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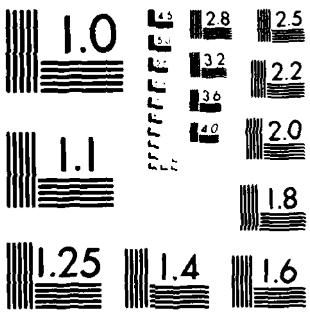
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AIR FORCE

HUMAN RESOURCES

# VELOCITY CONTROL DECISION-MAKING ABILITY: RELATIONSHIP TO FLYING CAPABILITY AND EXPERIENCE


By

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OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85224



December 1983

Interim Report for Period 1 June 1981 – 1 December 1982


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

Research investigated the ability of pilots of differing experience and capability to make vehicle control decisions. Three groups of pilots and three groups of pilot trainees performed the Flight Decision-Making Assessment Task (FDAT). The FDAT is a micro-computer based, discrete-time vehicle control task. Differences in FDAT performance were found as a function of pilot capability. Results are discussed in terms of pilot capability and of decision factors involved in vehicle control.

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# VELOCITY CONTROL DECISION-MAKING ABILITY: RELATIONSHIP TO FLYING CAPABILITY AND EXPERIENCE

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Reviewed and submitted for publication by

Robert B. Bunker
Chief, Technology Development Branch

This publication is primarily a working paper.
It is published solely to document work performed.

# PREFACE

This work was conducted under Project 2313, Task 2313T3, Work Unit 2313T312, Cognitive Aspects of Flight Training. The purpose of this basic research was to develop a methodology for investigating the decision-making processes involved in piloting an aircraft. The author is grateful to 1st Lt John Brunderman, who accomplished the developmental programming for the computer-based vehicle control task used in the research.

Velocity Control Decision-Making Ability:
Relationship to Flying Capability and Experience

# I. INTRODUCTION

A number of vehicle control tasks involve maintaining some predetermined steady state. Driving an automobile on a straight road, steering a ship on a constant heading, and flying an aircraft at constant heading and climb rate are examples of such tasks. In these types of tasks the operator's function is primarily one of detecting and correcting error, in the form of deviations from the desired motion path. For the most part, the operator acts as a simple closed-loop controller whose performance is determined primarily by its sensitivity to error and by its control lag (Jagacinski, 1977).

In a number of other tasks, the operator's role is much more complex. The operator seeks not simply to maintain a steady state but rather to achieve a particular vehicle state through execution of a sequential process of velocity changes. In these tasks the operator's actions are directed toward the goal state, which differs from the current state and from intermediate states. Intermediate vehicle states are important only insofar as they affect the ultimate vehicle state. Task sequences can be relatively short and uncomplicated, as in parallel parking a car, or quite long and complicated, as in the case of driving home in rush hour traffic in time to see the news on TV. In these instances control performance is determined both by the operator's interface with the vehicle and by the operator's performance as an information processor and decision maker.

Describing performance on these task sequences is complicated by the large number of control actions involved and by the fact that the optimum action at a given point in the sequence is determined by earlier events both internal to the operator-vehicle system and external to it. For example, the decision on whether to turn right at an intersection or to proceed through can depend on whether the vehicle will reach the intersection while the signal is green (internal), how long the red will last, how well traffic is moving on the two streets, and the length of the alternate paths (external). The operator steers the vehicle according to a goal-directed scenario which is updated continuously in response to changing conditions. The correctness of any particular control action in the sequence is determined by two factors: the correctness of the scenario and the appropriateness of the control action to the scenario.

At a macro level vehicular control scenarios are very similar to scripts. A script is a set of related facts which are organized hierarchically and sequentially (Smith, Adams & Schorr, 1978). In the motion scenario facts might be events or control actions which are organized by the importance or probability of occurrences at particular points in the process. Schvaneveldt et al (1982) have shown experienced fighter pilots to organize major events and actions related particular maneuvers in this way. Facts in these scripts are aircraft states, pilot actions, effects of these actions, controls and instruments, and actions of other combatants. These facts are organized primarily along a dimension of temporal criticality, analogous to a script, and secondarily along a dimension of relative energy.

At a finer level of detail, involving individual control inputs, vehicle control can be thought of as a sequential process of goal directed decisions and control actions. While the second-by-second control process may involve a sequence of control decisions, it is less well-suited to a scripts type of analysis since events occur rapidly and decisions are often based on information which is not organized semantically. The control decision process is similar to closed-loop tracking, but unlike tracking, it consists of a sequence of actions directed at establishing a particular state rather than at simply maintaining a particular state with minimal error.

In the goal-directed control process, several different control actions might be effective in achieving the desired state. The operator's decision about which actions to employ may depend on many factors, such as the degree and direction of motion required, the probability of success, and the cost of failure associated with a particular control action sequence. In the real-time motion control task, it is difficult to isolate the micro-decision making process from perceptual and psychomotor factors. If, for instance, a pilot ends up with excessive airspeed on final approach, it is not possible to know whether the error arose from the pilot's failure to perceive the airspeed buildup or from an inability to make the appropriate control inputs or whether the pilot saw what was happening and decided that everything was just fine.

One way of isolating the micro-decision making process is to present subjects a discrete-time vehicle control task. In this task the subject "steers" a computerized vehicle through a course in a sequence of moves. On each move, a set of driving equations determine the motion envelop according to the vehicle state at the end of the preceding move through . The task is self-paced, and the subject types the desired move on a keyboard. De Maio (1981) compared the performance of Air Force pilots with that of non-pilots on a discrete-time task in which subjects controlled vehicular movement by adjusting the length of two perpendicular driving vectors. As indexed by the number of moves required to complete the course, the pilot group performed better than did the non-pilot group. The pilots also made longer moves on the average, although the average total track length was the same for both groups.

In the present research, a discrete-time vehicle control task was used in which the driving equations more closely approximate those of an actual vehicle. The vehicle performed as a generic aircraft constrained to level flight. The work examined the relationship between performance on the discrete-time control task and flying capability and experience. Performance on individual moves was examined to determine the decision making process leading to superior task performance.

## II. METHOD

### Subjects

Three groups of Fighter-Attack-Reconnainance (FAR) qualified pilots served as subjects. These included: 25 F-16 T-course pilots, nine F-16 B-course pilots and 16 A-10 B-course pilots. The T-course pilots had 700 to 4500 hours miltary flying time; the B-course pilots had about 250 hours. Three groups of students in Undergraduate Pilot Training (UPT) served as subjects. These included: eight students awaiting the start of training, six who had just completed the T-37 phase and 10 who had just completed the T-38 formation phase. Average flying time for these groups was roughly 4 hours, 70 hours and 130 hours respectively.

## Apparatus

The Flight Decision-Making Assessment Task (FDAT) is a discrete-time vehicle control task programmed on a Terak 8510/A micro-computer. The FDAT driving functions are generic flight equations for an aircraft constrained to level flight and scaled to fit on the 320 x 240 Terak graphics screen. Three functions determine vehicle performance : maximum heading change, induced drag velocity penalty, minimum/maximum velocity change.

The FDAT involves "steering" a vehicle through a winding course in a series of moves. The subject's task is to traverse the course in as few moves as possible. The subject makes a move by entering two numbers. The first number entered is the amount of heading change desired, in degrees. Following this input the vehicle's velocity is decremented in proportion to the amount of heading change by an "induced drag" function. A thrust/drag function then determines the amount the subject may increase or decrease speed. The subject completes the move by entering the speed desired; that is, the length of the move. The ground track is then updated to show the move. The new heading, speed and associated maximum heading change and the induced drag penalty are shown on a digital display to the left of the course.

A complete listing of the vehicle performance limits is given in Table 1. The "stall" or minimum velocity is 7 units, and the maximum velocity is 27 units. Velocity units are pixels. The maximum allowable heading change reach minima of $13^{o}$ at stall and $23^{o}$ at maximum velocity and a maximum of $48^{o}$ at the 14 unit corner velocity. The course lengths are roughly 680 pixels.

Table 1

Vehicle performance limits at each velocity

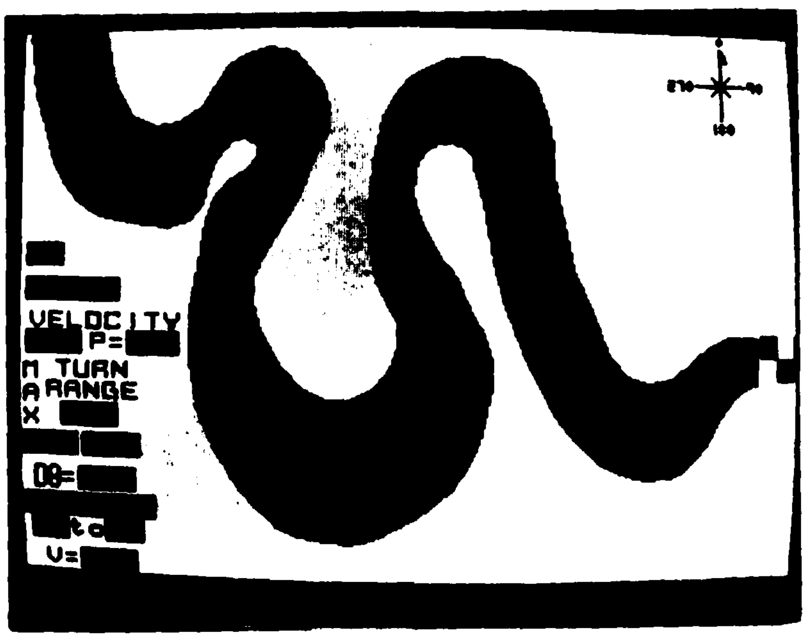
| Velocity | Heading Change Degrees Maximum | Induced Drag Penalty Maximum | Velocity Change Minimum | Velocity Change Maximum |
|---|---|---|---|---|
| 7 | 13 | 0 | 0 | 1 |
| 8 | 19 | -1 | -1 | 2 |
| 9 | 24 | -2 | -1 | 3 |
| 10 | 27 | -3 | -1 | 4 |
| 11 | 30 | -4 | -2 | 4 |
| 12 | 33 | -5 | -2 | 4 |
| 13 | 36 | -6 | -2 | 4 |
| 14 | 48 | -7 | -2 | 4 |
| 15 | 44 | -7 | -2 | 4 |
| 16 | 42 | -8 | -2 | 4 |
| 17 | 39 | -8 | -2 | 4 |
| 18 | 37 | -8 | -2 | 4 |
| 19 | 35 | -8 | -3 | 3 |
| 20 | 33 | -9 | -3 | 3 |
| 21 | 32 | -9 | -3 | 3 |
| 22 | 30 | -9 | -3 | 2 |
| 23 | 29 | -9 | -3 | 2 |
| 24 | 28 | -10 | -4 | 1 |
| 25 | 27 | -10 | -4 | 1 |
| 26 | 26 | -10 | -4 | 1 |
| 27 | 25 | -10 | -4 | 0 |

Procedure

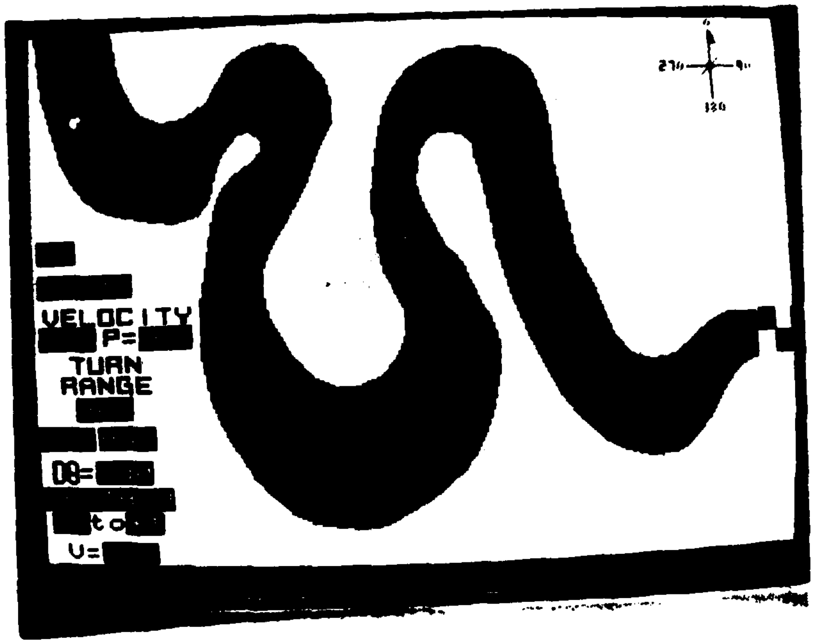
The subject sat before the computer terminal with the experimenter seated at the left. The experimenter explained that the purpose of the research was to examine the decision making process associated with aircraft control. The experimenter then made a series of demonstration moves showing turning, accelerating, and the effect of trying to exit the course boundaries.

Some of the demonstration moves are shown in Figure 1. In Figure 1a the initial condition is shown. The initial condition has heading 180° and a speed of 13 units. Figure 1b shows the state following input of a left 30° heading change. Speed has been decremented by six units to seven units. At seven units the allowable speed change (delta-v) is zero unit decrement to one unit increment. Figure 1c shows the state at the start of the second move. Heading is 150°, speed is eight units, and the maximum heading change is 19°. A line eight pixels long in the upper left represents the ground track. Figure 1d shows the third move just before input of the speed command. A 10-unit move along heading 150° was made on move two, and no heading change was made on move three so that the current speed is 10 units and the delta-v range is -1 to +4 units for a move length range of nine to 14 units. Figure 1e shows the state following move three.

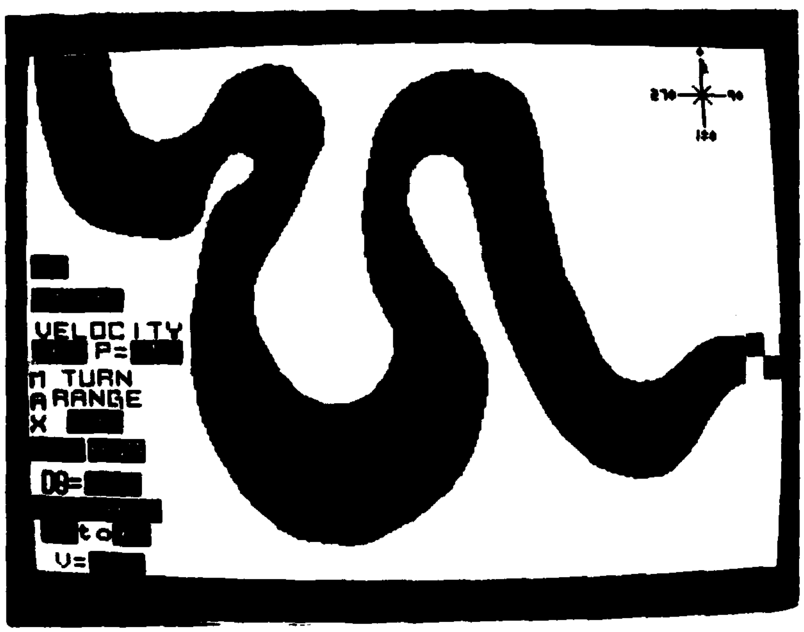
Following the demonstration moves, the subject was shown the effect of trying to exit the course boundaries, which was to reset the subject at the beginning of the move with the new heading and a speed of 10 units. The subject was also shown how to remove input mistakes and how to take a move over. The subject then completed two courses, always performing the easier course first. The experimenter was present throughout the session. The subject was allowed to ask questions, but questions about strategies were not answered.



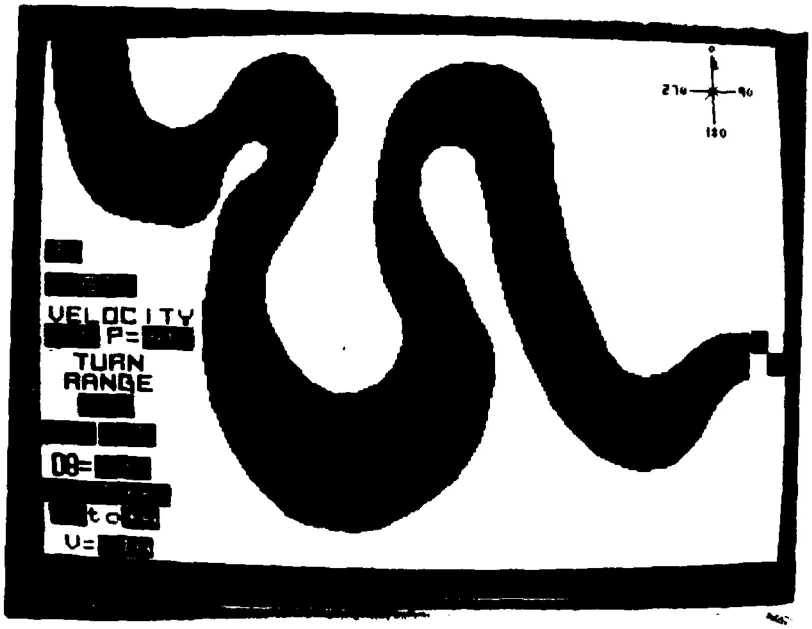

(a) Initial condition



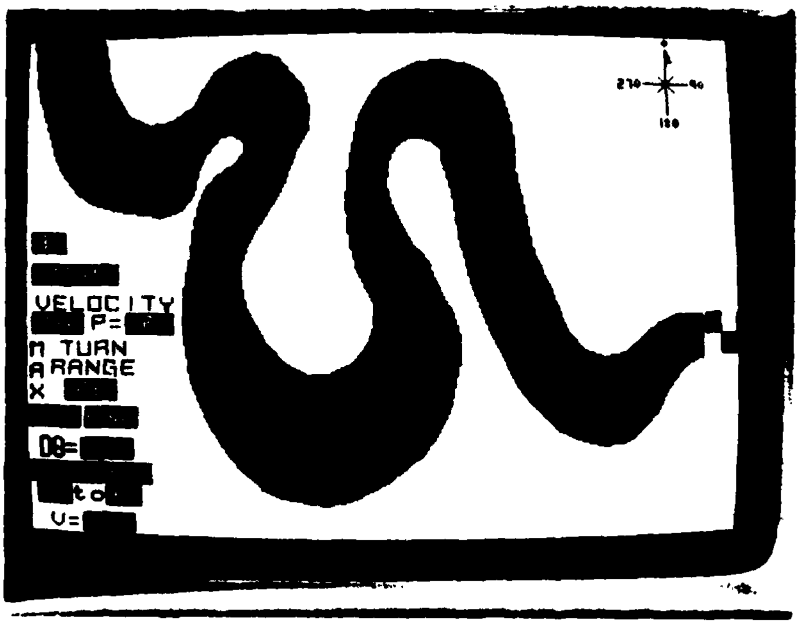

(b) Input left 30° heading change




(c) Start of second demonstration move




(d) Third demonstration move before input of speed command




(e) State after completion of third move

Figure 1. Examples of demonstration moves given to subjects

## III. RESULTS AND DISCUSSION

### Overall Performance

Overall FDAT performance was indexed by the number of moves required by each subject to traverse each course. The number of moves ranged from 38 to 75 for Course 1 and from 40 to 87 for Course 2. The mean number of moves required by each group to complete the two courses is shown in Figure 2.

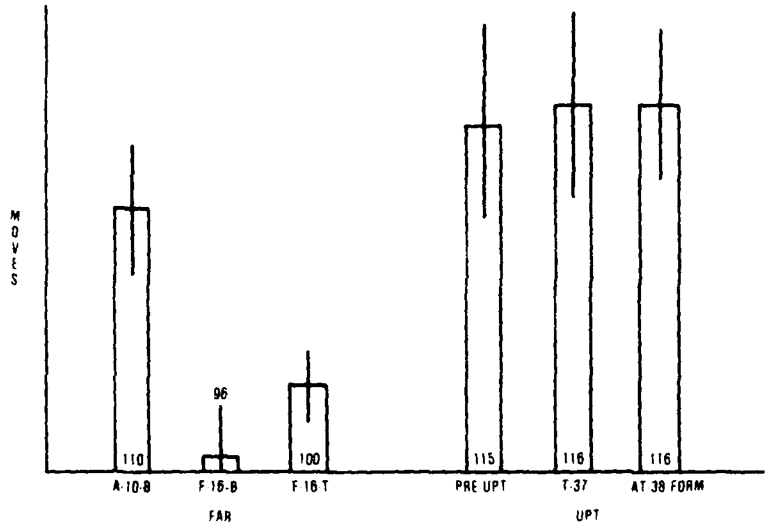



Figure 2. FDAT performance

An analysis of variance was performed on the combined data for both courses. The results of this analysis are shown in Table 2. A post-hoc analysis of three selected contrasts was performed by means of a Dunn test (Keppel, 1973).

Table 2

Analysis of Variance for Total Number of Moves to Complete Two Courses by Groups

| SOURCE | SQUARE | D.F. | F-RATIO | p |
|---|---|---|---|---|
| TOTAL | 202.2 | 73 | | |
| GROUPS | 839.8 | 5 | 5.4 | .05 |
| ERROR | 155.3 | 68 | | |

This analysis revealed a significant difference between the FAR pilot groups and the UPT groups ($T(68) = 4.19$, $p < .05$). This result is understandable since the FAR pilots have both more experience than do the UPT students and more capability than does the average Air Force pilot. The FAR pilots ranged in experience from 250 to 4500 hours of military flying time versus 0 to 130 hours for the UPT students. In addition the FAR groups represent the top 20% to 40% of UPT graduates while the UPT groups represent a random sample of all UPT students.

The effect of flying experience alone was determined by looking at differences within the FAR pilot and UPT groups. No differences were found as a function of experience either within the FAR groups ($T(68) < 1$, $p > .05$, Figure 3) or within the UPT groups (Figure 2). These results suggest that it is flying capability rather than flying experience which is related to FDAT performance.

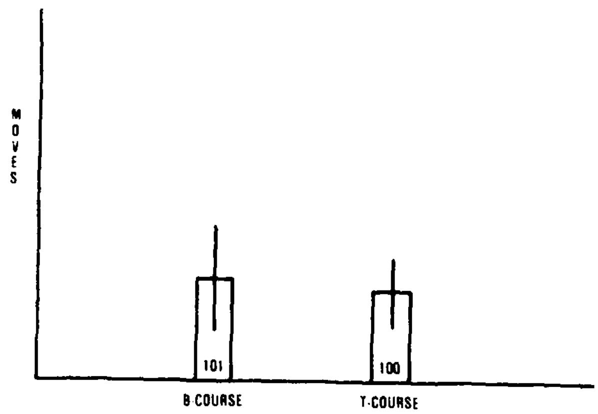



Figure 3. FDAT performance, T-course vs B-course

One surprising difference did occur within the FAR groups. The F-16 B course had much better performance than did the A-10 B course ($T(68) = 2.73$, $p$ .05). This difference reflects a difference in flying capability. At the time the data were collected, all UPT graduates assigned to the F-16 were Distinguished Graduates (DG); that is, they had graduated in the top 10% of their class. On the other hand, fewer than 10% of graduates assigned to the A-10 were DG. It was not possible to ascertain the class standing of some students, who had participated early in the study, but an analysis of variance was performed on the data for those students whose class standing was known. The DG pilots evidenced significantly better FDAT performance than did the non-DG pilots ($F(1,19) = 8.3$, $p < .05$, Figure 4).

## Internal Performance Analysis

Task requirements and the vehicle's handling qualities placed a high premium on maintaining a speed equal to or greater than 14 units. Due to the vehicle's low thrust/drag ratio it was not possible to sustain speed during intense cornering. As a result the subject needed to position The vehicle on the course in such a manner as to permit acceleration and to time turns to minimize heading changes and resultant loss of speed. Speed control and timing errors were identifiable by visual inspection of individual moves and move sequences.

Figure 5 contains examples of good and poor performances on both courses. Errors frequently consist of allowing speed to bleed off until the vehicle "stagnates" -- that is, loses cornering and accelerative power, of initiating turns too late, or of making unnecessary heading changes.

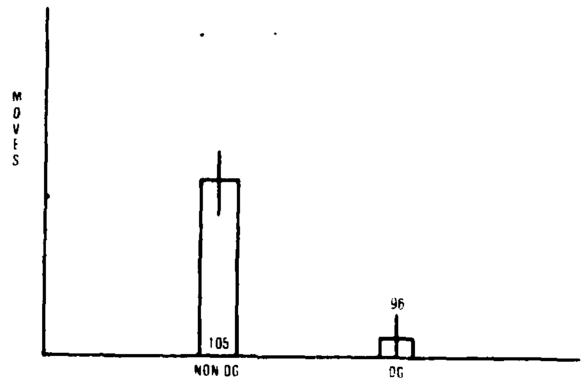
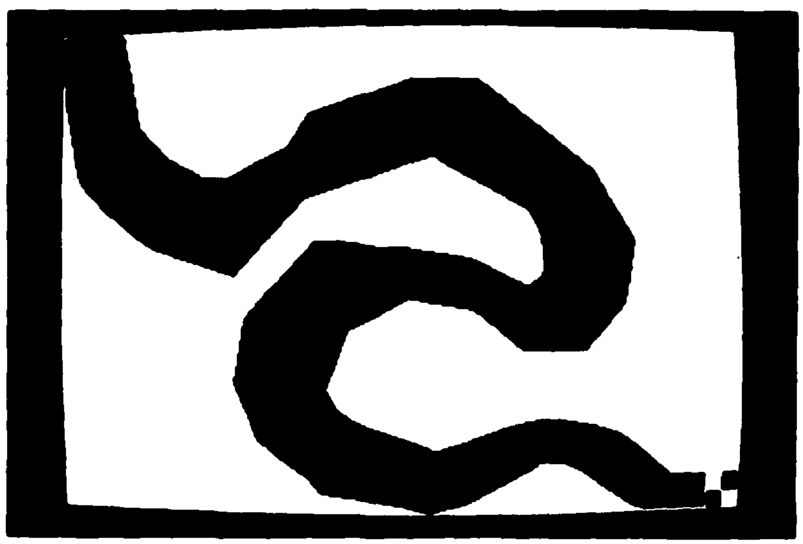
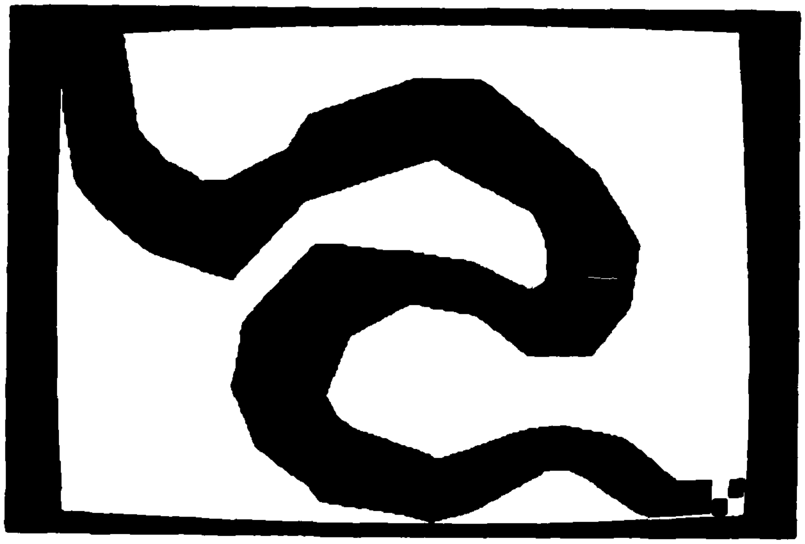


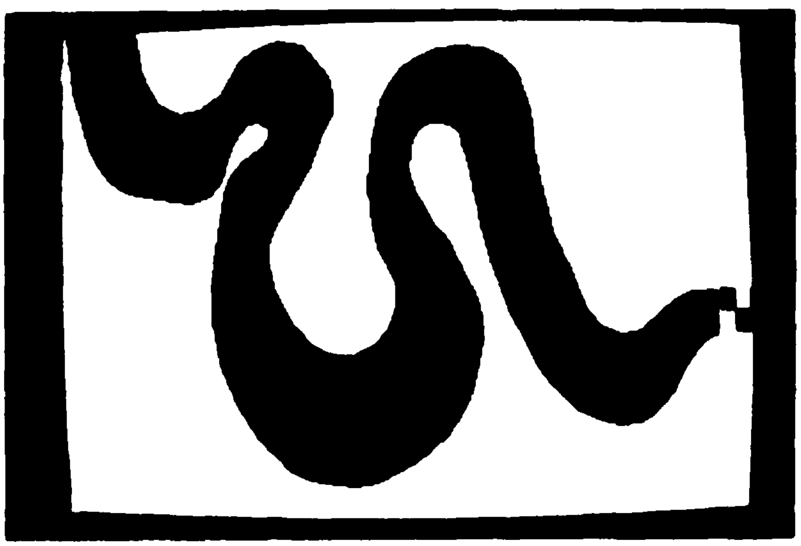

Figure 4. FDAT performance, DG vs non-DG



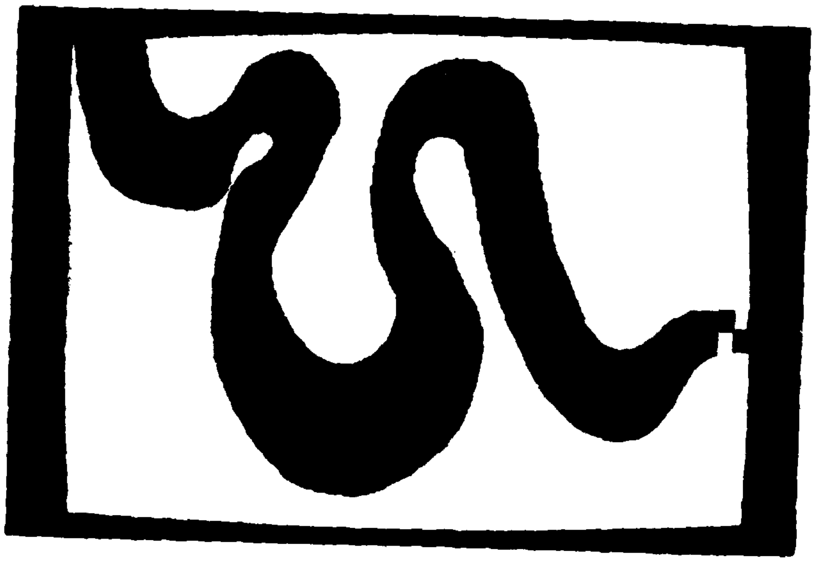
(a) Good performance on Course 1



(b) Poor performance on Course 1



(c) Good performance on Course 2



(d) Poor performance on Course 2

Figure 5 Examples of groundtracks

In order to quantify speed control and timing performance four categories of moves were defined:

1. Velocity control

   a. Extending moves - $5^{0}$ turn and accelerating

   b. Stagnating moves - deceleration $\geq$ 2 units or speed $\leq$ 10 units

2. Turning control

   a. Sustained turn moves - turn $5^{0}$-$30^{0}$ in constant direction with roughly constant speed

   b. Positioning moves - turn $5^{0}$-$30^{0}$ for only one move $\leq 5^{0}$ turn with 0-1 unit deceleration

Velocity control performance was given by the ratio of the number of extending moves to the number of stagnating moves. A measure of turning control performance was the ratio of the number of sustained turn moves to the number of positioning moves. A measure of timing was the total amount of heading change regardless of direction, since mis-timing turns necessitated corrective maneuvers which increased the total heading change for the course.

In order to determine the contribution of speed control performance, turning control performance and timing performance to overall performance a multiple regression of the two ratios and the total heading change was performed on number of moves for Course 1 and for Course 2 separately.

For Course 1 all three internal performance measures contributed significantly to overall performance (Table 3). The primary driver of performance was speed control. Timing, as measured by total heading change, also contributed substantially to overall performance. The ratio of sustained turn to positioning moves measures the smoothness of heading control and made only a small contribution to overall performance.

Table 3

Multiple regression analysis internal performance meaures on overall performance

| Factor | Course 1 Beta-weight | Course 2 Beta-weight |
|---|---|---|
| Extending/Stagnating | -.46 * | -.93 * |
| Sustained/Positioning | -.27 * | NS |
| Total Heading Change | .38 * | NS |
| R | .89 * | .93 * |

* $p \leq .001$

The results of the regression analysis for Course 2 differed substantially from those for Course 1 (Table 3). Speed control performance accounted for over 85% of the variance in overall performance. Neither of the turn control measures contributed significantly to overall performance. The differing results for the two courses probably stems from a design difference in Course 2. Course 2 contained 3 turns (out of 6) in which it was nearly impossible to avoid complete speed stagnation. As a result speed control was more highly correlated with both overall performance and with turn control performance on Course 2 than on Course 1 (Table 4). In addition a much greater proportion of moves was related to speed control on Course 2 than on Course 1 (Table 5).

Table 4

Individual correlations between internal performance variables and overall performance, Course 2 shown in ()

| | Overall | Extending Stagnating | Sustained Positioning | Total Heading Change |
|---|---|---|---|---|
| Overall | - | | | |
| Extending/Stagnating | -.79(-.93) | - | | |
| Sustained/Positioning | -.55(-.57) | .39(.46) | - | |
| Total Heading Change | .72(.69) | -.59(-.77) | -.24(-.41) | - |

Substantial differences were found between pilot groups in FDAT control performance. In particular FAR pilots showed performance which was superior to that of Undergraduates Pilot Trainees on the whole. Also Distinguished UPT graduates performed better than FAR pilots who were not DG. These differences appear to be related to flying capability. Performance on the FDAT does not appear to be affected by flying experience per se, since differences in performance as a function of flying experience were found neither within the FAR groups nor within the UPT groups.

Table 5

Proportion of moves in each performance category, SD in ()

| | Sustained Turn | Positioning | Extending | Stagnating |
|---|---|---|---|---|
| Course 1 | .22(.17) | .14(.10) | .32(.11) | .33(.20) |
| Course 2 | .26(.26) | .03(.02) | .21(.08) | .50(.19) |

The present work is based on the idea that the process of steering a vehicle from an initial energy-position state to a goal energy-position state can be described as a sequence of vehicle control decisions. Success in achieving the desired state will be a function of the quality of the control decisions made during the process sequence. The FDAT used in this work is a discrete-time vehicle control task in which subjects are required to make a sequence of decisions regarding three aspects of vehicle control: speed control, turning control, and timing of turns. Examining internal performance indicators which tap these decision making functions, makes it possible to quantify these decision functions and also to assess the relative importance of the decision making processes to overall task performance. The present results show that overall performance can be described by a linear combination of speed control, turning control, and turn timing performance.

When the FDAT course was appropriately designed, as in Course 1, the contribution of speed control in the regression accounted for 37% of the variance in overall performance. The contribution of turn timing, as indexed by total turn, accounted for 27% of the variance in overall performance. Turning control, as indexed by the ratio of sustained turn to positioning moves, had the smallest contribution to overall performance, accounting for 15% of the overall performance variance. On Course 2, only speed control affected overall performance. This was probably due to the high proportion of stagnated moves on Course 2 as compared to Course 1. Care must be used in designing discrete-time tasks to ensure that there is sufficient independence in the effects of the decision processes to permit analysis of individual decision components.

## IV. CONCLUSIONS

The ability to investigate individual decision process can be use to gain greater insight into the cognitive demands of vehicle control tasks. Varying task requirements, vehicle control dynamics, or course design, may make it possible to change the relative importance of differing decision components in determining overall task performance or the difficulty of making these decisions.

An additional area of study, which has not been addressed in the present work, is decision making speed. The discrete-time methodolgy can provide a powerful tool for studying this problem by permitting the unconfounding of effects arising from requirements for speeded perception and speeded responding from those due to the decision making process.

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