Effect of visual cues on line drawing performance

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Abstract—**This paper investigates how visual cues affect human performance at a line drawing task. Line drawing is a primitive and fundamental task using tools such as pens, (soldering) irons, and cutters. Many situations (for example, home, office, studio, and workshop) require drawing lines with tools. Assistive tools for improving performance might be especially useful for unskilled people. As a first step, we focus on visual cues as assistive tools and determine the kinds of visual cues that are effective for good performance. We asked subjects to draw a line on a displayed dotted line while the spacing and shape of the dots is changed, and we then analyzed the data. The results indicate that the cue that should be displayed for good performance should change according to subjects' performance: for good performers the cue whose geometrical center is easy to detect, and for not-good performers the cues whose occupied area is large. We also discussed the possibility of controlling performance in line drawing, and presented a strategy for displaying visual cues for good line drawing performance.**

Keywords-component; line drawing; performance control; visual cue;

I. INTRODUCTION

A high level of quality in (hand-made) products and operations requires highly developed skill. In the case of dyeing a kimono, artists color a drawing on cloth with brushes. This task requires precision in the position and force control of the brushes. Medical operations involving surgical cutting or burning of organs with such instruments as scalpels also require precise position and force control of the instruments in order to avoid injuring normal tissues around the affected area. Only a limited number of highly skilled experts can perform such tasks, and only after long training. Even when training is provided, the number of people who finally succeed in mastering the skills is small, so only a limited number of people can avail of complex and difficult surgical operations performed by experts. In the community of Japanese traditional crafts, the aging of crafters has become a serious problem, and preserving the technical tradition is a very important issue. One solution might be to increase the number of candidates who can become highly skilled.

Developing a skill support system would enable many people to have complex surgical operations, as well as enabling people who would like training to have a chance to become experts even without much physical dexterity. Even retired people would have the opportunity. The final goal of the research is to develop a system that augments peoples' skills so that even unskilled people can perform at the level of skilled people. As a first step, this paper focuses on the evaluation of human performance.

In recent years, surgical operations with robots have become popular [1-3]. One of the most popular surgical robotic systems is the da Vinci telemanipulation system (Intuitive Surgical, Mountain View, CA). In telerobotic master–slave systems, when the operator manipulates the master manipulator, the manipulation information is transferred to the slave manipulator, which contacts the real world. During the transfer, we can remove unnecessary information, such as a surgeon's tremor. This effectively helps surgeons to operate safely. In bilateral control systems, where force or position information at the slave manipulator is also transferred to the master manipulator, we can add a (virtual) motion constraint at the master manipulator to support operators so that the operators can manipulate operations precisely [4]. Such systems can be said to support the skill of the operators, but they are support systems for indirect manipulation by robots. The aim of this paper is direct manipulation using tools without robots acting as intermediates between the operators and tools. Examples of systems that directly support the tool manipulation skill of the operators are ICanDraw [5] and ShadowDraw [6]. ICanDraw provides instructional procedures and corrective feedback so that an operator can draw a reference human face accurately. ShadowDraw assists the operator in drawing by shadow. If an operator draws, the system infers what the operator is drawing and provides a suggestive shadow of the inferred image. The provided image is a blend of relevant images from a database. These systems work effectively, but the reasons for their effectiveness are unclear. Various analyses from different viewpoints might be needed for understanding human performance and constructing more effective systems. Focusing on sketching, several researchers have analyzed how humans recognize an image. Koenderink et al. [7] studied cues for recognition of shapes in pictures. Phillips et al. [8] studied how people identify landmarks on object surfaces. Isenberg et al. [9] compared drawings by humans and computers. Cole et al. [10] analyzed lines drawn by artists and compared them with lines derived by line drawing algorithms in computer graphics. They showed that computer-generated lines can describe lines drawn by artists with high accuracy. Eitz et al. [11] studied how humans and computers recognize the category of sketches drawn by non-experts, and developed a sketch recognition system. However, several problems still remain open.

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One of those problems is the effect of visual cues. Which kind of displayed visual information affects human performance and how is unclear. This paper focuses on this issue. A complex task can be regarded as a combination of simple primitive tasks. One of the most primitive tasks is drawing a line. Line drawings are used not only in sketching and coloring but also in soldering, cutting, grinding, burning (with scalpels), and so on. Therefore, it is worthwhile to evaluate human performance in line drawing, as we do here. We use a dotted line as a cue (visual displayed information). By displaying dotted lines with varying shapes and dot spacings, this paper determines the kinds of information that improve performance and the kinds of information that degrade performance.

The paper is organized as follows. In section II, we describe the methodology for the experiment, with the results shown in section III. We discuss the results in section IV.

II. METHODOLOGY

A. Subjects

Ten Japanese volunteers (men and women, mean age 21.5 ± 1.6 years (from 19 to 23 years)) participated in the experiment. They were all right-handed, and none of them had difficulty with their hands, vision, or haptics. In order to remove any effects of cultural difference, only Japanese participated. These experiments were approved by the Medical Ethics Committee of Kanazawa University.

B. Apparatus

Fig. 1 shows a schematic view of the experimental setup. The operator draws lines or curves using a pen tablet (Wacom Intuos5). The drawings are displayed on the monitor (HP ZR2040w), along with visual cues for helping the operators. The position and force of the pen can be measured through the tablet system.

C. Stimuli

Fig. 2 shows the visual information displayed to assist operators. The subjects were asked to draw a line along the dotted line. Because human arms are constructed from revolute joints and links, it is reasonable to expect that drawing straight lines will be more difficult than drawing curves. The first step in Japanese textbooks for calligraphy is drawing straight lines. For these reasons, drawing not a curve but a straight line was selected. Methods such as connecting points and drawing lines along dotted lines (which constructs letters) are popularly used in Japan when teaching letters to children. In this regard, we evaluated dotted lines as a means of assisting operators. By changing the shapes and spacings of the dots, we examined the effects of different visual cues on performance. Circles, rectangles, and triangles were chosen as the shapes of the dots in order to observe the effects of isotropy, occupied area, and geometrical center position of the shapes. We prepared two kinds of spacing between dots to determine the effect of spacing. The spacing for nominal lines was determined such that the space is almost the same as the width of one dot. The spacing of wider lines is two times the space of that of the nominal lines. In total there are six types of visual cues. The dotted lines (visual cue) were displayed at 0° to the horizon for observing the performance of fundamental operations.

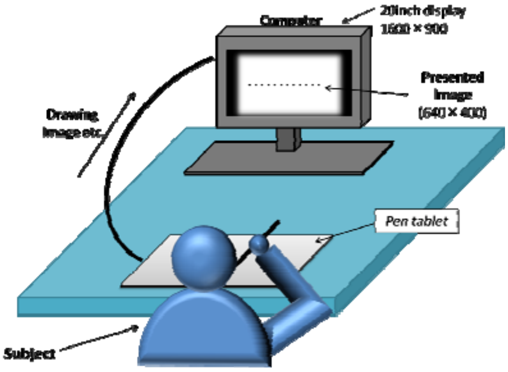
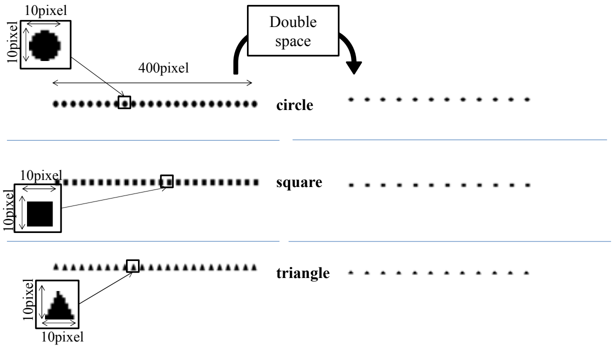


Fig. 1 Schematic view of the experimental setup



(a) nominal **(b) wider**

Fig. 2 Displayed visual cues for helping operators

TABLE I. DEFINITION OF SYMBOLS EXPRESSING VISUAL CUES

Symbol	Visual cue
●●●	●●●●●●●●●●●●●●●●●●●●●●
■■■	■■■■■■■■■■■■■■■■■■■■■■■
▲▲▲	▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲▲
● ●	● ● ● ● ● ● ● ● ● ● ● ●
■ ■	■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■
▲ ▲	▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲

D. Procedure

First, to let the subjects familiarize themselves with the system so that they could draw anything normally, every subject was asked to draw freely. This preliminary experiment was continued until the subject reported being comfortably familiar with the system. After the preliminary experiment, every subject was asked to draw a line along the displayed dotted line from left to right so that the drawn line could be as close as possible to the dotted line. The presented dotted lines are the six shown in Fig. 2 and TABLE I. We designated the trials for the six kinds of visual cues as one trial cycle. Every subject conducted one trial cycle four times. As the first cycle, we displayed the visual cues in the order ●●●, ● ●, ■■■, ■ ■, ▲▲▲, ▲ ▲, and subjects drew lines along the cues. After the first trial cycle, the second trial cycle was conducted in the reverse order of that of the first trial. The third trial cycle was conducted after the second trial cycle in the same order as that of the first cycle. The order at the fourth cycle (after the third cycle) was the same as that of the second cycle. In this way, we took the effect of learning and practice (getting used to drawing lines) into account. It is possible to feed back the magnitude of forces by the thickness of the drawn lines, but this paper focuses on errors in positioning, so the thickness of the drawn lines was set to be constant such that only the position error could be fed back.

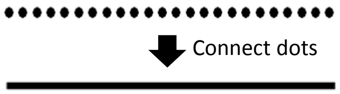


Fig. 3 Reference line

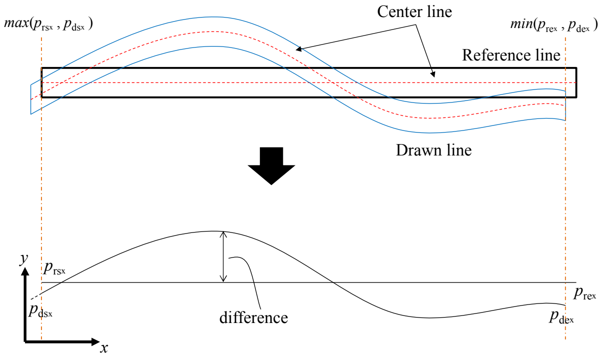


Fig. 4 Comparison of the difference between the center lines for the reference and drawn lines

E. Data analysis

The reference line was the line constructed by connecting the displayed dots (Fig. 3). We compared the reference line with the drawn line and observed the performance of positioning. Because the thickness of the lines has no significance, we compared the difference between the centerlines of the reference and drawn lines (Fig. 4).

As shown in Fig. 4 , we defined x- and y-axes. Let $\boldsymbol{p}_{\mathrm{rs}}$ and $\boldsymbol{p}_{\mathrm{re}}$ be the position vectors of the extreme left and right (start and end) on the reference line, respectively. Let $\boldsymbol{p}_{\mathrm{ds}}$ and $\boldsymbol{p}_{\mathrm{de}}$ be the position vectors of the start and end points on the drawn line. With regard to the differences between the reference and drawn lines, we considered the following three evaluation criteria.

1. **The distance between the start point of the drawn line and the extreme left point of the reference line** ($|\boldsymbol{p}_{\mathrm{rs}} - \boldsymbol{p}_{\mathrm{ds}}|$): The positioning performance of placing the pen on the desired point from free space can be observed from this.
2. **The distance between the drawn and reference lines**: How close to the reference/desired line the operator can draw the line can be determined from this.
3. **The distance between the end point of the drawn line and the extreme right point of the reference line** ($|\boldsymbol{p}_{\mathrm{re}} - \boldsymbol{p}_{\mathrm{de}}|$): This can reveal the performance of inclining the pen as closely as possible to the desired point.

Let $\boldsymbol{p}_{\mathrm{r}} = [p_{\mathrm{rx}}, p_{\mathrm{ry}}]^{\mathrm{T}}$ and $\boldsymbol{p}_{\mathrm{d}} = [p_{\mathrm{dx}}, p_{\mathrm{dy}}]^{\mathrm{T}}$ be the vectors expressing the points on the reference and drawn lines, respectively. We denote p_{ry} (p_{dy}) at $x = p_{\mathrm{rx}}$ (p_{dx}) by $p_{\mathrm{ry}}(x)$ ($p_{\mathrm{dy}}(x)$). In regard to the second criterion, we calculated the difference between the reference and drawn lines along the x (horizontal) axis from $max(p_{\mathrm{rsx}}, p_{\mathrm{dsx}})$ to $min(p_{\mathrm{rex}}, p_{\mathrm{dex}})$ (see Fig. 4). Because the unit of x is pixels, we calculated the difference at each pixel.

$$|p_{\mathrm{ry}}(x) - p_{\mathrm{dy}}(x)| \;\; x \in \;[max(p_{\mathrm{rsx}}, p_{\mathrm{dsx}}), min(p_{\mathrm{rex}}, p_{\mathrm{dex}})] \tag{1}$$

Then, the mean difference is expressed by

$$d_m = \sum_{x=\max(p_{\mathrm{rs_x}},\, p_{\mathrm{ds_x}})}^{\min(p_{\mathrm{re_x}},\, p_{\mathrm{de_x}})} | p_{\mathrm{ry}}(x) - p_{\mathrm{ry}}(x) | \tag{2}$$

and the standard deviation is expressed by

$$d_{std} = \left(\frac{\sum_{x=\max(p_{\mathrm{rs_x}},\, p_{\mathrm{ds_x}})}^{\min(p_{\mathrm{re_x}},\, p_{\mathrm{de_x}})} (| p_{\mathrm{ry}}(x) - p_{\mathrm{ry}}(x) | - d_m)^2}{\min(p_{\mathrm{re_x}},\, p_{\mathrm{de_x}}) - \max(p_{\mathrm{rs_x}},\, p_{\mathrm{ds_x}}) - 1} \right)^{\frac{1}{2}} \tag{3}$$

The line drawn by Sub. 3 when the displayed visual cue was ● ●

The line drawn by Sub. 2 when the displayed visual cue was ■■■

The line drawn by Sub. 4 when the displayed visual cue was ●●●

Fig. 5 Several examples of lines drawn by subjects

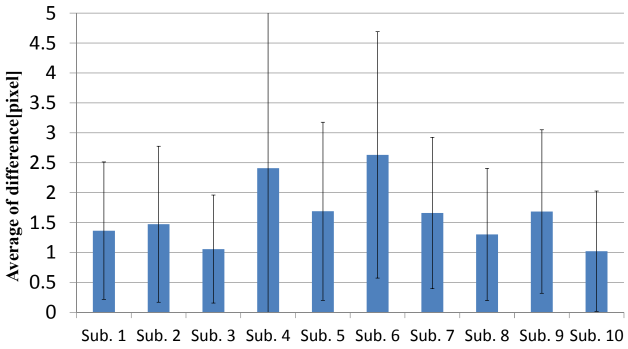


Fig. 6 Average difference between the reference and drawn lines (corresponding to the second criterion: d_m)

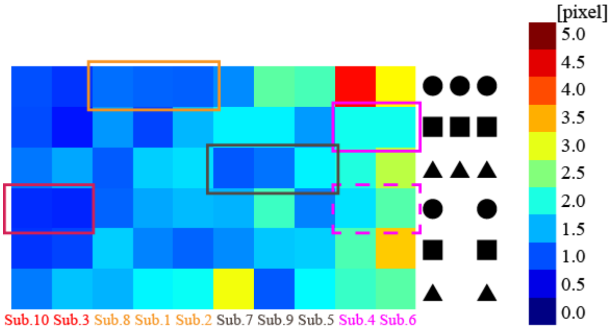


Fig. 7 Average difference between the reference and drawn lines for every displayed visual cue (corresponding to the second criterion: d_m)

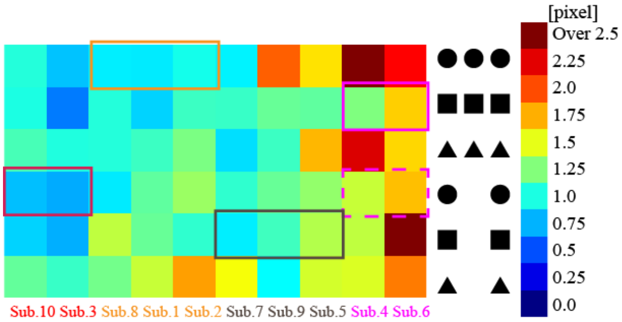


Fig. 8 Standard deviation of the difference between the reference and drawn lines for every displayed visual cue (corresponding to the second criterion: d_m)

III. RESULTS

Examples of the lines drawn by subjects are shown in Fig. 5 . These are typical very good, good, and low results. First, we focus on the results related to the second criterion because it is the most significant owing to the possibility of controlling the performance, for example, by changing a cue during drawing lines. The average difference for all data (all visual cues) with respect to every subject is shown in Fig. 6 . Note that a difference of 1 [pixel] on average means that the total difference reaches about 400 [pixel], which corresponds to the length of the reference line. It can be seen that the performance varied with visual cues, suggesting the possibility of controlling performance with visual cues. Hereafter, we will discuss the results based on the performance level determined by the average difference shown in Fig. 6 , since the average difference is associated with total error for every subject. Fig. 7 and Fig. 8 show the average and standard deviation of the difference between the reference and drawn lines for every visual cue and every subject. The order of subjects is the order of the performance level as determined by the results shown in Fig. 6 . Arranging the results according to the performance level reveals several features. The details will be described in the next section.

The results for the other evaluation criteria are shown in Fig. 9 and Fig. 10 . These figures respectively show the average difference between the start points of the reference and drawn lines for every displayed visual cue and every subject, as well as those for the end points. The order of subjects is the same as in Fig. 7 and Fig. 8 .

The writing pressure (force) was not a target of evaluation, but we measured it for reference. Fig. 11 shows the results for the average pressure for every displayed visual cue with respect to every subject.

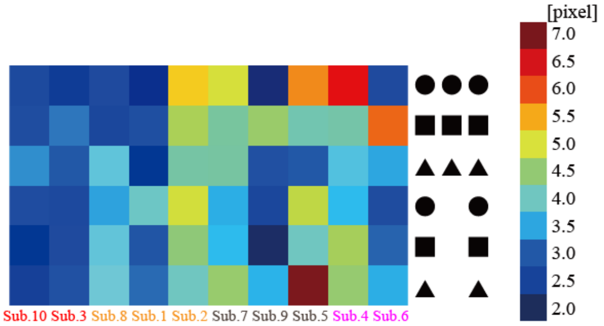


Fig. 9 Average difference between the start points of the reference and drawn lines for every displayed visual cue (corresponding to the first criterion)

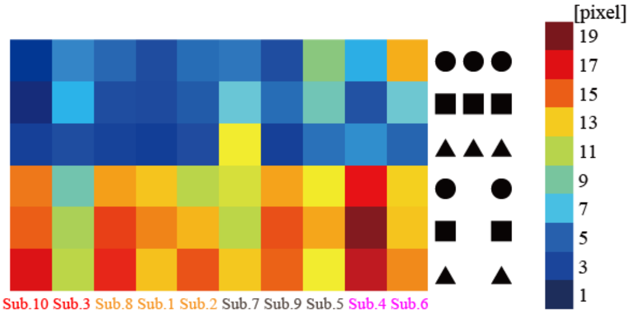


Fig. 10 Average difference between the end points of the reference and drawn lines for every displayed visual cue (corresponding to the third criterion)

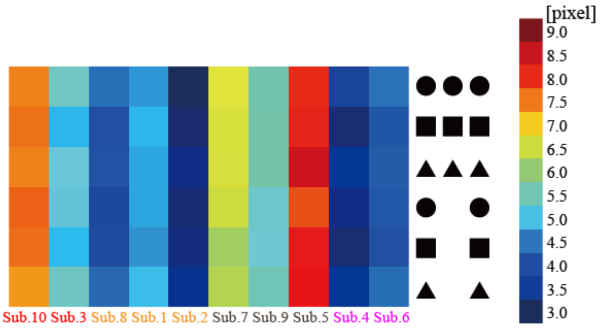


Fig. 11 Average writing pressure for every displayed visual cue with respect to every subject

IV. DISCUSSION

First, we categorize the subjects into four groups by applying K-means classifier (K = 4) to the average difference for all data (Fig. 6). The obtained group (class) is considered to correspond to their performance level (very good, good, medium, and low). The color of *subject* in Fig. 7 indicates the categorized group. The area for the visual cue where the average (standard deviation of the) difference for subjects in every group is the lowest is surrounded by a colored rectangle in Fig. 7 (Fig. 8). Note that a dashed-lined rectangle shows the second best performance for subjects with low-level performance, because the difference between the values for ■■■ and ● ● was small.

The visual cue ● ● is most effective for reducing the difference (obtaining good performance) for subjects with a very good performance level (see the area surrounded by a red rectangle). Taking the good performance at ●●● into account, the cue ● is considered to be very effective for good performance, because it is easy to find the geometric center for the cue ●. The reason the space should be wider may be that having more information than the subjects required undermines/decreases their performance.

For subjects with good-level performance, the visual cue ●●● was most effective for obtaining good performance (see the area surrounded by an orange rectangle), perhaps for the same reason that the cue ● is effective for the very good performers. However, they might need more information than the very good performers, and the results for ●●● were better than for ● ●. Another feature is low performance for ▲ ▲. This is true of both very-good-level and good-level performers. It is not easy to detect the geometrical center for the cue ▲. In addition, the wider space might worsen the performance.

For subjects with medium-level performance, the visual cue ▲▲▲ was most effective for obtaining good performance (see the area surrounded by a black rectangle) from the viewpoint of average difference. From the viewpoint of standard deviation, ■ ■ was the best. The difference of the lowest area appeared for only the medium-level performer. As can be seen from Fig. 7 , the performances for ●●● and ● ● were low. In particular, the performance for ●●● was unstable as can be seen from Fig. 8 . These are considered to not be good at targeting the geometrical center of the cue and might target not a point for ● but an area for ▲ and ■. The horizontal side of ▲ could be the base line for targeting, and the subjects with medium-level performance are considered to target the area above the base line even though the drawn lines are likely to be close to the base line, high accuracy is not expected, and the drawn line tends to be unstable (as can be seen from Fig. 8). In fact, regarding the base line as the reference line, the average difference from the reference line for the cue ▲ (▲▲▲ and ▲ ▲) is smaller than that for the other cues. That ▲ has only one horizontal side might be an additional important factor and facilitate the medium-level performers in finding the target area, compared to the case of ■. The performance for ■ ■ can be said to be the second best for the medium-level performance group (in this case, they showed the most stable performance, as shown in Fig. 8). In this case, ■■■ was considered to be much more information than the subjects required. The cue ■ occupies more space than the other cues, and the subjects may think that the target (desired) area (point) is wider. This might be the reason that the medium-level performers can show good performance at ■ ■.

For subjects with a low-level performance, the visual cues ■■■ and ● ● were most effective for obtaining good performance (see the area surrounded by a magenta rectangle). For ■■■, the target (desired) area (point) is large, i.e., a lot of information can be displayed, which perhaps contributes to good performance. Non-low performance for ▲ ▲ is another interesting feature, because the subjects with the other levels of performance showed low performance for ▲ ▲. One reason for high performance for ● ● and ▲ ▲ might be that the subjects with low-level performance do not take account of the geometric center of the cues but of the space occupied by the cues. (The target is not a point but an area.) Another feature is low performance for ●●●, which might be related to the difficulty of targeting a point.

The correlation between the average differences for all data (see Fig. 6) and for ●●● (with respect to every subject) was high, 0.90, and the groups categorized by applying the K-means classifier (K = 4) to the results for ●●● were very close to the categorized group shown in Fig. 7 (only Sub. 7 was categorized to a different group: good performance level). Therefore, considering the **possibility of performance control**, we could take the following approach:

1. Ask subjects to draw a line along the displayed cue ●●● in order to infer the performance level.
2. Change the displayed visual cue according to the inferred performance level. If the performance level is very good, show ● ●. If it is good, show ●●●. If it is medium, show ▲▲▲. If it is low, show ■■■.

Next, we considered the positioning of the start points of lines (Fig. 9). Comparing Fig. 6 and Fig. 7 with Fig. 9 , the subjects with very good and good performance levels (determined by the result in Fig. 6) show good performance. However, the performance of subjects with other performance levels does not always correspond to the performance of the positioning of the start point. As discussed above, the subjects with good performance tend to target the geometric center of a cue, but the other subjects do not. This might be because the ability to position does not always correspond to the ability to draw lines along the desired lines.

When placing the pen on the start point of a line from free space, the placement is done for a very short time. Then it is impossible to control the performance to be a good one by changing the displayed visual cue during the placement. Therefore, when considering which visual cue to display for good performance, we should display the cue for which subjects with any level can show good performance. If considering the average and maximum difference, it is considered that ▲▲▲ should be displayed.

Next, we considered the positioning of the end points of lines (Fig. 10). Fig. 10 shows an interesting tendency: the performance for small spaced visual cues ●●●, ■■■, and ▲▲▲ is very good, compared to the performance for large spaced visual cues ● ●, ■ ■, and ▲ ▲. The influence of a shape difference of cues was not obvious. This suggests that small-spaced visual cues are effective for stopping to draw lines precisely. When comparing the results of average difference and selecting one cue among the three cues, ▲▲▲ is considered to be the best.

Last, we evaluate the writing pressure. Note that the subjects were not asked to take forces into account, and force information was not displayed and fed back. Fig. 11 shows very interesting results; there is no obvious difference with respect to the different visual cues for every subject. This indicates that in the absence of force information, subjects can easily maintain a constant force, perhaps because there is no mental pressure to keep the force constant and control the force at a desired value. This might be an interesting feature of human beings. In the da Vinci telemanipulation system [2], there is no force feedback. Nonetheless, the system works very effectively for assisting and supporting the work of surgeons. In this system, surgeons do not need to take force into account and can concentrate on controlling the positions and poses of surgical instruments. The surgeons' disregard of force could unintentionally provide appropriate force control. Validating the details is left to future work.

V. CONCLUSION

We investigated the effect of visually displayed cues for drawing lines. We conducted experiments in which subjects were asked to draw a line along a displayed dotted line as close as possible to the dotted line. The displayed dotted lines served as visual cues for drawing. We investigated the effect of changes in the shape (circle, rectangle, and triangle) and space (narrow and wide) of the dotted line. We evaluated the results from three different viewpoints: positioning the start point of a line, the difference between the reference and drawn lines, and positioning the end point of a line. We categorized the subjects into four groups (very good, good, medium, and low), according to results about the difference between the reference and drawn lines, and we analyzed the results. The results suggested that the kind of visual cue effective for good performance varies with the performance level, and visual cue can be used as a control variable for controlling the performance. The cue whose geometrical center is easy to detect should be displayed for very-good and good performers while the cues whose occupied area is large should be displayed for medium and low performers. We summarize our study by constructing a method of displaying visual cues for good performance:

1. *Display ▲▲▲ for good positioning of the start point.*
2. *After drawing starts, display ●●● for inferring the performance level.*
3. *Change the displayed visual cue according to the performance level. If the performance level is very good, show ● ●. If it is good, show ●●●. If it is medium, show ▲▲▲. If it is low, show ■■■.*
4. *Around the end point of a line, display ▲▲▲.*

Future work will involve 1) increasing the sample size and enhancing the validity of the results, 2) constructing a system that automatically infers users' performance levels and displays appropriate visual cues, and 3) investigating performance at other line and curve drawing tasks.

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