INTRODUCTION

Our interest in how people use the mouse in drawing stems from a desire to model behavior, extract relevant features of particular choices, and predict some aspects of the mouse events that occur. By predicting behavior in this way, it is possible to automate parts of the drawing process; indeed, a programming-by-example system for communicating structured drawings has already been reported which generalizes user action sequences into programs with loops and conditional branches (Maulsby & Witten, 1988). A deeper understanding of mousing behavior would provide a foundation for more powerful aids to producing structured drawings. In conventional drawing, left- and right-handers differ significantly in how they draw lines; perhaps the distinction carries over to mouse usage so that user models should be tailored to handedness. When drawing a constrained line, people tend to begin at the end which is most highly constrained; if this effect holds for rubber-band lines drawn by mouse then programs can make sensible inferences about how a line, once started, might be terminated, and gravity adjusted accordingly. People draw structured objects through a process of accretion, which—if true when mousing—justifies certain ways of generalizing drawing actions.

In his landmark book *Drawing and Cognition*, Peter van Sommers (1984) reported a fascinating study of human performance in conventional drawing. A very extensive series of experiments with adults and children alike revealed astonishing regularities in the way we produce graphics. Principles which were abstracted ranged from ones that govern the character of simple stroke making, through others that dictate the ordering of strokes according to how their end-points are anchored by constraints, up to rules that predict the kind of decompositions we make when constructing pictures hierarchically. Some of this work already has application to computer drawing. For example, van Sommers noticed that when one asks a group of untrained adults or children to draw common objects, the vast majority of their strokes are simple lines, arcs, circles, or dots—and include relatively few freehand contours. This upholds both the idea behind common drafting programs of providing a menu of common primitives, and the particular selection of primitives that is offered.

Do similar habits govern drawing with mouse and drafting program? The simplest and most basic question to investigate is how people move the mouse, and a natural place to begin is by looking at directionality of mouse motion. This paper reports a series of five experiments which were conducted to investigate preferences in stroke drawing and stroke ordering. While results obtained at such a low level may not in themselves seem strikingly significant, by comparing them with van Sommers' findings we can assess whether mouse-drawing is similar to pen-drawing and whether further experiments on higher-level effects might be worthwhile.

THE SERIES OF EXPERIMENTS

The purpose of the experiments was to discover whether any directional bias exists in people's production of straight lines, and to determine what factors might influence the bias. Each experiment required 24 subjects (12 left-handers and 12 right-handers) to trace or draw straight lines using a rubber-band-line tool. The experimental equipment was an Apple Macintosh running the professionally-oriented graphics application program MacDraft.

The first experiment required subjects to trace over several short lines that were presented on the screen in various different orientations. We are interested in the direction in which they choose to trace: left-to-right *vs* right-to-left in the case of horizontal lines, top-to-bottom *vs* bottom-to-top in the case of vertical ones, and similarly for lines in other orientations. For each line, the subject had only one simple choice to make. The intention is to assess the basic mechanical bias in the physical system by looking at direction of execution as a function of orientation.

The second experiment evaluated the extent to which that bias persists in spontaneous behavior. Subjects could draw lines in any orientation they chose, although they were encouraged to use all orientations. Both the orientation selected and the direction of execution were measured. The intent was to see whether subjects favored certain orientations.

The third experiment assessed the effect of preference on order of execution. Subjects drew several lines, and the sequence they chose was noted to see whether the directional bias when making individual strokes also applies when determining the order in which to build components of rudimentary structured drawings.

The fourth added a new constraint—accuracy. Subjects copied lines, striving to preserve both orientation and length. We were interested to see whether accuracy of execution correlated with preferred direction of execution: do subjects draw more accurately in directions that they favor?

The fifth investigated the extent to which directional bias might affect the creation of more complex structures. It employs subjective rating scales to determine whether subjects have conscious preferences for different directions when drawing simple compound objects.

DIFFERENCES BETWEEN MOUSE AND PEN

In each experiment we compare our results with those of van Sommers, who performed similar experiments with pen and paper. Comparisons must be made with caution because of the methodological discrepancies which inevitably arise from the use of different tools; and also because he does not describe the experimental conditions exactly.

There are several basic differences between the mouse- and pen-drawing situations. The mechanics of holding a mouse are quite different from holding a pen. Our subjects tended to move the whole arm; in contrast, drawing with a pen involves fine finger and wrist control. Users are free to position arm and puck for ease of drawing motion by lifting and moving it; they do not so readily re-orient paper or chair. When using a mechanical rather than an optical mouse, they can change the relationship between direction of motion of the hand and direction on the screen by holding the puck in a rotated position. Although our subjects, by and large, held the puck so that it lined up with their forearm, we know one computer user who holds it at an angle of about 30°.

Other differences stem from the visual feedback provided. Subjects' view of the line on the screen is always unobscured by the hand. Moreover, the use of rubber-band feedback shifts the focus of attention from executing the line itself to placing its end-points in turn. Movements need not be smooth to ensure straightness. Rhythm is lost in drawing a series of parallel strokes; each is positioned individually. Once one end has been placed, the line can be previewed and fine adjustments made before committing the other.

Conduct of the experiments

With a few exceptions, the subjects were undergraduate university students. Although many had previously used a computer, few had used a mouse before. It is likely that the results of the experiment are influenced by the subjects' lack of experience of mouse usage.

Subjects were classified as left- or right-handed according to the way they wrote. Wishing to capture their natural behavior, we decided to allow them a free choice of which hand to drive the mouse with. In the event, all right-handers and all but 4 of the 12 left-handers moused with their dominant hand. As one of the minority (who had never held a mouse before) remarked, it is just as easy to move the mouse with the right hand as with the left. (We know experienced computer users who also control the mouse with their other hand, leaving their dominant one on the keyboard.) In all cases the mouse was placed to the appropriate side of the keyboard and display screen.

Prior to the experiments, subjects were given a practice exercise to help familiarize them with the mouse and the selection and drawing of rubber-band lines. The training session typically lasted for 5 minutes, after which subjects were taken through the five experiments in turn. The whole series took each subject about 45 minutes to complete.

The MacDraft program made it easy to set things up so that subjects drew plain lines which the experimenter could later display as arrows and thus see the direction of production; this facility was used for experiments 1 through 3. Commercial programming-by-example systems such as Tempo (Affinity Microsystems, 1985) provide a convenient way to record subjects' mouse selections in Experiment 4 so that their order can be studied later. In contrast, van Sommers had to videotape his subjects for later manual analysis.

Unfortunately, the task of tracing or drawing many straight lines over and over again was rather monotonous for subjects, particularly for new mouse users. Some subjects tended to adopt a playful attitude, and instead of generating natural responses tried to figure out what was expected from the experiments and produce results accordingly. Furthermore, the left-handers were from mixed backgrounds and seemed to have a more casual attitude to the experiments. In future it may be worthwhile to attempt to embed such experiments in a game scenario to make them more palatable to subjects (Carroll, 1982; Jansonius, 1987).

Experiment 1: Preferred stroke direction (line tracing)

Description. Sixty lines each 2.5 cm long, randomly scattered in different orientations, are presented on the screen. The display is divided vertically in half with 30 lines on each side (Figure 1a shows a part). Subjects are asked to trace over all the lines, selecting alternately from left and right sides.

Purpose. The object is to determine whether drawers have a tendency to prefer one direction of stroke production over another.

Result. The directions in which the lines are drawn are recorded and totalled. Figure 1b shows one subject's results, although he did not see the arrowheads. Figures 1c and 1d show the proportion of lines that were traced in each direction by left- and right-handers respectively. These should be interpreted as circular histograms. For example, referring to Figure 1c, about 75% of left-handers draw horizontal lines to the right (0°); the remaining 25% draw them to the left (180°). About 20% draw vertical lines upwards (90°); the remaining 80% draw them downwards (270°). Right-handers (1d) favor stroke directions to the right, between 270° and 90°. Left-handers (1c) prefer to stroke towards the bottom right, between 30° and 210°.

Interpretation. Figures 1c and 1d reveal significant biases in direction, and significant differences between left- and right-handers. Van Sommers also found different biases: his left-handers tended to draw downwards and to the left, while his right-handers drew down and to the right. He explained that upward strokes were avoided because of the awkward finger flexion as well as the difficulty of keeping the wrist steady; lateral strokes away from the dominant side and towards the center were avoided because the hand would obstruct the view of the line drawn so far. With mouse and screen, these mechanical constraints are removed: upward movement is as easy as downward, and in either case the line drawn is always exposed to view. Thus the fact that we find a bias probably indicates some hangover from the traditional drawing situation.

However, the preferred directions we observe are not the same as van Sommers': indeed, his results were what would be obtained by rotating Figures 1c and 1d roughly 45° clockwise. We do not know the reason for this. Although the right-handers' results are explained by the assumption that it is as easy to move the mouse upwards as it is downwards, the left-handers' are not. (A simple explanation for both cases would be that subjects held the mouse rotated relative to their forearm, but this was not so.)

We conclude that while the drawing instrument influences their performance, subjects by and large import the habits acquired from drawing with a pen. With experience, it may be that preference for particular stroke directions is reduced or even eliminated. Indeed, the preferences we found already seem somewhat less marked than those reported by van Sommers.

EXPERIMENT 2: PREFERRED STROKE DIRECTION (FREE DRAWING)

Description. The numbers from 1 to 60 are presented in random positions on the screen. Beginning at each number in turn, subjects are asked to draw a 2.5 cm line in a direction of their choice. They are specifically requested to try to generate lines "randomly in all directions."

Purpose. The object is to determine whether a bias exists in the direction of subjects' straight line production given that they are free to draw where they like.

Problems encountered. Some subjects (particularly right-handers) had an impoverished notion of orientation, drawing only vertically, horizontally, and diagonally. On the other hand, one or two tried too hard to exhaust all possible directions. From time to time they stopped and reexamined lines previously drawn to determine the orientation of the next one. One subject began by drawing almost all horizontal lines until he was reminded of the instructions.

Result. The findings correspond closely to those of Experiment 1, in that right-handers prefer stroke direction to the right, while left-handers stroke to the bottom right (Figures 2b and 2a respectively). Left-handers also showed some preference to the bottom left. Right-handers were inordinately fond of vertical and horizontal lines. (The calibrations in Figure 2 give the percentage of all lines which were drawn in that direction.)

Interpretation. Van Sommers found even more marked biases in choice of stroke direction in free drawing, though he too asked subjects to make sure they drew in every direction, and discouraged them from working systematically. Again we conclude that while habits acquired during pen-and-paper drawing carry over to the mouse, they lose some of their force in transit.

EXPERIMENT 3: PREFERRED ORDER OF MAKING STROKES

Description. There are four sets of four parallel lines, in vertical, horizontal, and two diagonal orientations (Figure 3, but without the dashed lines or arrow-heads). Subjects are asked to trace over all lines in each set.

Purpose. The object is to determine whether the same principles that govern stroke direction also dictate stroke order.

Problems encountered. A subject may accidentally lose the line cursor and have to reselect it from the appropriate menu. This may affect the choice and direction of his next stroke.

Result. In general, stroke directions correspond to those observed in Experiment 1. The order of execution of lines in the vertical and horizontal sets is similar for both right- and left-handers; namely, lines are drawn from top to bottom and left to right. Some variation was observed in the diagonal sets but the preferred order is still left-to-right. A few subjects—notably one or two who encountered great difficulty in driving the mouse, and also experienced users—alternated line directions to minimize mouse motion and so complete the experiment with least effort. One subject's results are illustrated in Figure 3.

Interpretation. Van Sommers also detected no difference between left- and right-handers in the order in which the lines in each set were chosen, and he concluded from this that order of stroke-making is not related to stroke direction but is associated with starting positions and proximity. Subjects work systematically through the lines in each group, minimizing movement from one to another. However, all his subjects drew lines in each group in the same direction, and never alternated directions (as in the third group of Figure 3). Apparently, compared with the pen the less regular actions associated with mouse movement sometimes sacrifice rhythm to minimize motion.

EXPERIMENT 4: STROKE ACCURACY

Description. Sixty 2.5 cm lines, each with a prominent dot at one end, are scattered in all different orientations in the left-hand half of the display. To the right the dots (only) are reproduced in identical positions (see Figure 4a). Subjects are asked to fill in the missing lines accurately to reproduce the exact lengths and angles.

Purpose. The principal objective is to test for correlation between preferred stroke direction and accuracy of orientation. Drawers may avoid certain directions because they have difficulty in judging the precise angles. We are less concerned with absolute accuracy than with directional effects on accuracy. A secondary goal is to study the distribution of accuracy of line *length.*

Result. Figure 4b shows mean absolute value of error, in degrees, plotted against drawing angle; while 4c shows mean absolute value of length, in millimeters. With the exception of the lines close to the vertical and horizontal axes, which enjoyed the greatest accuracy, no strong directional effect was observed for either left- or right-handers. Results for length accuracy were similarly inconclusive. Left-handers were generally less accurate than right-handers, possibly because they had a more casual attitude to the experiment and were less familiar with the mouse.

Interpretation. On the whole, subjects were strikingly accurate. Mean errors for right-handers were only 1.4° and 1.4 mm; for left-handers 2.2° and 1.4 mm. Right-handers record relatively low orientation accuracy in the lower left quadrant of Figure 4b; yet the same region shows high accuracy in line length (Figure 4c). This could indicate that they diverted attention from orientation to length in this region.

Van Sommers observed greatest orientation accuracy in the preferred stroke directions, and least in the directions that subjects naturally shun. In our case, however, digitally-drawn lines introduce strong artifacts. The jaggedness of the lines gives away their exact angles—which of course accounts for the highest accuracy being associated with vertical and horizontal lines. With mouse and screen, arm movements are easy in all directions and the view is always open.

EXPERIMENT 5: SUBJECTIVE DIFFICULTY IN EXECUTING STROKES

Description. Thirty-six similar rectangles are scattered in different orientations (Figure 5a). Beginning at the black bar, subjects are asked to trace along the remaining three edges of each rectangle, beginning in the direction of the arrow, and rate the difficulty of the task on a scale of 1 to 5, 1 being the easiest.

Purpose. The object is to determine what angles subjects feel are easiest to draw and whether their intuitions are correlated with their bias towards certain stroke directions.

Problems encountered. Initially the experiment used 60 rectangles and was reduced to 36 after the first three subjects because it was felt to be too long. It suffers from the inevitable unreliability of subjective rating scales. Some subjects confined themselves to the middle of the scale so that any distinctions they were making tended to be swamped by those who used extremes; however, when subjects' ratings were normalized the results proved to be very much the same.

Result. Subjects felt it was just as easy to draw lines in any direction (see Figure 5b).

Interpretation. Van Sommers' right-handed subjects showed a large area of difficult stroke making to the left and (to a lesser extent) top; while left-handed subjects showed the reverse. The almost complete lack of discrimination in our results (Figure 5b) confirms our belief that from the point of view of mechanical ease of use, mouse use is fairly isotropic.

CONCLUSIONS

First, subjects using a mouse to either trace or draw lines prefer to draw in some directions over others, and thereby reveal their handedness. This is not so easily explainable in mechanical terms as it is with pen drawing; moreover the favored directions are not quite the same as with the pen. We conclude that habitual preferences in drawing direction carry over to the mouse domain—at least for fairly inexperienced mousers. Second, when drawing parallel strokes the order of working is not correlated with handedness. However, users at both ends of the experience scale sometimes optimize mouse movement in circumstances where they would not optimize pen movement, possibly because mouse strokes seem to be executed less rhythmically than corresponding pen strokes. Third, even inexperienced subjects can be very accurate in both orientation and line length when copying lines from one part of the display to another. This suggests that aliasing effects, long the bane of computer graphics, may actually help users achieve accuracy in drawing.

Finally, whereas with a pen subjects regard certain drawing directions as difficult, they view mouse usage as relatively isotropic. The fact that orientation accuracy when mousing is no higher in the preferred direction (whereas with a pen people draw more accurately in the preferred direction) corroborates this finding. Thus directional preference is manifested only at the subconscious, not the conscious, level—users tend to draw lines in certain directions when given a choice, but when forced to draw other lines neither perform worse nor believe them to be any harder to execute.

We plan to report soon on a second series of experiments which has subjects draw and trace simple figures and objects. Its purpose is to discover the order, strategies and organization which people employ in their graphic production. Further, we would like to determine the extent to which the directional biases discovered in the present experiments affect the hierarchical structure of objects in drawings. Apart from its intrinsic interest, our purpose in these investigations is to determine generalization heuristics to improve the performance of systems for programming by example within highly-interactive direct manipulation interfaces.

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REFERENCES

Affinity Microsystems (1985) *Tempo*. Boulder, Colorado.

Carroll, J.M. (1982) "The adventure of getting to know a computer" *IEEE Computer 15*(11): 49-58; November.

Jansonius, C. (1987) "Making learning fun." MSc Thesis, Department of Computer Science, University of Calgary, Canada.

Maulsby, D.L. and Witten, I.H. (1988) "Acquiring graphical know-how: an apprenticeship model" *Proc European Knowledge Acquisition Workshop 88*, 34/1–34/16, Bonn, West Germany, June 19-23.

van Sommers, P. (1984) *Drawing and cognition.* Cambridge University Press, Cambridge, England.

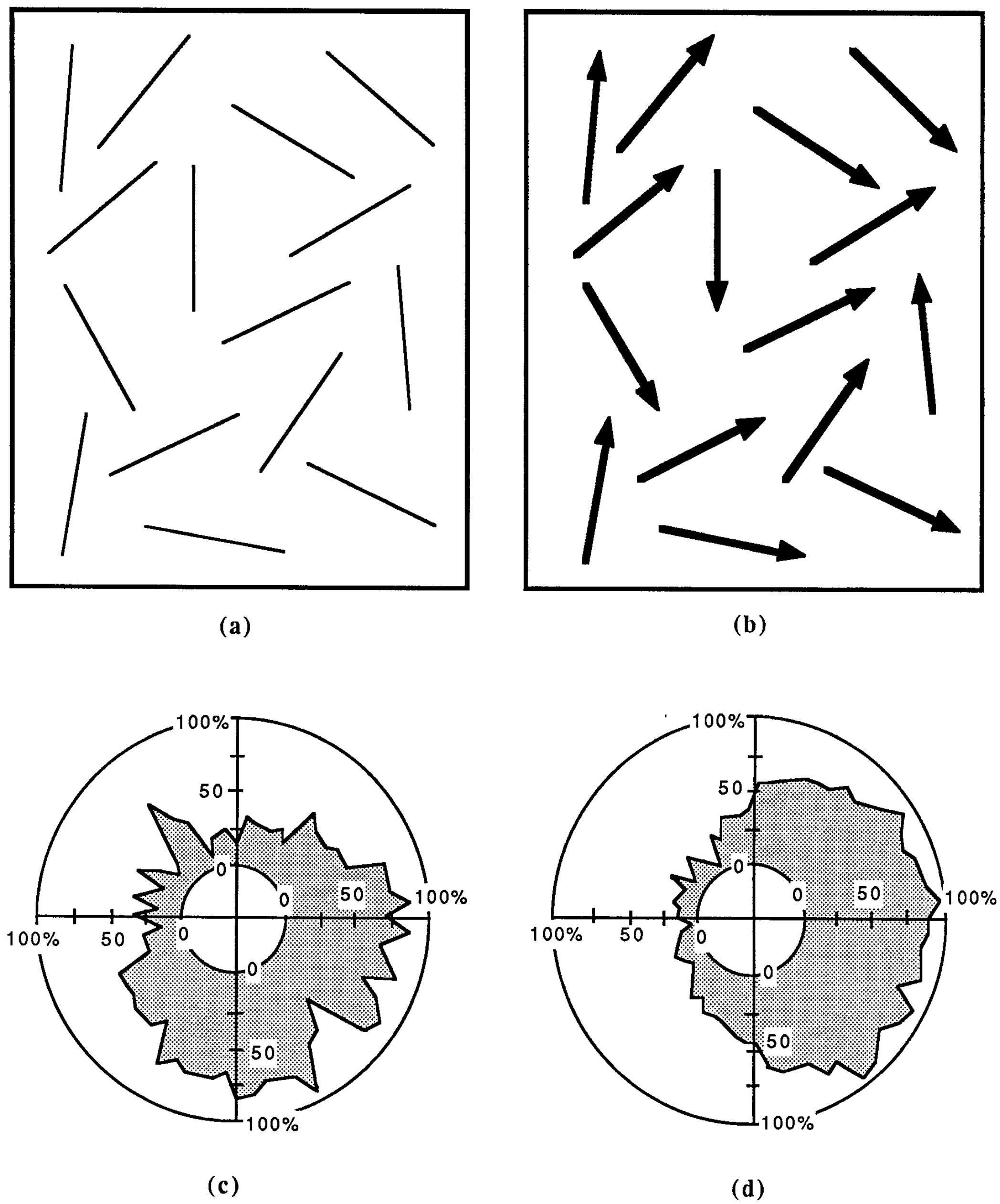
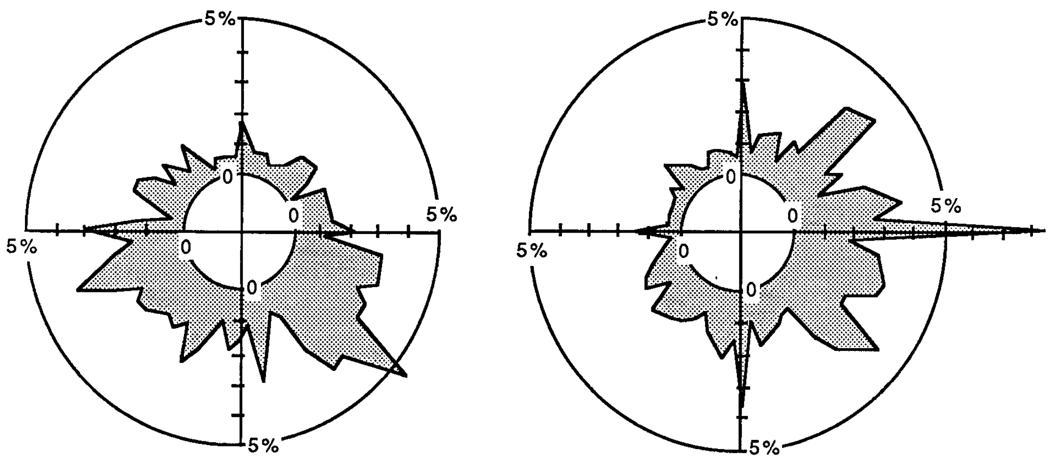


Figure 1 Experiment 1
a. The task (only part is shown)
b. Lines drawn by a typical right-hander
c. Pooled results for 12 left-handers, in the form of a circular histogram
d. Results for 12 right-handers



(a) (b)

Figure 2 Experiment 2
a. Results for 12 left-handers
b. Results for 12 right-handers

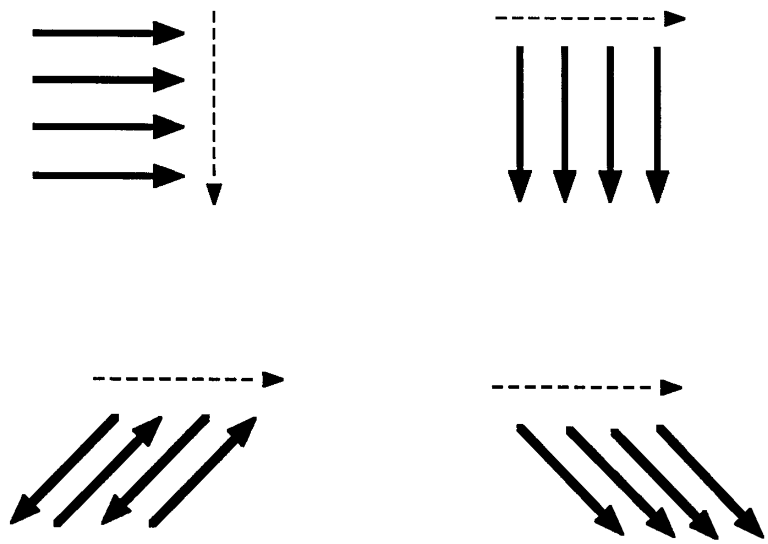
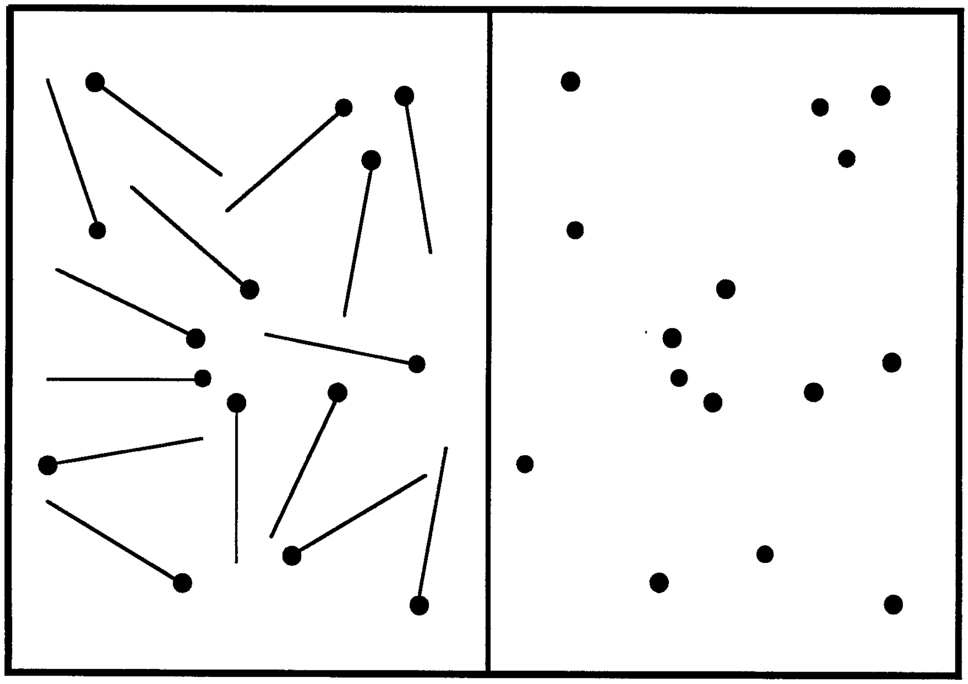
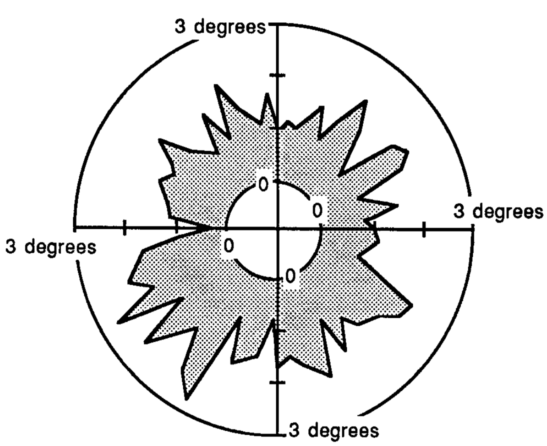


Figure 3 Experiment 3
One subject's results (dashed lines show order of execution)



(a)



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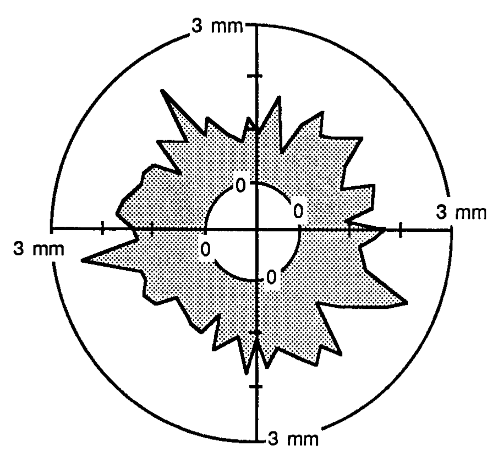
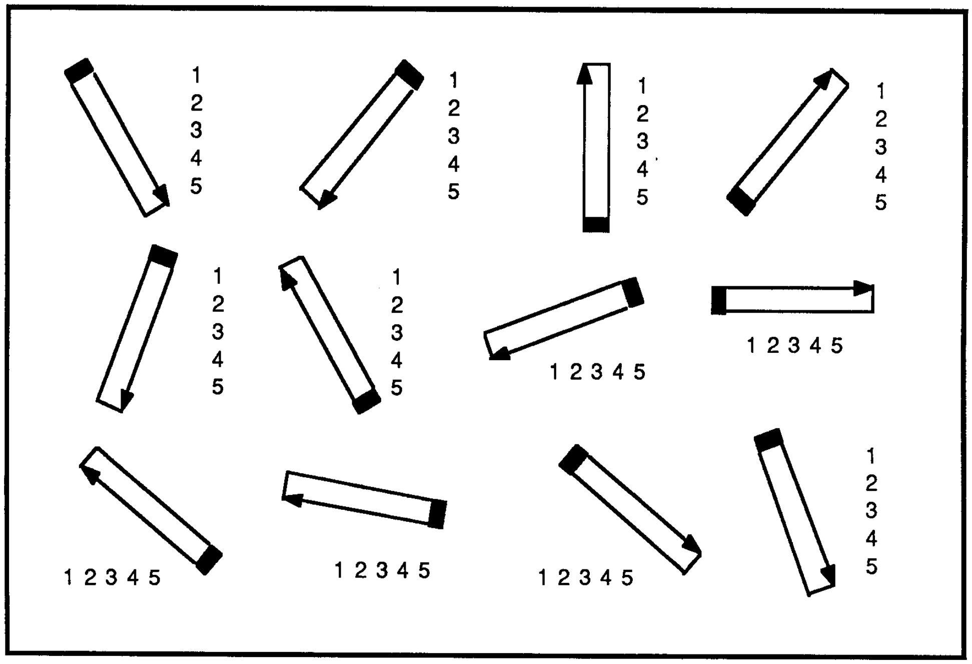
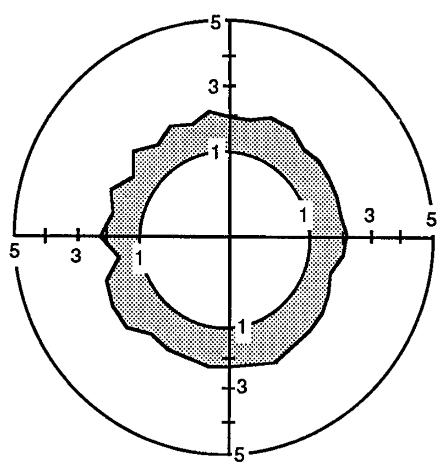


(c)

Figure 4 Experiment 4
a. The task (only part is shown)
b. Orientation accuracy (right-handers)
c. Length accuracy (right-handers)



(a)



(b)

Figure 5 Experiment 5
a. The task (only part is shown)
b. Results for 12 right-handers