ANALYSIS OF THE FACTORS OF THE WORK-LOAD IN HANDWRITING

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ABSTRACT

Analysis of the factors which influenced the work load in handwriting were studied using the new apparatus for simultaneous measurement of grip and pen-point pressures developed by the author. Thickness of the pen holder was shown to be a factor which influenced the work load, and diameter of pen holder for minimum load was determined. Nature of the pen-point was also one of the factors, and it was shown that the ball-point pen gave the greatest load and felt-point pen gave the smallest load in three kinds of pen-points; ball-point pen, felt-tip pen and pencil. Number of copies also influenced the load to the upper extremities, and taking more than three copies gave excess work load to female workers.

INTRODUCTION

Handwriting has become one of the subjects of occupational health studies, since the impairment due to handwriting work such as "writer's cramp" in previous years and the so-called "ball-point pen disease" in recent years have been noticed.

Although it is widely accepted that "writer's cramp" is a kind of occupational cramp and that it is due to psychogenic factors, it should be fully appreciated that the basis for this disease is the excess load to the muscles of the arm and hand caused by gripping the stencil pen with a certain strength for long duration in order to cut stencil paper.

In recent years, with the rapid development of industry, especially in the area of the tertiary industry, specialization in office work has been carried out rapidly for rationalization of business, and various office supplies and writing instruments have been extensively developed and applied in order to increase business efficiency. In these circumstances, the "ball-point pen disease" seems to have been produced by the excess load to the muscles of the
upper extremities.

Therefore, studies on the load to the muscles of the hand and arm from the standpoint of occupational health are needed in order to decrease fatigue and to prevent impairment caused by handwriting work.

So far only a few has been done to study the load to the muscles caused by handwriting,¹ and this is partly due to the existing methods of electromyography and the measurement of grip pressure which are considered to be insufficient for analysing the causes and degrees of load applied to the upper extremities.

The author developed a new apparatus for simultaneous measurement of grip and pen-point pressure on handwriting. In order to solve the problem of load to the muscles of the upper extremities caused by handwriting, experiments were carried out on the relationship between pen-point and grip pressures, and several factors such as thickness of pen holder, nature of the pen-point and number of copies, using this apparatus.

**METHOD**

(1) Apparatus

An apparatus which satisfies the following three conditions is needed: 1) Grip and pen-point pressure can simultaneously be measured and recorded: 2) Several performances of the pen such as the point material, the shape, and the size of pen can be changed intentionally: 3) The wide ranges of pen-point pressure and grip pressure during writing can be measured and also the addition or reduction of the pressures can be detected sensitively.

![Apparatus for the measurement of grip pressure, pen-point pressure and EMG.](image)
Apparatus for the measurement of pen-point pressure have already been supplied commercially, and there have been a few reports on the apparatus for simultaneous measurement of pen-point pressure and grip pressure. However, none of these apparatus did not satisfy all the above mentioned conditions.

As shown in Fig. 1, the apparatus consists of three compartments; the pickup, amplifier and recorder.

1. The Compartment for Pickup

a) Measurement of Grip Pressure:—The holder of the pen was made of plastics. Its cross section was round and it measured 145 mm in length. Three kinds of pen holders with the diameter of 12 mm (thick type), 9 mm (medium type) and 6 mm (slender type), respectively, were prepared. Attachments for each commercially available ball-point pen, felt-tip pen and pencils were prepared at the point of the holder. A bar of phosphor bronze, 35 mm in length, was so placed on the holder as to keep a distance of 20 mm from the point of the holder to the tip of the bar. On this occasion, the side of the bar contrary to the tip was fixed at the holder. The width of the bar was 3 mm in the 6 mm-sized type of the holder, 6 mm in the 9 mm sized-type of the holder, and 7 mm in the 12 mm-sized type of the holder. The M101 type of Shinkoh polymicron strain gage was so fixed at the edge of the tail side
as to keep a distance of 17 mm from the edge of the bar to the center of the gage.

b) Measurement of Pen-Point Pressure:—In the center of the plastic plate which was 600 mm in length and 420 mm in width, a plate, 65 mm in length and 35 mm in width, was made a receptor for the pen-point pressure. This plate was made floatable by applying the principle of the balance. The opposite side of the plate was lined with the plate of phosphor bronze, to which Shinkoh multi-spindle strain gage FD116 type was so fixed as to measure an equal value by equivalent pressures. A metal guard plate was set to prevent fingers from touching to the receptor plate and to prevent the pen from departing from the plate during writing.

Moreover, in order to study the activities of the arm muscles, electromyography was carried out employing two channels apparatus with disposable superficial electrodes of Nihon Kohden, as well as the measurement of grip pressure and pen-point pressure.

2. The Amplifier and The Recorder

The compartment for pickup was connected to the AD2-22 type or the MP-3 type of Nihon Kohden, which was connected to the W1-260 type of recorder of the company using ink. The special attention should be paid to adjust it at the established position, because the strain produced on the bar

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**Fig. 3** Calibration curve of pen-point pressure.

**Fig. 4** Calibration curve of grip pressure.
varied widely by the distance from the fixed edge. The gripping site was marked on the bar in order to fix the gripping position on the pen.

Fig. 3 and 4 show the calibration curves of pen-point pressure and grip pressure, which proved to be almost rectilinear. The adjustment of sensitivity of the apparatus enables the measurement of the pen-point pressure and the grip pressure from the minimal value of 25 g to the maximal value of 2,000 g.

The response promptitude of the strain gage system was examined, by placing and removing a load of 500 g balance weight to the receptor plate for pen-point pressure or to the bar on the holder for grip pressure. As shown in Fig. 5 both the grip and the pen-point pressures well responded for the purpose of the study.

![Fig. 5 Response time of grip pressure and pen-point pressure when a load of 500g is added and removed.](image)

(2) Experimental Procedures

a) Thickness of Pen Holder and Writing Rate

The cores of ball-point pens for slender writing were attached to each
of three kinds of pen holders with diameters of 6 mm, 9 mm and 12 mm. Five male medical students were seated in front of the apparatus for measurement of pen-point pressure and instructed to assume the usual writing posture. The figure "0"s with a diameter of about 7 mm lengthwise were continuously written at rates of 60 letters and 200 letters per minute for two minutes on white paper over a receptor plate, using a pen for measuring grip pressures. The experiments were carried out at twenty minute intervals to recover muscular fatigue.

b) Nature of the Pen-Points

The cores of ball-point pens for slender writing, felt-tip pens for slender writing and pencils with hardness of HB were attached to 9 mm diameter pen holder. Following the same instructions as a), five medical male students wrote "0"s with diameters of 7 mm at a rate of 200 letters per minute for three minutes on the paper over the receptor plate. There were twenty minute intervals between experiments.

c) Number of Copies

The relationship between pen-point pressure and the number of copies was examined. Using pens for measurement of grip pressure with the ball-point pen core for slender tip, the figure "1"s were written on ten thicknesses of carbonless duplicating sheets with pen-point pressures of 100, 200, 300, 400, 500, 600, 800 and 1000 g as shown on the recorder. Then, the number of copies with distinct handwriting duplicated was counted according to pressure. In addition to the evaluation of distinctness of handwriting duplication on the copies with eye, a photograph of the duplication of the handwriting on the copies was taken, and the degree of extinction was deduced from the density of handwriting on the film in order to evaluate it objectively. After the photograph of each copy was taken under an established condition, the degree of extinction of the film was determined by the FD-AN type of automatic densitometer of Fuji Riken.

RESULTS

a) Thickness of the Pen Holder and Handwriting Rate

As shown in Figure 6 and Table 1, no significant differences of pen-point pressure were observed by changing the diameter of the holder. On the other hand, it was distinctly observed that the grip pressure was less in the 9 mm holder than in the other holders. In addition, further analysis of the grip pressure was carried out. The stroke pressure, of the grip pressure which makes a rhythmical stroke of a pen, was maximum in the 12 mm
Fig. 6 Average grip pressure (stroke pressure and tight grip pressure) and pen-point pressure by pen axis with different diameters and different writing speeds.

Table 1

Grip pressure, tight grip pressure and pen-point pressure by pen holder with different diameters and different writing speeds

<table>
<thead>
<tr>
<th>Diameter of pen holder (mm)</th>
<th>Writing rate (letter/min)</th>
<th>Grip pressure</th>
<th>Tight grip pressure</th>
<th>Pen-point pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
<td>S.D.</td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>60</td>
<td>530.0</td>
<td>211.3</td>
<td>130.6°</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>524.8!</td>
<td>191.4</td>
<td>287.6°</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>398.0**</td>
<td>131.1</td>
<td>147.2**</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>404.0*!</td>
<td>110.3</td>
<td>211.0*</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>547.0**</td>
<td>222.1</td>
<td>274.6**</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>568.8*</td>
<td>194.1</td>
<td>415.8*</td>
</tr>
</tbody>
</table>

** Significant (P<0.05) between 9 mm diam, and 6 mm diam, with 60 letter/min.
* Significant (P<0.05) between 9 mm diam. and 6 mm diam, with 200 letter/min.
† Significant (P<0.05) between 12 mm diam. and 9 mm diam, with 200 letter/min.
* Significant (P<0.05) between 60 letter/min and 200 letter/min with 12 mm diam.
# Significant (P<0.05) between 60 letter/min and 200 letter/min with 6 mm diam.

diameter holder, and minimum in the 6 mm diameter holder. The tight grip pressure, of the grip pressure needed to hold a pen to prevent it from slipping
off the pen holder, was high in the 6 mm diameter holder and low in the 9 mm diameter holder.

These results revealed that the thickness of the pen holder is one of the factors which influence the load to the muscles of the upper extremities by handwriting work. Moreover, it was shown that the load to the upper extremity muscles was maximum with a 6 mm diameter holder and minimum with a 9 mm diameter holder, of these three kinds of pen holders.

Figure 6 and Table 1 also shows the relationship between the rate of handwriting and the load to the muscles. From this, no significant differences were observed in pen-point and grip pressures between the writing rate of 60 letters per minute and the writing rate of 200 letters per minute. However, with the 6 mm and 12 mm diameter holder, tight grip pressure in grip pressure was observed to be greater significantly in the writing rate of 200 letters per minute. This indicated that tight grip pressure increases with rapid writing, and that the handwriting speed also influences the load to the upper extremity muscles.

b) Nature of the Pen-Point

Fig. 7 Average grip pressure (stroke pressure and tight grip pressure) and pen-point pressure (stroke pressure and press pressure) by different pen-points.
Table 2

<table>
<thead>
<tr>
<th>Type of pen-point</th>
<th>Grip pressure</th>
<th>Tight grip pressure</th>
<th>Pen-point pressure</th>
<th>Press pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>S.D.</td>
<td>X</td>
<td>S.D.</td>
</tr>
<tr>
<td>Pencil</td>
<td>184.6</td>
<td>128.0</td>
<td>83.0</td>
<td>69.9</td>
</tr>
<tr>
<td>Felt pen</td>
<td>83.2*</td>
<td>103.3</td>
<td>15.4*</td>
<td>23.6</td>
</tr>
<tr>
<td>Ball pen</td>
<td>360.0*</td>
<td>169.3</td>
<td>229.4*</td>
<td>157.5</td>
</tr>
</tbody>
</table>

*  **  #  ** Significant (P<0.05) between felt pen and ball pen

Figure 7 and Table 2 show that both pen-point pressure and grip pressure are maximum in the ball-point pen and minimum in the felt-tip pen. When the pen-point pressure was divided into the stroke pressure and the press pressure, no differences in the stroke pressure were observed by changing the nature of the pen-point while obvious differences in the press pressure were observed. Moreover, for the grip pressure as well as the pen-point pressure, no differences were observed in the stroke pressure, while obvious differences were observed in the tight grip pressure by varying the nature of the pen-point.

As for the relationship between pen-point pressure and grip pressure, with three kinds of pen-points, the grip pressure was high compared to the pen-point pressure with a ball-point pen, while no differences were found between pen-point pressure and grip pressure with a felt-tip pen and a pencil.

These results demonstrated that the type of pen-point was also one of the factors which influenced the load applied to the muscles of the upper extremities upon handwriting.

c) Number of Copies

Figure 8 shows the degree of extinction which was deduced from the density of the color of handwriting duplication on the recording paper of the densitometer. The higher degree of extinction shows the darker duplication.

Figure 9 shows the relationship between the degree of extinction, that is the density of the color of the handwriting duplication, and pen-point pressure. The density of the color of the original sheet is extremely high compared to that of the other copies. These distinct differences of degree of extinction are attributed to writing with black ink on the original sheet, while the duplicates have a blue color.

The density of the color of duplications which can be recognized clearly
Fig. 8 Density of copied letter on copying slips by various pen-point pressure shown as absorption curve.

is equivalent to more than a 40 mm of extinction degree. In order to maintain this density of the color, a 100 g pen-point pressure is needed for duplication of three copies, 700 g for duplication of seven copies and 1100 g for duplication of 10 copies. These facts indicated that the number of copies also influences the load to the muscles of the upper extremities.

DISCUSSION

(1) Grip and Pen-Point Pressure as the Indicators of Load Applied by Handwriting

Electromyography is usually employed in order to examine the condition of the muscles during the muscular activity. However, it seems impossible to
determinate the output of muscles from electromyography, and the information about each muscle from the electromyography is of little significance in studying handwriting which consists of compound activities of various muscular groups of the upper extremities. The author considered that the overall muscular activity of the upper extremities is well represented by grip pressure, of the pressure directly applied to the pen, and that not only the study on the pen-point pressure itself, but also the study on the relationship between the pen-point pressure and the grip pressure on the pen holder is necessary, in order to examine the work load to the muscles of the upper extremities during handwriting.

Based on these considerations, the relationship between pen-point pressure and grip pressure was examined and the following findings were obtained: The grip pressure is not directly and effectively converted to the pen-point pressure. Although the grip pressure increases with the increase of pen-point pressure, some grip force be used to hold the pen not to slip off from the finger.
(2) Thickness of Pen Holder

The experiments revealed that the thickness of the pen holder is one of the factors which influence the load applied to the muscles of the upper extremities by handwriting. Among the three sizes of the pen holders, the load was minimum with the 9 mm holder and it increased when pens with diameter under or over 9 mm were used. This corresponded to our study on the subjective impressions on the ease of pen holding and using. The study was carried out on student nurses and female subjects whose occupation requires extensive handwriting. Using the rating-scale method with seven grades, the initial impressions of holding the pens and the impressions after using them for one week were examined with seven kinds of round-shaped plastic ball-point pens with the holders from 6 mm to 12 mm in diameter. The results showed that both the student nurses and the other female subjects managed in handwriting felt that the easiest pen to hold was the 9 mm one, followed by the 8 mm and the 10 mm in its order. This fact suggests that the impression of easy writing and fatigue-free holding corresponds to little load to muscles of the upper extremities, especially the tight grip pressure of the grip pressures.

(3) Nature of Pen-Point

The differences in grip and pen-point pressures according to nature of the pen-point seem to be caused by the following reasons: In felt-tip pens, both grip and pen-point pressures are low, because of the fibrous core. The core is elastic and holds ink well, and there is no need to press the point of pen on the paper upon writing, since the ink flows out smoothly with the slightest contact of the pen-point on the paper. On the other hand, with a ball-point pen the ink flows out of space between the tube and a small ball-bearing which is held in the tip of the tube by rolling the bearing on paper. The necessities of pressing the point of pen to the paper and rolling of the ball cause high rating of both pen-point and holding pressures. In other words, the small coefficient of friction causes hard writing of the ball-point pen. For easier writing, various kinds of devices for increasing the coefficient of friction such as prevention of using underlays, prevention of using papers with smooth surface, using piles of several papers instead of writing on one paper, prevention of using ball-point pen for slender writing can be used.

(4) Number of Copies

The needs of duplicate making using ball-point pens has increased lately to increase the business efficiency. The load to the muscles of the upper extremities on such job should be carefully checked in young women mostly
follow on this handwriting job. According to the author\textsuperscript{4} and Komoike \textit{et al.}\textsuperscript{5} the median of pen-point pressure with young women is about 160 g. If young women did duplicate making at their usual grip pressure, half of them could only make distinct duplications until the third copy. However, in fact, duplicate making of only three copies is rare, and most of the female workers are forced to write with greater pen-point pressure, in order to make distinct duplication to the last copy, and it also needs greater grip pressure of the pen holder and causes excess load to the muscles of the upper extremities.

\section*{SUMMARY}

Various factors which influence the load to the muscles of the upper extremities by handwriting were investigated using the apparatus for simultaneous measurement of grip and pen-point pressures developed by the author, and the following results were obtained:

1) The battery of grip pressure and pen-point pressure is a good indicator in the study of the load applied to the upper extremity muscles by handwriting.

2) A 9 mm diameter pen holder gives the minimum load to muscles of the hand and arm, and the load is increased when pen holder under or over 9 mm in diameter are used.

3) The load to the muscles increases in proportion to the handwriting speed.

4) Various types of pen-point influence differently on the load given to the muscles of the upper extremities. Among the three kinds of pen-points used in this experiment, the load produced by ball-pen point was the greatest, followed by pencil point, and the least by felt-pen point.

5) The load to the muscles increases in most of young women when making more than three handwriting copies.

\section*{REFERENCES}