE(6,555)TEMP(1),TEMP(2),TEMP(3)
555           FORMAT(1H ,' SUBJECT NUMBER = ',I3,
            1 //' KEYBOARD NUMBER = ',I3,
            1 //' TEST NUMBER = ',I3//)
              WRITE(6,666)
666           FORMAT('  TX CHORD',10X'  RX CHORD',10X'  TIME TAKEN',
            1 10X'  TX CHORD',10X'  RX CHORD',10X'  TIME TAKEN'//)
              WRITE(6,777) (TEMP(I),I=4,128)
777           FORMAT((/3X,I3,16X,5(I7,13X)))
2040          CONTINUE
              GO TO 90
```

```
000         CALL CLEARS
            TYPE 2010
            ACCEPT 110,SUBNUM
            IF(SUBNUM.GT.30)GO TO 90
            TYPE 3010
010         FORMAT(// ' INPUT KEYBOARD NUMBER'//)
            ACCEPT 110,KBNUM
            IF(KBNUM.GT.3)GO TO 90
            IF(INIT.NE.1)GO TO 50
            IF(SUBNUM.EQ.1)GO TO 48
            DO 45 I=1,SUBNUM*239
            CALL RAND(N)
5           CONTINUE
8           INIT=-1
0           IREC=1+(SUBNUM-1)*9
            TCOUNT=1
            TEMP(1)=SUBNUM
            TEMP(2)=KBNUM
5           CALL CLEARS
            PAUSE 'PRESS RETURN TO START TEST'
            CORDNO=1
            TEMP(3)=TCOUNT
0           CALL UNIQRD(TX)
            CALL DOTEST(INIT,TX,RX,TIME)
            TEMP(2*CORDNO+(CORDNO+1))=TX
            TEMP(2*CORDNO+(CORDNO+2))=RX
            TEMP(2*CORDNO+(CORDNO+3))=TIME
            CORDNO=CORDNO+1
            CALL CLEARS
            WRITE(7,3500)TX,RX,TIME
3500        FORMAT(//' TX=',I4,10X'RX=',I7,10X'TIME=',I7)
C           WRITE(6,3500)TX,RX,TIME
            IF(CORDNO.LE.31)GO TO 70
            IF(TCOUNT.LE.9)GO TO 321
            GO TO 333
321         TCOUNT=TCOUNT+1
            WRITE(4'IREC,ERR=5000) (TEMP(I),I=1,128)
            IF(TCOUNT.EQ.10)GO TO 333
            GO TO 55
333         TCOUNT=TCOUNT-1
            CALL CLEARS
            WRITE(7,99)TCOUNT,SUBNUM
99          FORMAT(//' TEST NO ',I3'  COMPLETE.FINISHED WITH SUBJECT NO ',I3)
            DO 444 I=1,25000
            DO 444 K=1,10
444         CONTINUE
            CALL CLEARS
            PAUSE 'PRESS RETURN FOR OPTIONS'
            GO TO 90
4000        CALL CLOSE(4)
            STOP
5000        WRITE(7,5010)
5010        FORMAT(//' **** ERROR READING/WRITING DATA FILE')
            GO TO 4000
            END
C
C
            SUBROUTINE UNIQRD(TX)
            INTEGER HOLD(31),TX
            DATA HOLD/31*0
200         IPTR=1
```

```
          CALL RAND(TX)
)         IF(HOLD(IPTR).EQ.0)GO TO 100
          IF(HOLD(IPTR).EQ.TX)GO TO 200
          IPTR=IPTR+1
          IF(IPTR.NE.31)GO TO 10
          DO 300 I=1,31
          HOLD(I)=0
)0        CONTINUE
          RETURN
)0        HOLD(IPTR)=TX
          RETURN
          END


          SUBROUTINE RAND(N)
          DOUBLE PRECISION XO,X1,XK,XM
          DATA XO,XK,XM/4095.0D00,32765,0D00,6777216.0D00/
0         X1=XK*XO
          I=X1/XM
          XO=X1-XM*I
          IF(XO.LT.0.0)XO=XO+XM
          IF(XO.GT.XM)XO=XO-XM
          RD=XO/XM
          RDM=RD*32.0
          N=IFIX(RDM)
          IF(N.EQ.0)GO TO 10
                                TYPE 444,N
:444                            FORMAT(/' N=',I5)
          RETURN
          END

          %%%     FILE DOTESTST.MAC       FOR J MARTIN PROJ       %%%


          .title dotest
          .globl dotest
CALL DOTEST(INIT,TX,RX,TIME)
                drin: b7 <- strobe
                      b4 to b0 <- input data lines from keys

                drout:b6 -> clear JK
                      b5 to b1 -> output data to display lamps
                      b0 -> ready lamp
          ckcsr=170404
          bufpre=170406
          drout=167772
          drin=167774
          drcsr=167770
          lpcsr=177514
          lpbuf=177516
   dotest: tst (r5)+          ;skip no of args
          tst @(r5)+          ;check state of init
          bpl setup           ;if init is positive then initialise
          start the test proper
          bis £100,@£drout           ;pulse to clear JK
          jsr r3,delay               ;give relay plenty of time to energise
          bic £100,@£drout
          inc @£drout         ;send the ready signal
          jsr r3,delay        ;delay
          mov £100000,r1      ;put -32768 into r1 to act as 'incorrect Rx' marker
          mov @(r5)+,r2       ;get Tx chord into r2; do not use @(r5) cos Tx is about
                              to be changed and do not wish to change value of
                              Tx as it is required for later print out in FORT prog
```

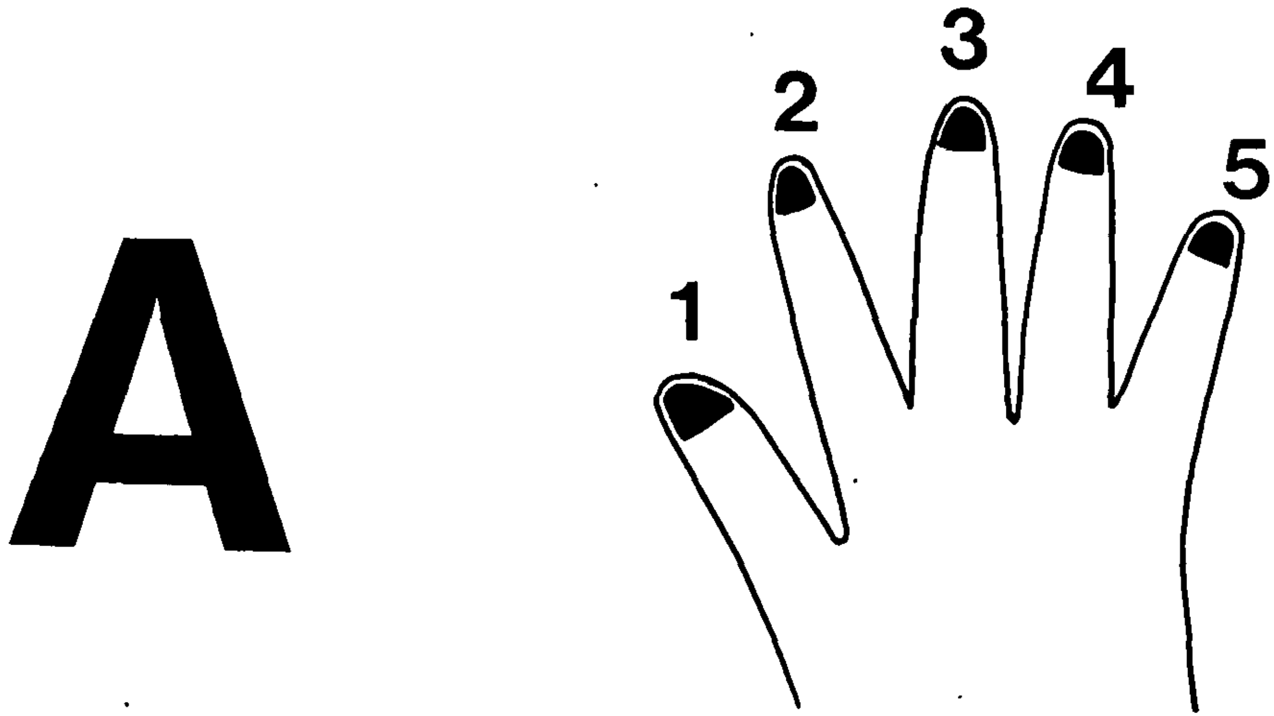
Contd.

```
          asl r2  ;rot left to skip 'ready' line, lsb is automatically set to zero
          thus turning off ready lamp when we ...
          mov r2,@£drout  ;so turn off 'ready' lamp and present Tx chord
          clr r0  ;clr lms counter
)$:       mov £377,@£bufpre      ;load 1
          inc @£ckcsr     ;kick clock
5$:       tstb @£ckcsr    ;test for overflow
          bpl 25$
          inc r0  ;ro stores response time in approx lms increments
          tst r0  ;time up ?
          bmi timeup
          bic £201,@£ckcsr       ;stop clock and clear ovf
          tstb @£drin     ;look for strobe
          bpl 20$         ;no response yet
          mov @£drin,rl   ;response time in r0 now: Now grab the RX chord-put it in rl
          bic £177740,rl  ;strip to 5 bits
imeup:    mov rl,@(r5)+   ;return the RX chord
          mov r0,@(r5)+   ;and the time taken
          clr @£drout     ;turn off the displayed Rx chord
          rts pc

etup:     clr @£ckcsr
          mov £377,@£bufpre      ;set preset to one count
          mov £10,@£ckcsr ;set lkhz,no interrupts,single interval mode
          clr @£drout     ;make sure the output display is clear
          rts pc

elay:     clr rl          ;delay coming up
0$:       tstb @£lpcsr    ;using LP as delay device
          bpl 10$
          mov £0,lpbuf    ;null char
          inc rl
          cmp £3600,rl
          bne 10$
          rts r3
          .end
```

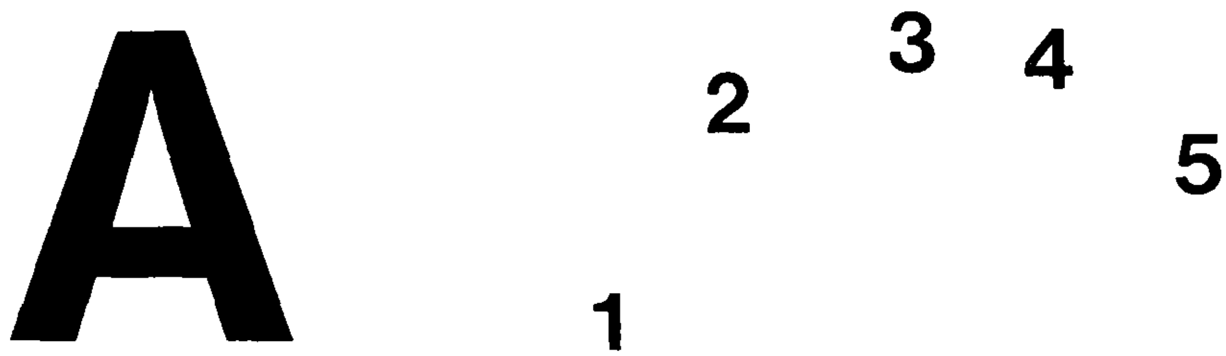
General Introduction to the Rationale of the OMNIBUS Test

"OMNIBUS can be most easily understood as a non-parametric version of Analysis of Variance. The analogy is not perfect but it serves as a first approximation. The test is called 'non-parametric' because all scores are replaced by ranks at the beginning of the computation and it is these ranks - not the original scores - which are subsequently analysed. OMNIBUS is a very general procedure and replaces many popular non-parametric tests such as the sign-test, Mann-Whitney test, Page's trend test, Friedman's test, the Kruskal-Wallis test and others less familiar. It can cope with frequency tables under certain circumstances (for example, when the categories of the dependent variables are rankable). Rank correlation (for example, Spearman's rho and Kendall's W) also falls under the test's general umbrella. OMNIBUS also deals with experimental designs which existing tests have difficulty in handling."

R. Meddis.
February 1st, 1979



An Example of a Tachistoscope Card
Used in the Pilot Study.



An Example of a Tachistoscope Card
Used in the Main Study.

Results from the Pilot Study

Sex of Subject	Age Range (years)	Number of Chords to Learn	Trials taken until Remembered *
M	21 - 30	16	9
F	21 - 30	15	7
M	21 - 30	16	8
F	21 - 30	16	7
F	31 - 40	16	4
F	21 - 30	16	6
M	21 - 30	15	5
F	41 - 50	10	7
M	51 - 60	10	7
M	21 - 30	10	3

* The criterion for having learned all the chord patterns was to be correct on two successive trials. These two trials were included in the final score.

Verbal Instructions Given to Subjects

You will be presented with cards one at a time and for a fixed amount of time via the tachistoscope. There are 16 cards and they each show a letter or a number, and a series of numbers which could be any between 1 and 5. The first time that I go through the cards, all I want you to do is watch the tachistoscope screen and try and remember the associations.

The second time I present the cards, I will only show you the letter or number and ask you if you can remember the corresponding set of numbers. At the end of this second showing, the identical procedure will be repeated again until all 16 have been successfully identified.

It sounds hard work, but it is surprising how quickly you will learn the 16 associations. Most people at some point become despondent and feel that they will never learn them, but the majority do complete the list.

The purpose of the experiment is to find which combinations of numbers are easiest to learn and remember. So when applying chord combinations to the letters of the alphabet, the easiest chords will be allocated to the most frequent letters. It is worth remembering therefore that the person who learns the 16 combinations immediately provides no useful information for this study!

At the end of the experiment, I will ask you how you remembered the various associations. Have you any questions or is there something that you would like explained more fully?

Description of Subjects - Main Study

Subject Number	Sex	Age-Group	Occupation
1	M	31 - 40	Computer Programmer
2	M	41 - 50	Factory Worker
3	F	41 - 50	Midwife
4	F	31 - 40	Nurse
5	M	41 - 50	Teacher
6	F	21 - 30	Researcher
7	F	21 - 30	Lecturer
8	M	21 - 30	Technician
9	M	31 - 40	Computer Programmer
10	F	21 - 30	Technician
11	F	31 - 40	Housewife
12	M	41 - 50	Technician
13	F	21 - 30	Teacher
14	M	21 - 30	Electronics Apprentice
15	F	21 - 30	Technician
16	M	31 - 40	Technician
17	F	21 - 30	Researcher
18	M	21 - 30	Postgraduate
19	M	31 - 40	Electrician
20	F	41 - 50	Housewife
21	M	21 - 30	Postgraduate
22	F	21 - 30	Library Assistant
23	F	21 - 30	Social Worker
24	F	31 - 40	Secretary
25	M	31 - 40	Computer Programmer
26	M	31 - 40	Researcher
27	F	21 - 30	Secretary
28	M	31 - 40	Technician
29	F	< 20	Unemployed
30	M	21 - 30	Teacher

Data from Main Study (n=30)

Chord	Number of Trials Until Remembered	Mean
12345	5 5 1 1 3 1 2 1 4 1 2 1 1 2 1	(mean = 2·06)
1234	4 6 6 3 5 4 3 2 4 2 1 4 4 5 6 6 5	(mean = 4·12)
1 345	2 6 6 3 3 5 3 6 6 6 4 1 3 6 2 2 4	(mean = 4·0)
123 5	4 6 5 5 3 2 3 6 3 2 3 5 6 6	(mean = 4·21)
12 45	6 5 6 6 1 3 5 6 1 4 3 3 6 1 1 3 4 3	(mean = 3·72)
2 45	6 4 5 6 3 1 2 2 1 3 6 6 6 1	(mean = 3·71)
12	5 3 1 4 2 2 2 1 5 1 1 5 4 3	(mean = 2·78)
23	1 3 5 6 2 6 3 4 5 3 4	(mean = 3·82)
34	6 2 6 4 4 1 6 6 1 4 2 1 2 5 3	(mean = 3·53)
45	5 3 4 2 6 1 3 2 1 6 1 5 6 5 6 6	(mean = 3·87)
1 5	3 6 3 1 3 5 5 4 4 6 4 5 2 4 1	(mean = 3·73)
1 4	5 2 4 1 3 1 5 4 1 6 5 5 1 1 2	(mean = 3·07)
1 3	4 3 1 1 2 2 1 3 3 3 5 3 4	(mean = 2·69)
2 4	4 5 3 6 1 3 4 4 3 1 4 1 3 5 4 6 6	(mean = 3·71)
2 5	3 6 2 6 6 3 4 3 5 2 6 3 3 1 5 4 5	(mean = 3·94)
3 5	5 2 1 4 2 6 1 5 3 6 2 5 6 1 2 5 6 6	(mean = 3·77)
1	3 2 2 1 1 1 4 1 1 1 3 1 1 4 1	(mean = 1·8)
2	6 1 1 1 2 1 1 6 2 1 2 3 1 2 1 1 1 1	(mean = 1·89)
3	5 1 1 3 3 3 1 3 1 3 3 3 1 4 3 6	(mean = 2·75)
4	1 4 1 2 1 4 1 1 2 1 1 2 1 3 5 4 1	(mean = 2·06)
5	1 2 6 1 3 1 3 1 1 4 2 1 1 4	(mean = 2·21)
123	6 1 5 2 2 4 1 2 1 6 5 3 3 1	(mean = 3)
234	4 2 1 1 5 3 4 2 6 4 5 4 3 6 5	(mean = 3·66)
345	3 3 3 2 3 4 1 1 1 4 1 3 3 5	(mean = 2·64)
12 4	1 6 6 5 2 1 1 5 5 6 4 6 4 6 6	(mean = 4·26)
12 5	6 6 1 6 3 5 2 5 2 3 1 5 4 3 6 6 2 6	(mean = 4)
1 34	3 6 1 5 6 1 5 4 6 2 6 6	(mean = 4·25)
1 3 5	6 6 6 1 6 3 1 1 3 6 2 6 4 3	(mean = 3·86)
1 45	4 4 5 6 6 4 3 6 6 1 5 3 6 5 3 6 2 6	(mean = 4·5)
2 45	6 2 2 4 6 4 4 5 4 6 6 6 3 4 6	(mean = 4·53)
23 5	3 4 4 4 2 1 6 6 6 3 6 2 6 4 5 3	(mean = 4·06)

Comparative Rankings by Frequency of Occurrence of Letters in English Words (Hardy, 1978)

Continuous Text				Subject Word	Proper Names
Dewey (1923)	Platt (1939)	Meaker (1956)	Ohaver (1956)	Bourne and Ford (1961)	
E	E	E	E	E	E
T	T	T	T	I	A
A	A	A	O	R	R
O	O	O	A	O	N
I	N	N	N	A	L
N	R	I	I	T	O
S	I	S	R	N	I
R	S	R	S	S	S
H	H	H	H	L	T
D	L	D	L	P	D
U	F	C	C	M	M
C	C	U	F	D	C
F	M	P	U	U	B
M	U	F	M	H	G
W	G	M	P	G	U
Y	YP	W	Y	Y	W
G		Y	W	B	Y
P	W	B	G	F	J
B	B	G	B	V	K
V	V	V	V	K	P
K	K	K	K	W	F
X	X	Q	X	X	V
J	J	X	J	Z	Z
Q	Q	J	Q	J	X
Z	Z	Z	Z	Q	Q

Description of Subjects - Follow-up Study

Subject Number	Sex	Age-Group	Occupation
1	F	21 - 30	Secretary
2	M	21 - 30	Researcher
3	M	31 - 40	Office Clerk
4	F	21 - 30	Librarian
5	M	21 - 30	Mental Nurse
6	M	31 - 40	Industrial Psychologist
7	M	21 - 30	Insurance Clerk
8	F	$<$ 20	Sixth Former
9	F	21 - 30	Office Clerk
10	F	21 - 30	Secretary

The Attitudes Rating Scales After Piloting

The following questionnaire has been designed to obtain some idea of your attitudes towards the chord keyboard system, which you have used.

The questionnaire consists of a number of statements followed by a rating scale. What I would like you to do is to indicate your agreement/disagreement with each statement by placing a circle in the appropriate scale.

An example will serve to illustrate what is meant by this.

1. I DISLIKE THE THOUGHT OF HAVING TO USE A CHORD KEYBOARD

1 2 3 4 5

Agree Disagree

1 and 5 indicate extreme views

2 and 4 moderate

3 indicates a neutral position.

If I agreed moderately with the statement, I would mark the line at position 2 with a circle.

For example,

1 (2) 3 4 5

Agree Disagree

Please answer all the statements.

Section A:

1. I FOUND THE CHORD KEYBOARD AWKWARD TO USE.

1 2 3 4 5

Agree Disagree

2. I THINK MY ARM WOULD ACHE AFTER KEYING FOR LONG PERIODS OF TIME.

1 2 3 4 5

Agree Disagree

3. I THOUGHT THE MAJORITY OF THE CHORDS WERE EASY TO MAKE.

1 2 3 4 5

Agree Disagree

4. I WOULD ALTER THE POSITION OF THE KEYS.

1 2 3 4 5

Agree Disagree

5. THE CHORD KEYBOARD WAS COMFORTABLE TO OPERATE.

1 2 3 4 5

Agree Disagree

6. THE MNEMONICS CHART WAS CLEAR.

1 2 3 4 5

Agree Disagree

7. I WAS UNSURE WHEN I HAD DEPRESSED THE KEYS.

1 2 3 4 5

Agree Disagree

8. I WOULD ALTER THE SHAPE OF THE KEYBOARD.

1 2 3 4 5

Agree Disagree

9. THE CHORD KEYBOARD WAS GOOD FUN TO USE.

1 2 3 4 5

Agree Disagree

10. I THINK THAT I WOULD HAVE PROBLEMS REMEMBERING THE VARIOUS CHORD COMBINATIONS.

1 2 3 4 5

Agree Disagree

11. SOME CHORDS WERE DIFFICULT TO FORM.

1 2 3 4 5

Agree Disagree

12. I WOULD LIKE TO USE THE KEYBOARD FOR LONG PERIODS OF TIME.

1 2 3 4 5

Agree Disagree

13. I FOUND THE DEVICE INTERESTING TO USE.

1	2	3	4	5
Agree				Disagree

14. I THINK MY HAND WOULD ACHE IF I USED THE KEYBOARD FOR LONG PERIODS OF TIME.

1	2	3	4	5
Agree				Disagree

15. OPERATION OF THE DEVICE WAS STRAIGHTFORWARD.

1	2	3	4	5
Agree				Disagree

16. I THINK THE CHORD KEYBOARD IS A NOVEL IDEA.

1	2	3	4	5
Agree				Disagree

Section B:

1. How would you modify the size of the keyboard to suit your particular needs?
2. How would you modify the shape of the keyboard to suit your particular needs?
3. How would you alter the position of the keys for your handsize?
4. Did you think the 'mnemonics chart' was the best way of representing the chords?
   Can you suggest a better alternative?
5. Which chords were easy?
6. Which chords were difficult?
7. Have you any further comments to make concerning the chord keyboard system or this experiment?

Description of Subjects - Main Study

Subject Number	Sex	Age-Group	Occupation
1	M	31 - 40	Police Inspector
2	F	21 - 30	Social Worker
3	F	21 - 30	Office Clerk
4	M	21 - 30	Production Engineer
5	F	< 20	Unemployed
6	M	21 - 30	Research Fellow
7	F	21 - 30	Unemployed
8	F	21 - 30	Secretary
9	M	21 - 30	Lecturer
10	F	31 - 40	Secretary
11	M	21 - 30	Insurance Clerk
12	F	< 20	Sixth Former
13	M	31 - 40	Civil Servant
14	M	21 - 30	Engineer
15	F	21 - 30	Librarian
16	M	21 - 30	Research Student
17	M	31 - 40	Computer Programmer
18	F	41 - 50	Housewife
19	M	31 - 40	Technician
20	F	31 - 40	Teacher

Verbal Instructions Given to Subjects

In front of you is a chord keyboard. You will probably find it most comfortable to operate by resting in your lap and supported with your left hand. However if you dislike this position, please feel free to find a more satisfactory one.

Keying on a chord keyboard is carried out by patterned pressing of keys. The various patterns needed to generate the letters of the alphabet are shown in this mnemonics chart. As you can see, A has the number 1, 2, 3, 4 and 5 surrounding it, which indicates that all five digits are needed to key the letter A. All keypressings will have to be made simultaneously as the computer only reads the keys which are pressed at the same time. The number 1 represents the thumb key while the number 5 is the little finger. Is there anything about the mnemonics chart that you do not understand?

Letters will appear one at a time on the screen and all that you are required to do is make the appropriate key-pressing. If you are correct, the next letter will appear whereas if you have made a mistake, the word INCORRECT will flash up. This indicates that you have another opportunity to make the correct chord. After you have worked through the alphabet on three occasions, some lines of prose will be shown for you to key in. No performance measures such as speed and accuracy scores are being collected, so do not concern yourself with responding quickly or worry if you make a large number on errors.

At the end of the experiment, a short questionnaire will be administered. This very briefly outlines the experiment and the experimental procedure. Have you any questions?

Listing of JANKB Program Implemented on the PET Computer

```
1Ø   REM....PROG: JANKB. J SMITH. OCT 80
2Ø   REM....GOES THRO ALPHABET, LOOPS ON
21   REM....INCORRECT REPLIES
22   REM....NOTE:K/B MUST BE ATTACHED
23   REM....     AND POWERED UP.
3Ø   PRINT"3"
35   PRINT"     "
37   PRINT"CHORD KEYBOARD EXERCISER"
38   PRINT"      ( JANKB) J SMITH. OCT 80
45   FORG=1TO4ØØØ:NEXTG
11Ø  POKE59459,128
12Ø  I=65
13Ø  PRINT"3"
15Ø  POKE59471,128
16Ø  POKE59471,Ø
17Ø  POKE59471,128
18Ø  IFI 9ØTHENI=65
19Ø  PRINT"                            "CHR$(I)
21Ø  A=PEEK(59471)
23Ø  A=AAND32
24Ø  IFA<>32THENGOTO 21Ø
28Ø  A=PEEK(59471)
32Ø  A=NOTA
33Ø  A=AAND31
36Ø  IFA=31THENA=65
37Ø  IFA=21THENA=66
38Ø  IFA=12THENA=67
39Ø  IFA= 9THENA=68
4ØØ  IFA= 1THENA=69
41Ø  IFA=17THENA=7Ø
42Ø  IFA=19THENA=71
43Ø  IFA=3THENA=72
44Ø  IFA=28THENA=73
45Ø  IFA=22THENA=74
46Ø  IFA=18THENA=75
```

```
47Ø  IFA=7THENA=76
48Ø  IFA=27THENA=77
49Ø  IFA=8THENA=78
5ØØ  IFA=16THENA=79
51Ø  IFA=2ØTHENA=8Ø
52Ø  IFA=14THENA=81
53Ø  IFA=5THENA=82
54Ø  IFA=4THENA=83
55Ø  IFA=2THENA=84
56Ø  IFA=1ØTHENA=85
57Ø  IFA=29THENA=86
58Ø  IFA=3ØTHENA=87
59Ø  IFA=13THENA=88
6ØØ  IFA=24THENA=89
61Ø  IFA=15THENA=9Ø
62Ø  IFA<>ITHENGOTO68Ø
63Ø  PRINT
64Ø  PRINT"                      CORRECT"
65Ø  FORD=1TO5ØØ:NEXTD
66Ø  I=I+1
67Ø  GOTO13Ø
68Ø  PRINT
69Ø  PRINT"
7ØØ  FORD=1TO5ØØ:NEXTD
71Ø  GOTO13Ø
```

Listing of JANTEXT Program Implemented on the PET Computer

```
100   PRINT"3"
110   PRINT"  PROGRAM JANTEXT"
120   PRINT"  J SMITH DEC 80.
130   FORG=1TO2000:NEXTG
150   POKE59459,128
160   PRINT"3"
170   PRINTCHR$(13)
180   READ S$
190   IF S$="EOF"THENGOTO780
200   PRINT S$
205   PRINT "-";
207   PRINT CHR$(157);:REM CURSOR LEFT
210   GOSUB 270
220   :REM INTO C$
230   IF ASC(C$)=13 THEN PRINT CHR$(32);:GOTO170
240   IF ASC(C$)=11 THEN PRINT " ";CHR$(157);:GOTO 760
250   PRINT C$;
260   GOTO205
270   REM RESET PULSE
280   POKE59471,128:FORK=1TO50:NEXTK
290   POKE59471,0:FORK=1TO50:NEXTK
300   POKE59471,128
320   A=PEEK(59471)
340   A=AAND32
350   IFA<>32THENGOTO 320
390   A=PEEK(59471)
430   A=NOTA
440   A=AAND31
450   IFA=31THENA=65
460   IFA=21THENA=66
470   IFA=12THENA=67
480   IFA=9THENA=68
490   IFA=1THENA=69
500   IFA=17THENA=70
510   IFA=19THENA=71
```

```
52Ø   IFA=3THENA=72
53Ø   IFA=28THENA=73
54Ø   IFA=22THENA=74
55Ø   IFA=18THENA=75
56Ø   IFA=7THENA=76
57Ø   IFA=27THENA=77
58Ø   IFA=8THENA=78
59Ø   IFA=16THENA=79
6ØØ   IFA=2ØTHENA=8Ø
61Ø   IFA=14THENA=81
62Ø   IFA=5THENA=82
63Ø   IFA=4THENA=83
64Ø   IFA=2THENA=84
65Ø   IFA=1ØTHENA=85
66Ø   IFA=29THENA=86
67Ø   IFA=3ØTHENA=87
68Ø   IFA=13THENA=88
69Ø   IFA=24THENA=89
7ØØ   IFA=15THENA=9Ø
71Ø   IFA=6THENA=32
72Ø   IFA=23THENA=46
73Ø   IFA=25THENA=13
74Ø   C$=CHR$(A)
75Ø   RETURN
76Ø   PRINT"  ";:PRINT"  ";:PRINT" .";
77Ø   GOTO2Ø5
78Ø   PRINT
79Ø   PRINT"END OF RUN"
8ØØ   DATAGOODS MAY BE TRANSPORTED BY LAND SEA
81Ø   DATAOR AIR.  IN THIS COUNTRY THE GREATEST
82Ø   DATATRANSPORTATION OF COMMODITIES IN
83Ø   DATALARGE BULK IS BY RAILWAY ALTHOUGH
84Ø   DATAA VERY CONSIDERABLE QUANTITY OF GOODS
85Ø   DATAIS NOW TRANSPORTED BY FLEETS OF LARGE
86Ø   DATAMOTOR LORRIES FOR WHICH TRUNK SYSTEMS
87Ø   DATACOVER THE WHOLE COUNTRY.
875   DATA
88Ø   DATA
885   DATA
89Ø   DATA EOF
```