(12)

Research Report 1328

VISUAL-MOTOR ORGANIZATION: BETWEEN- AND WITHIN-INDIVIDUAL DIFFERENCES

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Princeton University

BASIC RESEARCH

U.S. Army
Research Institute for the Behavioral and Social Sciences

November 1981

U. S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the Deputy Chief of Staff for Personnel

JOSEPH ZEIDNER Technical Director	**L. NEALE COSBY** Colonel, IN Commander

Research accomplished under contract
for the Department of the Army

Department of Psychology, Princeton University

NOTICES

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER
Research Report 1328

2. GOVT ACCESSION NO.
AD-A145 459

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (*and Subtitle*)
VISUAL-MOTOR ORGANIZATION: BETWEEN- AND WITHIN-INDIVIDUAL DIFFERENCES

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(*s*)
Joseph M. Notterman, Daniel R. Tufano, and Jeffrey Scott Hrapsky (Princeton University)

8. CONTRACT OR GRANT NUMBER(*s*)
MDA903-79-C-0426
DAHC19-76-G-0012

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Princeton University
Department of Psychology
Princeton, NJ 08544

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
2Q161102B74F

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Avenue, Alexandria, VA 22333-5600

12. REPORT DATE
November 1981

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)

15. SECURITY CLASS. (*of this report*)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
--

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

Contracting officer's representative was Richard M. Johnson.

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)
training skills
sensory motor skills
visual discrimination
motor discrimination

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

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Study 2 determined that the originally observed test-retest individual differences in visual-motor organization not only persisted in the absence of practice, but also withstood active practice intervention. This study additionally showed that subjects differed reliably in their ability to plan, i.e., to take advantage of coherence in visual-motor organization.

Together, the two studies indicate that between- and within-individual differences exist in fundamental, nonverbal cognitive or perceptual modes of discriminating and organizing static and dynamic, visual and motor components selected from the tracking paradigm of voluntary action.

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5001 Eisenhower Avenue, Alexandria, Virginia 22333

Office, Deputy Chief of Staff for Personnel
Department of the Army

November 1981

Army Project Number
2Q161102B74F

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FOREWORD

ARI performs research and development in the areas of human performance and training with applicability to military training and human operator characteristics of hardware systems. This report presents the results of two experiments which investigated the processes by which people learn and perform complex visual and spatial tracking tasks that are similar to tasks often required of soldiers in target acquisition and gunnery. Research of this nature provides vital information for design and training in the context of the human-machine interface.

Joseph Zeidner

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Technical Director

ACKNOWLEDGMENTS

We thank Jeanette F. Koffler for laboratory assistance; Stephen L. Koffler for statistical advice; Paul Bree and Joseph Pylka for technical assistance; Marc Bornstein for help in taking brightness readings; and William Hirst, Michelle Millis-Wright, Diane Schiano, and Michael J. Watkins for their careful reading of the manuscript.

Portions of this article were discussed by J. M. Notterman in invited addresses at City College of New York (Globus Lecture Series, 1979), at the Midwestern Association of Behavior Analysis (Dearborn, Mich., 1980), and at the Colloquium on Selected Topics in Behavioral Science Research, US Army Research Institute, April 1980. The research was supported by the Army Research Institute under Grant DAHC19-76-G-0012, and Contract MDA903-79-C-0426. Requests for reprints should be sent to Joseph M. Notterman, Department of Psychology, Princeton University, Princeton, N.J. 08544.

EXECUTIVE SUMMARY

The research described in this report uses control theory's tracking paradigm of voluntary movement to identify nine elementary psychomotor tasks that are simple to administer, and that tap nonverbal cognitive or perceptual attributes. Two series of experiments are reported. Study 1 examined the hypothesis that dissimilar arrays of individual differences, as determined through test-retest correlations, may exist among the *same* subjects across the various static and dynamic visual and motor components which enter as terms into the mathematical expression of control theory's tracking equations and also in the organization of these components. The hypothesis could not be rejected. For example, the test-retest rho for judgments of differences in Target Velocity was .57; for differences in Target Acceleration, .58 ($N = 30$, $p < .01$, 2-tailed). However, the correlation between how the same subjects arrayed themselves on these two dynamic visual discriminations was not significant (rho = .21).

Study 2 determined that the originally observed test-retest individual differences in visual-motor organization not only persisted in the absence of practice, but also withstood active practice intervention. This study additionally showed that subjects differed reliably in their ability to plan, i.e., to take advantage of coherence in visual-motor information.

Together, the two studies indicate that between- and within-individual differences exist in fundamental, nonverbal cognitive or perceptual modes of discriminating and organizing static and dynamic, visual and motor components selected from the tracking paradigm of voluntary action.

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VISUAL-MOTOR ORGANIZATION: BETWEEN- AND WITHIN-INDIVIDUAL DIFFERENCES

Since the term "visual-motor organization" has broad meanings, it is necessary first to set constraints on what this report is about and to provide the reasons for our interest in the underlying topic.

The research concerns the fact that people can organize spatial-temporal signals in a manner such as to produce continuous motor behavior. Variations in the availability, type, and amount of visual and motor information requiring organization determine how organization occurs. Through working toward a clearer description of the parameters affecting organization, we may better understand why different theories of perception and of motor skills evolve. By doing so, we may also be able to isolate a few key variables and phenomena that can help optimize personnel selection and training, specifically for those occupational specialties concerned with the proficient execution of continuous motor behavior. These specialties demand effective response to both analog and digital computer displays, and range occupationally from the industrial, through the paramedical, to the military.

The production of motor behavior lies along a continuum of visual-motor information processing, the two endpoints of which reflect either sensory or perceptual modes of organization. The latter is what is ordinarily referred to as perceptual-motor behavior. Among other reasons, the word "visual" is eliminated because, under certain circumstances, the need for concurrent visual feedback is or becomes of little importance to efficient interaction with the environment.

Perceptual organization is fundamentally just as sensory as sensory organization, but involves a greater (there is no sharp dichotomy) utilization of synthesizing and planning operations. By "synthesizing" we mean combining different sources of information in such a way that the result transcends the components, even though it depends upon them. By "planning" we mean taking advantage of whatever coherence or predictability may exist in a situation, thereby reducing the need to make moment-to-moment corrections in ongoing behavior.

In a task involving sensory visual-motor organization, the development of skill is based mainly upon improvement in the speed and accuracy with which exteroceptive and kinesthetic information can be put together directly and processed. The same holds true for perceptual organization, but the acquisition of skill is abetted by the greater possibility of being able to synthesize information more readily and to develop plans.

The study of individual differences in visual-motor organization has a long history. In his doctoral dissertation on the accuracy of voluntary movement, R. S. Woodworth included a brief passage concerning his observation of individual differences among his subjects. Without going into statistical detail, he wrote, "We notice that the individuals differ markedly in accuracy; but that it is not always the same individual that is most accurate at all speeds or in all the varieties of the experiment" (Woodworth, 1899, p. 36).

Three-quarters of a century later, W. F. Battig lectured on individual differences at the Third Loyola Symposium on Cognitive Psychology. He stated, "We could find nobody who had seriously considered the possibility that the variance assumed to reflect individual differences might be due to differences within, rather than between, individuals" (Battig, 1975, p. 204, emphasis in original).

Although the earlier research involved human performance and the later research dealt with verbal learning, both Woodworth and Battig raised the overriding point that the same individual is not necessarily equally gifted in each of the constituent components of organized behavior.

Current contributions to the field of human performance have produced at least one major exception to Battig's observation. E. A. Fleishman and his associates have drawn a distinction between basic traits (or abilities) and molar proficiencies (or skills). For example, a person may be gifted in an ability identified as Arm-Hand Steadiness but not in another ability such as Tapping. Fleishman has specified 11 basic abilities and has shown that clusters of these abilities can predict the level of individual skill in more complicated situations, such as flying an airplane or working on a demanding assembly line (Fleishman, 1972; see also Parker & Fleishman, 1960).

We have no quarrel with Fleishman's research approach (which is an interlocking combination of factor analysis and experimentation), nor with his research findings. However, our approach has entirely different goals. We are not concerned with the issue of predicting success in dissimilar molar proficiencies. Our purpose is to use within- and between-individual differences as a way of assessing the effect of hierarchically increasing cognitive or perceptual demands upon visual discrimination and motor action. To achieve this purpose, we deal with a single case of visual-motor organization, the familiar eye-hand pursuit tracking paradigm. Thereby, we extract in advance the specific discriminations and actions of experimental interest.

The tracking paradigm has been used for many years by scientists concerned with the central-peripheral underpinnings of voluntary movement (see Poulton, 1974). The impetus for the growth of theoretical and applied interest in tracking came with the onset of World War II. Academic psychologists were quickly pressed into service as engineering psychologists (Alluisi & Morgan, 1976). Their assignment was to determine the ways in which men and machines could be brought together to function efficiently as integrated systems. One major consequence was the development of control theory, with its fairly precise, pursuit tracking account of visual-motor organization. In brief, control theory is concerned with how far one can push the Cartesian argument that the human brain functions as a biophysical error detector and error corrector. Error is defined as the momentary discrepancy between either visual or motor indicants of current vs. required behavior. Departures from expected performance may be attributable to the general properties of the human body, to the human modes of cognition and perception, or, more to the point of this report, to the existence of individual differences in proficiency of organizing visual and motor information. Thus, various arrays of individual differences may exist among the same subjects across the various components--detecting and responding, visual and motor--that enter specifically into the equations of control theory and its account of tracking.

The examination of equation-related individual differences can serve as an analytic device for understanding how components of tracking affect overall performance. For example, it may elucidate (a) the extent to which the ability to judge visual velocity of targets rests upon proficiency in judging separately the entering components of space and time, the physical determinants of objective velocity; (b) the way speed, accuracy, and planning interact in the development of limb movements when these movements are executed without concurrent visual feedback from a cursor; and (c) the degree to which an individual's level of proficiency in a single kind of complete visual-motor organization, as represented here by the eye-hand pursuit tracking paradigm, is or is not dependent upon the same individual's proficiency in dealing with the various entering components, such as static and dynamic visual discriminations, and static and dynamic motor actions. The attempt to obtain understanding of these and related phenomena may contribute toward satisfying one of the "12 most important" needs confronting cognitive psychology--that of drawing together theories of human performance and of cognition (Norman, 1980).

The static and dynamic, visual and motor informational components considered to be minimally necessary to produce continuous visual-motor behavior were identified by way of two conventional equations drawn from control theory. For visual input (i.e., the target's momentary location as it moves back and forth), the equation is

$$\underset{\text{Position}}{s_t = s} \quad + \quad \underset{\text{Velocity}}{ds/dt} \quad + \quad \underset{\text{Acceleration}}{d^2s/dt^2}$$

For motor output (i.e., momentary force production), the equation is

$$\underset{\text{Limb Displacement}}{F_t = K\theta} \quad + \quad \underset{\text{Limb Velocity}}{K\, d\theta/dt} \quad + \quad \underset{\text{Limb Acceleration}}{K\, d^2\theta/dt^2}$$

(The motor output situation was deliberately chosen to represent a quite simple force-movement transfer function, one describing a control stick loaded only with elasticity (K) through a torsion rod.)

Nine tasks based upon these equations were selected.

Visual Discriminations

Three of the tasks employed visual discriminations. One required subjects to judge differences in Target Positions (s), specified as horizontal space between successively presented pairs of points of light displayed on the midline of an oscilloscope ("% correct" was used as an index of task proficiency). The other two tasks required subjects to judge differences in Target Velocities (ds/dt) and differences in Target Accelerations (d^2s/dt^2). Quasirandom combinations of spaces and times were used to determine Target Velocities and Accelerations.

Temporal Discrimination

This task required subjects to make temporal discriminations. Specifically, subjects were asked to judge differences in Target Durations (t) of successively presented pairs of points traveling the same horizontal distance at various speeds.

Motor Actions

This third set of tasks had subjects perform three motor actions with no concurrent visual feedback: Limb Displacement, consisting of angular displacement of an elastically loaded control stick about its axle, with the coefficient of elasticity and angle of rotation each being limited to a single value ($F = K\theta$); Limb Velocity ($dF/dt = K\ d\theta/dt$); and Limb Acceleration ($d^2F/dt^2 = K\ d^2\theta/dt^2$).

Visual-Motor Organization

Finally, two tasks were employed to assess visual-motor organization of the continuous behavior variety. One task was to track a target possessing predictable motion (horizontal representation of a sine wave), and the other was to track a target possessing relatively unpredictable motion (horizontal representation of band-limited frequencies).

We recognize the limitations inherent in drawing these nine tasks from the rudimentary pursuit tracking version of visual-motor organization. However, what the analysis lacks in complexity it gains in quantifiability and testability. Moreover, the analysis of visual-motor organization into higher-order space-time components fits in well with Gibson's (1979) flux theory of perception and Johansson's (1977) distinction between the explanatory utility of static vs. dynamic stimulus configurations. Indeed, it lends support to Johansson, von Hofstein, and Jansson's (1980) conclusion that the "direct vs. indirect" controversy in perception is exaggerated (cf. Notterman & Farley, in press).

With the foregoing analysis providing a conceptual structure, two studies were implemented. The main purpose of the first study was to assess individual differences in synthesis and planning, and to do so on a test-retest basis. The second study determined the extent to which test-retest differences in visual-motor organization persisted in the absence of training, and remained despite training.

STUDY 1

Method

Subjects

The subjects were 17 female and 13 male undergraduates, all of whom were right handed. They were tested with an eye chart to assure that they had normal or corrected-to-normal vision. They were paid for their services.

Apparatus and Procedure

The design of the experiment required that each subject appear in the laboratory twice a week for an entire semester, taking a test in the beginning of the week and a retest on the same task in the latter part of the week. Subjects were run one at a time, with a maximum of five subjects run during the course of a full day. The subjects performed the tasks in the order in which they are here described.

The apparatus for the Visual and Temporal Discrimination tasks consisted of a Tektronix 604 oscilloscope (P-32 phosphor) and a push-button panel for initiating trials and for registering binary response choices (e.g., "faster" or "slower"). The apparatus for the Motor Action and Pursuit Tracking tasks, located in an adjoining room, consisted of another Tektronix 604 and a control stick. A PDP-12A digital computer was programmed to provide the visual and temporal stimulus configurations, to record responses, to generate the motor action and pursuit tracking conditions, and to perform routine calculations.

Visual Discrimination. The basic procedure used for all three types of visual discrimination (judgments of differences in target position, velocity, and acceleration) was a modified method of constant stimuli. We describe the Target Position task in some detail for illustrative purposes.

1. Target Position. The subject was seated in front of the oscilloscope, with his or her head positioned in a chinrest located 25.4 cm distance from the faceplate. The faceplate was approximately 12 cm high and 14 cm wide. The target was approximately .33 mm in diameter (or 4.51 minutes of visual angle) and 17.10 cd/m^2 in brightness. Luminance of the oscilloscope's faceplate was minimal. Room illumination was somewhat dimmer than a fairly well-lit classroom, and yielded brightness of 8.55 cd/m^2 at the faceplate.

The subject was instructed to press a button labeled "initiate trial" upon receiving a ready signal (a beep), whereupon the target appeared immediately on the far left of the horizontal midline (not inscribed) of the screen, approximately 1.5 cm from the edge. It remained there for .60 sec, and then disappeared. The target reappeared after .70 sec at one of five positions to the direct right of the starting place,'and remained there for .60 sec. In 3.0 sec, a second target appeared at the same place as the first had started, disappeared, and reappeared at one of the five positions to the right. Subjects were instructed to judge whether the distance traversed by the second point was shorter or longer than that traversed by the first point. A judgment of shorter or longer was registered by pressing the button labeled #1 or #2, respectively. Subjects were further instructed that they had to press one or the other button, even if they thought that the distances traversed were equal. The intertrial interval was 10 sec.

There were eight practice trials in which subjects received knowledge of results after each trial if their responses were correct. Pairs of equal distances were not presented during these trials. The subjects than received 70 actual trials *without* receiving knowledge of results. There was a brief rest period after the first 35 trials.

The distances presented to the subjects included 9.0 mm (121.82 min of visual angle), 10.0 mm, 11.0 mm (the "standard"), 12.0 mm, and 13.0 mm

(175.96 min of visual angle). A given trial could consist of any of the following pairs of stimuli: the standard followed by any of the four other stimuli, and vice versa for time-order control (eight possibilities); the standard followed by the standard and vice versa (two possibilities); the shortest distance (9.0 mm) followed by the next to shortest distance (10.0 mm), and vice versa (two possibilities); and the longest distance (13.0 mm) followed by the next to longest distance (12.0 mm), and vice versa (two possibilities). Thus, a total of 14 possible pairs of distances were compared. Each of these pairs was randomly presented five times during the course of a session. A "% correct" measure was used as an index of precision of judgment. It was computed from the total of all required comparisons, except standard vs. standard, yielding a total of 60 paired comparisons as a basis for computation.

2. Target Velocity. The stimuli used in the dynamic cases (Target Velocity and Target Acceleration) were constructed so as to preclude the presence of any systematically correlated space or time cue. Each value had to be synthesized on the basis of a particular quasirandom combination of long or short spaces and times. For example, the combination of a short space with a short time or a longer space with a shorter time could yield either a fast or a slow target movement. For Target Velocity, the spaces used ranged from 8.0 mm (108.28 min) to 14.0 mm (189.50 min). The times used ranged from .41 sec to .94 sec.

As with judgments of differences in target position, the subject initiated the trial upon receiving the ready signal. The target appeared at the starting place, remained stationary for .60 sec, and then moved at one of the five velocities. It then remained stationary for .60 sec before disappearing. Within 3 sec, the same or another velocity was quasirandomly selected and presented. The subject had to judge whether the second stimulus was faster or slower than the first. The intertrial interval was the same as before, 10 sec.

The target velocities were 13.30 mm/sec (180.0 min/sec), 15.69 mm/sec, 18.33 mm/sec (the "standard"), 20.90 mm/sec, and 23.18 mm/sec (313.72 min/sec). The number and composition of pairs of stimuli were selected on the same basis as for Target Position.

3. Target Acceleration. The routine for Target Acceleration was identical to that of Target Velocity, with the single exception that all stimuli started moving with an initial velocity of 5.3 mm/sec. Pilot work indicated that unless the targets were given an initial velocity, the accelerations were too readily distinguishable from each other within a range of distances traversed that was roughly equivalent to that of Target Velocity. Target accelerations were generated from quasirandom combinations of space, ranging from 9.5 mm (128.59 min) to 12.5 mm (169.20 min), and of time, ranging from 1.03 sec to 1.63 sec. The target accelerations were 1.58 mm/sec^2 (21.39 min/sec^2), 2.53 mm/sec^2, 4.47 mm/sec^2 (the "standard"), 7.63 mm/sec^2, and 7.71 mm/sec^2 (104.36 min/sec^2). The number and composition of pairs of stimuli were selected on the same basis as for the other types of visual discriminations.

Temporal Discrimination. For judgments of differences in time, we used pairs of targets moving a constant distance but at different velocities. Since the traverse of the targets was always the same, a faster target would take less time to cover the same distance than a target having slower speed.

Responses were longer or shorter with respect to duration. As with the ability to discriminate space (or differences in target position), we wanted to determine how the ability to discriminate time (or differences in duration) entered into the space-time synthesis of target movement. A dynamic display was used rather than a motionless display (e.g., one involving judgments of differences in duration of a stationary target) because time discrimination was considered unlikely to enter into judgments of differences in position (s). It could conceivably enter as a component into judgments of differences in target velocity (ds/dt), and in target acceleration (d^2s/dt^2). Although both the Time Discrimination and the Target Velocity tasks involved first-derivative situations, the dynamics were quite dissimilar. The ability to discriminate differences in time was tapped through an equal-distance velocity display; the ability to discriminate differences in target velocity was assessed through a synthesized/velocity display, in which each target movement was generated from quasirandom combinations of spaces and times.

The fixed distance was 11.0 mm (148.89 min of visual angle). The durations were .471 sec, .538 sec, .600 sec (the "standard"), .695 sec, and .825 sec. The mode of presenting stimuli was the same as for visual discriminations, as were the number and composition of stimulus pairs.

Motor Actions. The faceplate of the oscilloscope used for the motor action conditions was inscribed with two circles on its horizontal midline. Each circle was 1 cm in diameter. The centers of the two circles were located 22 mm from the vertical edges of the faceplate. Approximately 90 mm separated the centers. When the control stick was in its resting position (angularly offset 26° left of vertical), the cursor was located in the center of the left-end circle. The cursor itself was a vertical line 5 mm (67.7 min of visual angle) in length.

The control stick was a 15.25-cm aluminum rod affixed perpendicularly to its shaft or axle. A torsion rod was attached end-to-end to the shaft. Its coefficient of elasticity (or responsivity to twist) was 12.13 newtons/radian. Such an arrangement is described by the transfer function $F = K\theta$, where F is a constant and sustained force applied to the stick, K is the coefficient of elasticity, and θ is the angle assumed by the stick relative to its resting position when force is applied.

For the three types of motor action (Limb Displacement, Limb Velocity, and Limb Acceleration), movement was always unidirectional, from left to right. Thereby, we could examine simple actions unconfounded by the effects of momentum during reversal of motion. Scheduling constraints permitted using only one value for each type of motor action.

1. Limb Displacement. We go into some detail regarding the instructions given to the subjects for Limb Displacement. With slight and obvious changes, the same instructions applied for Limb Velocity and Limb Acceleration.

The subject was seated in front of the oscilloscope and was told to use the chinrest (same distance from faceplate as with visual discriminations). The subject was instructed to place the right hand on top of the control stick, with the thumb on a button switch, the fist on a resting plate, and the elbow on a pad.

The subject was informed that the start of each trial was indicated by the joint appearance of the target (same size as that used for visual discriminations) and the cursor at the center of the circle on the left, with the cursor and target being superimposed on each other. Upon hearing the ready signal, the subject was to press and quickly release the thumb switch, whereupon both target and cursor would briefly disappear.

The subject's task was to place the unseen cursor over the target's eventual reappearance position--in the center of the circle on the right--and to do so within 4 sec, before the target reappeared. Once the response was executed, the subject was to hold the control stick steady because the cursor would reappear at the same time as the target. By looking at the separation between the cursor and the target, the subject could learn how accurate the response was. The separation between cursor and target was sensed by the computer.

The subject was further instructed that the target would remain for 2 sec in the circle on the right before disappearing, indicating the end of a trial. Subjects were also told that the intertrial interval was 10 sec, during which time they were not to practice by repositioning the cursor over the circle on the right, but only to return the cursor to the left by releasing force on the stick.

There were 10 practice trials and 50 routine trials without a break.

2 and 3. Limb Velocity and Acceleration. The routine was the same for Limb Velocity and for Limb Acceleration, except that the target remained visible as it moved across the screen. Target velocity for the former was 22.5 mm/sec; target acceleration was 11.25 mm/sec^2 (average velocity = 22.5 mm/sec). The cursor was not present during the 4-sec trial, only at the beginning and end. Therefore we could determine whether reliable individual differences existed in the ability to develop motor programs for simple, unidirectional movements when concurrent visual feedback was absent. From another study we already knew that individual differences in executing these actions tended to be masked by a floor effect when concurrent visual feedback was present (Notterman & Weitzman, 1981).

The dependent variable for Limb Displacement was the absolute error between cursor and target at the end of the trial. For Limb Velocity and Limb Acceleration, the dependent variable was the time integral of error during the 4-sec trial.

Visual-Motor Organization as Represented by Pursuit Tracking. The same target, cursor, control stick, and torsion rod were used for the two types of pursuit tracking ("predictable" and "unpredictable" target motion) as were used for the motor actions. Predictable, or regular, target motion had a frequency of .50 Hz and was the horizontal representation of a sine wave. Unpredictable, or irregular, target motion was Gaussian noise with a double corner frequency at .33 Hz. The effect of the double corner is to reduce the presence of high-frequency reversals in direction of motion (cf. Notterman & Page, 1962). Thus, the general frequency pattern of even unpredictable target motion was not completely unlearnable (Hrapsky, 1981). Pilot research indicated that both motions were of moderate difficulty in tracking at the very outset of practice. For pursuit tracking, the starting position of the target was at the center of the screen. The resting position of the control stick was vertical, thus superimposing the cursor and the target. Upon hearing the ready signal, the subject pressed the thumb switch and initiated the target's movement. The subject was instructed to keep the cursor, which remained visible, over the target while the target was in movement. Each trial lasted 30 sec. The intertrial interval was 10 sec and there were five practice trials. A brief rest period was provided midway between the 50 trials comprising the session.

The dependent variable was the time integral of error. Neither verbal nor numerical knowledge of results was given. The test-retest sessions for predictable target motion preceded those for unpredictable motion.

Results and Discussion

It is evident from Table 1 that the strategy of using control theory's tracking equations as a way of identifying components entering into visual-motor organization yields an impressive set of individual differences. Surprisingly, the test-retest Spearman rhos for pursuit tracking represent the first nonfactorial evidence that we know of for consistency of individual differences in so fundamental a laboratory paradigm of voluntary, continuous corrective movements. Their extraordinary persistence is described in Study 2.

Table 1

Test-Retest Rhos and r's for Tasks Drawn from Control Theory

	rho	r
Visual Discrimination		
1. Target Position	.63***	.63***
2. Target Velocity	.57***	.61***
3. Target Acceleration	.58***	.58***
Temporal Discrimination		
4. Target Duration	.68***	.76***
Motor Action (no concurrent cursor feedback)		
5. Limb Displacement	.52***	.57***
6. Limb Velocity	.74***	.61***
7. Limb Acceleration	.87***	.87***
Visual-Motor Organization (concurrent cursor feedback)		
8. Pursuit Tracking: Predictable target motion	.92***	.88***
9. Pursuit Tracking: Unpredictable target motion	.92***	.82***

***$p < .01$, 2-tailed.

In order that our purpose in showing these correlations not be misunderstood, several caveats are in order, even at the expense of occasional reiteration. We are not attempting to argue a case for mental mechanics. To the contrary, one of our major aims is to show how these individual differences contribute to, but are transcended by, the cognitive or perceptual processes involved in overall visual-motor organization. This particular table leaves open the question of whether the rhos depend upon the same subjects arraying themselves in roughly similar order across the various visual, temporal, and motor tasks. The presence of within-individual differences--in addition to between-individual differences--is yet to be discussed, with a view as to whether they provide further evidence for the influence of cognition or perception. We take seriously the .01 level of confidence shown for the rhos in the table, but not their precise values. During the several years that transpired while the sample of subjects was gradually increased, too many extraneous variables (e.g., examination tensions, sleeping habits, seasonal changes) may have affected the results. We do not believe that a further increase in the number of subjects is necessary to our main arguments, since all test-retest correlations are significant at $p < .01$, 2-tailed. Our use of nonparametric statistics is deliberate. First, there is no reason to assume that the attributes we are examining are normally distributed (Poulton, 1974). Second, a relatively small sample of subjects exposed to all conditions of the experiment was logistically mandated, since no more than one subject could be run at a time with the available apparatus.[1] Nevertheless, Table 1 includes test-retest r's for purposes of comparison with the rhos.

Since all the test-retest rhos were significant, we combined each subject's Session 1 and Session 2 mean scores on each of the several tasks, thereby doubling the number of trials used to assess proficiency.[2] We then

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[1] With larger samples, an argument for parametric statistics might well be more persuasive. With much larger samples, an argument for comparing different samples of subjects across the nine tasks as if they were the same sample would become tenable. At present, such a strategy requires reliance on the use of paper-and-pencil tests. Problems inherent in the mass usage of tests depending upon apparatus are a major reason for the continued use of paper-and-pencil tests as a way of assessing sensory-motor and perceptual-motor skills (Shields, 1980). It is apparent that both the growing sophistication in computer technology and the increasing demand for personnel capable of efficiently using advanced control and display configurations might well diminish such reliance in the future, perhaps leading to some combination of paper-and-pencil and apparatus testing.

[2] We note here that there was reliable improvement upon retest in three of the nine tasks: Limb Displacement and the two types of pursuit tracking. Where relevant, we consider these practice effects.

Using combined test and retest scores, we compared proficiency of the 17 females vs. the 13 males separately on each of the tasks. There was no significant difference on any of the nine tasks, with the single exception of Unpredictable Pursuit Tracking (females performed worse than males, $p < .02$, 2-tailed, by Wilcoxon's Unpaired Replicates). We believe that the difference is probably exertional in origin and reflects the sudden reversals in limb momentum required in this type of tracking.

cross-correlated between those particular tasks that seemed to be of special theoretical and empirical interest, especially where the topic of within-individual differences is concerned.

Table 2 gives the results of the between-task correlations for selected pairs of visual and temporal comparisons. It is apparent that a person gifted in spatial judgments is not necessarily gifted in temporal judgments. The absence of a relation cannot be fully understood as a matter of the former tapping a peripheral capacity and the latter, a central ability, since all subjects had normal or corrected-to-normal vision. Apparently, spatial judgments require more than good visual acuity; otherwise, there would not have been a reliable test-retest correlation for judgments of differences in visual extent. The possibility must be entertained that even quite elementary spatial judgments may be centrally influenced.

Table 2

Between-Task Correlations for Selected Pairs of Visual Discrimination and Temporal Discrimination

Combined test and retest		Combined test and retest	rho[a]
Visual Position (Judgment of Space)	vs.	Duration (Judgment of Time)	NS (.11)
Visual Position	vs.	Visual Velocity	NS (.26)
Duration	vs.	Visual Velocity	NS (.29)
Visual Position	vs.	Visual Acceleration	NS (.19)
Duration	vs.	Visual Acceleration	NS (.34)
Visual Velocity	vs.	Visual Acceleration	NS (.21)

[a] The values for the NS rhos are indicated in parentheses in this and in subsequent tables.

Kant, in his Critique of Pure Reason, advanced the idea that intuitions of both space and time were innately characteristic of mind in general. We show here that these perceptions are separately and reliably spread among individuals, and that the ability to judge space is quite unrelated to the ability to judge time.

One expected finding from a Piagetian perspective is that discrimination of visual velocity is unrelated to proficiency in separately discriminating the entering components of space and time. Piaget used velocity discrimination to distinguish between pre-operational stages of perceptual-cognitive development. The reason for the present finding may be that velocity discrimination is a synthesis depending equally upon, but transcending, independent judgments of space and time. The case is not quite so clear for discrimination of visual acceleration; there may be a marginal correlation with durational judgments.[3] A more complex synthesis is involved because during acceleration an object traverses space as a direct function of the square of time. Regardless, the two types of dynamic syntheses are sufficiently disparate for a reliable talent in one to be unrelated to the other.

Table 3 shows that unlike the situation with visual discrimination, for which judgments of differences in Target Velocity and in Target Acceleration were not significantly related, the opposite occurs in comparing Limb Velocity with Limb Acceleration. This correlation could be explained as follows: Since the subjects are instructed to place and keep an unseen cursor over the target, the only exteroceptive feedback they receive is when the cursor reappears at the end of the trial. Accuracy is then reflected by the separation between cursor and target. Thus, the instructions effectively become the following: Learn how to organize force-movement feedback information in the absence of concurrent exteroceptive feedback, so as eventually to produce a time-patterned limb response that results in minimal cursor-target error at the end of the trial.

To succeed in dynamic motor action tasks, the subject must not only match the target's motion, but also compensate for the resting and moving properties of inertia. If the subject actually attempts to "keep the unseen cursor over the target," inertial effects will yield greater rather than less separation between the cursor and the target. That is, subjects will overshoot the target, unless they compromise by beginning to brake at some point during the 4-sec trial. They must develop a plan or strategy to deal with this problem. That they are different in either developing or executing these plans was suggested in Table 1 by the significant test-retest correlation of error scores for Limb Velocity (.74) and Limb Acceleration (.87). Further, the significant between-task correlation (combined test and retest for Limb Velocity vs. combined test and retest for Limb Acceleration, rho = .79) implies that there is something in common between the strategies developed to execute the two types of dynamic motor actions. A careful examination of strip-chart records supports this conjecture.

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[3] As a safeguard, r's as well as rhos were computed for all the between-task correlations (see Appendix, Tables A and B). The only instance of a marked discrepancy in levels of confidence occurs between Visual Acceleration vs. Duration. For rho, the correlation is .34 ($p < .05$, 1-tailed); for r, it is .58 ($p < .01$, 2-tailed). We do not know whether to attribute the discrepancy to chance or to infer that the more reliable r reflects a greater sensitivity to stable differences among subjects in the precision with which duration is judged. An argument could be made for the importance of the latter consideration, since the effect of variations in judging time is markedly greater in estimating target acceleration than in target velocity. The reason, of course, is that the target's position varies as the square of time during acceleration, but only linearly with time during velocity. Further analysis was done to determine whether the r's for space vs. velocity (.33) and time vs. velocity (.32) were significantly different from each other. The null hypothesis could not be rejected ($t = -.047$, $df = 27$). The r's for space vs. acceleration (.27) and time vs. acceleration (.58, $p < .01$, 2-tailed) were also not significantly different from each other ($t = 1.63$, $df = 27$).

Table 3

Between-Task Correlations for Selected Pairs of Motor Actions and Temporal Discrimination

Combined test and retest		Combined test and retest	rho
Limb Displacement	vs.	Duration	NS (.22)
Limb Displacement	vs.	Limb Velocity	NS (.14)
Duration	vs.	Limb Velocity	NS (.34)
Limb Displacement	vs.	Limb Acceleration	NS (.10)
Duration	vs.	Limb Acceleration	NS (.26)
Limb Velocity	vs.	Limb Acceleration	.79***

***$p < .01$, 2-tailed.

In Limb Velocity, subjects must catch up with a target that starts out moving at 22.5 mm/sec. Thus, an initial accelerative component is obligatory to effect efficient initiation of the action. Subjects must then slow down to match the target's velocity, and then start braking to keep from widely overshooting the target by the trial's termination. (Note that the subjects begin to hold the stick steady at 3.8 sec.) In Limb Acceleration, subjects need not begin the action with compensating acceleration, since the target's motion starts at zero velocity. Nonetheless, subjects start out with more of an acceleration than is required (see the portion of the cursor-plot between roughly 2.0 and 2.5 sec), then slow down to a fairly constant (or average) velocity (at roughly 2.5 to 3.0 sec), and finally begin braking. (In this case, the subjects start holding the stick steady at 3.6 sec.) With increased practice in producing the limb velocity and the limb acceleration, the two actions come to share the properties of each, at least as far as the subjects' strategies for coping with the dynamics of momentary accuracy vs. momentary inertia are concerned. This inference seems warranted on the basis of an increase in between-task rho from test (.63, $p < .01$, 2-tailed) to retest (.76, $p < .01$, 2-tailed).

These strategies yield motor programs of a rather remarkable sort. Corrections in limb movement are made during the course of the trial without benefit of concurrent, exteroceptive feedback. At places of inflection, these corrections occur at rates of up to .5° angular movement per 20 millisec (in Figure 1, 1 mm "unseen cursor" movement per 20 millisec).

Analysis has emphasized that motor programs are developed in the absence of concurrent-cursor feedback, and (except for the effects of inertia) that their acquisition depends upon observation of target motion. Proficiency in executing Limb Velocity and Limb Acceleration, then, should be correlated with the subject's ability to judge visual velocity and visual acceleration. However, dynamic visual discriminations require synthesis, storage, and

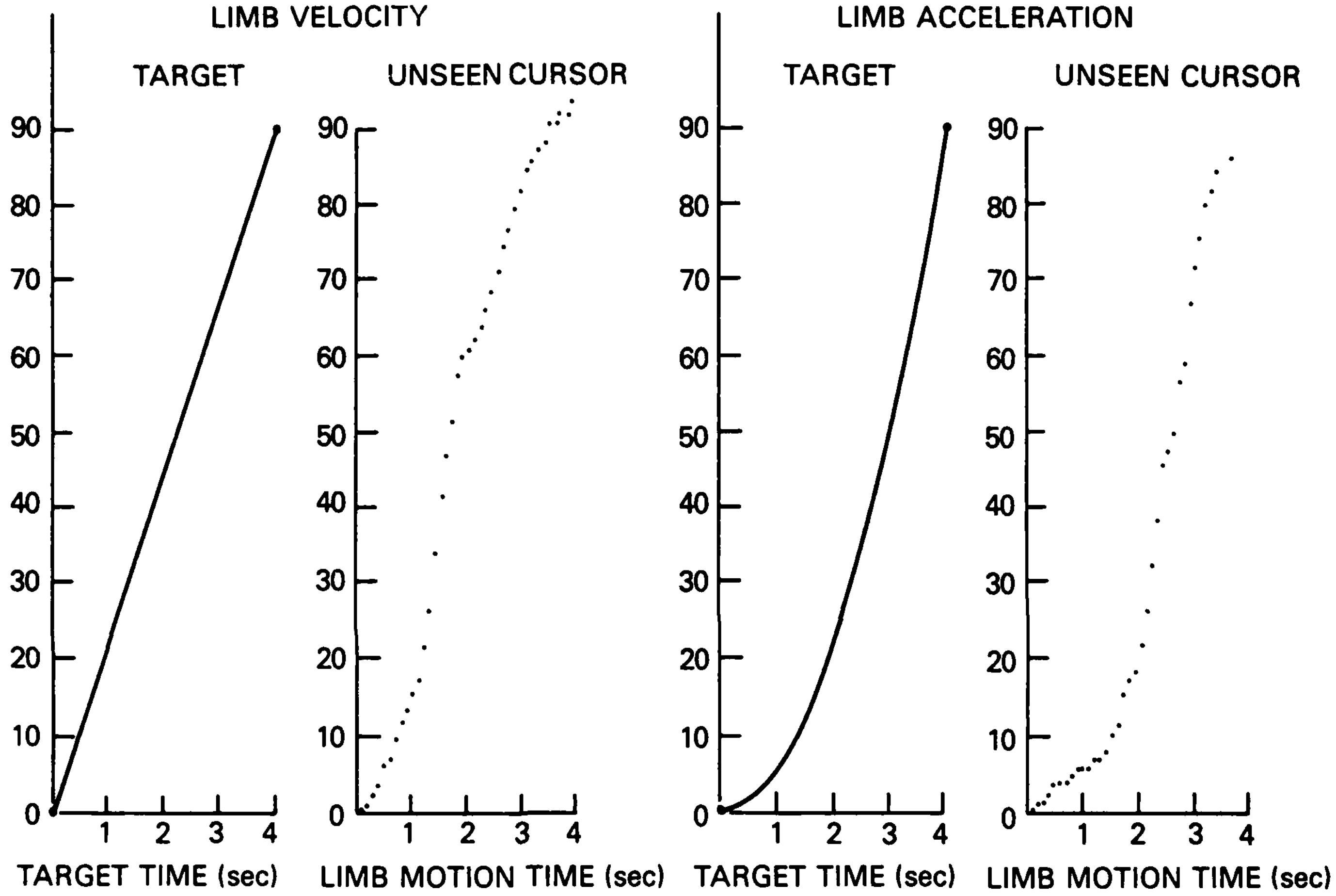

Figure 1. Motor programs for Limb Velocity and for Limb Acceleration, developed in the absence of concurrent cursor feedback. Target motion was from left to right for 90 mm. The points plotted in the "Unseen Cursor" panels were obtained from strip-chart recordings on trial 40, test session.

experimenter-mandated comparisons of specific combinations of spatial traverses and temporal durations. In the contrasting case of motor actions, the experimenter specifies the target's change of position with respect to real time, but the subject determines the spatial and temporal intervals the subject uses. Since the sampling is subject determined, no significant cross-correlations between the dynamic motor actions and either of the dynamic visual discriminations should exist. In fact, there are none.

If the sampling rate for any particular subject is fairly constant, then the distance a target traverses between sampling, or within successive spatial and temporal perceptual windows, should provide a key to the target's type of motion. For a target possessing velocity, there are no differences in extent of target traversal from window to window that, upon comparison, can be discriminated. However, an accelerating target will be seen to traverse increasingly greater distances within these windows and so there are target positional differences which exist and which can be compared and discriminated.

Thus, there should be no relation between proficiency in Limb Velocity and ability to judge differences in spatial extent (Judgment of Space), since the judgment of spatial differences constitutes a discrimination which is not tapped in executing Limb Velocity. However, Limb Acceleration and Judgment of Space should be correlated. In brief, the hypothesis asserts that there should be a significant correlation between proficiency in Limb Acceleration and visual Judgment of Space, but not between Limb Velocity and Judgment of Space. Finally, to the degree that the subjects' sampling pattern is not at fixed temporal intervals, there should be some tendency for both of the dynamic actions to be correlated with judgments of differences in time. The results of Table 4 support these ideas.

Table 4

Between-Task Correlations of Dynamic Motor Actions and Judgment of Space and Judgment of Time

Dynamic motor actions		Judgments of Space and of Time	
Combined test and retest		Combined test and retest	rho
Limb Velocity	vs.	Judgment of Space	NS (.19)
Limb Velocity	vs.	Judgment of Time	NS (.34)
Limb Acceleration	vs.	Judgment of Space	.43**
Limb Acceleration	vs.	Judgment of Time	NS (.26)

**$p < .02$, 2-tailed.

The argument can be pressed further, however, by way of the following considerations: If subjects do indeed rely upon spatial judgments during the acquisition of an accelerative motor program, then the subjects' performance during the test (or first) session should be more closely associated with ability to judge space than the same subjects' performance upon retest. That is, subjects should rely less upon careful attendance to (or sampling of) the target's changing position once they start developing motor programs. No such trends should be evident for any of the other between-task comparisons. The rho column of Table 5 gives some measure of reassurance since the entries are in agreement with the analysis.

Table 5

Between-Task Correlations of Dynamic Motor Actions and Judgment of Space and Judgment of Time Showing the Effect of Motor Action Practice

Test		Combined test and retest	rho
Limb Velocity	vs.	Judgment of Space	NS (.12)
Limb Velocity	vs.	Judgment of Time	NS (.28)
Limb Acceleration	vs.	Judgment of Space	.50***
Limb Acceleration	vs.	Judgment of Time	NS (.35)
Retest		**Combined test and retest**	
Limb Velocity	vs.	Judgment of Space	NS (.25)
Limb Velocity	vs.	Judgment of Time	NS (.33)
Limb Acceleration	vs.	Judgment of Space	.36*
Limb Acceleration	vs.	Judgment of Time	NS (.30)

*p < .05, 2-tailed.

***p < .01, 2-tailed.

Visual-Motor Organization as Represented by Pursuit Tracking. How are each of the tasks separately correlated with the two types of pursuit tracking? In particular, what correlation would one expect between the components of visual-motor organization and the pursuit tracking tasks themselves (Table 6), given the correlations between motor action and judgments concerning time and space (Table 4)? Limb motions involved in pursuit tracking are for all practical purposes accelerative and decelerative in nature, since there is hardly any constancy of velocity in the observed target's motion. This is true both for the horizontal representation of the sine wave used to specify predictable target motion and for the jerky resultant of the band-limited frequencies used to specify unpredictable target motion. Regular limb acceleration accompanies predictable target motion, and irregular limb acceleration follows unpredictable target motion. Thus, Judgment of Space should be significantly correlated with both types of pursuit tracking, since Judgment of Space is significantly correlated with Limb Acceleration. (Parenthetically, the rho is higher for Predictable Pursuit Tracking than for Unpredictable, probably because the former provides the opportunity to sample and recall an identical repeating pattern of changing positional differences.) Judgment of Time is not correlated with either type of pursuit tracking, since Judgment of Time is not significantly correlated with Limb Acceleration for reasons offered earlier. Neither Target Velocity nor Target Acceleration should be correlated with pursuit tracking, since, as previously discussed, they are not correlated with Limb Velocity or Limb Acceleration. Also, it may be that Target Velocity and Acceleration are uncorrelated with pursuit tracking because the visual discriminations are based upon experimenter-mandated comparisons, whereas pursuit tracking and the dynamic motor actions are based upon subject-determined samplings. Finally, Limb Displacement should be correlated with Predictable but not Unpredictable Tracking, since full excursions are required for both Predictable Tracking and Limb Displacement. An examination of Table 6 supports the foregoing analyses.

Table 6

Between-Task Correlations of Visual Discrimination, Temporal Discrimination, Motor Action, and Visual-Motor Organization

	Visual-Motor Organization	
Combined test and retest	Combined T/R Predictable rho	Combined T/R Unpredictable rho
Visual Discrimination		
Target Position (Judgment of Space)	.49***	.38*
Target Velocity	NS (.27)	NS (.13)
Target Acceleration	NS (.02)	NS (.04)
Temporal Discrimination		
Target Duration (Judgment of Time)	NS (.11)	NS (.12)
Motor Action		
Limb Displacement	.44**	NS (.24)
Limb Velocity	NS (.14)	NS (.16)
Limb Acceleration	.45**	.43*

*$p < .05$, 2-tailed.

**$p < .02$, 2-tailed.

***$p < .01$, 2-tailed.

As Table 7 indicates, modest but quite reliable coefficients of concordance are obtained for Visual Discrimination vs. Temporal Discrimination vs. Motor Action and either type of pursuit tracking.[4] Since the respective $\underline{\omega}$'s are based upon arrays of ranks derived from a single subject's performance on the seven component tasks, the rho between Predictable vs. Unpredictable Tracking should be above chance levels. In point of fact, the rho is .84 ($\underline{p} < .01$, 2-tailed) for the comparison between combined test and retest scores. Given that the test-retest rho for both Predictable and Unpredictable Tracking was .92, the lower between-task correlation may have resulted from different strategies in organizing regular vs. irregular visual-motor information. When the percent change from test to retest for each subject was compared for the Predictable vs. Unpredictable tasks, the results were as follows: First, for Predictable Tracking, the change is 24% and for Unpredictable, 6%. In both cases, the change is significant ($\underline{p} < .01$, 2-tailed, by Paired Replicates) and consists of a reduction in error score. Second, the percent change for Predictable is significantly greater ($\underline{p} < .01$, 2-tailed) than for Unpredictable. Third, the correlation of these percent changes (for the same subjects, between two tasks) is not significant. Fourth, for neither type of tracking is there a correlation between the subjects' test scores (or, for that matter, retest scores) and percent change. Still, we cannot rest a case for the presence of within-individual differences in mode of visual-motor organization on the absence of a significant rho.

Study 2 helped settle this as well as other issues.

Table 7

Coefficients of Concordance Computed Directly from the Same
Arrays of Ranks Used to Determine the
Between-Task Correlations in Table 6

	ω
Predictable Tracking vs. Visual Discrimination vs. Temporal Discrimination vs. Motor Action	.32***
Unpredictable Tracking vs. Visual Discrimination vs. Temporal Discrimination vs. Motor Action	.31***

***$\underline{p} < .01$, 2-tailed.

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[4] A coefficient of concordance was also obtained for the subjects' foreperiods across all nine tasks. For the Visual Discriminations, foreperiod was specified as the time taken to press the "initiate trial" button after hearing the ready signal. For both Motor Actions and Pursuit Tracking, foreperiod was specified as the time taken to press the thumbswitch (thereby starting target motion) after hearing the ready signal. Subjects were arrayed in terms of average foreperiod for combined test and retest trials. The coefficient of

Recapitulation of Major Results from Study 1

1. Test-retest, between-individual differences were shown to be reliable for each of the nine tasks identified in the foregoing (Spearman's rho, $p < .01$, 2-tailed, $N = 30$).

2. Proficiency for the same individuals across the nine tasks was then compared. Within-subject differences were found to exist, in that subjects who tended to excel at one task were not necessarily those subjects who did well at other tasks. For example, there is no direct relation between the ability to judge differences in Target Velocity and the ability to judge differences in Target Acceleration, even though both judgments have in common the perception and comparison of target movements. Apparently, the distinct space-time synthesis required of each type of perceived motion separates the two talents.

3. The results of Unpredictable and Predictable Pursuit Tracking indirectly imply that the same subjects differ reliably in their ability to utilize coherence of visual-motor information.

STUDY 2

In this study, we sought to answer three fundamental questions raised by the results of Study 1.

1. The first of these issues concerned whether the demonstrated existence of test-retest, between-individual differences in the tracking version of visual-motor organization were sufficiently robust and stable to withstand the passage of time. It must be kept in mind that the correlations were based upon only two sessions of practice. If they persisted in the absence of laboratory intervention, then both the theoretical and applied salience of the test-retest correlations obtained in Study 1 would be materially enhanced. The fact that motor skills are retained for long periods in the absence of practice is well established (see, e.g., Fleishman & Parker, 1962), but we know of no previous research from which we could generalize directly to the rationale and results of Study 1.

2. The second issue dealt, as it were, with the other side of the coin. Specifically, were between-individual differences in tracking obtained on a test-retest basis so inherently a part of the subjects' way of organizing visual-motor information as to withstand training intervention? Although practice might improve performance for each of the subjects, would they still tend to maintain their general standing relative to each other? If so, then the implications for motor-skill theories, and for practical problems of personnel selection and training, could be of major importance.

3. The third question was the lingering one of whether subjects differed reliably in their ability to take advantage of coherence in visual-motor

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[4] (continued) concordance is .97 ($p < .01$, 2-tailed), and leaves little doubt that subjects differ in the time taken to respond to a ready signal, regardless of the behavior required of them.

information, i.e., in their ability to plan. If so, then this fact of human performance would have to be recognized in the formulation of theories bearing upon nonverbal cognition and perception.

Method

Subjects

In order to deal with the first issue framed above, we recalled as many of the subjects in Study 1 as were still available. They consisted of 11 females and 9 males, constituting a sample of 20 recalled subjects out of the original 30.

The remaining two issues were examined by way of two new groups of subjects. Group 1 consisted of eight females and seven males; Group 2, of seven females and seven males. All subjects were right handed and had normal or corrected-to-normal vision. They were paid for their services.

Apparatus and Procedure

The apparatus was the same as that used for pursuit tracking in Study 1.

The 20 undergraduates who helped to determine the persistence of individual differences were recalled after approximately 1 year. They were exposed to test and retest sessions for Unpredictable Tracking only, scheduling pressures prohibiting any further investigations. In all other respects, their treatment was the same as that for the year before (see Study 1).

The two groups used to examine the effects of training upon Unpredictable and Predictable Pursuit Tracking received 10 consecutive daily sessions of practice under their assigned conditions. (No sessions were held on Saturday and Sunday.) Group 1 (Unpredictable) tracked a target moving back and forth horizontally, with its motion specified as Gaussian noise, limited by a double corner frequency at .33 Hz. Group 2 (Predictable) tracked a target moving at .50 Hz, the horizontal representation of a sine wave. The regimen was initiated on any of the 5 working days that meshed with the subjects' schedules and the demands of other laboratory commitments. Effectively, the starting day was randomized, thereby attenuating any possible effect of the intervening weekend.

Instructions, number of trials per session, intertrial interval, and so on, were all identical to the procedure followed in Study 1.

Results and Discussion

The test-retest rho for their original sessions was recomputed for the sample of 20 recalled subjects and was found to be .93 ($p < .01$, 2-tailed). This compared quite favorably with the test-retest performance for all 30 subjects, which was computed at .92 ($p < .01$, 2-tailed). The group mean error score of the original retest session for these 20 subjects was 164.7 mm-sec. One year later, the error score for the same 20 subjects upon test was 160.7 mm-sec. The rho between original retest and subsequent test for these 20 subjects was .91 ($p < .01$, 2-tailed). The test-retest rho for recalled test-retest sessions was .94 ($p < .01$, 2-tailed).

Taken together, the evidence is clear that individual differences in pursuit tracking of a target in unpredictable motion, when obtained on a test-retest basis, are sufficiently robust and stable to persist in the absence of training intervention.

Since the results of Study 1 suggested that even Unpredictable Tracking lends itself to some degree of planning, the high correlations of the recalled subjects imply that strategies acquired in Study 1 persisted with time. Enduring nonverbal, cognitive attributes, which can be assessed quite readily in just two sessions, must have contributed to the performance of the recalled subjects.

It is to the further examination of these hypothesized attributes that the training experiment proper was addressed.

Figure 2 shows the consequences of practice upon two groups separately exposed to Unpredictable and Predictable Pursuit Tracking. Unlike the situation in Study 1, practice effects are unconfounded since the same subjects did not experience the two types of tracking in sequence.

Before engaging the two main issues which prompted this experiment, we first comment on the initial separation (Session 1) in mean error score between the two groups; the difference is $p < .01$, 2-tailed, by Wilcoxon's Unpaired Replicates. The separation occurs even though the two types of target motion were selected so that they would be roughly equal in challenging tracking ability (Notterman & Tufano, 1980). For an idea of what is involved in assessing tracking difficulty, consider that the untracked time integral of error generated by predictable target motion is 859 mm-sec and by unpredictable is 484 mm-sec. Going by these values, it would appear that the subjects assigned to Group 2 (Predictable) would find that their tracking task is much more stringent than that encountered by the subjects in Group 1 (Unpredictable). However, with practice, they could learn to utilize the organization in the harmonic motion. A quick comparison of Figures 3 and 4 makes the point. The cursor-target plots in Figure 3 are for a trial early in the first session of practice; the plots in Figure 4 are for a trial in the last session of practice. (To remove between-subject differences in tracking skill, the same person was used in obtaining these illustrative plots.)

Returning to the main objectives of the training experiment, we inquire first as to the effect of practice upon the rhos established by the first two sessions. For Group 1, the Session 1 vs. Session 2 (test-retest) rho is .86 ($p < .01$, 2-tailed); for Group 2, .85 ($p < .01$, 2-tailed). Both these rhos are somewhat lower than those obtained in Study 1, probably because the N's are much smaller (Group 1, $N = 15$; Group 2, $N = 14$; Study 1, $N = 30$). The Session 1 vs. Session 10 rho is .71 ($p < .01$, 2-tailed) for Group 1 and .78 ($p < .01$, 2-tailed) for Group 2. Although practice affects the original standing of subjects relative to each other, regardless of type of pursuit tracking, practice does not diminish materially the correlational value of early test-retest assessment. Hence, people may differ remarkably and stably

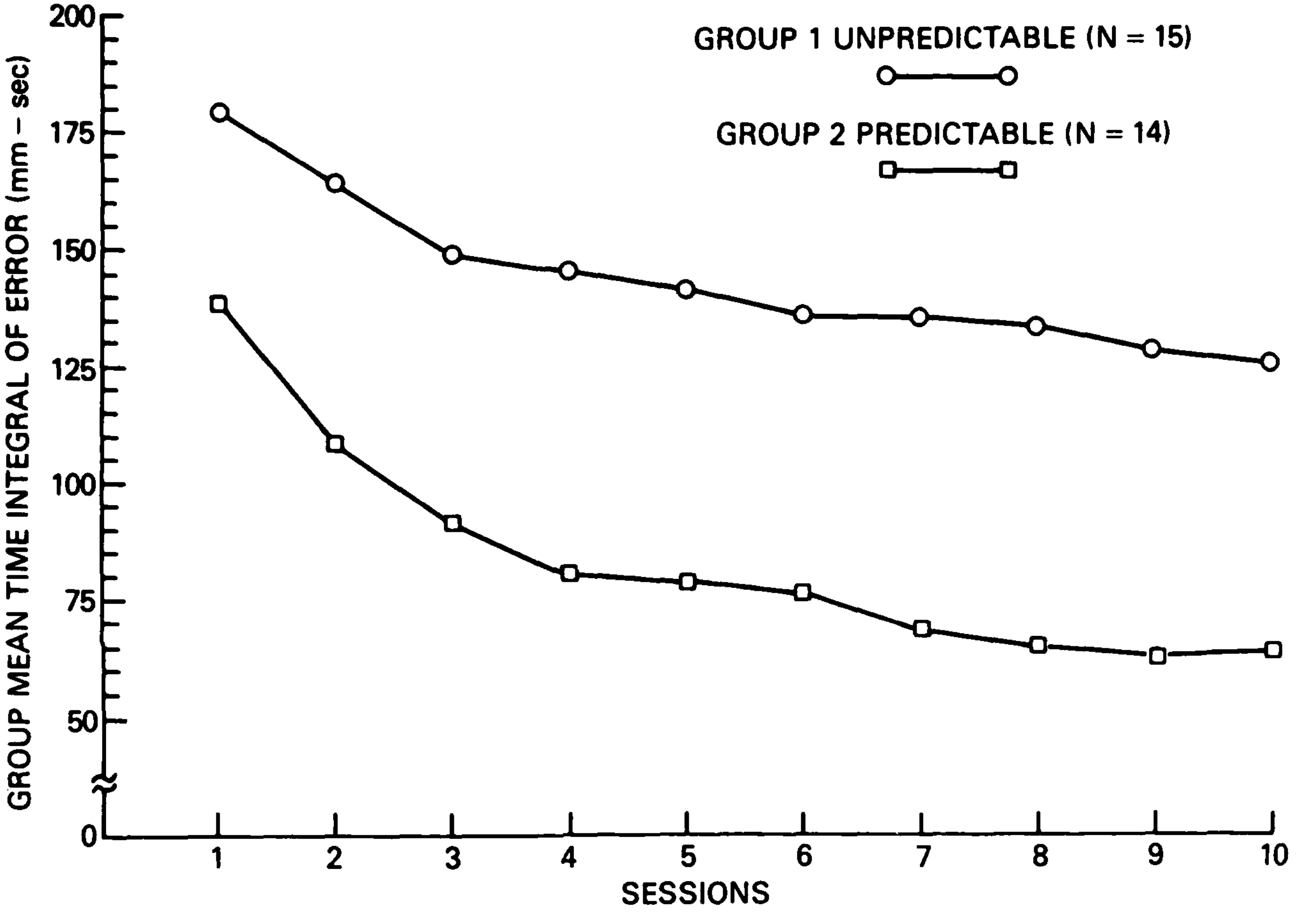

Figure 2. Group mean time integral of error per trial as a function of practice. Group 1 tracked a target moving back and forth horizontally, with its motion specified as Gaussian noise, limited by a double corner frequency at .33 Hz. Group 2 tracked a target moving at .50 Hz, the horizontal representation of a sine wave. Statistical analysis indicates that there is greater initial diversity among subjects in Predictable Pursuit Tracking than in Unpredictable Tracking.

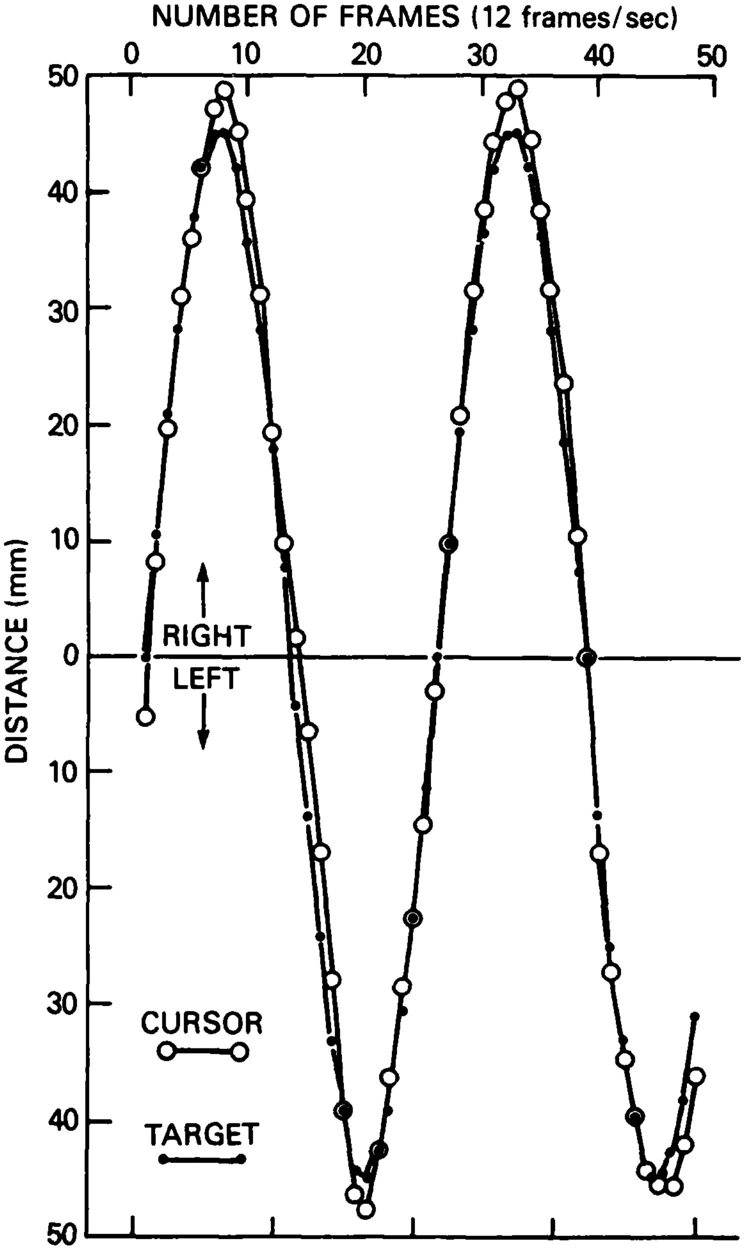

Figure 3. Tracking a target having predictable motion. Respective displacements of cursor and target from CRT midline during the first 4 sec of the third trial to which the subject had been exposed. The data are plotted from film records taken at 12 frames/sec (0.083-sec intervals).

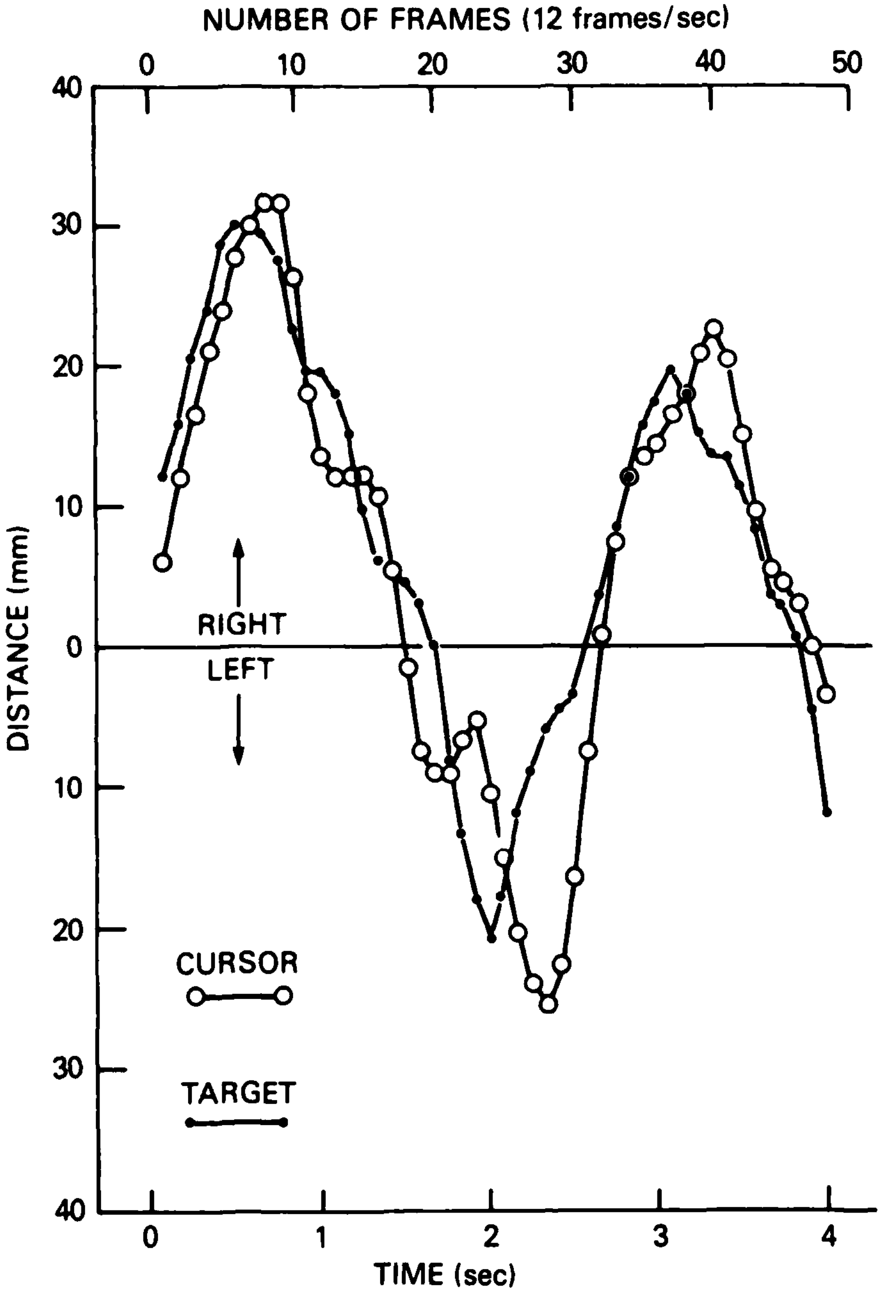

Figure 4. Tracking a target having unpredictable motion. Respective displacements of cursor and target from CRT midline during the first 4 sec of the 453rd trial to which the subject had been exposed. The data are plotted from film records taken at 12 frames/sec (0.083-sec intervals).

in their possession of nonverbal, cognitive attributes which provide the underpinnings of how they organize visual-motor information.

If such an interpretation were indeed warranted, then there should be greater initial diversity among subjects in Predictable Pursuit Tracking than Unpredictable Tracking. The hypothesis follows from two considerations. First, the more the challenge to cognitive or perceptual ability, the larger should be the spread among persons with regard to their utilization of available planning. Second, the basic reflexes making for differences in speed and accuracy among individuals are the same regardless of whether pursuit tracking is regular or irregular. Moreover, once strategies have been acquired for the two types of pursuit tracking, separate steady states of further improvement in visual-motor organization should result. From that stage on, subjects should maintain their standings relative to each other, within each type of pursuit tracking; the intersessional rhos obtained <u>within</u> the respective kinds of tracking should remain roughly equivalent to each other.

In order to test these hypotheses, we must use a measure of improvement, one that is tied to each subject's own level of visual-motor organization. As previously discussed in relation with Study 1, "percent change" affords such an index. In this experiment, we can use this index with greater assurance, since the possibility of interfering practice effects has been removed through employing two separate groups.

It is clear from observation of Figure 2 that the $\frac{\text{Session 1 - Session 2}}{\text{Session 1}}$ percent change is larger for Group 2 than for Group 1. The actual percentages are approximately 23% vs. 8% ($p < .01$, 2-tailed, by Unpaired Replicates) and are similar to those obtained in Experiment 1, 24% vs. 6% ($p < .01$, 2-tailed, by Paired Replicates). The $\frac{\text{Session 1 - Session 10}}{\text{Session 1}}$ percent change for Group 2 is approximately 54%, for Group 1, 30% ($p < .01$, 2-tailed, by Unpaired Replicates).

In order to test the first hypothesis, that there should be greater diversity in initial performance for Predictable Tracking, rhos must be obtained between the percent changes computed for $\frac{\text{Session 1 - Session 2}}{\text{Session 1}}$ vs. those obtained for $\frac{\text{Session 1 - Session 10}}{\text{Session 1}}$.

As can be seen, Table 8 supports the hypothesis, but only tentatively. To make the case more solid, we turn to the "steady state" hypothesis. Unpaired Replicates tests between the two groups were applied to $\frac{\text{Session n - Session 10}}{\text{Session n}}$, where "n" was Session 1, then Session 2, and so on, until the first session was reached which yielded a null difference in percent change. This was the fourth session. If a steady state were attained, then any subsequent session should yield roughly the same arrays as those obtained with Session 4. That is, the rhos between $\frac{\text{Session 4 - Session 10}}{\text{Session 4}}$ vs. the $\frac{\text{Subsequent Session - Session 10}}{\text{Subsequent Session}}$ should be significant <u>within</u> each group. We selected the session midway between Session 4 and Session 10

Table 8

Correlations for Selected Intersession Percentage Changes in Tracking Scores

Intersession percent changes in error scores used to obtain rho		Group 1 (N=15) Unpredictable rho	Group 2 (N=14) Predictable rho
$\frac{\text{Session 1} - \text{Session 2}}{\text{Session 1}}$ $\frac{\text{Session 1} - \text{Session 10}}{\text{Session 1}}$	vs.	.59*	NS (.33)
$\frac{\text{Session 4} - \text{Session 10}}{\text{Session 4}}$ $\frac{\text{Session 7} - \text{Session 10}}{\text{Session 7}}$	vs.	.64**	.59*
$\frac{\text{Session 4} - \text{Session 10}}{\text{Session 4}}$ $\frac{\text{Sessions 5,6,7,8,9} - \text{Session 10}}{\text{Sessions 5,6,7,8,9}}$	vs.	.60* (avg)	.59* (avg)
$\frac{\text{Sessions } \overset{\text{mean}}{\overline{1,2,3}} - \text{Sessions } \overset{\text{mean}}{\overline{8,9,10}}}{\text{Sessions } \overset{\text{mean}}{\overline{1,2,3}}}$ $\frac{\text{Sessions } \overset{\text{mean}}{\overline{5,6,7}} - \text{Sessions } \overset{\text{mean}}{\overline{8,9,10}}}{\text{Sessions } \overset{\text{mean}}{\overline{5,6,7}}}$	vs.	.89***	NS (.42)

*$p < .05$, 2-tailed.

**$p < .02$, 2-tailed.

***$p < .01$, 2-tailed.

(i.e., Session 7) to serve as the probe subsequent session. The results are consistent with the steady state hypothesis (see Table 8). To make sure that Session 7 was not a fortuitous selection, average rhos were computed by using Sessions 5 through 9 as probes. The results continue to support the steady state hypothesis, as indicated by the average rho entries in Table 8.

A final analysis was based upon the mean of each subject's error scores prior to Session 4 and subsequent to Session 4. If individual differences in planning ability do indeed emerge during the first three sessions, then percent change arrays computed from the mean of these early-session error scores minus the mean of the last three sessions, versus the percent change arrays computed from the mean of Sessions 5, 6, and 7 minus Sessions 8, 9, and 10 (the six steady state sessions), should show a lower correlation for Group 2 (Predictable) than for Group 1 (Unpredictable). The bottom entries of Table 8 indicate the trials and comparisons of relevance. The correlations obtained are in accord with the hypothesis that subjects differ in their ability to plan, and with the hypothesis that steady states are reached after Session 4 in both predictable and unpredictable types of tracking.[5]

Recapitulation of Major Results from Study 2

1. Individual differences in the ability to organize visual-motor information, as initially assessed by test-retest sessions of pursuit tracking, persist in the absence of training intervention.

2. Even with training, these initially observed individual differences in organizing visual-motor information tend to remain.

3. Subjects differ reliably in the ability to plan, i.e., to take advantage of coherence in visual-motor information. These individual differences stabilize quite early in training.

Collectively, these results point toward the existence of strikingly stable and robust individual differences in nonverbal, cognitive, and perceptual attributes, as originally seen through test-retest sessions.

GENERAL IMPLICATIONS OF THE RESEARCH

Together, the two studies contribute to the literature on individual differences in perceptual-motor behavior in five ways. First, control

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[5] Product moment r's were computed in addition to the rhos shown in Table 8. In all but the last entry of the table (the one indicating correlations based upon means), the r's and the rhos are quite close to each other. For the last entry, Group 1's r is identical to its rho (.89, $p < .01$, 2-tailed), but Group 2's r is .62 ($p < .02$, 2-tailed), as compared to its rho of .42. Perhaps a floor effect influences rho more than r. In any event, the r's are in the hypothesized direction, and are different from each other at $p < .05$, 1-tailed ($z = 1.73$).

theory's tracking paradigm of voluntary movement was used as an experimentally established, conceptual framework from which to select in advance the visual and motor tasks of interest. Second, between- and within-individual differences in executing these tasks were assessed by means of test-retest rhos. This type of correlational analysis is conservative; it requires only a minimum of statistical assumptions (a need first stressed by Poulton, 1974) to treat a modicum of data. Third, between- and within-individual differences were used to assess the effect of increased cognitive or perceptual demands placed upon subjects. Complexity was manipulated by increasing the time-orders of required visual discriminations and motor actions. Fourth, despite the utilization of parsimonious statistics and amounts of original training, the obtained indices of individual differences in visual-motor organization were strong and steady enough to withstand both the passage of time without training and subsequent training intervention. The point is that we are dealing with quite fundamental properties of perception and cognition, and that they are most readily ascertainable. Finally, the properties referred to include individual differences in the ability to take advantage of coherence in visual-motor information, or to plan.

REFERENCES

Alluisi, E. A. & Morgan, B. B., Jr. Engineering psychology and human performance. In M. R. Rosenzweig and L. W. Porter (Eds.), Annual review of psychology. Palo Alto, Calif.: Annual Reviews, 1976, pp. 305-330.

Battig, W. F. Within-individual differences in "cognitive" processes. In R. L. Solso (Ed.), Information processing and cognition: The Loyola Symposium. Hillsdale, N.J.: Erlbaum, 1975.

Fleishman, E. A. On the relation between abilities, learning, and human performance. American Psychologist, 1972, 27, 1017-1032.

Fleishman, E. A. & Parker, J. F., Jr. Factors in the retention and relearning of perceptual-motor skills. Journal of Experimental Psychology, 1962, 64, 215-226.

Gibson, J. J. The ecological approach to visual perception. Boston: Houghton Mifflin, 1979.

Hrapsky, J. S. Effects of training in visual observation upon subsequent visual-motor performance. Unpublished doctoral dissertation, Princeton University, 1981.

Johansson, G. Spatial constancy and motion in visual perception. In W. Epstein (Ed.), Stability and constancy in visual perception: Mechanisms and processes. New York: Wiley, 1977.

Johansson, G., von Hofstein, C., & Jansson, G. Event perception. In M. R. Rosenzweig and L. W. Porter (Eds.), Annual review of psychology. Palo Alto, Calif.: Annual Reviews, 1980, pp. 27-63.

Norman, D. A. Twelve issues for cognitive science. Cognitive Science, 1980, 4, 1-32.

Notterman, J. M. & Farley, J. Experimental psychology: Recent developments. In B. B. Wolman (Ed.), International encyclopedia of psychiatry, psychology, psychoanalysis and neurology. Progress Volume 1, in press.

Notterman, J. M. & Page, D. E. Evaluation of mathematically equivalent tracking systems. Perceptual Motor Skills Monograph, 1962, 15 (Monogr. suppl. 8-V15).

Notterman, J. M. & Tufano, D. R. Variables influencing outflow-inflow interpretations of tracking performance: Predictability of target motion, transfer function, and practice. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 85-88.

Notterman, J. M. & Weitzman, D. O. Organization and learning of visual-motor information during different orders of limb movement: Step, velocity, acceleration. Journal of Experimental Psychology: Human Perception and Performance, 1981, 7, 916-927.

Parker, J. F., Jr., & Fleishman, E. A. Ability factors and component performance measures as predictors of complex tracking behavior. Psychological Monographs, 1960, 74 (16, Whole No. 503).

Poulton, E. C. Tracking skill and manual control. New York: Academic Press, 1974.

Shields, J. L. Psychomotor testing: Promise/problems. Paper presented at the meeting of the Department of Defense Review of Behavioral Science Research, Washington, D.C., October 1980.

Woodworth, R. S. The accuracy of voluntary movements. Psychological Review Monograph Supplement, 1899, 3 (2, Whole No. 13).

APPENDIX

Table A

Rhos Computed from Combined Test-Retest Scores for All Visual and Motor Tasks

		Visual discrimination				Motor action			Tracking	
		Duration (time)	Position (space)	Velocity	Acceleration	Displacement (position)	Velocity	Acceleration	Predictable	Unpredictable
Visual discrimination	Duration (time)	—								
	Position (space)	.11	—							
	Velocity	.29	.26	—						
	Acceleration	.34	.19	.21	—					
Motor action	Displacement (position)	.22	.35	.22	.07	—				
	Velocity	.34	.19	.11	.15	.14	—			
	Acceleration	.26	.43**	.11	.19	.10	.79***	—		
Tracking	Predictable	.11	.49***	.27	.02	.44**	.14	.45**	—	
	Unpredictable	.12	.38*	.13	.04	.24	.16	.43**	.84***	—

*$p < .05$, 2-tailed.

**$p < .02$, 2-tailed.

***$p < .01$, 2-tailed.

Table B

Product Moment r's Computed from Combined Test-Retest Scores
for All Visual and Motor Tasks

		Visual discrimination				Motor action			Tracking	
		Duration (time)	Position (space)	Velocity	Acceleration	Displacement (position)	Velocity	Acceleration	Predictable	Unpredictable
Visual discrimination	Duration (time)	—								
	Position (space)	.26	—							
	Velocity	.32	.33	—						
	Acceleration	***.58	.27	.19	—					
Motor action	Displacement (position)	.17	.35	.09	.18	—				
	Velocity	.32	.20	.19	.17	.09	—			
	Acceleration	.31	**.45	.10	.30	.01	***.76			
Tracking	Predictable	.21	***.50	.23	.11	**.44	.28	**.46	—	
	Unpredictable	.20	.39*	.04	.08	.33	.29	**.42	***.80	—

*$p < .05$, 2-tailed.

**$p < .02$, 2-tailed.

***$p < .01$, 2-tailed.