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Manual Tracing Efficiency Contingent Upon Stimulus Shape and Performance Practice

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Summary

Tracing movements (hand-following the stationary contours of three two-dimensional figures: square, triangle and circle by means of a computer mouse-operated lightspot) were analyzed during five consecutive days. All three figures consisting of four (square, circle) or three (triangle) segments had the same circumference. Three parameters were chosen to express the tracing efficiency: average error, average time and performance quotient (average error per time unit) either for individual segments or the whole figures. The performance quotient was the best for the square and the worst for the circle, yielding better values for horizontal (than for others) segment orientation for the square and triangle. On the contrary, vertical segment orientation was found to be the best for the circle. The performance quotient and average error yielded better values in triangle segments when the right hand was used (all subjects were right-handed). However, considering the whole figures all three parameters displayed better values for the right hand. No differences were found with respect to the direction of tracing movements (clockwise or counter-clockwise). During the first three days both average error and time decreased, the change in later performance is caused by shortening of the average time only.

Key words
Tracing performance – Tracing error – Tracing time – Sensorimotor coordination

Introduction

The perception of general and special features of visual cues to be followed by corresponding hand movements, represents a basic sensorimotor phenomenon with cognitive and other aspects. The trajectory shape, direction and speed of target movement (together with corresponding hand movement) represent the general features mentioned, whereas the relationship between the movement of visual stimuli and instant motor performance comprises the special ones. Eye-hand tracking, i.e. following a regularly or randomly moving target (Poulton 1974, Bartram *et al.* 1985, Hacisalihzade *et al.* 1986), is the usual approach adopted in this field. Several sensitive and objective methods based on eye-hand tracking tasks have been developed to test and evaluate, for example, neurological patients in this situation (e.g. Kondraske *et al.* 1984, Jones and Donaldson 1986, Ranalli and Sharpe 1988, Abdel-Malek *et al.* 1988).

Tracing, i.e. tracking of motionless stationary trajectory changes standard pursuit tracking in such a way that it can be characterized as more spontaneous and less stressful as there is no moving target to be followed at a required speed. Besides tracing errors (i.e. deviations from ideal movement trajectory), it offers an additional parameter for evaluation – tracing time which might reflect subjective factors to a greater extent. This experimental arrangement resembles to a certain extent real life situations. We can directly see, for example, at least part of the required movement trajectory (highway etc.) in front of us and we usually have some sort of cognitive template of this trajectory in advance.

The potentially relevant characteristics of this trajectory and the corresponding movements considered in the present experiment were the following: (a) linear or circular; (b) vertical or horizontal or oblique; (c) clockwise or counter-clockwise tracking. Circle, square and triangle of equal circumference as representatives of simple two-dimensional shapes were therefore adopted to investigate the influence of the above features upon tracing (Fig.1). These figures composed of basic geometric elements/segments (horizontal, vertical and oblique lines or circle segments) do represent cardinal shapes or their details we meet in everyday life.

The aim of the experiments described was threefold: to analyze whether and to what extent (i) the geometrical features of visual figures in the global sense and their elements mentioned do influence tracing efficiency; (ii) tracing efficiency depends on the dominant and non-dominant hand; (iii) the tracing skill can be improved by brief training.

Methods

Subjects

Ten paid volunteers participated in the study. Each subject was examined during a series of five daily sessions, starting on Monday. The subjects, belonging mostly to staff members of our Institute, ranged in age from 25 to 45 years and all had normal or corrected to normal vision. Prior to the first session, the hand preference was assessed by the Edinburgh Handedness Inventory (Oldfield 1971) and evaluated as suggested by Salmaso and Longoni (1985). Before the first session, the subjects were instructed about the nature of the experiment and questioned about his/her skill in computer mouse operations. Only subjects completely naive and unskilled, as regards this operation, took part in the experiment.

Tasks

Throughout the session, the subject reclined in a comfortable chair with a large pad on the support in front of him/her, enabling free movements with the computer mouse. During each session the subject performed a series of 4 trials for each of the three figures. Stimuli were presented in random order.

At the beginning of any trial, a completed figure (square, equilateral triangle or circle) to be traced was displayed for 5 s on the computer screen positioned at a distance of 120 cm from the subject's eyes, the base of the square and triangle being oriented horizontally. The circumference of all figures was equal (320 mm), thus securing identical tracing pathway length. Every trial started with an initial projection of a small (2 mm diameter) circle on the screen, and the subject had to move the light spot by appropriate movement of the mouse into it. This triggered the appearance of a randomly chosen segment of the figure (one of two possible sides of the square and triangle or one of two possible quadrants of the circle) starting in this little circle. The task of the subject was to trace the segment as rapidly and accurately as possible to reach its end. At this moment, the next neighbouring segment of the figure appeared – a condition for this being that the light spot controlled by the mouse was close enough within 2 mm of the end point of the segment. During tracing, both the segment traced and the light spot controlled by the mouse were displayed on the screen thus giving the subject continual visual information about his/her performance. Two directions could be chosen for consecutive segment presentations: clockwise and counter-clockwise; the identical direction being always kept during the same trial.

An IBM PC controlled the whole experiment using a specially developed program (Indra 1992). Data values reflecting segment average tracing error (SAE) and segment average tracing time (SAT) were printed (separately for each segment) at the end of each trial during brief breaks for rough orientation about the subject's individual performance progress. SAE was calculated as the mean of absolute distances of the mouse coordinates to the traced segments measured for each segment with 100 Hz sampling frequency. SAT represented the time interval when the segment appeared on the monitor to the moment when the "hidden" circle on its end was hit by the subject and the segment disappeared. All measured data were stored for off-line processing and served for complete figure final evaluation of errors and time figures as AE (average error) and AT (average time), respectively.

Data analysis

The following three parameters were evaluated: (i) SAE, SAT and tracing performance quotient (SPQ) for every segment of each figure, SPQ being defined as SAE/SAT, (ii) AE, AT, and the tracing performance quotient (PQ) for the whole trajectory of the figure. AE was calculated similarly as SAE as the mean of absolute distances of the mouse coordinates to the whole circumference of the traced figure and AT represented the average time necessary for whole circumference tracing. PQ was defined as AE/AT. The above parameters were evaluated with respect to handedness, tracing direction, segment orientation and type of the traced figure. The learning curve of individual parameters was calculated for each figure.

The STATGRAPHICS ANOVA was used assessing the influence of the following factors: SUBJECT (10), HAND (2), TRACING DIRECTION (2), SEGMENT ORIENTATION (2), FIGURE (3), DAYS (5) on both SPQ and PQ parameters.

Results

Tracing performance

Figure segments

The four-way STATGRAPHICS ANOVA with factors SUBJECT (1.10), HAND (right, left), TRACING DIRECTION (clockwise, counter-clockwise) and SEGMENT ORIENTATION (horizontal, vertical/oblique) was used to test the influence of the various factors on parameters SAE, SAT and SPQ for each of three figures separately (horizontal and oblique segment orientation was chosen for the triangle).

Significant differences of individual parameters were found with respect to the segment orientations: SAE was significantly influenced by the triangle and circle segments only, SAT by the triangle and the square. SAE was lower for the horizontal segment than for the oblique ones [$F(1,599)=6.36$, $P<0.05$] for the triangle, and for those vertically oriented than for those oriented horizontally [$F(1,799=13.18$, $P<0.001$] in the circle figure. Similarly, SAT was shorter for the horizontal than for the oblique ones in the triangle [$F(1,599)= 8.78$, $P<0.01$], and the vertical than for the horizontal ones in the square [$F(1,799)=12.67$, $P<0.001$]. SPQ was found lower (tracing performance was better) for the horizontal than for the orientation of other segments (vertical or oblique) for the square [$F(1,799)=4.389$, $P<0.05$] and the triangle [$F(1,599)=8.49$, $P<0.01$]. However, SPQ for the circle was, on the contrary, lower for the vertical than for the horizontal orientation [$F(1,799)=8.87$, $P<0.01$] (Table 1).

Table 1
Factors influencing the segment performance quotient SPQ (values given in parentheses)

	SQUARE	TRIANGLE	CIRCLE
Segment orientation H: horizontal V: vertical O: oblique	$SPQ_H < SPQ_V$* (117.7, 125.1)	$SPQ_H < SPQ_O$** (148.6, 162.0)	$SPQ_H > SPQ_V$** (184.4, 173.5)
Hand R: right L: left	NS	$SPQ_R < SPQ_L$** (150.1, 164.9)	NS

*NS – non-significant, * p<0.05, ** p<0.01*

Handedness represented a significant factor in triangle tracing only. Both SAE and SPQ were lower for the right one than for the left one [$F(1,599)=10.172$, $P<0.01$], [$F(1,599)=11.34$, $P<0.001$]. No significant differences were found in SAT evaluation.

The factor TRACING DIRECTION revealed no significant effect in any of the three tested parameters.

Whole Figure

Four-way ANOVA with factors SUBJECT (1..10), FIGURE (3), HAND (right, left) and TRACING DIRECTION (clockwise, counter-clockwise) was used to evaluate differences in tracing efficiency over the whole circumference of figures. The factor FIGURE was found significant for all parameters: AE [$F(2,599)=55.33$, $P<0.001$], AT [$F(2,599)=45.07$, $P<0.001$] and PQ [$F(2,599)=93.14$, $P<0.001$]. According to post-hoc Tukey multiple range analysis the square exhibited the lowest AE and PQ values, and the circle the highest ones. As regards the AT parameter, the circle was traced more slowly than the square or the triangle (no difference in the tracing speed between the latter figures was found).

Handedness also represented a relevant factor, since significantly lower AE, AT and PQ values [$F(1,599)=5.95$, $P<0.01$], [$F(1, 599)=6.17$, $P<0.05$], [$F(1,599=5.413$, $P<0.05$], respectively, were achieved by the right hand in comparison with the left hand.

Thus the square was found to be the easiest and the circle the most difficult figure for tracing. The right hand exhibited a better performance than the left hand (Table 2).

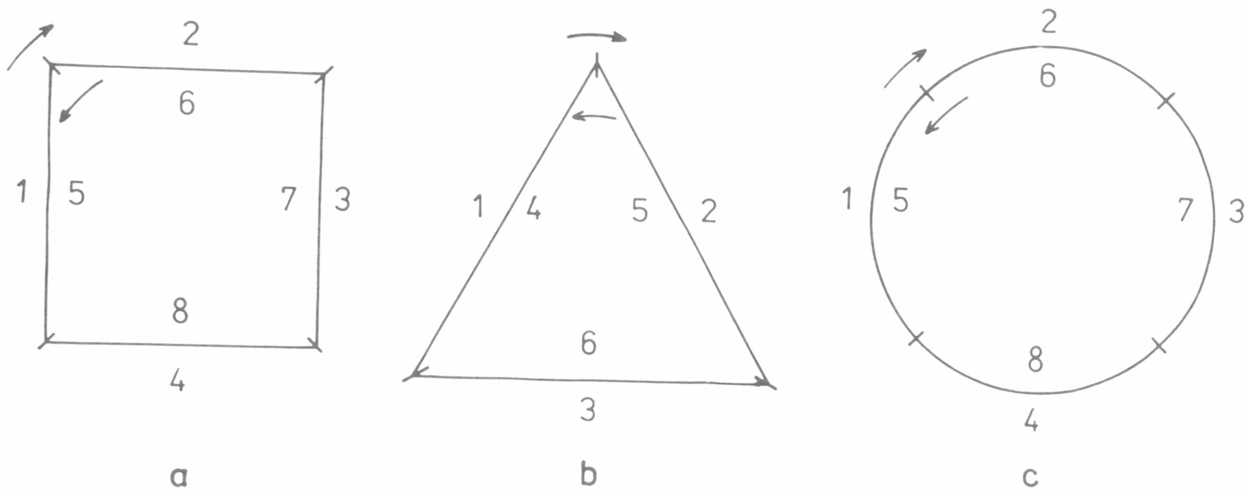

Fig. 1
Three traced trajectories (figures): a) square, b) triangle, c) circle. The trajectory segments are indicated as 1–4 for a) and c) or 1–3 for b) in the case of clockwise tracing, or 5–8 and 4–6 in counter-clockwise tracing, respectively.

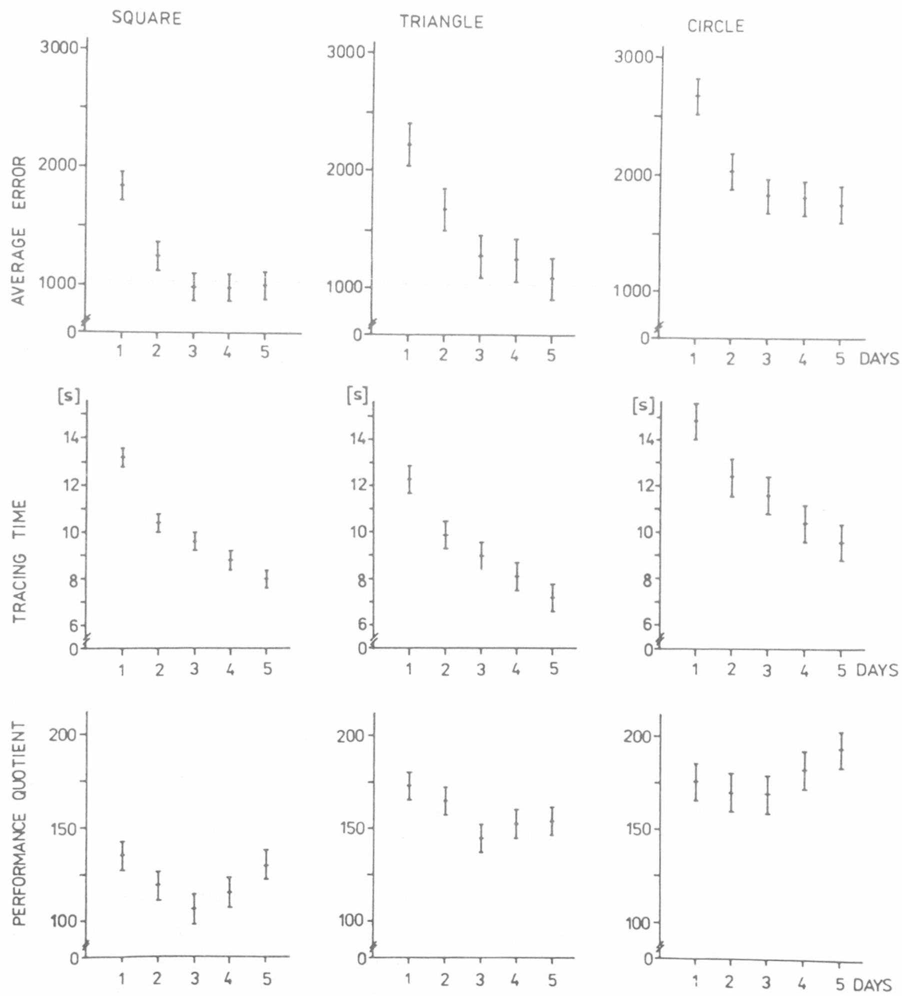

Fig. 2
Effect of learning on tracing task mastery using different performance measures: average error, tracing time and performance quotient, respectively. Means and corresponding 95 % confidence limits are given.

Learning effect

The learning effect in tracing the circumference of all three figures was studied for AE, AT and PQ using the three-way ANOVA with the following factors: SUBJECT (1..10), DAY (1..5) and HAND (right, left) for each figure separately.

The factor DAY had a significant influence on AE in all three figures: square, circle and triangle [$F(4,199)=15.02$, $P<0.001$], [$F(4,199)=12.45$, $P<0.001$] and [$F(4,199)=15.35$, $P<0.001$], respectively. There was a substantial decrease in AE mostly expressed between days 1 and 2 and less between 2 and 3, respectively, with no differences during the last three days. This effect (i.e. a decrease in AE) was most expressed for the triangle (50.73 %) and least for the circle figure (34.75 %), the square (46.05 %) being in-between.

Table 2
The total performance quotients (PQ) of traced figures

	Independent of hands			Independent of figures	
	SQUARE	TRIANGLE	CIRCLE	RIGHT HAND	LEFT HAND
PQ	121.9	157.9	178.4	148.7	156.7
SE	3.1	3.8	4.1	4.5	4.8

AT was also influenced by the factor DAY, with corresponding values for the square [$F(4,199)=52.99$, $P<0.001$], for the circle [$F(4,199)=41.01$, $P<0.001$] and for the triangle [$F(4,199)=42.43$, $P<0.001$]. Its decrease was, however, almost linear during all five days of the test. The learning effect, as regards the AT decrease, was most marked for the triangle (40.62 %), the square (39.4 %) and least for the circle (35.7 %).

PQ values were significantly influenced by factor DAY in the square figure only [$F(4,199)=3.64$, $P<0.01$]. There was a sharp decrease of the learning curve from the first to the third day and then it started to rise again, reaching almost the original value of the first day. The circle was characterized by a much higher initial value, with a slight decrease towards the third day and then a steep increase again above the initial value. The triangle values resembled those for the square, with higher initial values, however, and with a slight increase from the third day. Moreover, this figure was the only one, where a significant difference between hands was found, the right one being better (Fig. 2). These results indicate that the unequal decrease of AE and AT depending on the day of practice represents an explanation of the U-shape of the corresponding learning curve in all three cases.

Factor HAND produced no systematic effect either in AE or in AT.

Discussion

The present results have demonstrated that the global features of the stimulation patterns used significantly influenced the parameters of tracing efficiency. Although their circumference was the same, it seemed to be more simple to trace the square and most difficult to trace the circle, the triangle being in-between both. This was caused mostly by the fact that the error measure (AE) revealed lower values for the patterns consisting of linear elements, whereas the tracing of circular segments was characterized by considerably higher AE values. The strategy of performing one-dimensional movements (i.e. either horizontal, vertical or oblique) seems to be much simpler than that of angular ones. This is in accordance with the subjective "simplicity" of the movements, and was observed and reported separately by several subjects at the end of the completed experiment.

The evaluation of tracing efficacy for segments of the patterns pointed to a different conclusion. A few details might be worth mentioning: the tracing time (SAT) of horizontal segments of the square was longer than that of the vertical ones and thus less errors per unit time (i.e. lower SPQ) occurred during horizontal line tracing. However, the error measure (SAE) was more marked for tracing the oblique segments of the triangle than for the horizontal ones, resulting in lower SPQ for horizontal line tracing as well. This finding might reveal the effect of meridional anisotropy in tracing analyzed in other experiments performed currently in our laboratory. As regards SPQ in the circle, it disclosed a low value for vertically oriented segments, this finding being based mostly on the lower incidence of error during vertically oriented segments tracing. Thus, the square and circle do differ in their difficulty to be traced efficiently.

A further point is whether tracing of more or less identical elements of patterns with different global shape differs. Our experiments were not designed to analyze this question directly. It became clear, however, when comparing errors (SAE) or errors in a given time unit (SPQ) for the horizontal segments of the square and triangle, that these values revealed better performance for the square. It might be assumed, therefore, that global difficulty of tracing the triangle in comparison with the square (reflected also in subjective statements of the experimental subjects during and after the experiments), apparently caused by the oblique segments, became generalized in the whole pattern.

The use of the tracing task requires consideration of the speed/accuracy trade-off, to which the response of individual subjects may differ under different conditions. On the other hand, it offers a unique opportunity as it does not require a constant velocity (used in standard tracking tasks), which is not very common in natural movements. Significantly better tracing results for the right hand, when whole figures were taken into account, suggest the importance of handedness in this type of visuo-manual coordination tasks. It is not sufficiently clear, however, why similar statistical results did not appear in the situation of square and circle presentation, when their segments were considered only. Unfortunately, no comparable group of left-handers was available to verify the above conclusion.

The direction of tracing movements over the shapes, i.e. clockwise or counter-clockwise, did not seem to be the relevant factor. This demonstrates that the corresponding spatio-temporal maps engaged in motor control might be directionally the same.

The finding that subjects will be able to decrease their error scores and increase performance speed during the first sessions (over a couple of days) of performing a relatively simple eye-hand perceptual (cognitive) motor task is not new. For a pursuit tracking task, similar conclusions were reported e.g. by Franks and Wilberg (1984). However, according to these authors this performance improvement could be induced "by possibly changed strategies". Our results are in accordance with this assumption, which follows from speed (tracing time) accuracy (error) trade-off evaluation. These results suggest the existence of two learning stages: during the first three consecutive days performance increases, i.e. both the error rate and tracing time decrease (the error rate decreases more rapidly than the time of tracing). A further change in performance (expressed as average error per time unit), if any, is due to shortening of the tracing time, the incidence of errors per time unit increasing or remaining more or less stable. Evaluation of the development of speed/accuracy trade-off during performance training point to the possibility that committing errors (accuracy) and timing (speed) thus seem to be two more or less independent factors contributing to the efficiency of tracing performance.

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Reprint Requests

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