

# An Electromyographic Study of Two Different Types of Ballpoint Pens

## —Investigation of a One Hour Writing Operation—

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**Abstract:** Recently there has been an increasing incidence of occupational cervicobrachial disorders (OCD) and writer's cramp in office workers using ballpoint pens in writing operations. For the sake of workers who use ballpoint pens, it is essential to prevent such health hazards. It has been observed that a strong gripping pressure on the ballpoint pen significantly contributes to the development of these conditions. The present authors have been developing a new ballpoint pen by altering the grip area in such a way as to reduce the gripping pressure, and thus prevent OCD. The purpose of this study is to compare our ballpoint pen (new pen) with a conventional ballpoint pen (conventional pen) for the load that they exert on the upper limb during one hour of continuous writing. Electromyograms (EMG) and upper limb pain scores are used as indicators. The conventional pen used was selected from commercially available ballpoint pens widely used in offices. The grip area is cylindrical with an 8.3 mm diameter. It is manufactured of hard plastic, which can make it feel rigid and slippery to the user. The new pen has a cylindrical grip area that flares out at the bottom, near the pen-tip, and has a diameter ranging from 11.9–13.6 mm. In addition, the grip is constructed of a 2 to 3 mm-thick silicon rubber sleeve that is softer and less slippery in comparison with the conventional pen. Twelve students (5 males and 7 females) without any preexisting cervicobrachial disorders were asked to transcribe an English text for one hour, alternately using the two kinds of pens. The EMG of the flexor pollicis brevis was measured and recorded every second, while subjective pain scores were recorded every five minutes for the thumb, forefinger, middle finger, thenar, forearm extensor (forearm) and shoulder. The EMG of the flexor pollicis brevis and the pain scores for the thumb, forefinger, middle finger, forearm and shoulder were significantly lower for the new pen than for the conventional pen. These results suggest that after an hour of continuous writing, the new pen reduces the muscle load on the upper limb, and therefore mitigates fatigue in this area.

**Key words:** Ballpoint Pen, Ergonomic Improvement, Pen Grip, Prevention, Cervicobrachial Disorders, EMG

## Introduction

To date, disorders of the neck, shoulders and arms associated with writing operations have been widely known

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as ballpoint pen tenosynovitis or writer's cramp<sup>1-3</sup>). In particular, the health hazards of using a ballpoint pen for copying operations<sup>4,5</sup> have received attention. Hosokawa<sup>6</sup> observed occupational cervicobrachial disorders (OCD) among workers using ballpoint pens to do transcriptions onto duplicate slips. Maeda<sup>3</sup> has also reported that ballpoint pens aggravate the muscle load when transcribing onto duplicate slips. According to Maeda, office workers who usually use a ballpoint pen to write on single sheet of paper, develop writing-induced disorders because the writing tool itself obliges the user to increase his/her pen-point pressure. The resulting muscle load on the area of the forearm to the hand is 1.2 to 1.3 times greater than in the case of felt-tipped pens<sup>3</sup>).

Hand tension related to writing with a ballpoint pen includes the pressure used to hold the pen with the thumb, forefinger and middle finger (gripping pressure) and the pressure applied to the pen tip (pen-point pressure). To achieve a high pen-point pressure, a high gripping pressure is required. Shigeta<sup>2</sup> has claimed that in order to maintain a strong pen-point pressure when using a ballpoint pen, the writer must grip the pen tightly (use strong gripping pressure) to avoid pen slippage. Furthermore, he argues that strong gripping pressure is one of the main causes of OCD in the case of ballpoint pens. This indicates that the friction coefficient of the grip is one important factor related to gripping pressure, and thus to OCD<sup>7</sup>. The gripping pressure required to attain adequate pen-point pressure is believed to be dependent on the contact area of the pen with the fingers, or the diameter of the grip area and its friction coefficient. Therefore, any modified ballpoint pen with a larger diameter grip and a higher friction coefficient is likely to be effective in reducing the gripping pressure.

Udo *et al.*<sup>7</sup> focused on the diameter, which would help to reduce the gripping pressure, and thereby the muscle load placed on the neck, shoulders and arm during writing operations. Udo *et al.*<sup>8</sup> have also reported that the use of materials with a high friction coefficient for the grip area reduces the gripping pressure required to prevent the pen from slipping by increasing the friction between the fingers and the gripping area. It is also reported that a taper-shaped grip decreases grip pressure, as compared with a non-tapered grip<sup>9</sup>). Based on these viewpoints, they developed a ballpoint pen with a larger diameter grip, which flares out near the pen tip and is made of a rubber characterized by its higher friction coefficient.

The purpose of this study is to compare a new type of ballpoint pen (new pen, Mfg.: Pilot Inc.), which incorporates

these improvements, and a conventional ballpoint pen (conventional pen) for the load placed on the neck, shoulders and arm. Gripping pressure can be used as a criteria for evaluating the load on the hand during writing operations<sup>7, 8, 10, 11</sup>). From the point of view of preventing OCD, the hypothesis is that pens that require a low gripping pressure are best for writing. In past studies, EMG has been used to measure gripping pressure. Therefore, in this study we have used the EMGs of flexor pollicis brevis to measure gripping pressure, according to the method of Udo *et al.*<sup>7, 8, 12</sup>).

## Subjects and Methods

### Subjects

Twelve healthy students (five males, seven females) without preexisting cervicobrachial disorders served as subjects. All subjects were informed about the conditions of the experiment and signed an informed consent form prior to their participation. Anonymity was achieved by assigning each subject an identification number.

### Characteristics of the conventional and new ballpoint pens

The conventional pen's grip is plastic and has a cylindrical shape. It is 6.6 g in weight, 14.7 cm in length, and 8.3mm in diameter (Fig. 1).

The new pen's grip area is covered with a 2–3 mm-thick silicon rubber sleeve, and has a cylindrical shape, which tapers out by a gradient of 2 degrees near the pen tip. It is 16.0 g in weight, 15.0 cm in length, 11.9–13.6 mm in diameter (Fig. 1).

### Task

The subjects were asked to transcribe an English text alternately using the conventional pen and the new pen for one hour respectively. A break of 1.5 hours was inserted between the two tasks.

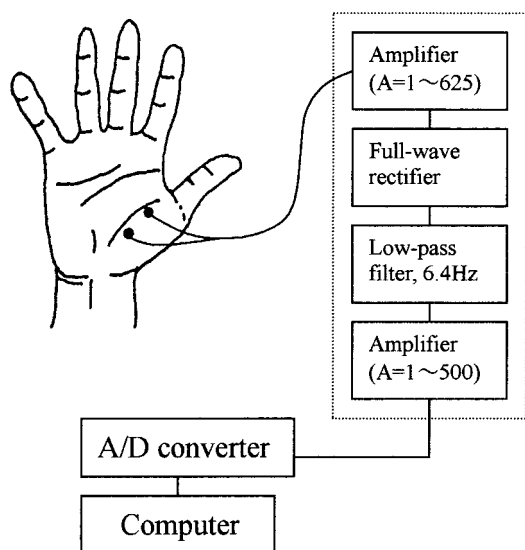


Fig. 1. Conventional Pen (bottom) and New Pen (upper).

### Measurements

1) EMG: the EMG at the flexor pollicis brevis (FPB)<sup>7, 8, 12)</sup> was monitored under dual-polar guidance using Ag/AgCl electrodes, as shown in Fig. 2. FPB plays an important role when gripping objects tightly in the hand<sup>13)</sup>. There is a very significant correlation between the EMG of FPB and the pinching power of the thumb as measured by a pinch meter from our preliminary test ( $r^2=0.971$ ,  $p<0.001$ , by Pearson's coefficient of correlation), therefore EMG of FPB has been selected as an index of the gripping pressure. The thenar of the writing hand was wiped with alcohol-soaked cotton. The two electrodes were then applied with center to center spacing 2 cm. The electrodes were connected with lead wires and fixed by applying tape over them. Also, an area approximately 7 cm from the hand joint striation along the inner forearm median line was wiped with alcohol-soaked cotton to apply the ground electrode. The EMG apparatus consists of an EMG amplifier and a computer, as shown in Fig. 2. The EMG signal was rectified, and then it was smoothed by passing it through a low-pass filter at 6.4 Hz. The y-axis of the signal (in micro-volts) was divided into 4096 sections for quantifying the amplitude of the signal. The EMG was recorded using a personal computer with an analogue-to-digital converter, at one-second intervals during the 1-hour writing task.

2) Subjective complaints: We used Borg's<sup>14)</sup> category ratio



**Fig. 2. Block diagram of the EMG apparatus.**

'A' values of amplifiers indicate gains of amplifiers calculated from following equation;  $A=(\text{output voltage of amplifier})/(\text{input voltage of amplifier})$ .

scale (CR-10) in our study because it is the most widely used method for evaluating subjective complaints. Subjective complaints of pain in the thumb, forefinger, middle finger, thenar, forearm extensor (forearm), and shoulder were ranked using a body discomfort rating chart. Following Borg's scale, we used 10 to indicate "extremely strong" pain and 0.5 for "extremely weak" pain (see Table 1). This table was shown to the subjects, who then used it to assess the level of their pain in answering the examiner's questions about the pain experienced. The subjects were asked about their subjective symptoms once every 5 min.

3) Measurement of the pen-point pressure and other parameters: Following Maeda's<sup>3)</sup> method of measuring pen-point pressure, the subjects were asked to transcribe three lines of English text with the conventional pen in their usual manner on a stack of 10 sheets of paper with carbon papers between each sheet. The sheets of paper were placed on top of the table with a piece of cardboard under them, in the same manner as described for the actual one-hour writing task. As well, the same English text and paper that were used for the one-hour writing task, were used to test pen-point pressure. The number of sheets of paper on which the inscriptions were legible excluding the first sheet was used as an index of pen-point pressure.

At the end of the transcribing task, the subject was asked to hold the conventional pen so that the finger configuration used for gripping the pen could be photographed with a Polaroid camera from the lateral and front sides. The finger configurations were evaluated according to the classification proposed by Udo *et al.*<sup>7)</sup>. The gripping power was measured using a dynamometer. The pinching power between the

**Table 1. Body discomfort rating chart**

Scale	Assessment
0	Nothing at all
.5	Extremely weak (just noticeable)
1	Very weak
2	Weak (light)
3	Moderate
4	
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong (almost max)
	Maximal

thumb and forefinger was measured using a pinch meter (Roken-shiki). The length of the thumb, forefinger and middle finger, width of the hand ranging from the forefinger to little finger, and the length from the fingertip to the hand (the length of the hand)<sup>15)</sup>.

Also, the number of transcribed characters including symbols such as commas and periods were counted for the two pens after the transcribing tasks were completed.

4) Writing conditions and room conditions: The table used in this study had a wooden tabletop at a height of 68 cm. The chair used had a backrest and the seat height could be adjusted. The seat height was adjusted for each subject so that the height of the elbow would match the tabletop when the subject was in a straight sitting posture.

The paper used for the transcribing exercise was 182 × 256 mm (B5) with 25 transverse ruled lines, spaced 8 mm apart. It was placed on the table with a piece of cardboard under it. The document that the subjects transcribed from was written in English, on paper that was 210 × 296 mm (A4/Letter Size) size paper was used.

The room conditions were controlled as follows: the temperature was kept within the range of 23 to 25°C; the relative humidity ranged from 51 to 63%; the background noise level ranged from 35 to 38 dB(A); the vertical background vibration level ranged from 43 to 46 dB; the lighting condition was 552 lx on the table. The room where the experiment was conducted has a tile floor.

5) Experiment procedures: The subjects were randomly divided into two groups composed of 6 subjects each, to ensure that the exercise sequence for the two pens was the same in both groups. The subjects were instructed to avoid any intense physical exercises and excessive alcohol intake on the day previous to the experiment in order to eliminate any adverse effects on the upper limb. They were also encouraged to have at least 7 hours of sleep the night before the experiment. On the day of the experiment, they were asked to enter the laboratory one-hour before the scheduled starting time of the experiment. Before the experiment was started, the subjects were asked about their health condition, and only the subjects without any ill conditions were accepted for the study. The procedure for the experiment was as follows.

- a. The subject was given an explanation of the experiment.
- b. The chair was adjusted to fit the subject.
- c. The subject was asked to transcribe an English text for about five minutes with the new pen to familiarize him/herself with the pen.
- d. The subject was asked to transcribe three lines of English

text onto a sheet of paper with carbon paper and paper stacked alternately under it, using the conventional pen. At the end of this transcription, a Polaroid photograph of the writing hand was taken.

- e. The electrodes were applied to the FPB.
- f. The measurements were started, and the subject began to transcribe an English text for one hour.
- g. There was a break of 1.5 hours, followed by another transcribing exercise, which followed the same procedure, but with the alternate pen.
- h. The measurements were made for gripping power, pinching power and the hand anthropometry.

### Analysis

There are two main methods of normalizing EMGs. One method is to normalize the EMG using the maximum voluntary contraction value of the EMG (%MVC)<sup>16)</sup> of the subject, and the other is to normalize the EMG using the mean and SD of the EMG value of the subject. Although the first method is more commonly used than the second, it has one major limitation, which is that it is difficult to ensure reliable measurements of MVC, and thus, of the % MVC, because it is a voluntary measure based on the subject's own evaluation of his/her maximum power. On the other hand, the second method is more sensitive than the first one because it does not use MVC, and because individual differences in the baseline and reaction characteristics of the EMGs are corrected by using both the mean and the SD<sup>17)</sup>. It is based on these advantages, that we chose to use the mean and SD as the method of normalizing the EMG in this study.

The average EMG was calculated once every five min from the start of the experiment. For example, the average value of the EMGs in the first 5-min interval is calculated using the EMG values between 0 min to 4 min, 59 sec (300 pieces of data). The average EMG was standardized by the mean and the standard deviation (SD) of the subject's total average EMG at specific sites, according to the following formula:

$$sEMG = \frac{(\text{average EMG} - \text{mean of the subject's total average EMG of 1 h}) \mu V}{(\text{SD of the subject's total average EMG of 1 h}) \mu V} \quad (1)$$

where sEMG indicates the standardized EMG. sEMG is a coefficient value, and has no unit, as shown in formula (1).

The mean and SD of the number of legible duplicates were derived from the all subjects' data as the index of the pen-point pressure of the subjects.

The mean and SE of the subjective complaints of all

**Table 2. Summary of subjects' data**

n	Total		Male		Female	
	Mean	SD	Mean	SD	Mean	SD
Age (yr.)	22.0	0.4	22.2	0.4	21.9	0.4
Stature (cm)	165.2	5.0	170.0	1.0	161.8	3.6
Weight (kg)	57.7	7.6	64.7	5.1	52.9	4.5

subjects were calculated for each 5-min interval (hereinafter referred to as pain scores).

To conduct statistical analysis, a paired *t*-test was applied to sEMG and the transcribed characters counted. The pain scores were analyzed with a paired Wilcoxon test. The anthropometric dimensions and thews were analyzed with a *t*-test.

## Results

### Subjects

Table 2 summarizes the data about the subjects. Their mean age was 22.0 years old, the mean height was 165.2 cm and the mean weight was 57.7 kg. Table 3 shows the dimensions and thews for the subjects' writing hand and fingers. No significant differences were observed between male and female subjects in terms of these dimensions. However, significant differences were found between male and female subjects in terms of pinching and gripping power. Eleven subjects were right-handed, while only one was left-handed.

Five subjects were classified into the high gripping pressure group, while three were classified into the slightly high gripping pressure group, with the other four subjects classified into the normal gripping pressure group. As for the pen-point pressure, the mean number of legible duplicates (Mean  $\pm$  SD) was  $2.8 \pm 1.0$  (mini.:1, max.:4).

### EMG

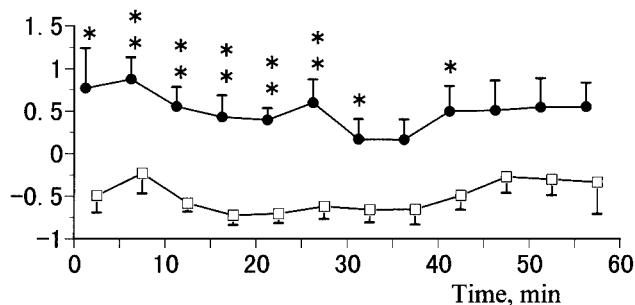
Figure 3 shows the changes in sEMG at FPB during one hour of writing operation. The vertical axis represents sEMG (Mean, SE) and the transverse axis represents the elapsed time. The sEMGs tended to decrease from after the first 10 min until 40 min and then to increase again. The sEMGs were lower for the new pen than for the conventional pen throughout the measurement period, indicating a significant difference between the two pens at 0–35 min and 40–45 min.

**Table 3. Subjects' anthropometric data**

n	Total		Male		Female		
	Mean	SD	Mean	SD	Mean	SD	
Thumb length (cm)	6.0	0.3	6.2	0.3	5.8	0.2	
Forefinger length (cm)	8.4	0.8	8.4	1.1	8.4	0.5	
Middle finger length (cm)	9.4	0.8	9.5	1.1	9.3	0.6	
Hand length (cm)	18.0	0.8	18.3	1.0	17.8	0.7	
Hand breadth (cm)#	8.3	0.6	8.7	0.2	8.1	0.7	
Pinching power	r (kg)	3.1	1.6	4.1	1.8	2.4	1.1
	l (kg)	2.9	1.7	4.1	1.7	2.0	1.2
Gripping power	r (kg)	35.6	12.5	48.2	7.1	26.6	5.0
	l (kg)	32.0	9.7	41.7	6.1	25.1	3.9

#: Breadth of II-V fingers at the middle of metacarpal.

### sEMG at FPB



**Fig. 3. Changes in sEMG at FPB (Mean, SE) during one hour of writing operation.**

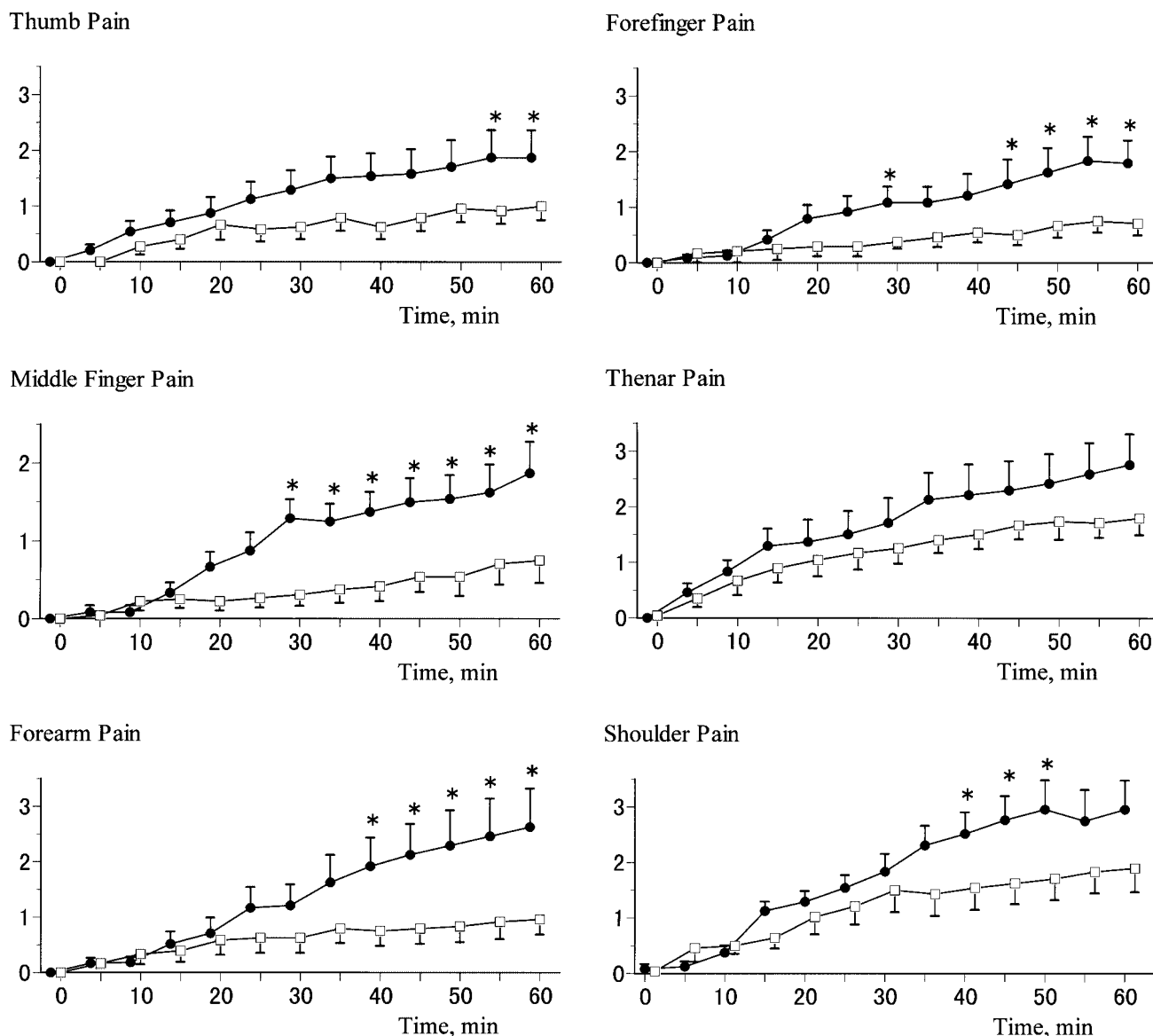
\*\*, \**p*<0.01, 0.05, significantly different between the two pens at the same time.  $\bullet$ : Conventional Pen,  $\square$ : New Pen

### Pain scores

Figure 4 shows the changes in pain scores for the thumb, forefinger, middle finger, thenar, forearm and shoulder during one hour of writing operation. The vertical and transverse axes show the pain scores (Mean, SE) and elapsed time, respectively. All pain scores tended to increase with elapsed time, and tended to be lower for the new pen than for the conventional pen. There were significant differences in the pain scores of the thumb, forefinger, middle finger, forearm and shoulder between the two pens.

### Workload

The mean number of transcribed letters (Mean  $\pm$  SD) was  $5,773 \pm 898$  for the conventional pen, and  $5,848 \pm 675$  for the new pen. There was no significant difference in the number of letters between the two pens.



**Fig. 4.** Changes in pain scores (Mean, SE) for the thumb, forefinger, middle finger, thenar, forearm and shoulder during one hour of writing operation. \* $p < 0.05$ , significantly different between the two pens at the same time. : Conventional Pen, : New Pen

## Discussions

### Measurements

This study used EMG at FPB and pain scores for the thumb, forefinger, middle finger, thenar, forearm and shoulder as indicators of the muscle load induced by use of the pens. During writing operations, the thumb, forefinger and middle finger, which hold the pen body, bear the muscle load. To determine the muscle activities involved in the writing operation, the EMG was measured at the FPB<sup>7, 8, 12</sup>, which

has an important role in gripping objects tightly in the hand<sup>13</sup>.

Muscle fatigue was evaluated based on the pain scores<sup>18-21</sup>. The scores were registered for the thumb, forefinger, middle finger, thenar, forearm and shoulder, which have been reported to bear a significant loads during writing operations<sup>3, 7, 22</sup>.

### Duration of writing operation

In this study, the subjects were asked to commit a continuous one hour-long writing operation for each the two pens. A study involving about 1 min writing operations has

previously been conducted<sup>7,8</sup>). However, both long (i.e. one hour) and relatively short (i.e. a few min) writing operations are commonplace in offices. Studies on short writing operations alone cannot fully determine the muscle load placed on the upper limbs, since prolonged writing operations add upper limb fatigue. Therefore, this experiment focused on relatively long writing operations.

#### *EMG and pain scores*

The EMG measurements revealed that the new pen results in lower EMGs for the flexor pollicis brevis than the conventional pen throughout the measurement period, and that the relevant differences were statistically significant.

In addition, the pain scores for the thumb, forefinger, middle finger, thenar, forearm and shoulder were lower for the new pen than for the conventional pen. The difference between the two pens was statistically significant for the thumb, forefinger, middle finger, forearm and shoulder.

The factors which may affect the muscle load or fatigue over the upper limb during writing operations includes 1) characteristics of the pen, 2) workload, 3) order effect and 4) individual factors. The present study selected the quantity of transcribed characters and symbols as indicators of the workload. No significant difference between the two pens in the quantity transcribed was observed. A possible order effect was avoided by ensuring the even arrangement of the orders for each pen. Possible individual factors were prevented from biasing the results by ensuring that the two pens were used alternately. Therefore, the differences in the EMG and pain scores between the two pens can be attributed to the differences in characteristics of the pens.

It has been reported that the EMG changes proportionately with the force exerted in isometric contractions such as writing operation<sup>23</sup>). Therefore, the differences in EMG observed in this study, justifiably indicate that the muscle activities in the flexor pollicis brevis involving the new pens were lower than those involving the conventional pen during the writing operation.

Also, since pain scores can serve as indicators of muscle fatigue, the differences in pain scores observed in this study mean that the muscle fatigue in the fingers, forearm and shoulder was lower for the new pen than for the conventional pen.

In this study, the mean sEMGs at FPB tended to decrease from after the first 10 min until 40 min and then to increase again. On the other hand, the pain scores tended to increase with elapsed time. Thus, there was a roughly inverse relation between the mean sEMG and the pain scores over time. Udo

*et al.*<sup>7</sup>) have reported that in a 13-min 20-sec period of writing with a ballpoint pen (8 trials of an 80-sec writing operation), the EMG at FPB tended to decrease from the 1st trial to the 6th trial and then to increase in the 7th and 8th trials. The average number of written characters increased with elapsed time. Since there was a significant inverse correlation between the writing speed and EMG, we suggested that the subjects exerted more gripping pressure when they wrote slowly than when they wrote quickly. From these results, we could infer that the changes in the mean sEMG in the present study could be explained by the tendency of subjects to change their writing method/style over time. In the beginning, most subjects tend to write slowly and carefully, so they grip the pen tightly, but as time goes on and they become more relaxed and accustomed to the task, they begin to write more quickly and carelessly, thus loosening their grip on the pen. Thus, the EMG decreases from the early stage to the middle-late stage, and at the end stage, increases again when the effects of thumb fatigue increasing EMG surpass the effects of increased writing speed. The observation that increase of EMG at the end stage occurred for the previous study<sup>7</sup>) within a shorter time than that for the present study can be explained by the fact that the previous study included patients with OCD, who developed fatigue in the thumb more quickly than our healthy subjects. In the future, we should investigate the changes in writing method/style over elapsed time.

#### *Load reduction by the new pen*

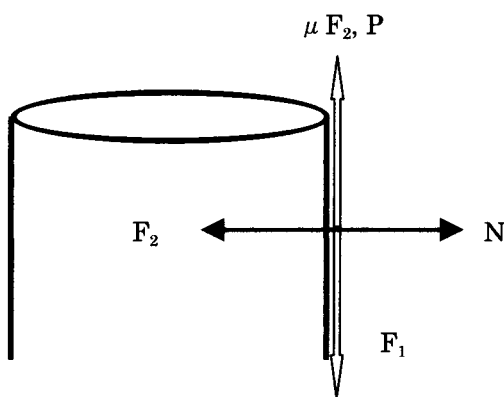
Several studies have been conducted to reduce the muscle load during writing operations<sup>2, 7, 8, 11, 22, 24</sup>). The following relationships have been reported concerning the size, friction coefficient and taper of the grip area.

Firstly, Udo *et al.*<sup>7</sup>) have reported that the optimum diameter for reducing gripping pressure ranges from 12 to 14 mm. The diameter is larger than that of the average pen, which is usually about 8.3 mm. The mechanism that causes the reduction in gripping pressure from using a pen with large diameter can be explained as follows. The contact area with the fingers is larger because the area in which the pen is gripped is greater, and thus the larger contact area may reduce gripping pressure. This association can be explained by biomechanical experimental data wherein the subjects apply additional gripping pressure to prevent an object from slipping when the object has a small gripping area as compared to objects with large gripping areas<sup>25</sup>). This finding suggests that increased gripping area will help adjust the gripping pressure to near the minimum value<sup>25</sup>).

Secondly, Udo *et al.*<sup>8)</sup> used three grip types with different friction coefficient (a smooth grip; a grip with grooves parallel to the pen axis, and a grip with concentric circular grooves) to investigate the relationship between pen grip friction and the gripping pressure/pen-point pressure. The results indicate that the grip with concentric grooves had the lowest EMGs of the flexor pollicis brevis and the lowest pen-point pressure due to a higher friction coefficient between the grip and the fingers. Since the friction coefficient of rubber is considerably higher than that of plastic materials<sup>26)</sup>, the new pen may reduce gripping pressure.

Finally, the design of the new pen incorporates a grip area that tapers out by a gradient of 2 degrees, at the end nearest the pen tip. It has been found that the gripping pressure of the thumb decreases by about 5.1% when holding a tapered object as compared to a straight (cylindrical/non-tapered) object<sup>9)</sup>. In this case, the objects being compared were plastic drinking cups, which had the same diameter at the point where gripping was performed. The tapered cup had a taper angle of 4 degrees. The grip pressure was measured using a contact pressure meter with a small air-pack sensor on the thumb. The findings in this study suggest that tapered objects require a lower gripping pressure than non-tapered ones. In the case of ballpoint pens, it is suggested that, through the same mechanism, the tapered pen grip reduces gripping pressure.

Figures 5-1 and 5-2 show the equilibrium force<sup>26)</sup> of gripping pressure and pen-point pressure for the non-tapered ballpoint pen and the tapered ballpoint pen, respectively.



**Fig. 5-1. Equilibrium force of gripping pressure and pen point pressure in the non-tapered ballpoint pen.**

$F_1$ : force against paper,  $F_2$ : gripping pressure for preventing slippage,  $P$ : reaction of pen-point pressure to each finger (3P: total reaction of pen point pressure),  $N$ : normal reaction from pen grip,  $\mu$ : static friction coefficient between finger and pen grip.

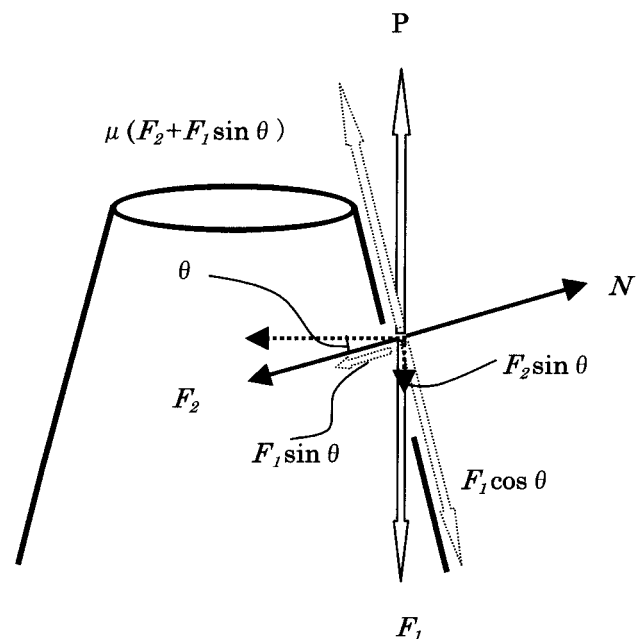
In these figures, it is assumed that: a) the level of gripping pressure is the minimum necessary to prevent the fingers from slipping; b) only three fingers—the thumb, forefinger and middle finger—are used when gripping the pen; c) the three gripping fingers are arranged around the circumference of the pen grip at an angle of 120 degrees from each other; d) the three fingers exert equal power; e) the friction coefficient between the finger and the pen grip is equal for each of the three fingers; and finally, f) the writing conditions are static.

From Fig. 5-1, the following formula has been derived.  $F_1$  is the force against the paper (1/3 of pen-point pressure), and  $F_2$  is the gripping pressure necessary to prevent the fingers from slipping.  $P$  is the reaction of the pen point pressure in each gripping finger.  $\mu$  is the static friction coefficient between the finger and the pen grip.

$$F_1 = P = \mu F_2 \quad (2)$$

from formula (2)  $F_2 = P/\mu \quad (3)$

From Fig. 5-2, the following formulas are derived.  $F_1$  is the force against the paper.  $F_2$  is the gripping pressure.  $\theta$  is the angle of taper. The new pen's grip has a taper angle of



**Fig. 5-2. Equilibrium force of gripping pressure and pen point pressure for the tapered ballpoint pen.**

$F_1$ : force against paper,  $F_2$ : gripping pressure for preventing slippage,  $P$ : reaction of pen-point pressure to each finger (3P: total reaction of pen point pressure),  $N$ : normal reaction from pen grip,  $\mu$ : static friction coefficient between finger and pen grip,  $\theta$ : angle of taper.

2 degrees. Therefore, this value is induced into formula (6).

$$F_1 + F_2 \sin \theta = P \quad (4)$$

$$F_1 \cos \theta = \mu (F_2 + F_1 \sin \theta) \quad (5)$$

induce formula (4) into formula (5)

$$\begin{aligned} F_2 &= \frac{P (\cos \theta - \mu \sin \theta)}{\sin \theta \cos \theta - \mu \sin^2 \theta + \mu} \\ &= \frac{P (1 - \mu \tan \theta)}{\sin \theta + \mu \cos \theta} \end{aligned} \quad (6)$$

induce  $\sin^2 \theta: 0.034899$ ,  $\cos^2 \theta: 0.999390$ , and  $\tan^2 \theta: 0.034921$  into formula (6)

$$F_2 = \frac{P (1 - 0.034921 \mu)}{0.034899 + 0.999390 \mu} \quad (7)$$

$$\begin{aligned} F_2 - F_2 &= \frac{P}{\mu} - \frac{P (1 - 0.034921 \mu)}{0.034899 + 0.999390 \mu} \\ &= \frac{P [0.034921 (\mu - 0.008734)^2 + 0.034896]}{\mu (0.034899 + 0.999390 \mu)} \end{aligned} \quad (8)$$

$$\begin{aligned} 0 < \mu, 0 < P \quad \therefore \quad F_2 - F_2 > 0 \\ F_2 > F_2 \end{aligned} \quad (9)$$

From formula (9), the gripping pressure of the tapered ballpoint pen is lower than the non-tapered one. In a past study, Udo *et al.*<sup>22)</sup> have reported that  $\mu$  is 2.79 between the rubber grip and the palm. If this value is assumed to be the same in this case, the gripping pressure of the tapered pen is supposed to be 10.8% lower than the non-tapered one. In this paper, the mechanism of the tapered grip in reducing gripping pressure is discussed from a theoretical viewpoint. In order to empirically prove this mechanism, further experiments, which focus specifically on this mechanism at work in the case of ballpoint pens, must be conducted in the future.

In addition to these improvements, the gripping area of the new pen is coated with a 2–3 mm thick rubber sleeve. The enhanced elasticity of this material may reduce compression of the finger surfaces and thereby the pain experienced in the fingers.

The increased size of the grip area, the higher friction coefficient of the rubber material, the flared shape of the grip, and the improved elasticity of the rubber which characterize the new pen, are believed to be effective in reducing the muscle load during writing.

## Conclusions

In this study, two different types of ballpoint pens, a new pen and a conventional pen, were compared in terms of the load they induced on the cervicobrachial muscles during writing. The new pen has a cylindrical grip area that flares out at the bottom, near the pen-tip, and has a diameter ranging from 11.9–13.6 mm. In addition, the grip consists of a 2–3 mm-thick silicon rubber sleeve that is softer and less slippery in comparison with the conventional pen. The latter has a cylindrical grip with an 8.3 mm diameter and is manufactured of hard plastic, which can make it feel rigid and slippery to the user. Twelve students without any preexisting cervicobrachial disorders were asked to transcribe an English text for one hour, alternately using the two kinds of pens. EMGs of the flexor pollicis brevis and subjective pain scores for the thumb, forefinger, middle finger, thenar, forearm extensor (forearm) and shoulder were recorded. The main results of this study are as follows.

The EMG of the flexor pollicis brevis and the pain scores for the thumb, forefinger, middle finger, forearm and shoulder for the new pen were significantly lower than the conventional pen. These results suggest that in an hour of continuous writing, the new pen reduces the muscle load on the upper limb, and therefore mitigates fatigue in this area.

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