Internal Aspects Of The Skill Transfer Of Manual Assembly Work

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ABSTRACT

In manual assembly work, parts are often assembled by applying force with a simple tool or by hand. A worker thus needs control the force he or she applies in working, as an appropriate level of force is requisite for minimizing work failures and improving efficiency. The object of this study is to clarify the relationship between the level of force and level of training difficulty in manual assembly work. Measurements of the training difficulty for 10 test subjects (persons being tested) at force gauges of 30, 40, 50, 60, 70, 80, 100, and 120N revealed a relationship between the force gauge internal to each test subject and the training difficulty

1. INTRODUCTION

In the production of household electric appliances, office equipment, and information communication equipment, manufacturers assemble identical products in large-volume lots to satisfy the consumer demand for large quantities. Many companies adopt cell manufacturing systems, while others rely on older, more conventional forms of line production. Sometimes line production is the only choice available, as difficulties in hiring adequate numbers of multi-skilled workers rule out cell manufacturing. Product lifetimes, meanwhile, are being reduced as a consequence of diversifying consumer requirements and the frequent introduction of new products to the market. As a result, manufacturers are often forced to change their production lines. The obvious solution, automated production lines geared to accommodate frequent changes, are very costly and cannot be justified from an economical point of view. Thus, manual assembly work by workers remains the mainstream.

In a survey of the actual assembly work on a production line for office equipment, the assembly of parts using manual force, either by hand or with simple tools (e.g., tightening screws to attach sheet-metal, mounting E rings, or connecting connectors), accounted for 60% of the total work performed. Though some of these procedures required special skills with tools (e.g., caulking, soldering, or wrapping connections), most of them did not, and most people in the plant believed that the assembly work progressed smoothly as a whole. Yet by closely observing the actual work in this plant, frequent problems were identified. In some cases parts fell apart, for example, and assembly procedures were impossible to complete with a single maneuver. In other cases parts were assembled at an angle, or were dropped, or sprang out, or the assembly work wasn't properly finished due to a worker's failure to apply just the right force. Problems of this type not only wasted time and compromised quality, but also led to variations in the time required for work. The methods of work used, including the manual work by hand or with simple tools, were clearly flawed.

Two types of skill are considered necessary for accurate results in manual assembly work.

- A means to control the hand and arm in order to accurately position a part at the point where it is to be assembled, by controlling the direction, angle, and speed of the hand as the hand holds the part or holds a tool with the part attached.
- A means to control the pressing force required to assemble a part after the part has been positioned at the point it is to be assembled.

In an earlier study[1)], the author developed a computerized training system which could convey the experience of "the ideal maneuver of a skilled worker" to a trainee. In testing with actual trainees, this system was found to be quite effective in improving control of the hand and arm motions, but not control of the pressing force applied through the hand motions. We therefore selected, as a target for the present study, a system which can train workers to keep the pressing force at necessary levels for the manual assembly work.

As suggested by Weber's law[2)] or Stevens' power law[3)], differences in the pressing force (hereinafter, the pressing force will be described as the "force") are expected to become more difficult to discriminate when the force gets larger, as the discrimination threshold becomes larger in parallel. Yet the experiments conducted to test these laws covered a relatively narrow range of stimulation. According to our survey of an assembly plant producing office equipment, the pressing force necessary for manual assembly was 30~120N, and the range of stimulation was much wider than that covered in experiments conducted on aesthesia. One study has even concluded that Weber's law and Stevens' power law are wholly inapplicable once the range of stimulation surpasses a certain point[4)]. In view of the foregoing, we have an interest in clarifying the force required for manual assembly work and the level of training difficulty (the "training difficulty"). Such being the case, we have conducted this study to clarify the relationship between the force and training difficulty, and to obtain the knowledge necessary for training workers to control the pressing force in manual assembly work.

2. TASK AND EVALUATION INDEX

2.1 Task

Manual assembly work involves various work maneuvers. With the tightening of sheet-metal screws and the mounting of E rings, for example, parts are assembled using simple tools such as motorized screwdrivers or E-ring holders. With the connecting of connectors, on the other hand, parts are assembled directly by hand. In this study we focused on processes reliant on manual force, a common requirement for many types of assembly work. To restrict the object of our study to maneuvers by hand, we eliminated any manual maneuver performed using simple tools. Thus, we selected a maneuver involving the simple application of force by the hand of the subject's primary arm (right arm for a right-hander, left arm for a left-hander), without the use of a tool (Figure 1)

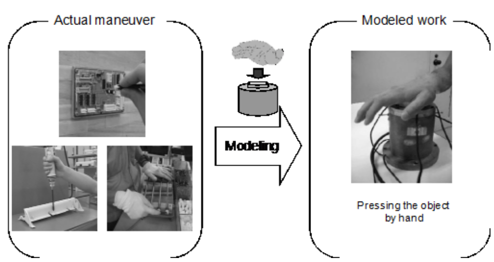

Fig 1. Work Maneuver Studied

According to our survey of an assembly plant for office equipment, the minimum force required for any one maneuver was 20N, for tightening a sheet-metal screw, and the maximum force required was 120N, for mounting an E-ring. Thus, we set the range of force for this study as 30~120N.

In the training experiment described later, the subjects were trained to remember the force required for the maneuver studied (hereinafter called "target value"). Later, we tested whether or not the subjects could apply the target value repeatedly and accurately.

2.2 Experimental setup and layout

The experimental setup for this study is shown in Figure 2. The measuring module developed by Matsumoto and others was used to detect the force[5)]. The detection module outputs the level of force as an electric signal via a load cell (Aiko Engineering: ultra miniaturized load cell for compression, CM-10K). The output from the load cell is amplified by an amplifier (Unipulse: Load cell converter, LC210), converted to a 12 bit digital signal by an analog/digital converter board (Contec: AD12-16S(98)H), and captured by a personal computer (IBM: ThinkCentre A51P, Pentium 3.6GHz). The voltages are continuously converted into force values, and the force values are automatically recorded every 0.015 seconds. The minimum measurement accuracy is 0.0958N. Using the data captured by the personal computer, a bar which expands or contracts according to the force (the “feedback bar”) is shown on a touch panel display (Iiyama: AX3844D) (Figure 2-(5)) to express the increase or decrease of force by the expansion or contraction of the feedback bar. In the training, the test subject learns the force of the target value by applying just enough force to the measuring device to keep the feedback bar as close as possible to the target value (indicated by a red line on the display). The software to display the feedback bar was developed using Visual Basic 6.0 from Microsoft.

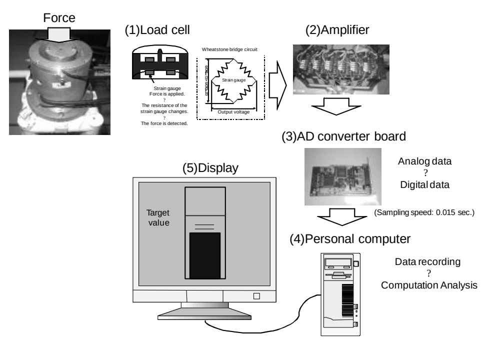

Fig 2. Experimental setup

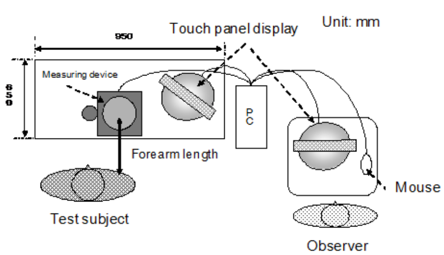

Fig 3. Layout

The layout of the experiment in this study is shown in Figure 3. The force measurement device is placed at a position in front of the test subject at a length obtained by adding the forearm length to the acromial point (uppermost point of the shoulder) of his/her better arm. The observer operates the personal computer behind the test subject to the right, where the observer cannot be seen. The working position is set in front of the test subject, at a point determined by adding the forearm length of the subject to the acromial point (so that the working position remains constant). By setting and fixing the work position in this way, the working posture of the test subject will also stay somewhat fixed. More postural parameters, such as the degree to which the subject stretches the muscles of his/her back or open his/her arm, are less precisely controlled. For general control, the subject is instructed to relax and take a natural posture. This seemed a suitable approach, as the best posture for easy application of force may differ from person to person.

2.3 Evaluation index

The difference between the maximum applied force at each test and the target value is recognized as the control error, and the control error during the test is used as the evaluation index for the training difficulty.

2.4 Internal gauge

Given that human aesthesia can always somehow be categorized[6)], there is assumed to be a force gauge internal for every test subject (the "internal gauge"). And if an internal gauge does exist to each test subject, it is very likely that the internal gauge affects the training result, and analysis of internal gauge during training will be necessary. For this reason, we researched the internal gauges of the test subjects in this study.

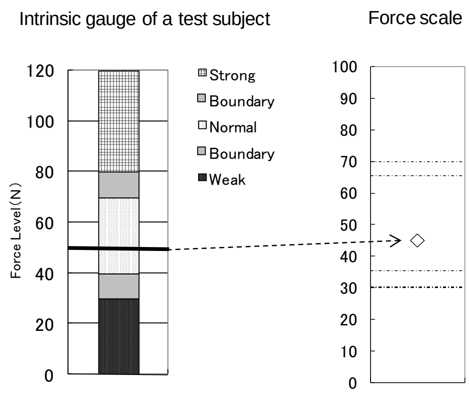

Fig 4. Internal gauge and force scale

For measurement of a psychological amount (such as an internal gauge), we decided to use reaction words for judgment, following the earlier example from the study by Campbell and others [7)]. Specifically, we decided to use three reaction words: "weak," "normal," and "strong." In an earlier study on weight lifting stimulation[8)], modifiers (e.g., "very") were added to reaction words (e.g., "light"), resulting in additional categories such as "very light" or "very heavy." In designing the present study, we speculated whether too many extra categories would make it difficult for the test subject to select between adjacent categories. To keep the things simpler for our subjects, we had them express their internal gauges as described above, in the categories of "weak," "normal" and "strong."

Thus, our research on the internal gauges proceeded in the following steps: 1) using the experimental setup described above, the test subjects were randomly subjected to 23 levels of force, set in increments of 5N within a range of 0~120N; 2) the subjects selected "weak," "normal," or "strong" on the touch panel after each force experience; 3) the test results were graphed (left side of Figure 4). When a test subject gave a conflicting response (e.g., by selecting "normal" for 70N but "strong" for 60N), the range in which the conflict appeared was regarded as the boundary of the internal gauge. No measurements were taken for ranges of less than 10N. Forces of 10N or less were assumed to be "weak" internal gauges, because the weight of a hand alone represents 5~10N, and thus corresponds to a state of zero force applied. Likewise, measurements of ranges of greater than 120N also went unmeasured. All 20 test subjects answered "strong" for 120N or higher in the preliminary test, hence 120N or higher was assumed to be "strong."

To clearly describe where a certain force f is relatively positioned in the internal gauge of a test subject, the internal gauge was expressed by a value in the range 0~100, and a force scale of $S(f)$ was made according to the steps described below.

1. To express the internal gauge by the numbers of 0~100, the value 30, that is, approximately one third of 100, is allocated to "weak," "normal," and "strong," and the remaining 10 is divided into two and allocated to two gray zones, one between "weak" and "normal" and one between "normal" and "strong." As a result, the force scale range where the test subject feels "weak" is 0~30, the gray zone force scale between "weak" and "normal" is 30~35, the force scale range for "normal" is 35~65, the gray zone force scale between "normal" and "strong" is 65~70, and the force scale range for "strong" is 70~100.

2. We also surveyed the subjects to determine the category (“weak,” “normal” or “strong”) into which *f* falls for the test subject, then computed the force scale S(*f*) by formula (1), assuming that the minimum value of force within the applicable range is Fmin, the maximum value of force within the applicable range is Fmax, the maximum value of the force scale within the applicable range is Smax, and the minimum value of the force scale within the applicable range is Smin.

$$S(f) = \frac{f - F_{\min}}{F_{\max} - F_{\min}} \times (S_{\max} - S_{\min}) + S_{\min} \quad \cdot\cdot\cdot\cdot \text{Formula (1)}$$

Figure 6 explains the procedure used to obtain the force scale $S(50)$ for f=50N, when a certain test subject perceives 40~70N as “normal.” Because *f* is a force the test subject perceives as “normal,” the range of interest in this case is “normal.” The minimum value that this test subject feels “normal” is 40N and the maximum value is 70N. Therefore, Fmin=40N and Fmax=70N. Furthermore, because the force scale perceived as “normal” is 35~65, Smin=35 and Smax=65. Therefore, we can obtain the result as shown in formula (2) below. Furthermore, the unit of force scale is S, and is described as 45S in the example above.

$$S(50) = \frac{50 - 40}{70 - 40} \times (65 - 35) + 35 = 45\text{S} \quad \cdot\cdot\cdot\cdot \text{Formula (2)}$$

3. EXPERIMENT ON FORCE AND TRAINING DIFFICULTY

3.1 Purpose of the experiment

The purpose of the experiment was set as investigating the relationship between the size of the target and the training difficulty level by assuming a training to acquire technique to control force in manual assembly work, establishing multiple target values, and measuring the training difficulty level at each target value.

3.2 Experimental plan

Eight target values were set up for the experiment: 30, 40, 50, 60, 70, 80, 100, and 120N. The targets were set at intervals of 10N between 30 to 80N, and at intervals of 20N between 80 to 120N, to adjust for muscle fatigue of the subjects. The test subjects were 10 male students, aged from 22 to 24. The experiment was conducted in the following steps in an environmentally controlled room maintained at a temperature of 20~25℃ and humidity of 50~55%.

<u>Experiment procedure</u>

1. The order of training for the above 8 target values was determined randomly.
2. The feedback bar was shown on the display, and the subjects memorized the target values in 10 consecutive training sessions.
3. The feedback bar was not shown on the display, and the subject was asked to keep the force at the target value level without the guidance of the feedback. Five consecutive tests were conducted.
4. The subject took a 30 minute break.
5. The target values were changed according to the order determined in 1 above, and steps 2 to 4 were repeated until the experiment was completed for all of the target values.

6. When the training and testing were completed for all of the target values, the investigation for the internal gauge was conducted. This was done after the experiment to prevent the internal gauge from biasing the experimental results. This was considered a risk, as a prior investigation of the internal gauge may have induced the subjects to form the internal gauge intentionally during the subsequent experiment.

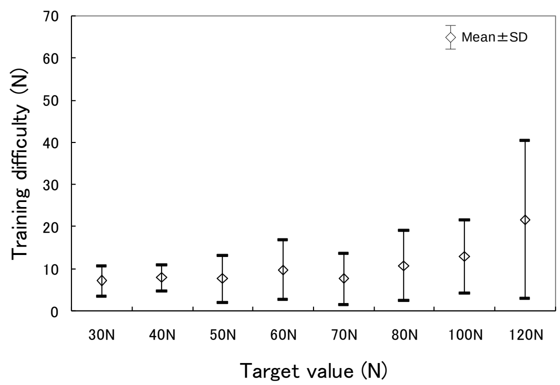

Fig 5. Relationship between the target value and training difficulty

3.3 Results of the experiment and observation

Figure 5 shows the average value and standard deviation of the training difficulty for all the test subjects, by target value (horizontal axis, target value; vertical axis, training difficulty). Judging from the figure, we can conclude as follows: there is little difference or variation in the training difficulty in the 30~70N range; the training difficulty rises as the target value increases in the range of 100N or higher; the variation also tends to rise at 120N.

Figure 6 shows the average value and standard deviation of the training difficulty by target value for each test subject (horizontal axis, target value; vertical axis, training difficulty). In looking at the relationship between the force and training difficulty of each test subject, we find two types of subjects: those such as h, who encounter lower training difficulty than the other test subjects for all of the target values; and those such as a, c, d, f and J, who encounter large training difficulty for certain target values. Based on this result, we can see that the training difficulty for each test subject tends to go up as the average target value increases (Figure 5) for all test subjects, while there should be some difference from one individual to another. We also note, significantly, that each test subject scores abnormal points when encountering high training difficulty in a discontinuous manner in the target value range of 50~70N (dotted line in Figure 6).

Weber's law and Steven's power law can explain the rise in the training difficulty to a high level as the target value rises, but they cannot explain why abnormal points appear in the 50~70N range. Therefore, we show the force scale of abnormal points in Figure 7 (horizontal axis: test subject, vertical axis: force scale) to clarify the relationship between the internal gauge of each test subject and the abnormal points. Each point in the figure shows the eight target values, and the white circles show the abnormal points. As the figure demonstrates, the abnormal points of each test subject appear within the force range of 35~65S (a range the subjects perceived as "normal").

In comparing Figures 6 and 7, we find the following. The training difficulty was small in the range of 30S or smaller (a range the subjects perceived as "weak"), and the difficulty change little even when the target value changed. The training difficulty also tended to rise as the target value rose in the range of 70S or larger (a range the subjects perceived as "strong"). Based on this result, the internal gauge of the test subject can be assumed to affect the training difficulty.

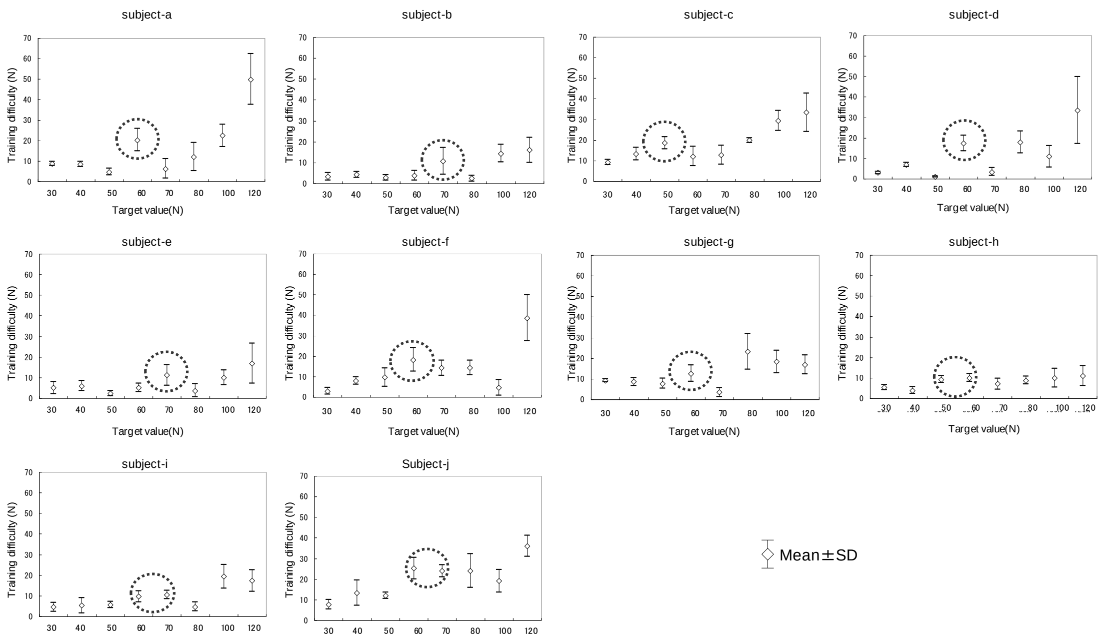

Fig 6. Training difficulty for each test subject

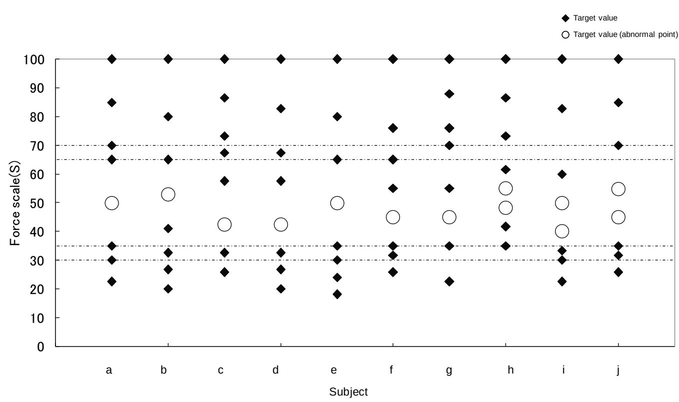

Fig 7. Force scale for each target value

3.4 Characteristic of the behavior of abnormal point

To analyze the actual forces applied by test subjects during the tests, Figure 8 graphs values obtained by converting the maximum abnormal points onto a force scale (horizontal axis, test subjects; vertical axis, force). Given that the maximum abnormal points are distributed around 68S, as the graph shows, we can assume that a so-called "centering trend" is taking effect[9]. When a neutral value is set as a reference point for making a judgment, a centering trend is at work when the values greater than the neutral point are underestimated and the values smaller than the neutral point are overestimated. If, however, we set 68S as a neutral point in our experiment here, the test subjects tend to apply a force larger than the target value in the test even for the target values greater than this neutral point, without any evident bias back towards 68S. Thus, we can consider this a phenomenon different from the centering trend. Based on this fact, there is a trend that the target value is overestimated for the target value of high training difficulty level, while the subject restrains the applied force more for target values of 35~65S, as the standard of the internal gauge of 68S for forces larger than the target value gives the subject the impression that the force isn't "strong." As a consequence, the force can be assumed to be assimilated into the force around 68S, the threshold between the force perceived as "normal" and the force perceived as "strong."

Based on the above analysis of the behavior of force, we see that it is important, when designing the training program, to have the trainees recognize their own tendency to overestimate the target values of high training difficulty. It also seems necessary that the training program add the adjustment capability at an early point, starting from lower forces which are easier to learn, such as 32S or 68S, and to have the subjects learn the size of the target value relative to the other values.

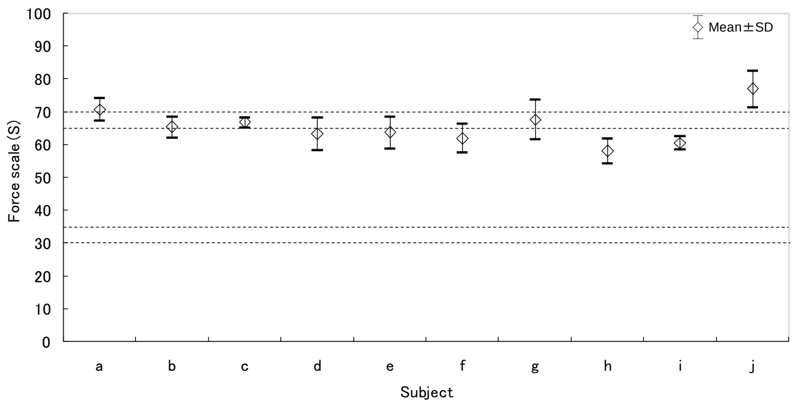

Fig 8. Maximum value at abnormal point (Force scale)

4. CONCLUSIONS

In this study, a training to learn the technique to control force is assumed, and experiments were conducted with an objective to clarify the impact of the target value size to the training difficulty level.

Based on Weber's law or Stevens' power law, we assumed that the training difficulty would continuously increase as the applied force for training increased. As it turned out, however, the training difficulty was low at target values of 32S or lower, stayed almost the same even as the target value changed, rose to high levels at the target level of 50S, dipped at the target level of 68S, and rose to high levels again at the target values higher than 68S. Based on this result, we concluded that a target value with high training difficulty for a test subject could be clarified by measuring an internal gauge of the test subject and computing a force scale.

Once the relationship between the force and training difficulty is clarified, the number of training session needs to be increased or a method of feedback needs to be devised if the training session is conducted for a force-control technique at a target value with high training difficulty. One way to improve work efficiency, in the design stage, is to eliminate any maneuver which requires a force of high training difficulty for many workers.

In the future we plan to develop a training method which is efficient for target values of high training difficulty.

AUTHOR INFORMATION

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