ꝸ *Handwriting Ergonomics*

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The purpose of this paper is to suggest a conceptual framework for the handwriting system, consisting of three elements: the hand, the writing instrument, and paper. Within this system the hand control mechanism, the writing instrument design, and their integration in the dynamic writing on the paper are discussed relative to efficient, legible, motivating as well as fatigue-reducing handwriting performance. Based on this systems framework, an overview of relevant studies and a proposal for needed areas of research are presented. Designs of the writing instruments (in terms of penpoints, shanks, and other physical characteristics), the reduction of writing fatigue, and comparisons of various instruments are analyzed.

1 *Introduction*

Man's handwriting ability has evolved over thousands of years, and in that time he has developed all kinds of writing instruments. But improvements aimed at efficient handwriting have been given little attention. In western civilization the ease of writing was greatly improved in the seventh century when religious scribes adopted the quill pen, and several centuries later when the Chinese method of making paper from rags became known in Europe. Not until the eighteenth century was the split steel-point pen introduced. The use of "black lead" or graphite for writing was discovered accidentally in England during the days of Elizabeth I. Subsequent to the development of steel pens and lead pencils, no change in handwriting equipment appeared until the ballpoint pen was introduced in 1940. The most recent innovation is the felt-tip pen, first introduced as a marking device.

Although pens, pencils, and paper have formed the primary bases of education, little systematic attention has been given to the design of writing instruments until fairly recent times. Aside from technical improvements in writing pens by manufacturing firms, systematic ergonomic investigations began only in the last

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ten years or so. This paper seeks to provide a conceptual framework for an ergonomic system of handwriting behaviour from which certain important design as well as performance considerations for handwriting may be derived.

2 *The Handwriting System*

Ergonomic analysis involves the study of those aspects of human sensory-motor control relative to design and construction of writing equipment as well as their interactions that affect the efficiency of the writing operation. Typically, we investigate how movements of the human body guide the writing instrument and how the instruments should be designed for particular individuals and for particular writing tasks, for training as well as for the practice of penmanship.

The handwriting system consists of three main components: the hand, the writing instrument, and the paper. Ergonomic considerations of design and improvement in the acquisition of writing skills and performance should, therefore, center around these elements and their interactions for the purpose of writing comfort, legibility, efficiency, and motivation. Essential to these elements is the sensory-motor feedback in the operation of the handwriting system.

Three sources of feedback about writing may be identified: from the hand itself, from the action of the writing instrument, and from the resulting handwriting traces on the paper. They are referred to respectively as reactive, instrumental, and operational feedback (Smith 1966). The most important of the three is the operational feedback from the focal action of the penpoint movement on the paper.

2.1 *The Hand Control System*

Systematic writing movements are achieved by coordinating distinct motions: those of the arm with hand-supporting functions, travel or transport movements, and the articulated movements of the thumb and fingers. The hand is positioned for postural support and pressure control. Muscles acting at the shoulder, elbow, and wrist periodically move the hand between words or bring it back to start a new line of writing. Meanwhile, wrist-hand movements and opposed or complementary thumb-finger movements hold the pen and drive the writing point to form the letters. Efficient writing depends on precision in coordinating the various movement systems of the arm, hand, and fingers.

2.2 *The Writing Instrument*

Modern writing instruments — whether pen, pencil, or other forms — are usually designed and produced for mass consumption with very little systematic improvement. This may be due to slow realization of the potential contributions of ergonomics and the general lack of clear direction in the various design considerations. Several indicators of whether a writing instrument is efficient may be seen in the relative smoothness of writing, writing legibility, pace of writing, control ease of the instruments, reduced error rate, cleanliness of writing, as well as subjective variables such as writer interest and satisfaction. In addition, the writing comfort and reduced fatigue effects in using certain types of poorly designed writing instruments are important factors. On a comparative level different types of writing instruments or various designs of the same type of instrument may be examined to provide certain guidelines for their choice and use by writers.

2.3 *The Writing Paper*

The third component of the handwriting system is the writing surface, usually in the form of paper or parchment. This element seems to have been taken for granted and has received the least attention in handwriting research. In its static characteristics paper varies in texture, smoothness, glare, thickness, surface configurations, size, as well as ink absorption. For normal writing use most paper is in the form of plain white sheets. Little work is available on the design of the paper surface configuration for facilitation of the user's hand and arm movements and for accuracy in positioning letters and words in either vertical or horizontal dimensions (depending upon the language used) by designing ruled sheets or boxed lines for specific writing purposes.

3 *Ergonomic Aspects of Handwriting Performance*

3.1 *Handwriting Control and the Measurement of the Hand*

Individuals differ in both the static and dynamic anthropometric measurements of the human hand. In theory, writing instruments should be compatible with individual hand configurations for optimal writing performance. Since there is nothing we can do to change the hand, we must look at various groups of people with distinctive writing requirements where general designs of instruments are inadequate. These groups include children at the kindergarten and early grade-school level, left-handers, and the manually handicapped. Kao (1974) reported one ergonomic study on writing performance by ten-year-old children using shank diameters of ¼, ⅜, and ½ inch. While the thickest pen was found to be the most effective for boys, the girls wrote equally well with the three sizes. Obviously, the lack of coherence between the size of children's hand and fingers and the size and design of their writing instrument may contribute to their difficulties in producing legible writing.

3.2 *Hand and Writing Pressure*

In writing, the hand typically is positioned at two points on the writing surface — at the side of the heel and on the lower side of the curled little finger. These two resting points provide a stable platform from which the fingers, thumb, and hand can control the action of the writing instrument and writing point pressure. The pressure exerted varies with the stability of the hand platform. The efficiency of the hand platform varies with the type of writing instrument as well as with the size and other anthropometric characteristics of the hand.

3.3 *Ergonomics of Writing Instrument Design*

The writing instrument as a component of the writing system is a passive tool of operation; the instrument itself can affect writing efficiency by causing discomfort, the need for increased visual-motor coordination in the writing process, the obscuration of written traces of the pen tips, etc. These become more pronounced in the acquisition of handwriting skill. The different types of writing instruments in use today give quite different visual, tactual, and kinesthetic feedback whch affects the dynamic process of letter formation.

Specific ergonomic design research should examine both the physical and the operational characteristics of the writing instrument. The former should include investigation of the size, weight, shape, and length of the instrument; the shape, surface texture, and hardness of the shaft for the requirements of hand control; and the size, shape, and loci of the point relative to the shaft axis. Operational characteristics should be analyzed in terms of writing

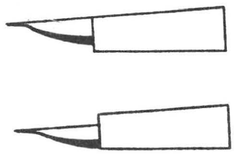

Figure 1. Comparison of centered and off-centered penpoints.

smoothness, ink flow, conspicuity of writing traces to serve as visual feedback, gravitational point, and point pressure of the instrument in action. Both types of characteristics must be coordinated for tasks different in nature and requirements; characteristics should always be considered relative to the manipulator of the writing instrument: the human hand.

3.3.1 *Penpoint Designs.* Kao, Smith, and Knutson (1969) investigated the locational variations of penpoints relative to the axis of the shank of fountain pens. With two different penpoint loci — centered and off-centered straight tips (Figure 1) — the subjects'

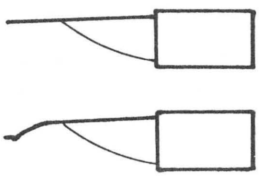

Figure 2. Comparison of straight and curved penpoints.

performance was measured in terms of the time taken in writing English letters and drawing small triangles. The off-centered penpoint design, providing generally a better visual feedback of the marking action, resulted in superior writing task performance compared to the centered tip. Another study (Smith, Kao, and Knutson, 1967; Kao, 1977) compared the designs of straight and curved penpoints relative to their visual feedback properties in writing tasks (Figure 2). Due to the obstruction of visual feedback of the writing traces with curved penpoints, as measured by task time the straight pen tips were found superior in writing efficiency.

A third study on the design of penpoints (Kao, 1973a) compared penpoints tilted at an angle from the straight axis with normal straight pentips (Figure 3). It was hypothesized that because of

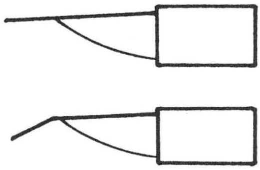

Figure 3. Comparison of straight and tilted penpoints.

their enlarged exposure of visual feedback the tilted penpoints would tend to result in higher writing efficiency than regular straight penpoints. The findings were as predicted; writing time was considerably shorter with the tilted pen tips. A fourth experiment (Kao, 1979a) focussed on the effects of differential levels of pencil tip hardness on handwriting performance. "Black," "hard-black," and "hard" pencils represented three levels of tip hardness. With both task time and task pressure as measures of writing performance, the "hard-black" pencils took significantly less writing time than the "black" pencils; the "hard" pencils did not differ significantly from either the "hard-black" or the "black" ones. No difference was found in the task pressure for the three types of pencils.

Other interesting studies along this line of investigation may include, for example, research on differential hardness of the pen tips in affecting grip pressure, and tip deterioration in relation to writing time and the legibility of pencil writing.

3.3.2 *Pen Shank Designs.* The pen shank affects handwriting in a number of ways: hand grip, pen movement, muscular fatigue, writing task pressure, as well as writing time. A recent study (Kao, 1979b) has investigated the differential weights of ballpoint pens in adult handwriting performance. Using 5-gram, 10-gram, and 15-gram weights separately attached to three identical ballpoint pens, the subjects' performance was measured with respect to the effect of shank weight on their writing pressure and writing time. Results showed a general advantage for the heaviest shank in producing shorter writing time and reduced point-tip pressure. This may indicate that increased shank weight alleviates both the grip pressure exerted on the shank and the point-tip pressure on the writing surface requred with the use of lighter instruments. Of course, individual differences play an important part in the optimal match between the pen and the hand.

3.3.3 *Ergonomic Comparisons of Writing Instruments.* Kao (1976) used a questionnaire-and-practice technique to study user preference for ballpoint pens, pencils, fountain pens, and felt-tip pens. Assessing such variables as writing ease, legibility, and control comfort, the survey revealed the ballpen to be the most favored writing tool, followed by the pencil. Fountain pens were considered by adult users as the least effective in writing practice. Another series of experiments (Kao, 1978) compared the writing efficiency of pencils, ballpoint, fountain, and felt-tip pens by measuring writing time and pen-tip pressure. The results confirmed the overall superiority of the ballpoint in requiring the least time when performing identical writing tasks. The research also confirmed the findings of the previous study on user preferences among writing instruments.

Comparisons are needed to differentiate the various types of instruments for different user groups. Although best for adults, ballpoints may not be best for very young children. Certain instruments may yield greater legibility due to minimal point deterioration. Ergonomic considerations should make efforts to differentiate instruments for different writing purposes and for different groups of users.

3.4 *Ergonomics and Writing Fatigue*

Individuals write differently at different times not only because of the variations in writing instruments but also because of emotional and physiological tension in writing control. Under strain, the pressure imparted to the pen becomes greater, degrading the focal or basographic feedback effect of the pen on the writing surface and causing a tendency toward increased size and reduced legibility. As a result, individuals may like one type of writing instrument when they work under pressure and a different type when they are relaxed. Some individuals write for long hours during the day most of their lives, but most people use a pen or pencil for only a limited time. Careful observations have suggested that writing fatigue as well as writing interest and motivation are closely related to the design of different parts of the writing instrument and do not depend entirely on the person.

Unduly small writing shafts or poor writing points tend to induce increased pressure in holding the instruments, increased point pressure, poor legibility, discomfort, dissatisfaction, fatigue — and writer's cramp, the painful muscular contraction of the arm and the hand. Many people develop callouses on the working side of the second finger or the tip of the index finger, making writing painful and interfering with the control of the writing instrument. Although a study has shown that moderate or even exhaustive short-time manual exercise helps increase writing pace at no sacrifice of writing accuracy (Kao, 1973b), prolonged muscular contraction in handwriting may create an extreme case of physical accumulation of exhausted muscles.

The ergonomic answer to writing fatigue, writer's cramp, and calloused fingers is the better design of writing instruments. Writing points that are friction-free — soft-lead pencils, fiber-tip pens, and well-designed metal points — are the starting points of investigation. Smooth paper is another consideration. The size and design of pen shafts should fit the writing hand in order to minimize the holding pressure. A pencil or pen wrapped with thin strips of plastic foam covered with masking tape to provide a bulging grip position, prevents callouses and can reduce or even eliminate writing fatigue or discomfort.

4 *Conclusions*

In this age of mechanization the view is often expressed that handwriting in time will become obsolete as a human skill. I believe this to be an unlikely possibility. Handwriting appears to be a necessary activity in the organization of human thinking. Special types of writing such as typewriting might be a substitute for penmanship, but mechanistic constraints are imposed on the expressive movements of handwriting by keyboards.

This paper has suggested a framework for the handwriting system within which the component elements are specified and analysed to identify the needed areas of concerted research. It has also provided an overview of the kinds of practical design applications currently in progress. It is expected that future research on handwriting will encompass more exact studies of the ergonomic principles in penmanship, legibility, learning and training of handwriting, development of handwriting skills, design of writing instruments, the proper integrations of hand, instrument, and paper, and the role of writing in the development of individuals. Ergonomic research of this nature can turn the study of handwriting from the limited investigations using legibility tests or personality correlates to more fundamental research on writing and human behavior. However, an expanded science of writing skills and instrument design needs the combined and enhanced efforts of ergonomists, educators, and industry for research and development of efficient new instruments as well as motivation toward expressive graphic activities in human handwriting and penmanship.

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