

(a) before start of experiment

(b) in experiment

Figure 7. Main panel of virtual figure presentation software

## b. Experimental procedure

We adopted four figures, a circle, triangle, square and pentagon, as virtual figures. Since these figures are randomly presented 10 times for each human subject per figure, 40 trials are performed for each test. The human subject answered as to which figure was presented within 1 minute. To prevent from providing any visual information related to the presented figure, the presentation screen is changed to black as shown in Fig. 7. After 30 minutes, a short break is provided because over 30 minutes of work causes deterioration of tactile feeling. Room temperature is kept at 24 °C.

To examine the effect of tangential stimulation on figure presentation, we performed two series of experiments: one is only distributed pressure presentation (single presentation); the other is combined presentation of pressure distribution and tangential stimulation (combined presentation).

## IV. EXPERIMENTAL RESULTS AND DISCUSSION

### a. Percentage of correct answers

To examine presentation capability of this tactile mouse, the percentage of correct answers is shown in Fig. 8. In the case of single presentation, the percentage of correct answers is around 80% for the triangle and square, while it becomes low for the circle and pentagon. In particular,



the percentage of correct answers for the pentagon is 54%. On the other hand, in the case of combined presentation, the percentage of correct answers is around 80% except for the pentagon, which is 60%.

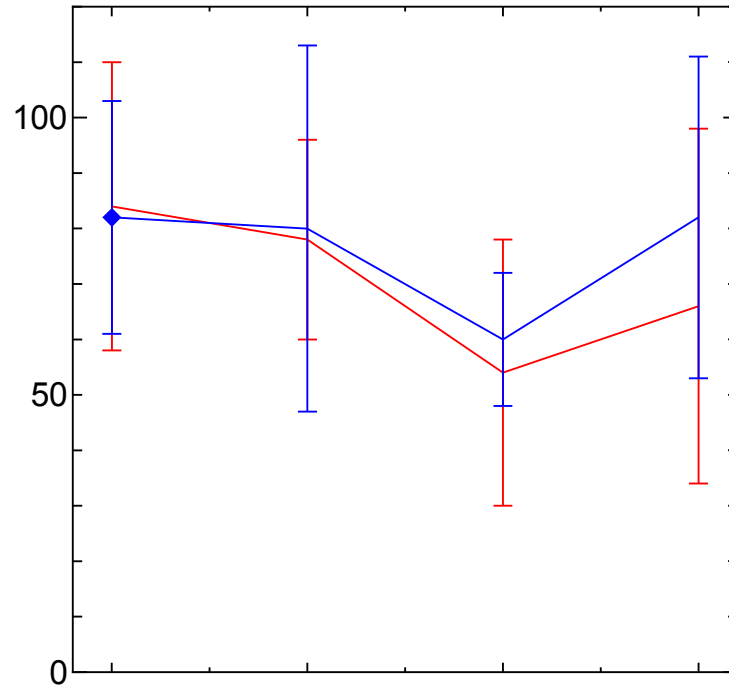


Figure 7. Percentage of correct answers for each figure

b. Figure selected by mistake

To examine mistakes in judgment, pie charts of answers are shown in Figs. 8-11 for each virtual figure. The ratio of components of the chart is close to same value between two presentation modes in the case of a triangle as shown in Fig. 8. Although the ratio is slightly changed for two presentation modes in the cases of the square and pentagon in Figs. 9 and 10, two presentation modes of square and pentagon have roughly similar ratios compared to the circle.

On the other hand, in the case of the circle, the result of combined presentation is completely different from single presentation. In particular, there is no triangle selection in the case of combined presentation, while 10% of answers were for triangle in the case of single presentation.

c. Effectiveness of combined presentation

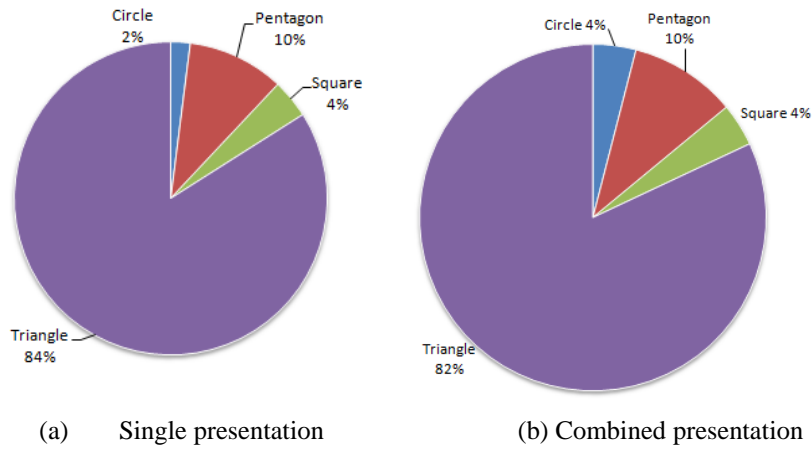


Figure 8. Ratio of answers for triangle presentation

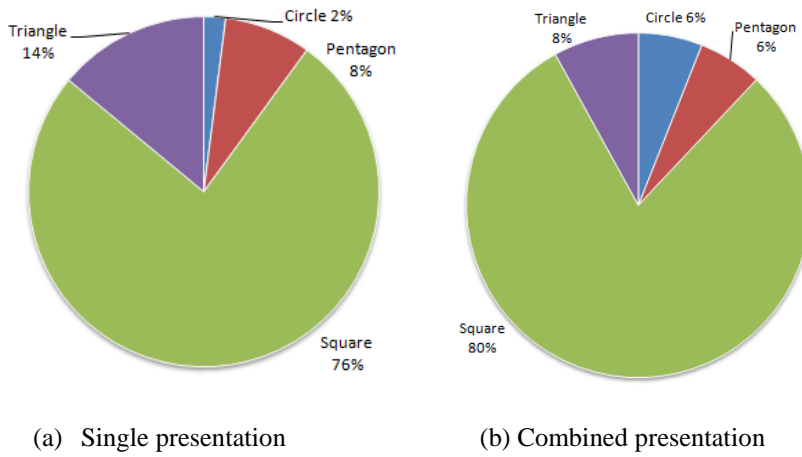


Figure 9. Ratio of answers for square presentation

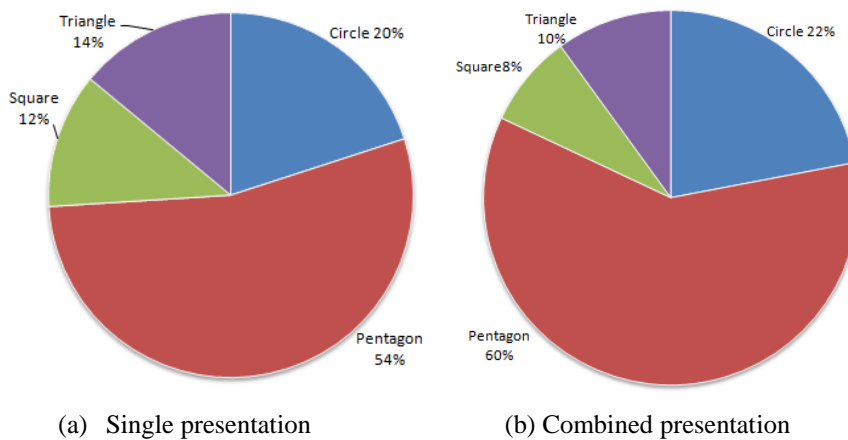


Figure 10. Ratio of answers for pentagon presentation

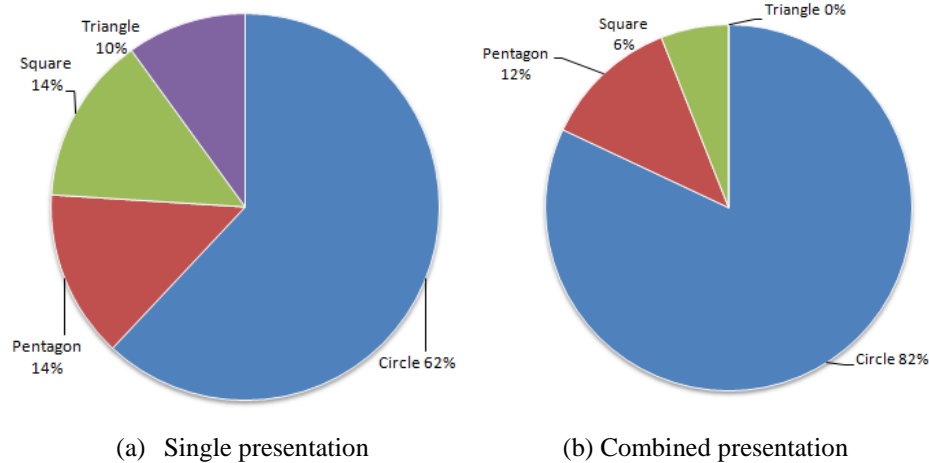


Figure 11. Ratio of answers for circle presentation

As previously described, the triangle, square, pentagon and circle have similar size because these figures have the same circumscribed circle. In the single presentation, if the positions of all the stimulus pins are on a virtual figure and the operators' fingers remain on it, all stimulus pins keep protruding and operators cannot judge whether the mouse cursor is on it or not because of adaptation. At that time, since the operators have to judge the presented figure based only on the contour of the virtual edge, they sometimes mistake the triangle for the circle if they miss the vertex of the triangle.

On the other hand, in the case of combined-mode presentation, since tangential stimulus distribution is added on the contour of the figure, ease of recognition from tactile information is enhanced. This mechanism is similar to the following characteristic of vision: a filled-in figure is easier to recognize than a line drawing. Furthermore, we sometimes perceive with tactile sensation the shape of a sticky area such as that left by peeled tape. Therefore, the operators did not mistake the circle for the triangle in the case of combined presentation as shown in Fig. 11 (b). Consequently, we can obtain a relatively high percentage of correct answers in the combined presentation.

## V. CONCLUSION

Since our tactile mouse can generate not only distributed pressure but also slippage force, it is expected that it can enhance the reality degree of virtual reality generated by it compared to conventional tactile displays.

In this paper, four virtual relief-like figures, a triangle, square, pentagon and circle, were presented using the tactile mouse. To evaluate the effectiveness of the combined presentation of pressure and slippage, not only pressure but also tangential force was generated on the tactile pad on which an operator put his finger in combined presentation tests when the mouse cursor traveled on the figure.

In a series of experiments, five male subjects judged which figure was presented. It was found that the percentage of correct answers increased in the combined presentation when the circle and pentagon were presented. Therefore, the combined presentation provides plain virtual sensation to allow the operator to more easily understand the sensation.

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