Effects of the Direction and Distance of Horizontal Arm Movements on Local Muscular Strain—A Fundamental Study on the Teller Workplace in Bank

Akira Yasukouchi¹, Kouhei Arai¹, Junya Ohashi¹, Hideki Sako¹ and Kimitaka Kato²

1) Department of Physiological Anthropology, Kyushu University of Design Sciences
2) Space Design Section, Soft Design Department, Design Laboratory, Fujitsu Limited

This study was conducted to examine the relative differences in the muscular strain of the hand-arm-shoulder system in the repetitive arm movements which would directly depend on the layout of devices at teller counter. The subjects were five young male adults. The manual handling task was standardized and the repetition frequency was in self-pace. The arm movements were characterized by the different direction measured from the frontal plane of the subject between 0° to 150° combined with the distance measured from the acromion to the fixed points of 300, 500 and 700mm. The movements to all of the fourteen points tested were evaluated on both sides of the arms and shoulders by the integration of the EMG signals (IEMG) as to m. deltoid pars media and clavicularis, m. trapezius pars descendens, m. pectoralis major pars clavicularis and m. extensor carpi radialis brevis. It was found that IEMG of the deltoid muscles were sensitive to the direction and distance of the arm movements while the trapezius muscle showed the relative lower dependence on the direction. There were significant combined effects of the direction and distance in all muscles; i.e. effect of reach distance was greater with decreasing the arm angle, which was obvious at distance longer than 500mm in the arm abduction. When IEMG was divided by the task time in self-pace which increased in the arm abduction, the peak value was observed at the angle of 30°. It was suggested that if the repetitive movement was required at the same frequency as at the angle of 30° the position near the arm abduction (the angle of 0°) would become the most expensive working direction.


Key words: Repetitive arm movements, Shoulder muscles, Teller counter, Direction of horizontal plane, Workplace design, Manual handling

As terminal system aided by the modern technology are nowadays applied more and more in bank, this should make a new problems of the layout of electronic tools, especially at teller counter. Because many of the tools have mono-function such as passbook printer, auto cashier, seal master, cut in printer, etc., in such a workplace, tellers have to move thier arm repetitively to required tools which are placed at different direction and distance; i.e. the movements depend on the layout of each tool. It is favourable to open the space in front of the teller in order to communicate with clients, so that the devices are required to be arranged around the teller except the front. Therefore, muscular loads of the manual handling at teller workplace would be affected by the different movements of the hand-
Effects of the horizontal arm movement on local muscular strain

Arm-shoulder system, which is depending on the spatial workplace design. As was known that the repetitive movements over a long period of time with unfavourable postures can cause considerable physical ailments and complaints to the sedentary workers (Armstrong et al., 1986; Chaffin, 1987), it is important to consider the arrangement of tools at the workplace. However, there are few systematic studies to be done in order to optimize the repetitive manual handling tasks in a horizontal plane at seated work although a tremendous amount of research in the field of lifting tasks (Snook, 1978; Ayoub and Mital, 1989).

The purpose of this study is to examine the dependency of the local muscular strain on the direction and distance of repetitive arm movements in the horizontal plane. It is expected that obtained data here would contribute to the improvements not only of the teller counter but of other workplace design at seated work.

**METHODS**

(1) Standardization of manual handling of materials for repetitive movements

Task for standardization was analyzed through video tape recording (VTR). Observations was carried out at low counter of urban bank in Kanto area, Japan, which was equipped with the electronic devices. Two-hour VTR recorded in the morning was analyzed. The jobs of teller at the low counter are registrating passbooks newly or renewedly, consulting with clients, coping with various alterations such as a type of passbook and client's address, and so on. Analyses for the manual handling of a teller by VTR are summarized in Table 1. High frequency of repetition was observed in the

<table>
<thead>
<tr>
<th>Table 1 Task characteristics of a teller at low counter.</th>
<th>Frequency of appearance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics of operations</strong></td>
<td></td>
</tr>
<tr>
<td>1. Grasping</td>
<td></td>
</tr>
<tr>
<td>Picking up light materials like papers on a point</td>
<td>40</td>
</tr>
<tr>
<td>within reach and bringing it to a point near the body</td>
<td></td>
</tr>
<tr>
<td>(base point)</td>
<td></td>
</tr>
<tr>
<td>Picking up a cylindrical seal and putting a seal to</td>
<td>24</td>
</tr>
<tr>
<td>papers at the base point</td>
<td></td>
</tr>
<tr>
<td>Picking up a money saucer on the counter near a client</td>
<td>10</td>
</tr>
<tr>
<td>Being handed over something from a worker behind a teller</td>
<td>2</td>
</tr>
<tr>
<td>2. Inserting</td>
<td></td>
</tr>
<tr>
<td>Inserting a paper</td>
<td>32</td>
</tr>
<tr>
<td>Putting back a stamp</td>
<td>11</td>
</tr>
<tr>
<td>3. Placing</td>
<td></td>
</tr>
<tr>
<td>Placing light materials like papers on a table</td>
<td>2</td>
</tr>
<tr>
<td>behind a teller</td>
<td></td>
</tr>
<tr>
<td>Placing a seal or a stamp after putting it to papers</td>
<td>14</td>
</tr>
<tr>
<td>Placing a money saucer on the counter near a client</td>
<td>10</td>
</tr>
<tr>
<td>4. Operating a keyboard</td>
<td></td>
</tr>
<tr>
<td>With both hands</td>
<td>1</td>
</tr>
<tr>
<td>With one hand (handling something with another hand)</td>
<td>20</td>
</tr>
</tbody>
</table>

The percentage indicates how much the operation appeared with regard to observed time in two-hour VTR.
The sum of all characteristics exceeds 100% because some were seen simultaneously at the same operation.
movements of picking up papers or stamps from a certain area and placing them near the body and vice versa. Therefore, in order to standardize manual handling materials, the following tasks were examined;

(i) Picking up a card; a card (105×50mm) was handled repetitively ten times from a start point within reach to a base point near the body.

(ii) Picking up a stick; a cylindrical wooden stick (diameter, 20mm; height, 90mm) was handled repetitively 6 times from a start point within reach to a slot on the wooden base near the body which has six slots.

(iii) Placing a card; a card was handled repetitively ten times, picking it up from the base point near the body and placing it on a fixed point within reach.

(2) Experiments

Subjects

The subjects were a relatively homogeneous group of five young males in respect of age 22.4±0.5 years), body height (171.8±4.6cm), sitting height (91.2±3.5cm) and upper limb lengths (right: 74.8±2.8cm, left: 74.9±3.0cm). All subjects were physically fit, without any traumas or musculoskeletal complaints in their life histories.

Layout of the repetitive movement

Experiments were carried out using the stand which consisted of a horizontal table and stool without back. The stool surface was adjusted to the popliteal height and the table height to the right elbow joint. The repetitive manual handling tasks were characterized by the different direction measured from the frontal plane of the subject from 0° to 90° and the distance measured from the acromion to the fixed points of 300, 500, and 700mm (Fig. 1). Furthermore, two points were added of the direction of 120° and 150° with the distance of 700mm. In general, 14 points were tested.

Preliminary experiments

Three repetitive manual handling tasks above mentioned were performed for all (14) tests in random order. During the repetitive tasks, the subjects were instructed to hold upright position and not to rotate the stool. Bipolar surface electrodes (silver-silver chloride) were attached to measure activities of m. trapezius pars descendens, m. trapezius pars ascendens, m. deltoid pars media, and m. extensor carpi radialis brevis. Electromyogram (EMG) for four muscles were recorded simultaneously and monitored on the pen recorder. The EMG evaluations were based on the traditional way, i.e. the amplified, rectified and integrated myoelectric signals.

Analyses of variance revealed that there was no significant difference between tasks except the EMG of m. deltoid pars media. However, the EMG of the detoid muscle indicated almost the same pattern between tasks as shown in Fig. 2 which data described relative changes in mean electromyographic activity. Therefore, it seems to be reasonable to select one task for experiment. Task of picking up a stick was selected because the subjects sometimes failed to pick up a card in the task of (i) and (iii).
Experiments

Experiments were carried out for a task (ii) for both sides of the hand-arm-shoulder system. Repetitive movement of the task was performed with self-pace and the working time was measured during each test. Fatigue and transfer effects were thought to be avoided or minimized by means of a short working time for each test and by interspersed relatively longer rest pauses between the tests. Two EMG registrations were added to those in the preliminary experiments, which were m. pectoralis major pars clavicularis and m. deltoid pars clavicularis, and the measurement of activity for m. trapezius pars ascendens was excluded because no difference existed between test points (F=1.75).

Finally, ten muscles for both sides of the hand-arm-shoulder system were measured. To ensure consistency of results, all the tests on a subject were done without disturbing the electrodes, once they were attached. All EMG data were stored on PCM data recorder (TEAC RD-110T) and digitized with a sampling frequency of 400Hz, then, stored on a disk. The EMG signals were integrated for the duration of repetitive movements in each test and defined here IEMG. The any resistance between electrodes was less than 10 kohm before the beginning of the recordings.

The statistical analysis was based on the analysis of variance. The factors examined for the statistical significances were lateral symmetry, test, and subject for all test conditions and lateral symmetry, direction, distance, and subject for tests except two conditions of 120° and 150°.

RESULTS

The results of the analysis of variance for all measurements were shown in Table 2, in which the factors tested for statistical significances were lateral symmetry, direction, distance, and subject for conditions except two tests of 120° and 150°. The activity of the muscles was demonstrated by the percentage of IEMG measured in the test of 0° and 700mm of the left hand.

Time

All the fourteen tests were performed with self-pace of the subjects. The task time for all tests was shown in Fig. 3. The analysis of variance indicated
Table 2 Summary of analysis of variance for all measurements obtained at conditions between 0° and 90° of the angle.

<table>
<thead>
<tr>
<th>Factors</th>
<th>M.D.P.M</th>
<th>M.D.P.C</th>
<th>M.T.D.</th>
<th>M.P.M.P.C</th>
<th>M.E.C.R.B</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Lateral symmetry</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B) Direction</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>C) Distance</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>D) Subject</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

M.D.P.M.; M. deltid pars media, M.D.P.C.; M. deltid pars clavicularis, M.T.D.; M. tapezius pars descendens, M.P.M.P.C.; M.pectoralis major pars clavicularis, M.E.C.R.B.; M. extensor carpi radialis brevis, *; P<0.05, **; P<0.01.

Fig. 3 The test time required for repetitive movements in self-space.

that the task time was significantly affected by the direction, distance and these interaction, but the difference between the right and left hands was not significant. The time was increased with decreasing angle from 90° to 0° and with increasing distance. The time was smallest in the area in front of the subject and the direction of 120°, although the time was measured only one condition of 700mm each at 120° and 150°.

M. deltid pars media and clavicularis
Relative changes in the activities of the deltid...
Fig. 4 Relative changes in IEMG of M. deltid pars media. The data was shown by the percentage of IEMG measured in the test of 0° and 700mm with a left hand.

Fig. 5 Relative changes in IEMG of M. deltid pars clavicularis. The expression of data was the same as in Fig. 4.

Muscles were not significantly different between the right and left hands but the significant interaction between the lateral symmetry and subject was observed (Figs. 4 and 5). The factors of direction and distance and the interaction between them were significant for both muscles. Maximal activities of the muscles were observed at the direction of 0° and the distance of 700mm. The effect of distances was
increased with the direction from 90° to 0°. IEMG of the muscles tended to be further decreased from 90° to 150°.

**M. trapezius pars descendens**

The significantly affecting factors on this muscle were almost the same as those of the deltoid muscles. However, IEMG pattern between the directions of 90° and 150° was different (Fig. 6). IEMG was smallest at 90° among the tests of 700mm.
M. pectoralis major pars clavicularis

IEMG of this muscle was characterized by the significant effect of lateral symmetry and the no effect of distance (Fig. 7). The factor of direction was significant and IEMG tended to increase at greater than 90°, but in general, the effect observed at smaller than 90° was relatively small.

M. extensor carpi radialis brevis

This muscle also indicated changes in IEMG and the factors of direction, distance, and these interaction were significant with no significance of lateral symmetry (Fig. 8). The effect of distance tended to increase with direction from 90° to 0°.

DISCUSSION

The purpose of this study was to examine the muscular load of repetitive movements required to tellers at a low counter, which is expected to be basic data to improve the workplace design at a seated work.

The muscular loads of the teller's task is considered to depend mainly on the type of operation and repetitive movements. Three types of task were selected in this study by the analysis of VTR, recorded at the real bank, preceded by the experiment. In the results of the preliminary experiment, the mean amplitude of EMG activity (MEA; IEMG divided by the test time) was almost the same among three tasks, which means that the repetitive movements have a dominant effect on the muscular loads of the teller's task rather than the type of operation. Then, it may be important to evaluate the loads of the upper arm and shoulder muscles in respect to the direction and distance of repetitive movements in order to consider the workplace design of the teller counter.

It is difficult to evaluate absolute values from different lead positions in this study because of uncontrollable contractions of the shoulder region muscles (Schuldt and Harms-Ringdahl, 1988) and of concomitant signals from several muscular activities other than the target muscle to which surface electrodes were attached. In the study of Hagberg (1981), when the arm was elevated either in the abduction or in forward flexion, the load on the
shoulder by the arm weight exceeded 10% of maximal voluntary torque in the glenohumeral joint, which led muscular fatigue of the arm and shoulder region within five minutes. Further, it was pointed out that the effect of forward arm reach on shoulder muscle fatigue became greater as weight held in hand was getting lighter (Chaffin, 1973). These observations imply that only keeping the elevated arm becomes relatively heavy load, so that the relative loads on the arm and shoulder muscles caused by the arm movements within reach are worth being evaluated.

The evaluation of muscular strain in this study was expressed by the integration of the EMG signals. The muscular loads of the repetitive movements were not significantly different between both sides of the hand-arm-shoulder system except clavicular part of the major pectoral muscle. Why the major pectoral muscle showed the difference was not explained in this study, however, greater activity was observed in both sides more than the angle of 90°. Only this muscle showed no difference in IEMG between distances, which imply probable independence on the fatigue of shoulder region. This is supported by the fact that clinical symptoms from the major pectoral muscle are not common.

The EMG activities of the deltoid muscles, being mainly responsible for the abduction (pars acromialis) and forward flexion (pars clavicularis), show similar features each other. IEMG of both of the muscles were sensitive to the direction and the reach distance of movements, and the interactive effects existed; i.e. the effect of reach became greater with decreasing the arm angle measured from the frontal plane. Especially, the effect was obvious in the arm abduction at reach longer than 500mm where exceeds regular work-space. IEMG of the upper part of trapezius muscle had also similar pattern to those of the deltoid muscle between the angle of 0° and 90°, however, relatively lower dependence on the direction. This indicates that the trapezius muscle should be always active in various movements of the elevated arm. This muscle suspends the scapula and prevents its downward rotation when the arm is elevated. Considering that the trapezius muscle is more susceptible to fatigue compared with the deltoid muscles in elevated arm positions (Hagberg, 1981), the continuous activity observed in this study might be one of causes of worker's neck complaints and tenderness over the shoulder muscle in occupational situations demanding elevated arms as have been reported common (Bjelle et al., 1979).

Task time for repetitive movement in this study increased (i.e. repetitive frequency decreased) as the arm angle decreased from 90° to 0°. The increased time in the arm abduction reflected the large values of integrated EMG signals. This led to decrease in MEA in the arm abduction. The results of MEA were almost the same as those of IEMG except at the angle of 0°and 30°. The peak value of MEA was observed at the angle of 30°, as also shown in Fig. 2. This results are in agreement with those of Strasser and Keller (1989) although their subjects were females. This might imply that the direction effect on MEA obtained from the muscles of the arm and shoulder is independent of sex. In the study of Strasser and Keller (1989), dynamic and static components were calculated from the time course of EMG activity with the arm repetitive movements, in which static component increased with increasing repetitive frequency but not with weight held in hand. This suggests that decreased repetitive frequency observed in the arm abduction in this study might be caused to have static load on shoulder muscles lightened. Therefore, it is supposed that the position near the arm abduction becomes the most expensive working direction if the repetitive movement at a constant frequency is required, although this feature is different from the results of Strasser and Keller (1989).

The activity of radial carpal breviextensor also became greater as the arm angle decreased, which was unexpected because this muscle is not directly
involved in the elevated arm movements. The functions of this muscle was related to the movements of carpal extension and/or abduction. The activity of this muscle in Fig. 8 suggests that stretched arm to the direction of a small angle with grasped something would cause extension and/or ulnar abduction of the hand, which is recommended to be avoided in repetitive work (Armstrong et al., 1982; Fernandez et al., 1991).

It was concluded that in the aspect of the muscle loads and working time examined in this study the best direction was the angle around 90° and the worst was the angle less than 30°, especially the angle of 0° in a constant frequency of the repetition. The effect of the arm reach was greater as the angle became smaller, especially in the reach over 500mm.

REFERENCES
Bjelle, A., Hagberg, M. and Michaelsson, G., 1979:

(Received April 15, 1993)

Akira YASUKOUCHI  Department of Physiological Anthropology, Kyushu University of Design Sciences, 9-1 Shiobara 4-chome, Minami-ku, Fukuoka 815, Japan
安河内  朗  〒815 福岡市南区塩原4-9-1 九州芸術工科大学生理人類学教室