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OPTICAL AND EVENT-DURATION VARIABLES
AFFECTING SELF-MOTION PERCEPTION

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November 1985
Interim Paper for Period January 1984 – April 1985

LABORATORY

AIR FORCE SYSTEMS COMMAND
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NOTICE

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REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
Unclassified	

2a SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT
	Approved for public release; distribution unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	

4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
	AFHRL-TP-85-23

6a NAME OF PERFORMING ORGANIZATION	6b OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
Ohio State University Research Foundation		Operations Training Division

6c ADDRESS (City, State, and ZIP Code)	7b ADDRESS (City, State, and ZIP Code)
1314 Kinnear Road Columbus, Ohio 43210	Air Force Human Resources Laboratory Williams Air Force Base, Arizona 85240-6457

8a NAME OF FUNDING/SPONSORING ORGANIZATION	8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
Air Force Human Resources Laboratory	HQ AFHRL	F33615-83-K-0038

8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS			
	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO
Brooks Air Force Base, Texas 78235-5601	61102F	2313	T3	31

11 TITLE (Include Security Classification)

Optical and Event-Duration Variables Affecting Self-Motion Perception

12 PERSONAL AUTHOR(S)
Owen, Dean H.

13a TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Interim	FROM Jan 84 TO Apr 85	November 1985	200

16 SUPPLEMENTARY NOTATION

17	COSATI CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	ecological optics self-motion perception visual simulation
05	08		egomotion visual proprioception
05	09		optical flow visual psychophysics

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This paper includes four experiment sections. The first pair of experiments investigated the usefulness of optical flow acceleration in detecting descent. When sink rate and ground speed are constant, optical flow accelerates. Holding fractional loss in altitude constant throughout a descent event also holds flow rate invariant, eliminating flow acceleration as a potential source of information. Detection of descent was accomplished easily without flow acceleration, and it was found that at least one of the remaining functional optical variables specifying fractional loss in altitude must be highly salient. Also, the effect of optical texture density was optimal when linkages with other relevant variables were taken into account. The third experiment compared eyeheight and ground-unit size as metrics for global optical information specifying descent. Given that flow acceleration is not an essential source of information, the study focussed on eyeheight-scaled change in optical splay and ground-unit-scaled change in optical density as functional specifiers of fractional loss in altitude. The fourth experiment investigated the interaction between global optical flow rate and duration of a constant-speed preview period. Of particular interest was the possibility that preview periods of different durations would differentially favor or interfere with sensitivity given

(Continued)

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT	21 ABSTRACT SECURITY CLASSIFICATION
[X] UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	

22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code)	22c OFFICE SYMBOL
Nancy A. Perrigo, Chief, STINFO Office	(512) 536-3877	AFHRL/TSR

19 (Concluded):

particular optical conditions, e.g., different flow rates. The results indicate that this is a complex issue. The fifth experiment assessed the effect of preview period on sensitivity to different fractional losses in altitude. Preview periods ranging from 1.25 to 5 seconds may interfere with sensitivity to change in speed and altitude in a fashion that produces a speed versus accuracy tradeoff.

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OPTICAL AND EVENT-DURATION VARIABLES
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SUMMARY

The experiments presented in this paper are part of a program that has the goals of mathematically isolating global optical candidates for self-motion information and of empirically assessing their usefulness. The first section of the paper treats the problem of dealing with sets of optical variables that are linked either initially or throughout an event and introduces an empirical distinction between functional and contextual optical variables. The first pair of experiments tested sensitivity to loss in altitude, varying the duration of the test segment of the event and isolating global optical flow acceleration as potential information for descent detection. The third experiment contrasted eyeheight-scaled and ground unit-scaled optical information for loss in altitude and investigated the negative influence of global optical flow rate on descent detection. The fourth experiment tested the effects of preview-period duration and flow rate on sensitivity to loss in speed. The fifth experiment was concerned with the influence of preview period on sensitivity to loss in altitude. The latter two sets of results indicate that preview periods in the range of 1.25 to 5 seconds interfere with sensitivity to change in speed and altitude in a fashion which produces a speed/accuracy tradeoff. Theoretical and methodological implications for the study of active control of self motion and applications to the evaluation of visual simulation systems are discussed.

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PREFACE

This project was accomplished in support of the Aircrew Training Thrust of the Air Force Human Resources Laboratory (AFHRL), Operations Training Division. Its purpose was to test theoretical hypotheses concerning the effects of optical flow variables on perceived self motion. The research is intended to advance the understanding of the role of optical variables for flight simulator visual system applications.

Appreciation is extended to the following individuals at The Ohio State University: Dave Park for equipment development and programming necessary for conducting the studies; Tanya Barger, Larry Boehm, Susan Carpenter, Marci Dolan, Pamela Emmert, Jeff Fogt, Mary Hunsinger, William Jelinek, Kevin Lawson, Mike KcKinley, Karen Novak, Craig Perry, Jon Rosenthal, Chris Sorensen, Debbie, Valido, and Brian Zaff for assistance in data collection; and William Jelinek for assistance in preparation of this paper. The Behavioral Sciences Laboratory is acknowledged for use of space and services. The authors have also benefited from the advice and encouragement of Dr. Thomas M. Longridge, the AFHRL technical monitor for the project.

The project was sponsored by AFHRL under contract number F33615-83-K-0038, Task 2313-T3.

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THE INFLUENCE OF PREVIEW PERIOD ON SENSITIVITY TO LOSS IN ALTITUDE

OPTICAL AND EVENT-DURATION VARIABLES AFFECTING SELF-MOTION PERCEPTION

INTRODUCTION

Dean H. Owen

The Ohio State University

The experiments reported herein are part of a research program concerned with determining the informational support for detecting and controlling self motion, under the assumption that locomotor goals are achieved by effective control of what is perceived. Broadly conceived, the effort involves two stages: the mathematical isolation of potential sources of visual information for self-motion perception conveyed by the structure of global optical flow, followed by tests of the effectiveness of the variables for detecting and controlling self motion.

The Metric Problem

Self motion can be scaled in metrics which are either extrinsic or intrinsic to the event under consideration. Extrinsic metrics are arbitrary in the sense that the units of measurement were derived to provide standards that are independent of their application to a particular event, e.g., feet or meters per second, miles or kilome:ers per hour, knots, degrees per second. Intrinsic metrics are nonarbitrary in the sense that the units of measurement are derived directly from characteristics of the event. Since motion of the self is relative to the surrounding surfaces, intrinsic metrics can be derived from measures that relate either to the self or to the environment.

Any of the above metrics have mathematical reality in that they can provide consistent systems for describing events. In the study of visual sources of information, interest is focussed on those that have optical reality, i.e., those that index change and nonchange in the structure of available ambient light.

An individual's path speed can be self scaled in terms of the distance from the self to an environmental surface. This variable has an optical reality in that it is a multiplier on the angular velocities in every direction in the optic array. Hence, it is a global index of optical flow rate. For cases of motion over a ground surface, the distance from the eye to the ground directly below (the individual's eyeheight) has an additional kind

of optical reality because the optical horizon is always at the observer's eyeheight. The horizon thus provides a visible referent for changes in the optic array.

The size or spacing of environmental elements can also serve as a metric for self motion. An individual's motion can be scaled in terms of the distance between edges, intersections of edges, or objects on the ground along the path of locomotion. Two examples having optical reality are (a) variation in optical density with change in eyeheight, specified as change in altitude scaled in ground units, and (b) edge rate (the rate at which optical discontinuities pass a particular optical locus), which specifies ground speed. (Cases a and b both apply when ground-element spacing is regular or stochastically regular.)

Finally, having isolated potential sources of visual information, there is an interest in determining which optical variables have psychological reality, i.e., which are actually informative and for what purposes. The empirical issue of the psychological effectiveness of optical variables and invariants can be divided for research purposes into (a) the sensitivity problem (assessing perceptual effectiveness) and (b) the control problem (assessing skill at guiding locomotion). Given the large number of potentially informative variables, it is strategically important to eliminate those that observers are not sensitive to before turning active control of the remaining varibles over to the individual.

The approach outlined above eliminates some thorny problems that have plagued perceptual theorists. The assumption that perception is anchored to higher-order relations intrinsic to a self-motion event means that particular kinds of prior knowledge need not be assumed. The individual need not know absolute sizes or distances measured in any arbitrary, extrinsic metrics. If self-motion perception is based on information intrinsic to the event, the only assumption that needs to be made concerning prior experience is that the individual has learned to attend to the functional optical variables and ignore the irrelevant variables. There are, however, problems in experimentally separating the effects of higher-order variables.

The Linkage Problem

Global optical variables are expressed in terms of ratios of lower-order

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environmental variables (e.g., altitude, sink rate, path speed and slope, ground-unit size and spacing). Two optical variables are physically linked whenever the same environmental variable appears in the expressions for both. In addition, optical variables become linked or unlinked as an event unfolds, since some variables change, often at different rates, while others remain invariant during the event. These linkages complicate the task of experimental design and analysis, often making traditional factorial designs inappropriate (Warren & Owen, 1982). Linkages must be dealt with, rather than avoided, since an understanding of the dynamic interrelationships among sources of information is propaedeutic to an understanding of the active control of these variables during self-guided locomotion. The very fact that two variables formerly linked have become unlinked may be information for a change in speed, heading, or even safety of self motion.

Functional Versus Contextual Variables

A pattern of results has evolved from a series of experiments suggesting that there are two classes of event variables influencing sensitivity to changes in self motion. These classes will be called _functional_ and _contextual_ variables.

A functional variable is a parameter of an optical flow pattern used to detect a property of self motion and guide an action. If the variable is specific to the event parameter that the individual intended to distinguish or control, the action is considered correct or effective. (Actions are scored relative to the task demands and the stimulation available.) Results to date indicate that fuctional variables are of an order high enough to be completely relative, i.e., not specific to either absolute optical or event variables. Thus, an individual need not know absolute size, distance, speed, or flow rate to be sensitive to change in speed or altitude. To date, functional variables have been exclusively fractional rates of change, a finding that may be a result of the particular tasks used or may indicate a fundamental principle concerning perception of the relation between self and environment.

Contextual variables are those optical parameters which influence sensitivity to a functional variable. A subcategory might be called _support_ variables because they are essential to perception of the event. There must be some optical discontinuity to mainfest flow-pattern changes, for example.

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Other variables, like preview time or cyclic change, are not essential, but can affect functional sensitivity. Some contextual variables are irrelevant to the task but have an _interfering_ effect; for example, the higher the flow and/or edge rate, the poorer the detection of loss in altitude (Hettinger, Owen, & Warren, this paper; Wolpert & Owen, this paper).

The operational distinction between the two classes appears to be evident in the structure of the psychophysical functions. (a) Increasing the magnitude of a functional variable results in increasingly better performance; decrease leads to increasingly poorer performance. These functions tend toward linearity when the functional variable is logged. Equal ratio increments produce equal interval decrements in performance, at least in the middle range of sensitivity. Ceiling and floor effects may bend this function into a cubic form. (b) In contrast, contextual variables reveal an optimum level of performance; hence, they have a quadratic form. Very low _or_ high flow rates, optical densities, or preview periods should result in poorer performance than do values in the middle range.

Different levels of lower-order environmental or optical variables can produce the same (higher-order) fractional change. If performance is optimized at the same level of one contextual variable (e.g., flow rate), but at progressively different levels of the second contextual variable (e.g., flow acceleration), there is an indication that the first variable is more basic, and the second is subsidiary or auxiliary (Tobias, 1983; Tobias & Owen, 1984). Whether the one is basic in terms of the perceptual _mechanism_ or in terms of the perceptual _task_ will require some empirical effort. For example, there is evidence that the optimal level of density is four times as high for detecting loss in altitude (Hettinger, Owen, & Warren, this paper) as for detecting loss in speed (Tobias, 1983; Tobias & Owen, 1984), i.e., is _task_ specific.

Note that the distinction between functional and contextual variables is _empirically_ based. It differs from the distinction between primary and secondary variables, which is an experimental _design_ distinction (Warren & Owen, 1982). Primary independent variables are the subset of orthogonal optical variables to which the experimenter has chosen to allocate the degrees of freedom available from a given set of event parameters. Secondary

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variables exist as a consequence of their mathematical relationships with primary variables. Since secondary variables are not orthogonal to primary variables, they would be considered as confounding factors by traditional design criteria. It is more ecologically valid, however, to consider the fact that the two classes of variables are physically linked. In cases where a set of linked variables all have relationships with performance, it is clearly inappropriate to consider one or more primary and the remainder secondary. Techniques which do not have the constraints of factorial analysis must be developed to deal with these linkages. Also note that a given optical variable could be either a functional or a contextual variable, depending on the task. Fractional loss in flow rate is functional for detecting deceleration, but contextual for detecting descent.

The Experiments

The paper is divided into four sections, the first two parts being concerned with isolating sources of information for detecting loss in altitude, and the second two investigating the influence on sensitivity to loss in speed or altitude of various durations of a preview period of level, constant-speed self motion preceding the test segment of an event. The preliminary experiment in the first section is the completion of a design that was interrupted due to hardware problems and relocation of the laboratory (Hettinger, 1981; Hettinger, Warren, & Owen, 1982). Half the data are new, as well as all analyses and the data presentation showing linkages among the independent variables.

The first study (Hettinger, Owen, & Warren, this paper) is an investigation of the usefulness of optical flow acceleration in detecting descent. An earlier experiment had indicated that observers are primarily sensitive to fractional loss in altitude when detecting descent (Owen, Warren, Jensen, Mangold, & Hettinger, 1981). When sink rate is constant, optical flow accelerates. Holding fractional loss constant throughout the course of a descent event also holds flow rate invariant, eliminating flow acceleration as a potential source of information. The preliminary experiment demonstrated that detection of descent was accomplished easily without flow acceleration and that at least one of the remaining functional optical variables specifying fractional loss in altitude must be highly salient. In addition, the new data

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revealed an optimal effect of optical texture density when linkages with other relevant variables were taken into account. Using the results of the preliminary experiment to select levels of optical variables, the second experiment was designed to directly assess the usefulness of flow acceleration by contrasting descent events in which it was present versus absent.

The second section (Wolpert & Owen, this paper) presents an experiment based on an earlier attempt to contrast eyeheight and ground-unit size as metrics for information specifying descent (Wolpert, 1983; Wolpert, Owen, & Warren, 1983). Given that flow acceleration is not a useful source of information, this study focusses on eyeheight-scaled change in optical splay and ground-unit-scaled change in optical density as functional specifiers of fractional loss in altitude.

The third section (Owen, Hettinger, Pallós, & Fogt, this paper) documents an experiment investigating the interaction between global optical flow rate and duration of a constant-speed preview period. Based on two studies showing different effects of short (Tobias, 1983; Tobias & Owen, 1983) and long (Denton, 1973, 1974) preview periods, the concern was for the possibility that preview periods of different durations would differentially favor or interfere with sensitivity given particular optical conditions, e.g., different flow rates. The results indicate that this is a complex issue.

The fourth section (Johnson & Owen, this paper) presents a preliminary experiment assessing the effect of preview period on sensitivity to different fractional losses in altitude. Although at least one more experiment crossing flow rate and fractional loss in altitude with preview period is needed, the results at this stage are, by contrast with the findings for deceleration in the previous section, markedly uncomplicated.

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GLOBAL OPTICAL FLOW-PATTERN INFORMATION FOR LOSS IN ALTITUDE

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In Gibson's (1955, 1958a, 1958b) discussions of properties of the optical flow pattern during aircraft landings, he maintained that the ability to execute a proper landing necessarily involved picking up two related types of visual information, (a) the optical magnification of textural elements and objects on the ground surface and (b) the acceleration of the flow of optical texture elements in the optic array. He noted the following:

> Approach to a solid surface is specified by a centrifugal flow of the texture of the optic array. Approach to an object is specified by a magnification of the closed contour in the array corresponding to the edges of the object. A uniform rate of approach is accompanied by an accelerated rate of magnification (Gibson, 1958a, p. 188).

Lee (1974) attempted to mathematically describe the nature of the optical flow pattern at the eye of an observer moving along a rectilinear path through the environment. He noted that the optic flow field contains "exterospecific" properties which are specific to properties of the environment and "propriospecific" properties that are specific to properties of the observer's body parts relative to each other. For example, the rate of change in occlusion and disocclusion of surface texture elements provides exterospecific information about the vertical characteristics of the ground surface. Turning one's head from side to side modulates the optical flow field in a way that provides propriospecific information for that activity.

There also exist what Lee termed "expropriospecific" types of information that are specific to the perceiver's relation to the environment. The changes that take place in the optical flow field corresponding to the changes in direction or velocity of self motion are examples of this type of information.

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Following Gibson (1958a), invariant exterospecific, propriospecific, and expropriospecific properties of the flow field are conceived as being the potential information for detecting different forms of motion by Lee (1974) and others (e.g., Koenderink & van Doorn, 1978). For example, descent will be optically differentiable from level flight because of differences in the properties of the optical flow pattern during each kind of event. In terms of expropriospecific visual information, descent is differentiable from level flight due to the increasing magnification of optical texture elements (decreasing optical density) and to the acceleration in the optical flow of texture elements which accompany loss in altitude, given a constant path speed.

In a previous study (Owen, Warren, & Mangold, in press), it was observed that along with decrease in optical texture density and acceleration in optical flow rate, there existed at least a third source of optical information for descent, i.e., change in optical (perspectival) splay. Optical splay is defined as the angle (θ) between two lines on the fronto-parallel projection plane. One line is perpendicular to the horizon, and specifies the direction of locomotion by passing through the vanishing point and the focus of expansion. The other line passes through the vanishing point and the optical projection of a ground-texture discontinuity lateral to the path of locomotion (Warren, 1980b). Its mathematical expression is

$$\theta = \arctan g_y/z \qquad (1)$$

(where g_y = the lateral distance of a ground-texture discontinuity from a line directly below the path of locomotion, and z = altitude). As eyeheight decreases along a path slope, the splay angle for a texture element increases. Change in splay is defined as

$$\dot{\theta} = (\dot{z}/z)\cos\theta\sin\theta \qquad (2)$$

(where $\dot{z}$ = descent rate).

When an observer approaches the surface of the ground by descending along a linear path at a fixed speed, all three of these sources of information (optical flow acceleration, decrease in optical density, and increase in optical splay angle) are linked with one another. One way to assess the functional utility of these three sources of optical information is to adopt an accretion/deletion paradigm in which one or more sources of information are

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selectively added to or removed from a simulated event (Owen & Warren, 1981). For example, in the case of optical splay, the use of only horizontal texture will effectively eliminate splay change information for detecting loss in altitude. Systematic variations in performance which correspond to the presence or absence of an optical variable should provide evidence of its functional utility as information for a particular event.

In the current series of experiments, optical flow acceleration was deleted for the purpose of assessing observers' sensitivity to descent based on remaining sources of information. Warren (1980a) derived equations to specify global optical flow rate mathematically. In the case of a linear path slope ($\dot{z}/\dot{x}$ = k, where $\dot{x}$ = forward speed), flow rate may be mathematically represented as the ratio of speed ($\dot{s}$) along the path slope to altitude (z), and measured in eyeheights (h) per second. In the case of level flight at a constant forward velocity, flow rate is constant. However, in the case of descent at a constant path speed, flow rate increases as altitude decreases. Therefore, in order to negate flow acceleration as information for descent, flow rate must be held constant ($\dot{s}/z$ = k).

Global optical flow acceleration is expressed as

$$(\ddot{s}/z) - (\dot{s}/z)\,(\dot{z}/z) \tag{3}$$

(where $\ddot{s}$ = acceleration in path speed). Flow rate can be held constant during descent by decreasing path speed by exactly the magnititude needed to compensate for the flow acceleration due to decreasing eyeheight.

Elimination of flow acceleration can be accomplished by application of the following equations:

$$\dot{x}_t = \dot{x}_o e^{(\dot{z}_o/z_o)t} \tag{4}$$

(where $\dot{x}_t$ = forward speed at time t, $\dot{x}_o$ = initial forward speed, e = 2.718, $\dot{z}_o$ = initial descent rate, and $\dot{z}_o$ = initial altitude), and

$$\dot{z}_t = \dot{z}_o e^{(\dot{z}_o/z_o)t} \tag{5}$$

(where $\dot{z}_t$ = descent rate at time t). Initial path speed ($\dot{s}_o$) and path speed at time $\underline{t}$ ($\dot{s}_t$) will be completely determined by and take the same form as did $\underline{\dot{x}}$ and $\underline{\dot{z}}$ in Equations 4 and 5, respectively.

If descent is equally distinguishable in the absence of flow acceleration, observers must be sensitive to one or more of the other optical

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variables specifying loss in altitude. In light of a finding in the Owen, Warren, and Mangold (in press) study indicating that observers were sensitive to fractional loss in altitude ($\dot{z}/z$), rather than to descent rate per se, it is important to note that when flow rate is held constant, fractional loss is also constant over the duration of the event.

Two experiments were conducted to assess the functional utility of optical flow acceleration as information for detecting loss in altitude under the assumption that if optical flow acceleration is critical information for the detection of loss in altitude, then its elimination from simulated descent events should result in detection performance which is inferior to that when optical flow acceleration is present. Although the first experiment was carried out primarily to select variables and levels for the second, it also makes important contributions not explored subsequently.

Experiment 1: Method

The first experiment was conducted in two separate parts. Due to equipment malfunction, the two parts were completed at different times and with equipment modifications as described below. The design of the two parts is identical with the exception of the order of presentation of events which was reversed in the second section.

Apparatus and General Scene and Event Parameters

The simulated self-motion events were generated by a PDP 11/34 computer and a special purpose scene generator (see Yoshi, 1980). For Order 1, observers viewed events displayed via a Sony KP-7200 video projection unit, while observers receiving Order 2 viewed events displayed via a Sony KP-7240 video projection unit. Both units had a screen 1.5 m wide and 1.125 m high, producing a field of view 34.3 deg by 26.1 deg when viewed from a distance of 2.45 m. The sampling rate of 30 frames/sec for scene generation matched the scanning rate of the video projectors. Observers in Order 1 were seated in a stationary Singer-Link GAT-1 flight simulator, while observers in Order 2 were seated in an elevated chair. The observers' viewpoint was at the level of the simulated horizon (1.956 m above the floor).

All events represented level or descending self motion at an initial altitude (z_o) of 72 m over a flat, rectangular island extending 30.72 km parallel to the direction of travel (x dimension). Island width (y dimension)

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was a function of texture block width, since the number of edges along the y dimension was fixed at 20. For the three texture-block sizes used, 4.5, 18, and 72 m, the corresponding island widths were 85.5, 342, and 1368 m, respectively. For Order 1, texture blocks were filled in red, green, light blue, and dark blue; for Order 2 the colors were light green, dark green, light brown, and dark brown. The four colors were randomly assigned with the constraint that no two texture blocks of the same color were adjacent in the x dimension, and no more than two texture blocks of the same color were adjacent in the y dimension. The area above the horizon was a pale blue-gray, and the nontextured area surrounding the island was dark gray.

All events lasted 10 sec. If an event represented descent, loss in altitude was initiated immediately at the beginning of the event.

Design

In an earlier experiment (Owen, Warren, & Mangold, in press), it was determined that a multiplier of two for adjacent levels of independent variables produced a satisfactory range of error rates. However, in the case of path slope $((\dot{z}/\dot{x})_t)$, a narrower range was used in an attempt to keep the observer's task at an appropriate level of difficulty. A single starting altitude of 72 m was used.

The following values for the primary independent variables were chosen to approximate those from the Owen et al. study. Three values of global optical flow rate $((\dot{s}/z)_t)$, at 0.25, 0.50, and 1.00 h/sec (where h = eyeheight), were used to investigate its effect when held constant throughout a descent event. Three values of initial optical texture density (z_o/g, where g = the size of individual ground texture elements) at 1, 4, and 16 g/h, were used to determine whether the density of texture elements has any effect on sensitivity to loss in altitude. Finally, three values of path slope $((\dot{z}/\dot{x})_t)$, at 2%, 4%, and 6% were used.

The value of various "secondary" independent variables were determined as a direct function of the values of the primary independent variables (see Warren & Owen, 1982). The secondary variable of greatest interest is fractional loss in altitude $((\dot{z}/z)_t)$, which indexes the rate of change in optical flow rate, optical texture density, and perspectival splay angle. Seven levels of the variable, at 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 6.0%/sec,

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were determined by the values selected for flow rate $((\dot{s}/z)_t)$, path slope $((\dot{z}/\dot{x})_t)$, and initial altitude (z_o). Appendix Table A-1 contains the full factorial combination of primary variables and the resulting values of the secondary variables.

The three values each of global optical flow rate $((\dot{s}/z)_t)$, initial optical texture density (z_o/g), and path slope $((\dot{z}/\dot{x})_t)$, were fully crossed to produce 27 unique descent events. Setting descent rate $(\dot{z})$ equal to 0 produced nine unique level events that were repeated three times each for a total of 27 level events per block of trials. The 27 descent and 27 level events were combined to form one block of 54 events, with the constraint that no more than 3 events of the same type (level or descent) were displayed in succession. Each observer was tested on two blocks of events in one session. The random orders of events within blocks were reversed in the two orders.

Procedure

At the beginning of the experimental session, each observer was read the instructions in Appendix B. Observers were instructed to view each event and to identify it as representing either level flight or descent as quickly as possible, while also being as accurate as possible.

For Order 1, a verbal "ready" signal given by the experimenter instructed the observer to turn full attention to the screen, at which time the event was initiated. For Order 2, an acoustic tone replaced the verbal "ready" signal. The observer indicated his response of "level" or "descent" by pressing an appropriately labeled button on a hand-held response box. Reaction time from initiation of the event to the button press was surreptitiously recorded. Following each response in Order 1, the observer verbally indicated a rating of confidence in the accuracy of the decision ("1" = a guess, "2" = fairly certain, and "3" = very certain). For Order 2, the computer recorded which of three buttons the observer pressed to indicate the confidence rating. No performance feedback was provided during the testing.

Observers

Observers were 56 male undergraduates at the Ohio State University. Half of the observers received Order 1; the other half received Order 2. All observers participated in order to fulfill an extra-credit option of an introductory psychology course. Each claimed no previous simulator or

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piloting experience.

Experiment 1: Results

Results are discussed in terms of proportion error scores and reaction times for events on which the observer was correct. Correct reaction times are used, rather than all reaction times, in order to provide a more sensitive descriptive statistic with which to compare conditions under which classification was correct.

Analyses of variance were carried out using both error scores and correct reaction times as dependent variables. All effects discussed reached at least the $p < .01$ level of significance and accounted for at least 1.5% of the total variance, unless otherwise indicated. Table 1 summarizes the analyses of variance for those effects discussed in the text. (Complete analysis of variance summary tables for all variables are provided in Appendix C.)

Table 1. Partial ANOVA Summary Table for Descent Events

Source	df	SS	R^2(%)	F	$p < F$
Error					
Path slope (P)	2	61.349	12.23	167.56	.0000
Global optical flow rate (F)	2	52.588	10.48	145.56	.0000
Order (O)	1	6.953	1.39	12.89	.0007
Initial global optical texture density (D)	2	2.362	0.47	4.54	.0128
PF	4	8.140	1.62	16.72	.0000
Reaction time					
P	2	1738.355	6.82	100.90	.0000
F	2	2799.446	10.99	199.09	.0000
O	1	2698.040	10.59	15.60	.0002
D	2	39.222	0.15	3.38	.0371
PF	4	268.409	1.12	24.97	.0000

The analyses indicated significant differences between the two orders

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(error: F = 12.89, $\underline{p}$ < .0007; reaction time: F = 15.60, $\underline{p}$ < .0002), which accounted for 1.34% and 10.47% of the variance in the proportion error and reaction time data, respectively. The average error rate for Order 1 was 21.2% as compared to 13.5% for Order 2, while the average reaction time was 5.952 sec for the former and 4.283 sec for the latter. The Order factor did not, however, interact with any of the primary independent variables to a degree which merits discussion in light of the previously set criteria.

Primary optical variables. As illustrated in Figure 1, proportion error and reaction time decreased significantly with increases in global optical flow rate $((\dot{s}/z)_t)$ and path slope $((\dot{z}/\dot{x})_t)$. The former accounted for 10.4% and 11.0% of the variance in the proportion error and reaction time data respectively, while the latter accounted for 12.4% and 6.9% of the variance in the same dependent measures. The interaction between flow rate and path slope accounted for 1.7% and 1.2% of the variance in the proportion error and reaction time data, respectively. A steeper path slope matched with a more rapid flow rate resulted in fewer errors and more rapid detection.

The third primary independent variable, initial global optical texture density (z_o/g), though statistically significant, accounted for only 0.6% and 0.2% of the variance in the proportion error and reaction time data, respectively. However, as illustrated in Figure 2, there was a clear tendency for accuracy to be best for the middle value of density and worst at the extremes, although at the highest flow rate (1 h/sec) accuracy was greatest with the sparsest density used (1 g/h).

Secondary optical variables. One-way analyses of variance indicated that fractional loss in altitude $((\dot{z}/z)_t)$ accounted for 17.3% and 20.0% of the variance in the proportion error and reaction time data, respectively. As Figure 1 illustrates, both proportion error and mean reaction time decreased with increases in fractional loss in altitude. Figure 2 shows that error rates decreased with increases in fractional loss in altitude within each level of optical flow rate.

Area under the isosensitivity curve (A_g), a bias-free measure of an observer's sensitivity, was calculated for each pair of descent and level events matching on flow rate and texture density. However, since the results of the A_g analysis so closely approximated those for proportion error, it was

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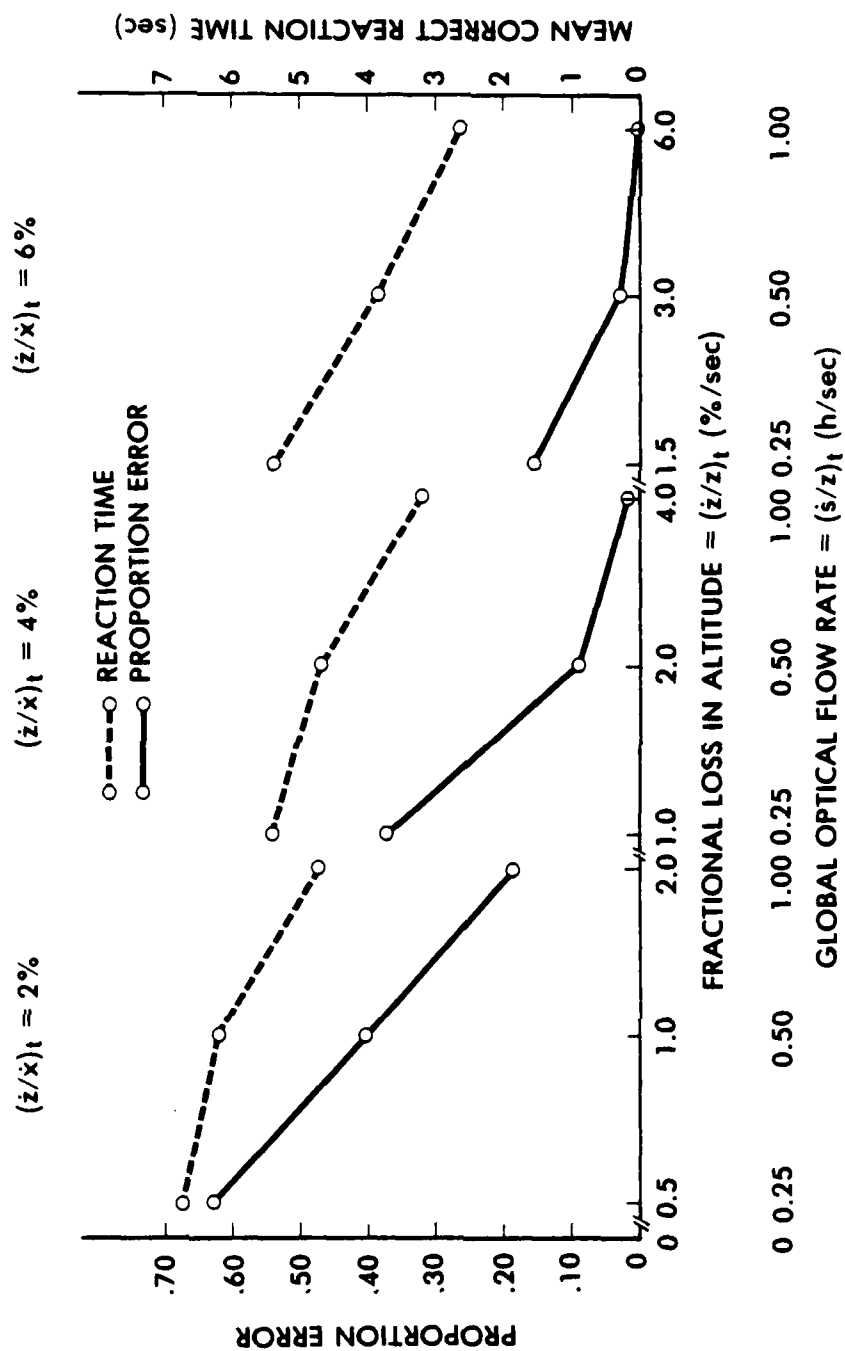
Figure 1. Proportion error and mean correct reaction time for linked levels of fractional loss in altitude $((\dot{z}/z)_t)$ and global optical flow rate $((\dot{s}/z)_t)$ across three levels of path slope $((\dot{z}/\dot{x})_t)$.

15
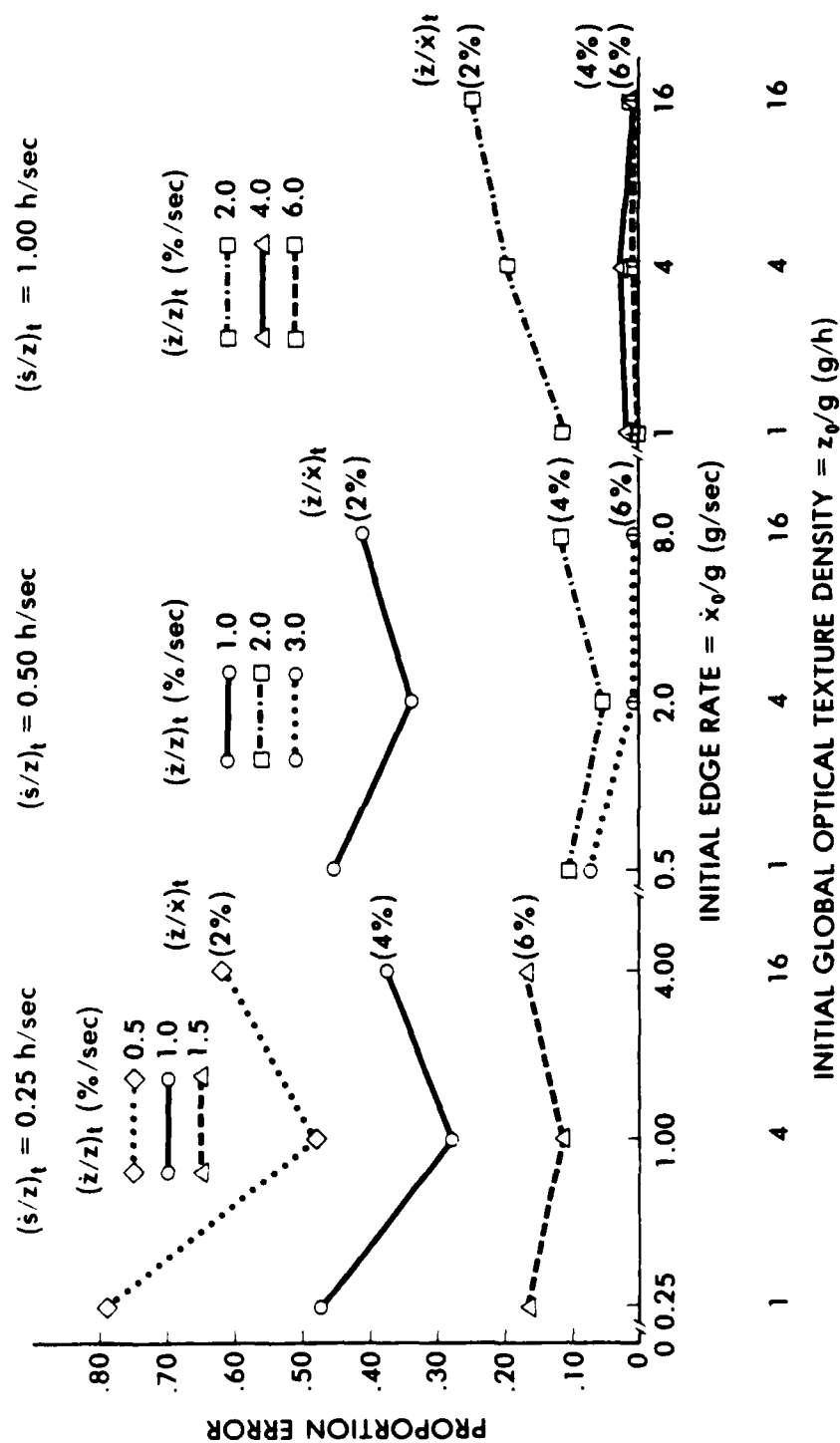
Figure 2. Proportion error for linked levels of initial edge rate ($\dot{x}_o/g$) and initial global optical texture density (z_o/g) across three levels of global optical flow rate (($\dot{s}/z)_t$) for the levels of fractional loss in altitude (($\dot{z}/z)_t$) linked to three levels of path slope (($\dot{z}/\dot{x})_t$).

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concluded that differences in proportion error scores were entirely a result of differential sensitivity, rather than being influenced by differential use of the two report categories.

Experiment 1: Discussion

The results of this study, when compared with those of Owen, Warren, and Mangold (in press), indicate that for comparable levels of fractional loss in altitude $((\dot{z}/z)_t)$, observers made fewer errors and took longer to respond. The fact that error rates were higher in the Owen et al. (in press) study appears to be counterintuitive in the sense that the removal of a source of optical information (acceleration in optical flow rate) would be expected to reduce accuracy. However, the longer reaction times in the current study may indicate that observers were taking longer to search for descent information and, as a result, were more accurate.

Optical flow rate $((\dot{s}/z)_t)$, accounted for the most variance of all the primary optical variables. However, its effect was not independent of that due to fractional loss in altitude. On the whole, detection of descent appeared to be both faster and more accurate the greater the optical flow rate. However, performance was probably better at the higher values of flow rate because the other kinds of optical information for descent, such as optical splay and density change, as indexed by fractional loss in altitude, were changing more rapidly under these conditions.

As in the Owen et al. (in press) study, fractional loss in altitude was the dominant factor in descent detection, even when optical flow acceleration was eliminated. This result strongly suggests that fractional loss should be a primary independent variable in future experiments, so that interactions with other variables of interest can be assessed.

Overall, the effect of initial global optical texture density was not great. However, Figure 2 shows that increasing density from 1 to 4 g/h can reduce errors by over 30% when fractional loss in very low $((\dot{z}/z)_t = 0.5\%/sec)$, i.e., when descent detection is very difficult. It is of great interest to note that when density optimizes, it is always at 4 g/h, i.e., when altitude equals the span of four fields on the ground. Although the functions are fairly symmetrical about 4 g/h, it is possible that with more levels density would actually optimize between 1 and 4 g/h or between 4 and 16

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g/h. It is of further interest to note that in a deceleration-detecting task, density optimized at 1 g/h for both errors and reaction time at all three levels of fractional loss in speed and when fractional loss was either constant or increasing (Figures 10, 11, and 12, Tobias & Owen, 1984). The contrast between the results of the two studies opens the intriguing possibility that optimal levels of optical density are task specific.

A simple explanation of optimal density levels could be made in terms of contrast sensitivity, since contrast sensitivity functions also reveal an optimal level of spatial frequency (cf. Ginsburg, 1981a, 1981b). Finding that self-motion sensitivity optimizes at different densities complicates this simple explanation, however. One possibility is that observers fixate different regions of the perspectival texture density gradient depending on the task. This gradient ranges from low spatial frequencies in the lower region of the optic array (toward the bottom of the screen) to high frequencies (constrained by raster-line width) near the horizon. Since descent detection optimizes at a higher density than deceleration detection, it would be predicted that observers would fixate closer to the horizon when looking for change in altitude than when looking for change in speed. If they do not fixate in the optimal region of the perspectival texture gradient initially, they could be trained to, and a subsequent improvement in sensitivity would be expected.

Given that optimal, but task-specific, optical densities are a reliable phenomenon, there is still the question of how density manifests its effect on descent detection. Since optical density (z/g) has no time-varying term, it is an appropriate descriptor of static, as well as transforming, optic arrays. Therefore, its effects may be explained by acuity, e.g., spatial frequency sensitivity, or by sensitivity to a variable that describes a dynamic property of optic arrays, but is linked to density. At least two ground-unit-scaled variables are already available as candidates: edge rate $(\dot{x}/g$, in ground units or edges per second) and change in optical density with change in altitude $(\dot{z}/g$, in ground units per second). Both can be varied independently of eyeheight-scaled variables, as evidenced by previous studies on sensitivity to change in speed (Owen, Wolpert, & Warren, 1984; Warren, Owen, & Hettinger, 1982) and change in altitude (Wolpert & Owen, this paper; Wolpert, Owen, &

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Warren, 1983). For example, all of the functions shown in Figure 2 could be optimizing at an edge rate of 1.0 g/sec. More levels of edge rate would be needed, and the strategy used by Tobias and Owen (1984) would have to be applied to determine whether performance optimizes for only one member of this set of linked variables.

If the optimal levels of optical density prove to be reliable, the implications for visual flight simulation are clear. Sensitivity to change in altitude is primarily a function of texture distribution in the lateral dimension, i.e., perpendicular to the direction of travel (Wolpert & Owen, this paper; Wolpert, Owen, & Warren, 1983). Given some altitude and rate of change in altitude, both perspectival splay angle and rate of change in splay are determined by the lateral distance between surface texture elements. In contrast, sensitivity to change in forward speed is a function of the distribution of texture elements in the dimension parallel to the direction of travel (Owen et al., 1984; Warren et al., 1982). To optimize control of optical variables specifying change in altitude <u>and</u> change in speed simultaneously, the distance between ground-texture elements should be one-fourth the altitude in the lateral dimension and equal to the altitude in the *forward dimension.*

On the basis of the above findings, the second experiment was designed to contrast descending events with constant versus accelerating optical flow rate in order to obtain a direct assessment of the effect of eliminating the latter as optical information for descent. Fractional loss in altitude was made a primary rather than a secondary variable, and only two levels of initial optical texture density were included. In addition, a time-stress factor was added to the design by displaying events that were 2, 4, or 8 sec in length to determine whether an observer makes use of the additional information that becomes available as an event unfolds.

<div align="center">Experiment 2: Method</div>

All details were the same as for Order 1 in Experiment 1, except for the following.

Design

It was determined from Experiment 1 that a multiplier of two for adjacent levels of variables produced a satisfactory range of error rates. Three

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levels of initial global optical flow rate ($\dot{s}_o/z_o$), at .25, .50, and 1.00 h/sec, were used to investigate its effects when (a) held constant or (b) allowed to accelerate throughout a descent event. Four levels of initial fractional loss in altitude ($\dot{z}_o/z_o$), at 0, 1.5, 3.0, and 6.0%/sec, were used to investigate the salience of change in optical splay and optical texture density as information for descent when varied independently of flow rate. The combinations of parameters produced the four event types or cases shown in Table 2.

<p style="text-align:center">Table 2. Event Types</p>

Case	Heading	Speed	Flow rate
1	Level	Constant	Constant
2	Descent	Constant	Accelerating
3	Level	Decelerating	Decelerating
4	Descent	Decelerating	Constant

In order to hold flow constant during descent along a linear path, path speed and loss in altitude must decrease identically at a rate proportional to the initial fractional loss in altitude (Warren, 1980a). The specific form of the equation is as follows:

$$r_{\dot{z}} = e^{(\dot{z}_o/z_o)} \qquad (6)$$

(where r_z = the rate of change in descent rate, and e = 2.71828).
The same equation holds for $r_{\dot{s}}$. The values of $\underline{r}$ used in the study, corresponding to $\underline{\dot{z}}_o/\underline{z}_o$ values of −1.5, −3.0, and −6.0%/sec, were .9851, .9704, and .9418, respectively.

Cases 2 and 4 constitute the main contrast of interest in the study: descent with versus without optical flow acceleration. Cases 1 and 3 served mainly as "catch" trials for the descent events. Path speed was matched in Cases 1 and 2, in which it remained constant, and in Cases 3 and 4, in which it decelerated.

Two values of initial optical texture density (z_o/g), at 2 and 4 g/h,

<p style="text-align:center">20</p>

were used to further assess the effect of density on sensitivity to loss in altitude. Finally, three different event durations, 2, 4, and 8 sec, were used to assess the effect of time stress on performance. In order that there be no uncertainty on the part of the observer with regard to the event duration, the three durations were separated into individual blocks of events. To further assess the effect of time stress, one group of 37 observers was instructed to view the entire event before responding, whereas a second group of 41 observers was instructed to respond as quickly as possible, but without guessing. The complete inventory of event variables is shown in Appendix D.

Procedure

At the beginning of the experimental session, each observer was read the instructions in Appendix E. Observers were instructed to view each event and, depending on which time-stress condition they were receiving, to identify the event as level flight or descent either (a) as quickly as possible without guessing, or (b) after the entire event had been displayed.

A verbal "ready" signal given by the experimenter instructed the observer to turn full attention to the screen before the event was initiated. The observer indicated a response of "level" or "descent" by pressing an appropriately labelled button on a hand-held response box. Following each choice response, the observer verbally indicated a rating of confidence in the accuracy of the decision ("1" = a guess, "2" = fairly certain, and "3" = very certain). Reaction time from initiation of the event to the button press was surreptitiously recorded, and the confidence rating was keyed into the computer by the experimenter. No performance feedback was provided during testing.

Observers

Observers were 78 undergraduate students (74 male, 4 female) at the Ohio State University, who participated in the experiment as an extra-credit option for an introductory psychology course. Each claimed no previous simulator or piloting experience.

Experiment 2: Results

Analyses of variance were carried out using both proportion error and reaction time as dependent variables. All effects discussed reached at least the $p < .01$ level of significance, and accounted for at least 1.5% of the

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total variance, unless otherwise indicated. The analyses indicated no significant differences in accuracy between the group instructed to respond as soon as possible and the group instructed to view the entire event before responding. Therefore all proportion error data presented have been pooled over the two grouping conditions. Reaction time data are reported only for the group that was required to respond as soon as possible. Table 3 summarizes the analyses of variance for those effects discussed in the text. (Complete analysis of variance summary tables for all effects are presented in Appendix F. Performance means for each event are presented in Appendix D.)

Table 3. Partial ANOVA Summary Table for Descent Events

Source	df	SS	R^2(%)	F	p < F
Error					
Fractional loss in altitude (Z)	2	385.232	22.48	284.11	.0000
Initial global optical flow rate (F)	2	63.090	3.68	95.26	.0000
Initial optical texture density (D)	1	2.646	0.15	6.90	.0107
Event duration (D)	2	2.596	0.15	6.17	.0028
Flow rate constancy (K)	1	0.022	0.01	0.24	.6529
Instruction (I)	1	2.846	0.17	1.63	.2059
ZF	4	27.063	1.58	33.35	.0000
FK	2	3.433	0.20	19.10	.0000
Reaction time					
Z	2	1449.312	11.01	118.09	.0000
F	2	71.277	0.54	16.60	.0000
D	1	1.804	0.01	0.85	.3627
E	2	4842.917	36.76	204.01	.0000
K	1	4.238	0.03	6.27	.0171
ZF	4	178.048	1.35	27.53	.0000
FK	2	20.561	0.16	10.10	.0001

The independent variable which had the strongest relationship with performance was fractional loss in altitude, accounting for 22.5% and 11.0% of the variance in the proportion error and reaction time data, respectively. As illustrated in Figure 3, the proportion of "level" judgments made in response to descent events decreased substantially with increases in fractional loss in altitude. Reaction time also decreased as fractional loss in altitude increased. Performance becomes more accurate and rapid with greater rates of change in optical splay and optical texture density.

A second primary independent variable of interest in the study, global optical flow accounted for 3.7% and 16.6% of the variance in the proportion error and reaction time data, respectively. As Figure 4 illustrates, accuracy of event classification becomes substantially poorer with increases in the initial value of global optical flow rate. Observers are evidently distracted by high values of flow rate to the point that sensitivity to descent information is adversely affected by attending to irrelevant forward speed information.

Figure 4 also shows the interaction between optical flow rate and fractional loss for proportion error scores. These results indicate that higher rates of optical flow interfere increasingly with descent detection for events which have lower values of fractional loss in altitude. The effect of the interaction on correct reaction time was such that reaction time tended to increase in a manner analogous to that of the error rates in Figure 4, although the effect on reaction time was not as dramatic as for errors.

As Figure 5 illustrates, flow rate constancy, i.e., holding global optical flow constant or allowing it to accelerate throughout a descent event, had a significant interaction with initial flow rate. However, this interaction accounted for only 0.2% of the variance in both proportion error and reaction time data. Allowing flow rate to accelerate resulted in more accurate performance at the lower values of initial flow rate, but poorer performance at the highest value.

Initial global optical texture density, appeared to have no substantial effect on performance. Overall, the two optical densities, 2 and 4 g/h, produced only a .5% difference in error rates, and a 40-msec difference in reaction time favoring greater density. Figure 4 shows that the effect of
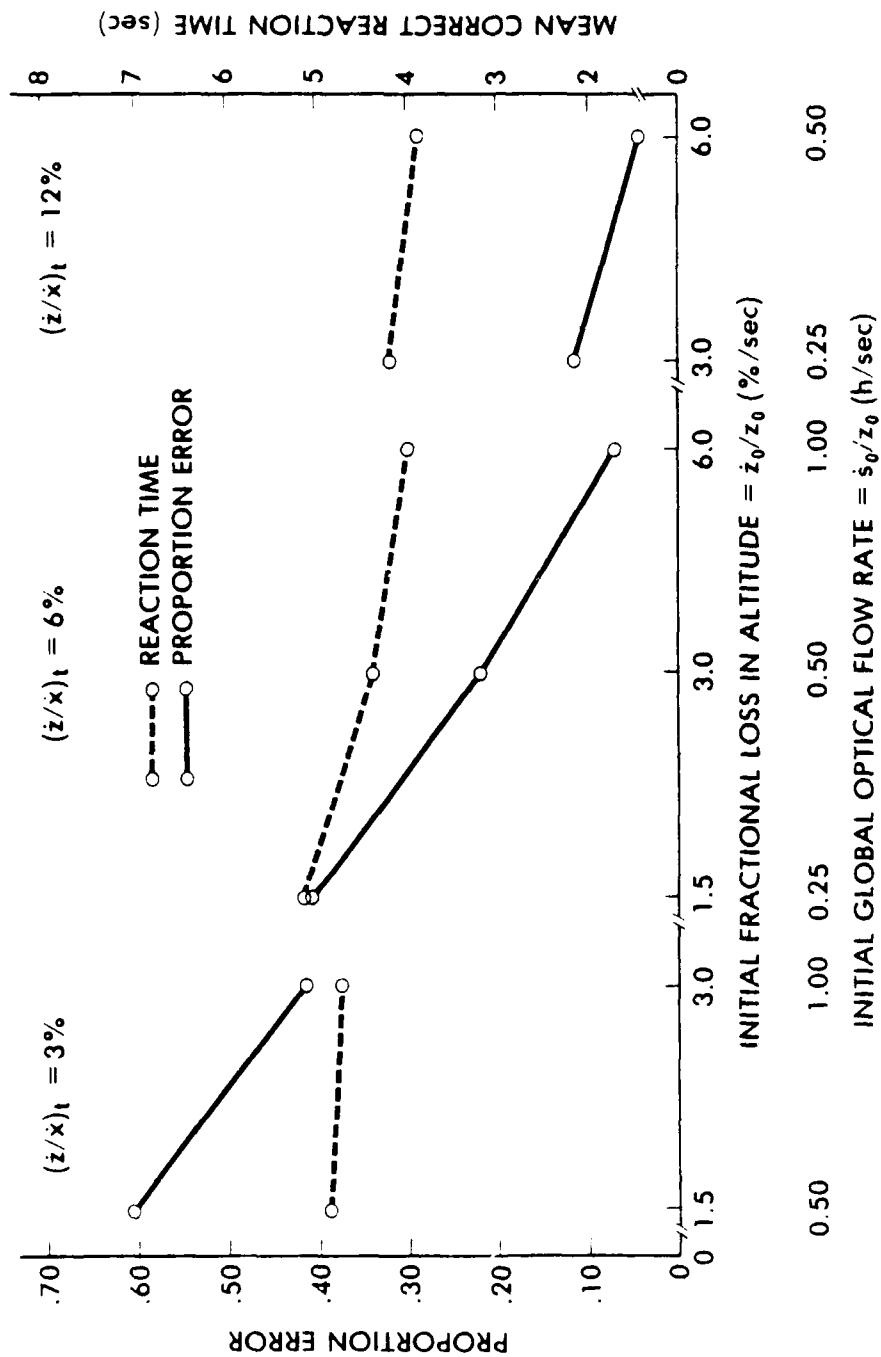
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Figure 3. Proportion error and mean correct reaction time for linked levels of initial fractional loss in altitude ($\dot{z}_o/z_o$) and initial global optical flow rate ($\dot{s}_o/z_o$) across three levels of path slope ($(\dot{z}/\dot{x})_t$).
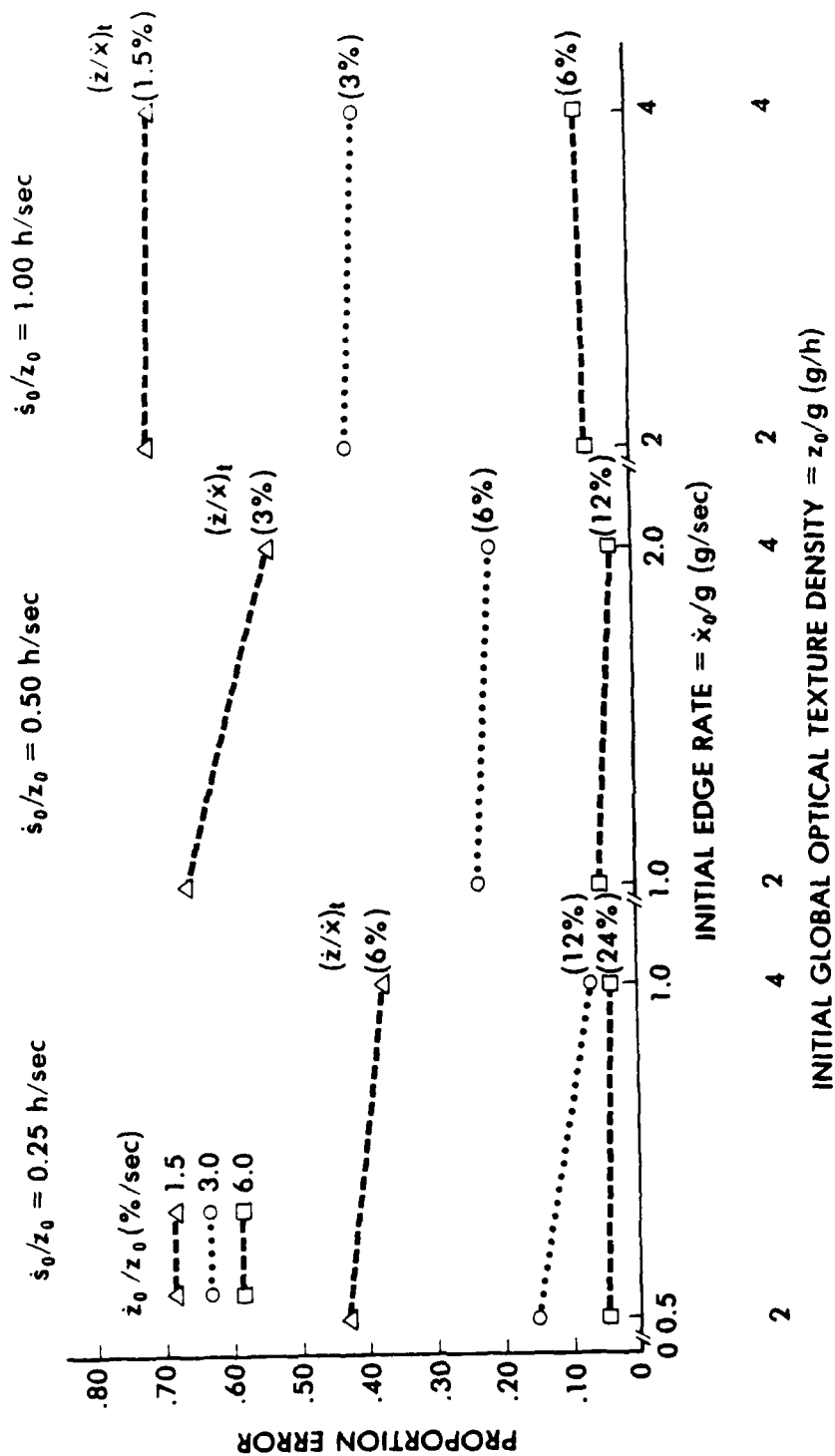
Figure 4. Proportion error for linked levels of initial edge rate ($\dot{x}_0/g$) and initial global optical texture density (z_0/g) across three levels of initial global optical flow rate ($\dot{s}_0/z_0$) for three levels of initial fractional loss in altitude ($\dot{z}_0/z_0$) linked to three levels of path slope (($\dot{z}/\dot{x}$)$_t$).

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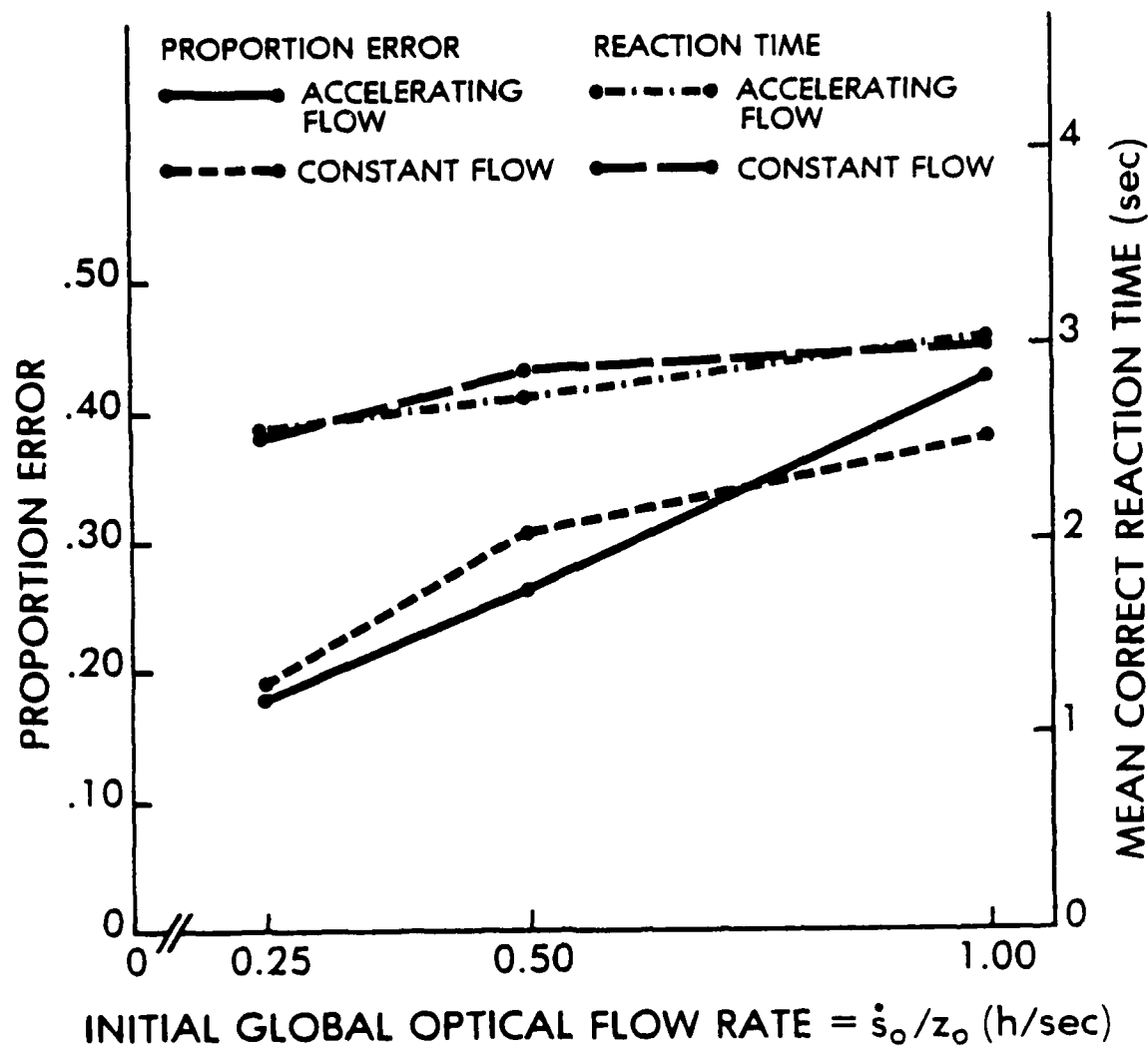
Figure 5. Proportion error and mean correct reaction time for three initial levels of constant and accelerating global optical flow rate $(\dot{s}_o/z_o)$.

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density and/or edge rate is much greater for lower levels of fractional loss in altitude, but the effect is attenuated as flow rate is increased.

Varying the duration of the event had no significant effect on accuracy of detection. The effect was in the direction of greater accuracy with greater duration, though it was surprisingly small and provided little evidence of any speed-accuracy tradeoff in observers' performance. Observers were in error in their classifications of events 31.5% of the time when the event duration was 2 sec, 28.3% for 4 sec, and 27.0% for 8 sec.

The A_g statistic, which specifies the area under the isosensitivity curve and therefore provides a bias-free measure of observers' sensitivity, was calculated for each matching descent-level cell in the design. Since, the results of the A_g analysis so closely approximated those of the proportion error analysis, it was concluded that changes in proportion error scores were a result of differential sensitivity, rather than a shift in the proportion of times the two report categories were used.

Experiment 2: Discussion

Four main points can be made concerning the significance of the results. First of all, there was a surprisingly small effect on performance of varying the amount of time available for viewing an event. Observers will use more time when they have it, as evidenced by their longer reaction times, but are nearly as accurate in detecting descent with short as with comparatively long event durations. This result is in contrast with the outcome of a similar manipulation of test-segment duration in a deceleration-detection experiment (Tobias & Owen, 1983). Marked improvement in accuracy of detecting 9%/sec deceleration was observed as the duration increased from 5.0 to 7.5 to 10.0 sec. As with optical texture density, the effect of temporal contextual variables may be task specific.

Secondly, there does not seem to be any substantial effect on sensitivity to loss in altitude as a result of eliminating optical flow acceleration. These results do not justify the emphasis on the flow acceleration found in the literature. In addition, the data indicate that at low altitudes and high speeds, the resulting high values of optical flow are likely to adversely affect detection of descent. Exactly why high values of optical flow rate should interfere with sensitivity to descent is not immediately evident from

the data. If flow acceleration were a dominant source of information for descent, then the higher the flow rate, the more frequently fast flow might be confused with accelerating flow. The fact that flow acceleration is not effective information for descent eliminates this confusion as a possible explanation of the interference. The following experiment by Wolpert and Owen (this paper) provides an insight concerning the relation between flow acceleration and the negative effect of flow rate.

Another variable which had little overall effect on observers' performance was intitial optical texture density. This result has implications for designers of flight simulation scenes, since large areas of fine texture density are expensive to generate and transform in real time. The results reveal conditions under which density may have an effect when a pilot has to distinguish between level flight and loss in altitude.

Finally, of great interest is the large effect on performance of fractional loss in altitude, which should be of interest to those concerned with the problems involved in low-altitude flight. With constant descent rates, it is at low altitudes that fractional loss takes on its highest values. For example, optical changes are much more perceptually profound given a 50-m loss in altitude from an intitial altitude of 200 m, as compared to the same loss in altitude from 1000 m. Since flow acceleration, under the conditions of this experiment, had little salience for descent detection, the remaining candidates for specifying fractional loss in altitude are increase in optical splay angle, an eyeheight-scaled variable, and decrease in optical texture density, a ground-unit-scaled variable. The experiment which follows (Wolpert & Owen, this paper) assesses the usefulness of these two sources of information.

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Appendix A: Inventory Of Event And Performance Variables

Table A-1. Inventory of Event and Performance Variables[a]

Event number	1 $(\dot{z}/\dot{x})_t$	2 $(\dot{s}/z)_t$	3 z_o/g	4 $(\dot{z}/z)_t$	5 g	6 $\dot{s}_o$	7 $\dot{z}_o$	8 $r_{\dot{z}}, r_{\dot{s}}$	9 % err	10 $\overline{RT}_c$	11 $\overline{Conf}$
1	0	.25	1	0	72.0	18	0	1.000	10.1	5.986	2.55
2	0	.25	4	0	18.0	18	0	1.000	12.5	6.013	2.68
3	0	.25	16	0	4.5	18	0	1.000	10.4	5.749	2.70
4	0	.50	1	0	72.0	36	0	1.000	6.8	5.481	2.58
5	0	.50	4	0	18.0	36	0	1.000	19.6	5.886	2.89
6	0	.50	16	0	4.5	36	0	1.000	14.6	5.461	2.86
7	0	1.00	1	0	72.0	72	0	1.000	16.7	5.433	2.90
8	0	1.00	4	0	18.0	72	0	1.000	17.6	5.483	2.96
9	0	1.00	16	0	4.5	72	0	1.000	14.0	5.108	2.90
10	2.0	.25	1	0.5	72.0	18	-.36	.995	78.6	7.551	2.78
11	2.0	.25	4	0.5	18.0	18	-.36	.995	48.2	7.717	3.61
12	2.0	.25	16	0.5	4.5	18	-.36	.995	61.6	5.947	3.34
13	2.0	.50	1	1.0	72.0	36	-.72	.990	45.5	6.406	3.74
14	2.0	.50	4	1.0	18.0	36	-.72	.990	33.9	5.924	4.09
15	2.0	.50	16	1.0	4.5	36	-.72	.990	41.1	6.422	3.94
16	2.0	1.00	1	2.0	72.0	72	-1.44	.980	11.6	4.721	5.13
17	2.0	1.00	4	2.0	18.0	72	-1.44	.980	39.3	4.882	4.89
18	2.0	1.00	16	2.0	4.5	72	-1.44	.980	25.0	4.311	4.64
19	4.0	.25	1	1.0	72.0	18	-.72	.990	47.3	5.701	3.77
20	4.0	.25	4	1.0	18.0	18	-.72	.990	27.7	5.735	4.45

Table A-1 (Continued)

Event number	1 $(\dot{z}/\dot{x})_t$	2 $(\dot{s}/z)_t$	3 z_o/g	4 $(\dot{z}/z)_t$	5 g	6 $\dot{s}_o$	7 $\dot{z}_o$	8 $r_{\dot{z}}, r_s$	9 % err	10 $\overline{RT}_c$	11 $\overline{Conf}$
21	4.0	.25	16	1.0	4.5	18	-.72	.990	37.5	6.039	4.13
22	4.0	.50	1	2.0	72.0	36	-1.44	.980	10.7	4.292	5.18
23	4.0	.50	4	2.0	18.0	36	-1.44	.980	5.4	4.578	5.28
24	4.0	.50	16	2.0	4.5	36	-1.44	.980	11.6	5.313	5.07
25	4.0	1.00	1	4.0	72.0	72	-2.88	.961	1.8	3.062	5.78
26	4.0	1.00	4	4.0	18.0	72	-2.88	.961	2.7	3.125	5.73
27	4.0	1.00	16	4.0	4.5	72	-2.88	.961	0.8	3.513	5.82
28	6.0	.25	1	1.5	72.0	18	-1.08	.985	18.8	5.536	4.81
29	6.0	.25	4	1.5	18.0	18	-1.08	.985	11.6	4.906	5.07
30	6.0	.25	16	1.5	4.5	18	-1.08	.985	16.9	6.236	4.71
31	6.0	.50	1	3.0	72.0	36	-2.16	.970	7.1	3.868	5.50
32	6.0	.50	4	3.0	18.0	36	-2.16	.970	0.8	3.800	5.70
33	6.0	.50	16	3.0	4.5	36	-2.16	.970	0.8	4.027	5.79
34	6.0	1.00	1	6.0	72.0	72	-4.32	.942	0.0	2.614	5.90
35	6.0	1.00	4	6.0	18.0	72	-4.32	.942	0.8	2.505	5.87
36	6.0	1.00	16	6.0	4.5	72	-4.32	.942	0.8	2.914	5.88

Note. A dot over a symbol indicates a derivative with respect to time. A subscript of zero indicates the value of a variable at the initiation of an event, while a subscript of t indicates the value of a variable at any time during the event.

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Table A-1 (Concluded)

[a]1. $(\dot{z}/\dot{x})_t$ = path slope (%).

2. $(\dot{s}/z)_t$ = global optical flow rate (eyeheights/sec).

3. z_o/g = initial global optical texture density (ground units/eyeheight).

4. $(\dot{z}/z)_t$ = fractional loss in altitude (%/sec).

5. g = ground texture unit size (m).

6. $\dot{s}_o$ = initial path speed (m/sec).

7. $\dot{z}_o$ = initial loss in altitude (m/sec).

8. $r_{\dot{z}}$, $r_{\dot{s}}$ = rate of change in loss in altitude and path speed.

9. % err = percent error.

10. $\overline{RT}_c$ = mean correct reaction time (sec).

11. Conf = mean confidence rating converted to a 6-point scale (1 = "very certain level" to 6 = "very certain descent").

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Appendix B: Instructions

EXPERIMENTER; SEAT THE OBSERVER, THEN READ EXACTLY:

Welcome to the Aviation Psychology Laboratory. We conduct research which deals with human factors in aviation, and in the visual perception of one's own motion.

In today's experiment we are interested in testing your ability to quickly and accurately identify level flight or descent. You will observe simulated flight events which will take place over a checker-board terrain, and your task will be to identify whether each event represents level flight or descent.

The specific procedure will be as follows:

1. At the beginning of each event you will hear a tone; please turn your full attention to the screen at that time.

2. Each event will represent either level flight or descent. As soon as you have decided which is represented, indicate your decision by pressing the button marked "L" for level flight, or "D" for descent. Try to make your decision as quickly as possible, but try to be as accurate as possible too.

3. After you have identified an event as representing either level flight or descent, we would like you to rate your level of confidence in your decision by pressing one of the three numbered buttons. Press "1" if you are unsure of your decision, "2" if you are moderately sure, or "3" if you are very sure of your decision. Please do not press any button twice within a single event, and do not press any button between events. Wait for the buttons to light up before you press.

At times you will notice some shimmering in the terrain toward the horizon. Please try to ignore this; it is due to the limitations of our equipment.

You will judge a total of 108 events, and the entire experiment will last half an hour.

Do you have any questions?

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Appendix C: Analysis Of Variance Summary Tables

Table C-1. Analysis of Descent Events: Error

Source	df	SS	R^2(%)	F	p < F
Path slope (P)	2	61.349	12.23	167.56	.0000
Global optical flow rate (F)	2	52.588	10.48	145.56	.0000
Observer group (O)	1	6.953	1.39	12.89	.0007
Initial global optical texture density (D)	2	2.362	0.47	4.54	.0128
PF	4	8.140	1.62	16.72	.0000
FO	2	4.088	0.81	11.32	.0000
FD	4	3.938	0.78	10.80	.0000
PO	2	1.953	0.39	5.33	.0062
PFO	4	2.712	0.54	5.57	.0003
PFD	8	2.126	0.42	2.35	.0176
POD	4	1.900	0.38	3.92	.0043
FOD	4	1.081	0.22	2.96	.0206
Pooled error	3011	380.142	75.77	-	-
Total	3017	501.393	100.00	-	-

Note. Each effect was tested using the appropriate error term given by the model. Main effects are reported without regard to the level of significance attained. Interactions which were significant at the $p < .05$ level or better are reported.

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Table C-2. Analysis of Descent Events: Reaction Time

Source	df	SS	R^2(%)	F	p < F
Global optical flow rate (F)	2	2799.446	10.99	199.09	.0000
Observer group (O)	1	2698.040	10.59	15.60	.0002
Path slope (P)	2	1738.355	6.82	100.90	.0000
Initial global optical texture density (D)	2	39.222	0.15	3.38	.0371
FP	4	286.409	1.12	24.97	.0000
OP	2	215.433	0.85	12.50	.0000
PD	4	74.803	0.29	8.37	.0000
FO	2	51.330	0.20	3.65	.0292
OD	2	43.326	0.17	3.73	.0271
FD	4	36.673	0.14	3.69	.0062
FPD	8	104.389	0.41	5.60	.0000
FOP	4	99.386	0.39	8.67	.0000
OPD	4	34.336	0.13	3.84	.0049
FOPD	8	81.635	0.32	4.38	.0000
Pooled error	3011	20653.315	81.08	–	–
Total	3017	25471.363	100.00	–	–

Note: Each effect was tested using the appropriate error term given by the model. Main effects are reported without regard to the level of significance attained. Interactions which were significant at the $p < .05$ level or better are reported.

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Table C-3. One-Way Analysis of Variance Summary Table for
Fractional Loss in Altitude: Error

Source	df	SS	R^2(%)	F	p < F
Fractional loss in altitude	6	121.251	24.18	160.07	.0001
Error	3011	380.142	75.82	–	–
Total	3017	501.393	100.00	–	–
Reaction time					
Fractional loss in altitude	6	4818.048	18.92	117.07	.0001
Error	3011	20653.315	81.08	–	–
Total	3017	25471.363	100.00	–	

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Appendix D: Inventory Of Event And Performance Variables

Table D-1. Inventory of Event and Performance Variables[a]

Event number	1 Duration	2 $\dot{z}_o/z_o$	3 $\dot{s}_o/z_o$	4 z_o/g	5 $\dot{s}_o/g$	6 $(\dot{z}/\dot{x})_t$	7 $\dot{z}_o$	8 $\dot{s}_o$	9 g	10 %err	11 $\overline{RT}_c$	12 $\overline{Conf}$
1	2	0	.25	2	9.0	0	0	18	36	9.3	2.001	2.59
2	4	0	.25	2	9.0	0	0	18	36	9.1	2.943	2.67
3	8	0	.25	2	9.0	0	0	18	36	12.1	5.347	2.79
4	2	0	.25	4	4.5	0	0	18	18	15.8	2.029	2.79
5	4	0	.25	4	4.5	0	0	18	18	12.8	3.110	2.85
6	8	0	.25	4	4.5	0	0	18	18	10.2	4.613	2.87
7	2	0	.50	2	18.0	0	0	36	36	12.6	1.874	2.71
8	4	0	.50	2	18.0	0	0	36	36	8.9	2.963	2.66
9	8	0	.50	2	18.0	0	0	36	36	14.9	4.806	2.90
10	2	0	.50	4	9.0	0	0	36	18	15.8	1.842	2.84
11	4	0	.50	4	9.0	0	0	36	18	13.6	2.987	2.82
12	8	0	.50	4	9.0	0	0	36	18	9.7	4.875	2.88
13	2	0	1.00	2	36.0	0	0	72	36	13.9	1.858	2.81
14	4	0	1.00	2	36.0	0	0	72	36	8.9	2.841	2.73
15	8	0	1.00	2	36.0	0	0	72	36	16.5	4.493	2.95
16	2	0	1.00	4	18.0	0	0	72	18	19.7	1.910	2.95
17	4	0	1.00	4	18.0	0	0	72	18	17.7	2.919	2.99
18	8	0	1.00	4	18.0	0	0	72	18	19.7	4.634	3.11
19	2	1.5	.25	2	9.0	6.0	-1.08	18	36	57.8	2.176	3.21

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Table D-1 (Continued)

Event number	Duration	$\dot{z}_o/z_o$	$\dot{s}_o/z_o$	z_o/g	$\dot{s}_o/g$	$(\dot{z}/\dot{x})_t$	$\dot{z}_o$	$\dot{s}_o$	g	%err	$\overline{RT}_c$	$\overline{Conf}$
		2	3	4	5	6	7	8	9	10	11	12
20	4	1.5	.25	2	9.0	6.0	-1.08	18	36	37.7	3.621	3.95
21	8	1.5	.25	2	9.0	6.0	-1.08	18	36	33.8	5.961	4.10
22	2	1.5	.25	4	4.5	6.0	-1.08	18	18	42.8	2.072	3.69
23	4	1.5	.25	4	4.5	6.0	-1.08	18	18	40.9	3.487	3.90
24	8	1.5	.25	4	4.5	6.0	-1.08	18	18	29.9	5.789	4.34
25	2	1.5	.50	2	18.0	3.0	-1.08	36	36	63.0	2.358	3.25
26	4	1.5	.50	2	18.0	3.0	-1.08	36	36	74.7	4.011	3.03
27	8	1.5	.50	2	18.0	3.0	-1.08	36	36	61.0	6.146	3.46
28	2	1.5	.50	4	9.0	3.0	-1.08	36	18	50.0	2.182	3.61
29	4	1.5	.50	4	9.0	3.0	-1.08	36	18	50.0	3.458	3.64
30	8	1.5	.50	4	9.0	3.0	-1.08	36	18	61.7	6.096	3.41
31	2	1.5	1.00	2	36.0	1.5	-1.08	72	36	80.5	2.101	2.81
32	4	1.5	1.00	2	36.0	1.5	-1.08	72	36	68.8	3.946	3.16
33	8	1.5	1.00	2	36.0	1.5	-1.08	72	36	64.3	5.477	3.45
34	2	1.5	1.00	4	18.0	1.5	-1.08	72	18	77.3	2.117	2.94
35	4	1.5	1.00	4	18.0	1.5	-1.08	72	18	63.6	3.645	3.27
36	8	1.5	1.00	4	18.0	1.5	-1.08	72	18	70.1	5.563	3.39
37	2	3.0	.25	2	9.0	12.0	-2.16	18	36	26.6	1.787	4.48
38	4	3.0	.25	2	9.0	12.0	-2.16	18	36	9.1	2.288	5.40

Table D-1 (Continued)

Event number	Duration	1	2 $\dot{z}_o/z_o$	3 $\dot{s}_o/z_o$	4 z_o/g	5 $\dot{s}_o/g$	6 $(\dot{z}/\dot{x})_t$	7 $\dot{z}_o$	8 $\dot{s}_o$	9 g	10 %err	11 $\overline{RT}_c$	12 $\overline{Conf}$
39		8	3.0	.25	2	9.0	12.0	-2.16	18	36	10.4	3.712	5.38
40		2	3.0	.25	4	4.5	12.0	-2.16	18	18	7.8	1.540	5.43
41		4	3.0	.25	4	4.5	12.0	-2.16	18	18	10.4	2.348	5.36
42		8	3.0	.25	4	4.5	12.0	-2.16	18	18	3.2	3.613	5.74
43		2	3.0	.50	2	18.0	6.0	-2.16	36	36	21.4	1.797	4.62
44		4	3.0	.50	2	18.0	6.0	-2.16	36	36	21.4	2.872	4.62
45		8	3.0	.50	2	18.0	6.0	-2.16	36	36	26.6	4.802	4.69
46		2	3.0	.50	4	9.0	6.0	-2.16	36	18	17.5	1.683	4.84
47		4	3.0	.50	4	9.0	6.0	-2.16	36	18	20.1	2.832	4.68
48		8	3.0	.50	4	9.0	6.0	-2.16	36	18	24.7	4.457	4.73
49		2	3.0	1.00	2	36.0	3.0	-2.16	72	36	44.8	2.021	3.89
50		4	3.0	1.00	2	36.0	3.0	-2.16	72	36	48.1	3.300	3.72
51		8	3.0	1.00	2	36.0	3.0	-2.16	72	36	33.1	5.512	4.32
52		2	3.0	1.00	4	18.0	3.0	-2.16	72	18	35.7	1.911	4.03
53		4	3.0	1.00	4	18.0	3.0	-2.16	72	18	48.1	2.972	3.84
54		8	3.0	1.00	4	18.0	3.0	-2.16	72	18	37.0	5.330	4.24
55		2	6.0	.25	2	9.0	24.0	-4.32	18	36	4.5	1.368	5.71
56		4	6.0	.25	2	9.0	24.0	-4.32	18	36	3.2	1.550	5.89
57		8	6.0	.25	2	9.0	24.0	-4.32	18	36	6.5	2.400	5.75

Table $\underline{D\text{-}1}$ (Continued)

Event number	Duration	1 $\dot{z}_o/z_o$	2 $\dot{s}_o/z_o$	3 z_o/g	4 $\dot{s}_o/g$	5 $(\dot{z}/\dot{x})_t$	6 $\dot{z}_o$	7 $\dot{s}_o$	8 g	9 %err	10 $\overline{RT}_c$	11 $\overline{Conf}$
58	2	6.0	.25	4	4.5	24.0	-4.32	18	18	4.5	1.331	5.79
59	4	6.0	.25	4	4.5	24.0	-4.32	18	18	3.9	1.625	5.86
60	8	6.0	.25	4	4.5	24.0	-4.32	18	18	3.9	2.321	5.83
61	2	6.0	.50	2	18.0	12.0	-4.32	36	36	7.1	1.357	5.58
62	4	6.0	.50	2	18.0	12.0	-4.32	36	36	3.9	1.870	5.79
63	8	6.0	.50	2	18.0	12.0	-4.32	36	36	4.5	3.380	5.73
64	2	6.0	.50	4	9.0	12.0	-4.32	36	18	3.2	1.403	5.77
65	4	6.0	.50	4	9.0	12.0	-4.32	36	18	2.6	1.704	5.88
66	8	6.0	.50	4	9.0	12.0	-4.32	36	18	3.2	3.051	5.81
67	2	6.0	1.00	2	36.0	6.0	-4.32	72	36	9.7	1.596	5.27
68	4	6.0	1.00	2	36.0	6.0	-4.32	72	36	4.5	1.984	5.69
69	8	6.0	1.00	2	3b.0	6.0	-4.32	72	36	5.2	3.231	5.74
70	2	6.0	1.00	4	18.0	6.0	-4.32	72	18	7.8	1.513	5.46
71	4	6.0	1.00	4	18.0	6.0	-4.32	72	18	9.7	2.051	5.37
72	8	6.0	1.00	4	18.0	6.0	-4.32	72	18	5.2	3.587	5.68

Note. A dot over a symbol indicates a derivative with respect to time. A subscript of zero indicates the value of a variable at the initiation of an event, while a subscript of $\underline{t}$ indicates the value of a variable at any time during the event.

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Table D-1 (Concluded)

^{a}1. Duration = event duration (sec).

2. $\dot{z}_o/z_o$ = initial fractional loss in altitude (%/sec).

3. $\dot{s}_o/z_o$ = initial global optical flow rate (eyeheights/sec).

4. z_o/g = initial global optical texture density (ground units/eyeheight).

5. $\dot{s}_o/g$ = path speed scaled in ground units (ground units/sec); approximately equal to edge rate ($\dot{x}_o/g$), where $\dot{x}_o$ = initial forward velocity or ground speed.

6. $(\dot{z}/\dot{x})_t$ = path slope (%).

7. $\dot{z}_o$ = initial loss in altitude (m/sec).

8. $\dot{s}_o$ = initial path speed (m/sec).

9. g = ground texture unit size (m).

10. %err = percent error.

11. $\overline{RT}_c$ = mean correct reaction time (sec).

12. $\overline{Conf}$ = mean confidence rating converted to a 6-point scale (1 = "very certain level" to 6 = "very certain descent").

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Appendix E: Instructions

EXPERIMENTER; SEAT THE OBSERVER, THEN READ EXACTLY:

ALL SUBJECTS:

Welcome to the Aviation Psychology Laboratory. We are interested in investigating visual factors in piloting aircraft and in the design of flight simulation devices. In today's experiment we will be testing your ability to distinguish descent (or loss in altitude) from level flight.

The scenes you will see will differ primarily in the length of time you will have for viewing them, either 2, 4, or 8 seconds. In each case, your task will be to press the red button if you decide the scene represents level flight, or the green button if you decide the scene represents descent.

GROUP 1:

Please indicate your decision as quickly as possible, but without guessing. You do not have to wait until the end of the scene to respond.

GROUP2:

Please do not press either button until you have viewed the entire scene.

ALL SUBJECTS:

Each time you press a button to indicate your decision, we would like you to also rate your confidence in your decision. Do this by saying "1" if you guessed, "2" if you are fairly certain of your answer, and "3" if you are very certain of your answer.

After viewing 4 initial practice scenes to familiarize you with the task, you will be shown a total 216 scenes. The entire experiment takes a little more than an hour.

Do you have any questions?

Appendix F: Analysis Of Variance Summary Tables

Table F-1. Analysis of Variance for Descent Events: Error

Source	df	SS	R^2(%)	F	p < F
Fractional loss in altitude (Z)	2	385.232	22.48	284.11	.0000
Initial global optical flow rate (F)	2	63.090	3.68	95.26	.0000
Initial optical texture density (D)	1	2.646	0.15	6.90	.0107
Event duration (E)	2	2.596	0.15	6.17	.0028
Flow rate constancy (K)	1	0.022	0.01	0.24	.6529
Instruction (I)	1	2.846	0.17	1.63	.2059
ZF	4	27.063	1.58	33.35	.0000
ZK	2	1.188	0.06	6.10	.0029
FK	2	3.433	0.20	19.10	.0000
ZD	2	1.081	0.06	3.85	.0238
FD	2	1.198	0.07	6.02	.0032
DK	1	1.711	0.09	18.45	.0001
ZE	4	1.946	0.11	3.75	.0055
FE	4	4.591	0.27	10.73	.0000
EK	2	1.306	0.07	6.56	.0019
DE	2	1.597	0.09	5.32	.0060
ZKI	2	0.606	0.01	3.12	.0476
ZFK	4	4.981	0.29	15.14	.0000
FDI	2	1.484	0.09	7.46	.0009
ZFD	4	1.201	0.07	2.72	.0300
ZDK	2	3.831	0.22	21.47	.0000
FDK	2	1.712	0.10	9.41	.0002
ZEI	4	1.421	0.08	2.74	.0294
ZFE	8	5.521	0.32	6.64	.0000
ZEK	4	1.863	0.11	4.96	.0007
FEK	4	2.517	0.15	7.90	.0000
ZDE	4	1.567	0.09	4.02	.0035
FDE	4	1.752	0.10	3.95	.0040
DEK	2	8.446	0.49	46.59	.0000

Appendix F-1 (Concluded)

Source	df	SS	$R^2(\%)$	F	p < F
ZFI x order	20	6.562	0.38	1.62	.0487
ZFDK	4	1.690	0.10	4.68	.0012
FEKI	4	1.483	0.09	4.65	.0012
ZFEK	8	2.641	0.15	4.06	.0001
ZDEI	4	0.969	0.06	2.49	.0439
ZFDE	8	1.773	0.10	2.27	.0216
ZDEK	4	5.075	0.30	12.93	.0000
FDEK	4	14.191	0.83	33.41	.0000
ZFDEK	8	9.576	0.56	12.84	.0000
Pooled error	3745	967.862	56.50	–	–
Total	3852	1713.678	100.00	–	–

Note. Each effect was tested using the appropriate error term given by the model. Main effects are reported without regard to the level of significance attained. Interactions which were sigificant at the $p < .05$ level or better are reported.

Table F-2. Analysis of Descent Events: Reaction Time

Source	df	SS	R^2(%)	F	p < F
Fractional loss in altitude (Z)	2	1449.312	11.01	118.09	.0000
Initial global optical flow rate (F)	2	71.227	0.54	16.60	.0000
Initial optical texture density (D)	1	1.804	0.01	0.85	.3627
Event duration (E)	2	4842.917	36.76	204.01	.0000
Flow rate constancy (K)	1	4.238	0.03	6.27	.0171
ZF	4	178.048	1.35	27.53	.0000
FK	2	20.561	0.16	10.10	.0001
ZE	4	350.947	2.66	42.93	.0000
FE	4	48.246	0.37	9.91	.0000
ZFK	4	15.826	0.12	2.88	.0248
ZFD	4	14.091	0.11	3.04	.0195
FKD	2	6.190	0.05	3.19	.0470
ZFE	8	71.484	0.54	6.30	.0000
ZKE	2	13.603	0.10	2.61	.0383
FKE	4	11.312	0.09	3.26	.0138
ZFKD	4	30.929	0.23	6.80	.0000
FKDE	4	13.361	0.10	2.64	.0364
ZFKDE	8	50.975	0.39	5.53	.0000
Pooled error	3745	5886.443	44.84	–	–
Total	3852	13127.907	100.00	–	–

Note. Each effect was tested using the appropriate error term given by the model. Main effects are reported without regard to the level of significance attained. Interactions which were sigificant at the p < .05 level or better are reported.

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FUNCTIONAL AND DISTRACTING INFORMATION INFLUENCING THE DETECTION
OF LOSS IN ALTITUDE

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When an individual moves through the environment there is a transformation of the entire optic array along the path of observation. The question which this experiment attempts to answer is whether the metric for visual information specifying self motion through the environment is taken from the environment or from the relation of the self to the environment. Is the scalar for optical information useful in detecting loss in altitude a ground-texture unit or an eyeheight, i.e., the height of the observer's eye above the surface?

An earlier study (Wolpert, 1983; Wolpert, Owen, & Warren, 1983) factorially contrasted eyeheight-scaled and ground-texture-unit-scaled metrics for descent detection. A third factor, texture type, was also introduced to isolate several sources of information. Use of square, vertical, or horizontal texture under conditions of constant fractional loss in altitude versus accelerating fractional loss allowed an analysis of the relative importance of increase in optical (perspectival) splay, decrease in optical density, and optical flow acceleration as sources of information for descent (see Hettinger, Owen, & Warren, this paper, for computational formulae).

While findings from the previous study suggested that an eyeheight unit rather than a ground unit was the perceptually relevant metric for the optical specification of loss in altitude, it should be noted that no information is available for forward velocity, only downward velocity, when flight is over ground texture edges parallel to the direction of travel. In cases where flow-pattern information about forward speed is available, sensitivity to descent is adversely affected (Hettinger, Owen, & Warren, this paper). (Also see Figures 2 through 5 in Wolpert, 1983, and Wolpert et al., 1983, for contrasts of vertical, square, and horizontal texture.) Unfortunately, three levels of initial optical flow were confounded with the levels of ground-unit-scaled loss in altitude, and as a result, the effect of flow could not be

independently ascertained. Thus, the present experiment crossed three rates of fractional loss in altitude with three levels of initial optical flow rate to test the two available metrics for descent detection and assess the potentially deleterious effect of higher flow rates. A lower range of fractional loss values was employed to increase the overall error rate in an attempt to avoid a possible floor effect, while the flow rates were maintained in approximately the same range as in the first experiment.

Method

Apparatus and General Scene and Event Parameters

The simulated self-motion events were generated by a PDP 11/34 computer and a special-purpose scene generator (Yoshi, 1980), and displayed via a Sony Model KP-7240 video projection unit. The sampling rate of 30 frames/sec for scene generation matched the scanning rate of the video projector. The video unit had a screen 1.5 m wide and 1.125 m in height, producing a field of view of 34.3 deg by 26.1 deg. The observer was seated on an elevated chair, 2.43 m in front of the screen, with his viewpoint at the level of the simulated horizon (1.956 m above the floor).

All events represented self-motion at an initial altitude (z dimension) of 72 m over a flat, rectangular island extending 30.72 km parallel to the direction of travel (x dimension) and 665 m perpendicular to the direction of travel (y dimension). The texture blocks representing fields on the island were squares of 18, 36, 72, 144, or 288 m on a side. Four earth colors (light green, dark green, light brown, and dark brown) were randomly assigned to the texture blocks with the constraint that no two texture blocks of the same color were adjacent in the x or y dimension. The area above the horizon was pale blue-gray, and the nontextured area surrounding the island was dark gray.

All events lasted 15 sec, consisting of a 5-sec preview segment of constant-altitude flight followed by a 10-sec test segment of either level or descending flight. Choice of the initial 5-sec period was based on the finding in a previous experiment that a 5-sec preview resulted in a marked reduction in both errors and reaction times compared with immediate onset of the events to be distinguished (Tobias, 1983; Tobias & Owen, 1983).

Design

Successive levels of the primary optical variables were in a ratio of two

to one. Three levels of initial rate of eyeheight-scaled loss in altitude ($\dot{z}_o/z_o$ = 0.01, 0.02, and 0.04 h/sec) were crossed with three levels of ground-unit-scaled loss in altitude ($\dot{z}_t/g$ = 0.01, 0.02, and 0.04 g/sec), $\underline{h}$ and $\underline{g}$ representing eyeheight and ground-unit size, respectively. (A dot over a symbol indicates a derivative with respect to time. A subscript of zero indicates the value of a variable at the initiation of an event, and $\underline{t}$ indicates the value at any time during an event.) These nine combinations were further crossed with two levels of a third factor, a within-event constant ratio, (i.e., either $(\dot{z}/z)_t$ = k or $\dot{z}_t/g$ = k). In the former, optical flow is invariant throughout the event while in the latter optical flow accelerates. Finally, the three factors were fully crossed with three levels of initial global optical flow ($\dot{s}_o/z$ = 0.25, 0.50, 1.00 h/sec).

The resulting 54 descent trials were paired with the same number of level trials, which matched the respective descent trials in flow rate throughout each event. (Appendix G provides an inventory of event parameters). All 54 matched pairs were incorporated in each of four random sequences (two random orders and their respective reverse orders), with the order within each pair (i.e., level followed by descent, or descent followed by level) randomly assigned. An observer viewed two of the sequences (a random order and its reverse), one in each of two sessions on subsequent days. The descent and level events were matched in adjacent trials in order to best reflect bias-free sensitivity at the time during the test session when the descent-trial data were collected. Previous studies (e.g., Owen, Warren, Jensen, Mangold, & Hettinger, 1981) have shown that sensitivity improves with practice; thus it was decided to present the two matching events contiguously.

Procedure

A verbal "ready" signal, given by the experimenter, instructed the observer to turn full attention to the screen. The initial 5 sec of level flight at constant speed and altitude was separated from the 10-sec test segment by an acoustic tone. During the test segment the observer was instructed to press either the "descent" or the "level" button on a hand-held box and to indicate verbally his confidence in his choice ("1" - a guess, "2" - fairly certain, or "3" - very certain) as soon as he had made his decision. Reaction time was surreptitiously recorded. No performance feedback was

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provided during the testing. (Appendix H provides the complete instructions.)

Observers

Fifty-eight male undergraduate students served as observers to fulfill an extra-credit option of an introductory psychology course. All observers claimed no prior experience as pilots or in flight simulators, and all reported normal vision.

Results

As in the previous study (Wolpert, 1983; Wolpert et al., 1983), the eyeheight metric, ground-unit metric, initial flow rate, and flow-rate constancy (i.e., the absence or presence of optical flow acceleration) reached the $p < .0001$ level of significance. In this type of experiment, however, significance in the conventional sense is easily obtained due to the large number of observations. Thus, in order to merit discussion, only effects that account for more than 1.5% of the total variance are considered. None of the interactions accounted for more than 1% of the variance in either error rate or reaction time even though a number did attain significance at the the .01 level. A detailed list of effects and interactions, significant at the .05 level, is provided in Appendix I.

While the eyeheight metric accounted for 12.0% of the variance in error rate and 16.5% in reaction time, the ground-unit metric accounted for only .46% and 1.22%, respectively. The greater slope in Figures 1 and 2 for the eyeheight scalar is not evident in Figures 3 and 4 for the ground-unit scalar. Averaging over levels of flow rate and flow-rate constancy revealed a reduction of 28% in error rate (from 32.4% to 4.4%) and 3 sec in reaction time (from 6.2 to 3.2 sec) over the three levels of the eyeheight-scaled variable, but only a 5% (from 19% to 14%) and .8-sec (from 5.1 to 4.3 sec) improvement for the ground-unit variable.

The initial level of flow rate accounted for 1.8% of the variance in error rate and 1.3% in reaction time, reflecting an increasingly negative effect on performance of increases in flow rate. This effect can be seen in Figures 1 through 4 in which error rates and reaction times increase across panels depicting the three flow rates. Within the limited range tested, increasing the initial flow rate from .25 to 1.00 h/sec resulted in an

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increase in descent-trial error rate from 10.2 to 21.7% and an increase in reaction time from 4.17 to 5.08 sec.

The fourth significant main effect, flow-rate constancy, accounted for 1.81% of the variance in error rate and 4.47% in the reaction time measure. As was found in the earlier study (Wolpert, 1983; Wolpert et al., 1983), constant optical flow resulted in performance superior to accelerating optical flow at every level of initial fractional loss in altitude. This too can be seen in Figures 1 through 4, in which error rates and reaction times for constant flow are consistently lower than for accelerating flow.

A third dependent variable, area under the isosensitivity curve (A_g) was analyzed to obtain a bias-free measure of sensitivity. Although more conservative, this measure provided a pattern of results similar to that for error rate. Descent scaled in eyeheights accounted for 7.0% of the variance versus .1% for the ground-unit metric. Figure 5 reflects this pattern, averaged over levels of initial flow rate. (Note that area above the isosensitivity curve ($1-A_g$) is presented to make the structure comparable to that for error rate and reaction time.)

Initial flow rate accounted for 1.91% of the variance in A_g, reflecting a negative effect on sensitivity with increases in flow rate. While only accounting for .99% of the variance, greater sensitivity resulted when optical flow was held constant throughout the event. No interaction accounted for more than .6% of the variance in the A_g measure.

Discussion

These results suggest that for specifying loss in altitude the eyeheight metric is much more functionally relevant than the ground-unit metric. Although variation indexed by both metrics was found to produce statistically significant effects, the eyeheight metric accounted for 26 times as much variance in the error data as the ground-unit metric, 13 times as much in reaction time, and 58 times as much in the A_g measure.

As suspected, global optical flow rate had a detrimental effect on sensitivity to loss in altitude as indexed by descent-trial error rate, reaction time and bias-free sensitivity. This effect substantiates the finding in the earlier study (Wolpert, 1983; Wolpert et al., 1983) of performance in the vertical-only condition that was superior to the square
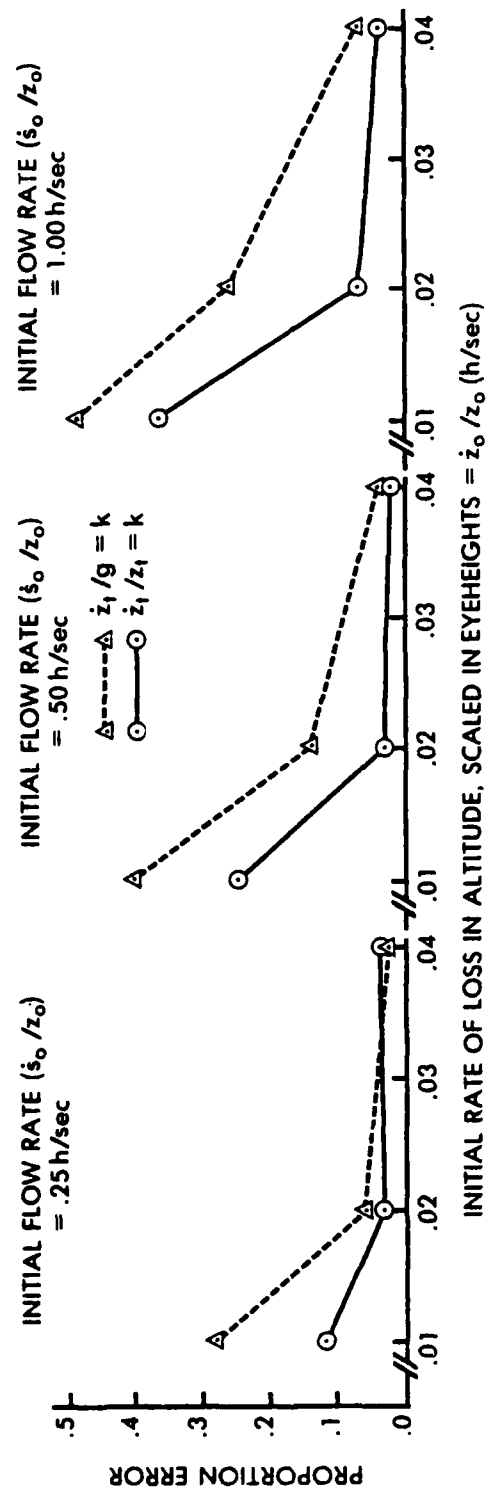
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Figure 1. Proportion error for the three levels of initial rate of eyeheight-scaled loss in altitude $(\dot{z}_o/z_o)$ across three levels of initial optical flow rate $(\dot{s}_o/z_o)$ under conditions of constant optical flow, when $(\dot{z}/z)_t = k$, and optical flow acceleration, when $\dot{z}_t/g = k$.

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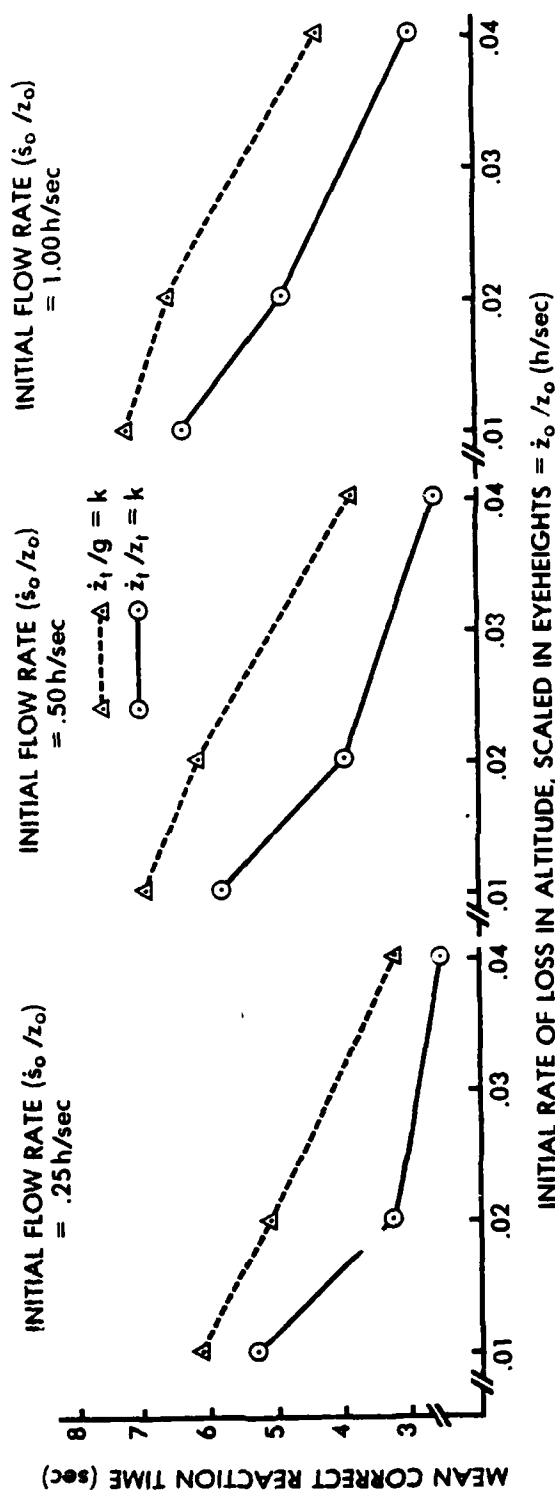
Figure 2. Mean correct reaction time for three levels of initial rate of eyeheight-scaled loss in altitude ($\dot{z}_o/z_o$) across three levels of initial optical flow rate ($\dot{s}_o/z_o$) under conditions of constant optical flow, when $(\dot{z}/z)_t = k$, and optical flow acceleration, when $\ddot{z}_t/g = k$.

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Figure 3. Proportion error for the three levels of initial rate of ground-unit-scaled loss in altitude $(\dot{z}_o/g)$ across three levels of initial optical flow rate $(\dot{s}_o/z_o)$ under conditions of constant optical flow, when $(\dot{z}/z)_t = k$, and optical flow acceleration, when $\dot{z}_t/g = k$.

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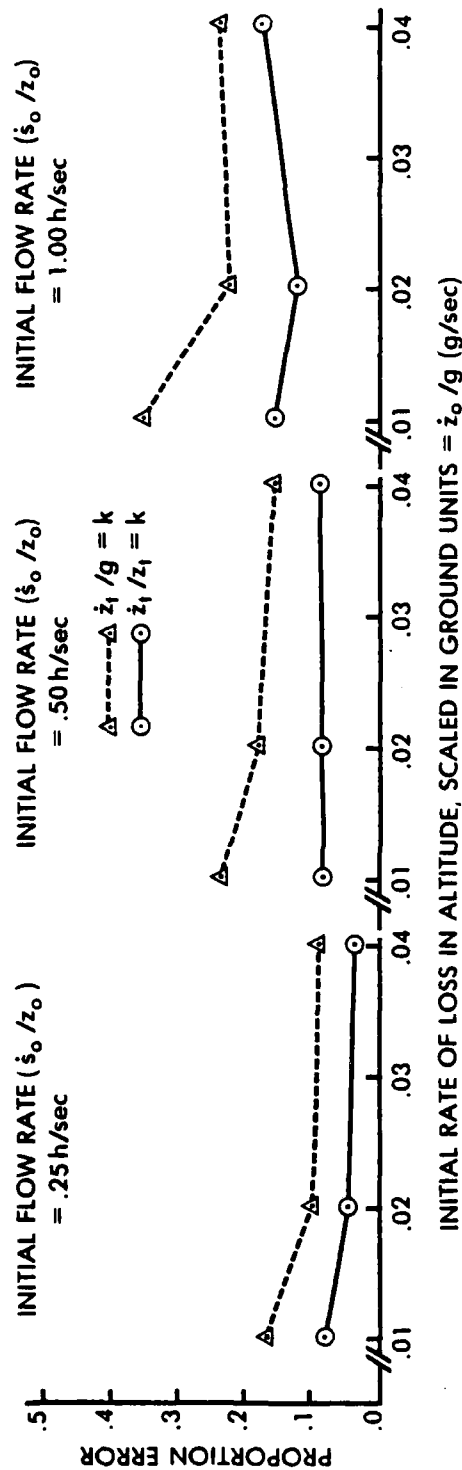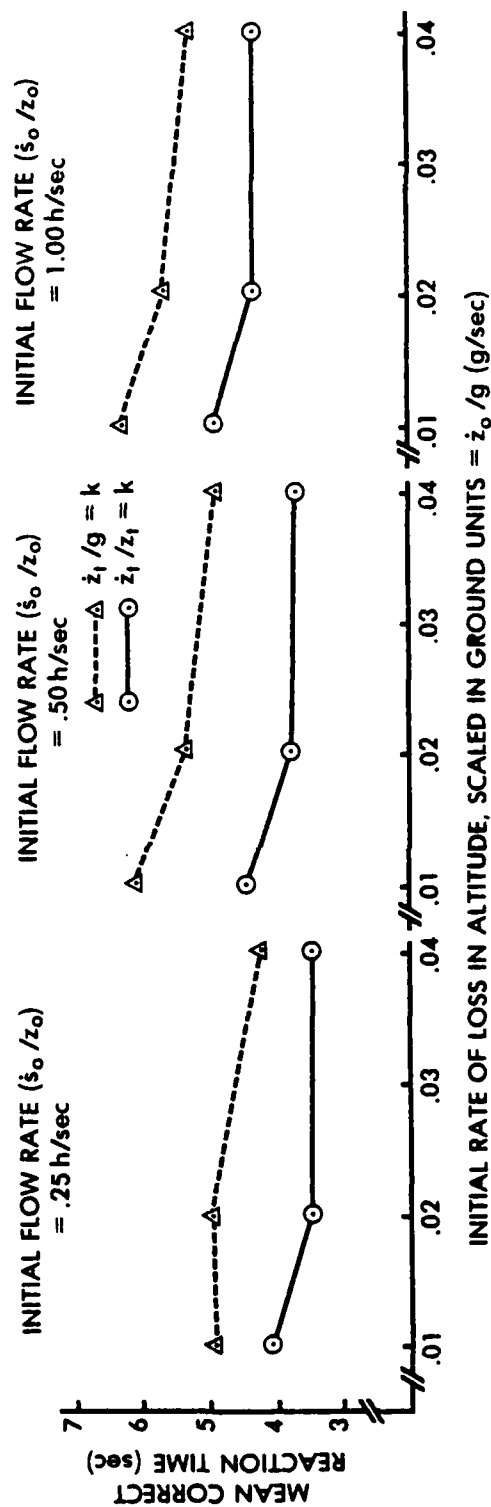
Figure 4. Mean correct reaction time for the three levels of initial rate of ground-unit-scaled loss in altitude $(\dot{z}_o/g)$ across three levels of initial optical flow rate $(\dot{s}_o/z_o)$ under conditions of constant optical flow, when $(\dot{z}/z)_t = k$, and optical flow acceleration, when $\dot{z}_t/g = k$.

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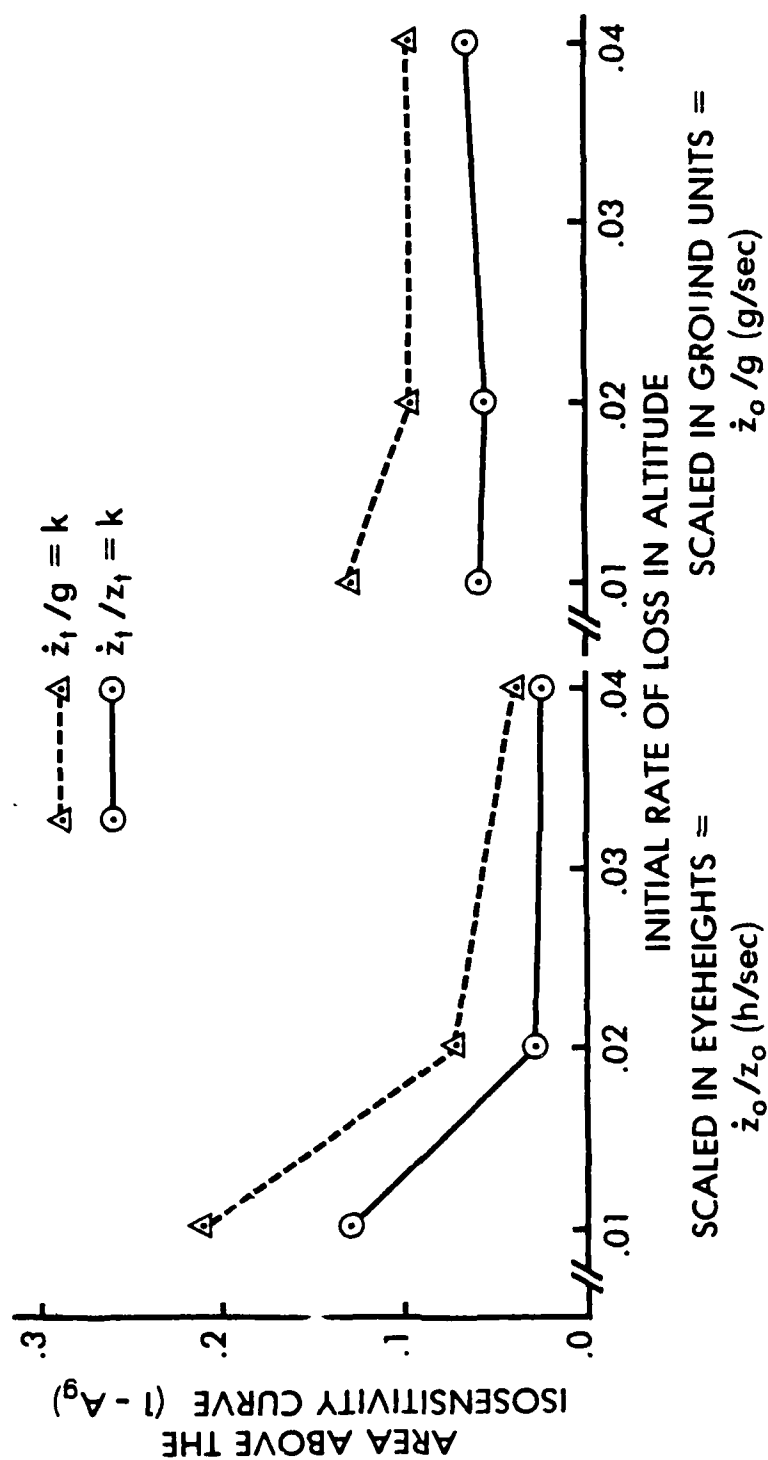
Figure 5. Area above the isosensitivity curve $(1-A_g)$ for three levels of initial rate of loss in altitude scaled in eyeheights $(\dot{z}_i/z_o)$ and scaled in ground units $(\dot{z}_o/g)$ under conditions of constant optical flow, when $(\dot{z}/z)_t = k$, and optical flow acceleration, when $\dot{z}_t/g = k$.

texture condition, where flow due to self motion in the forward direction was only available in the latter condition.

The detrimental influence of increased optical flow rate also provides an explanation for the observed superiority of within-event constant versus accelerating optical flow. Given any pair of events with the same initial flow rate, the flow rate at any point in time after onset of the event will be higher in the accelerating condition. As indicated by the manipulation in the present experiment, the higher the flow rate, the more difficult the detection of descent.

Whether this negative effect can be attributed unequivocally to flow rate is unclear. The experimental events necessarily have edge rate (the number of edges crossed per second), optical density (the number of texture units spanned by one eyeheight), and path slope as secondary variables. Edge rate has been shown to have an effect stronger than flow rate in eliciting acceleration reports during simulated level flight (Owen, Wolpert, & Warren, 1984; Warren, Owen, & Hettinger, 1982), while optical density seems to have an optimal effect specific to the task: at 1 g/h for deceleration detection (Tobias & Owen, 1983), and at 4 g/h in a descent-detection experiment (Hettinger, Owen, & Warren, this paper). Note that flow rate, edge rate, and density are optically linked, with only two degrees of freedom among them. Fractional loss, path slope, and flow rate are also a linked triad.

Whether the decrease in performance is due to flow rate or edge rate has important implications for high-speed, low-altitude flight. Given a fixed path speed, any subsequent loss in altitude would further increase the flow rate, thereby decreasing the likelihood of the pilot detecting this change in altitude. Thus poorer performance is predicted in conditions where the safety margin is already reduced. In the same condition, edge rate does not change provided that the ground texture is stochastically regular.

On the other hand, should edge rate increase (e.g., due to more closely spaced edges), flow rate would remain constant provided that path speed and altitude did not change. Depending on the pilot's sensitivity to edge and/or flow rate, performance would be duly affected. Earlier studies (Owen et al., 1984; Warren et al., 1982) have indicated large individual differences in sensitivity to edge and/or flow rate in detecting accelerating events, and

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this too might serve as an evaluative tool in pilot selection.

Findings from the present study hold theoretical significance as well. The fact that the eyeheight metric is the relevant one for specifying descent is in accordance with other studies that have shown the importance of self-scaled referents with dimensionless metrics. For example, Warren (1984) demonstrated that the ease of climbing stairs was perceived relative to the observer's leg length, while Hallford (1984) found that the perceived graspability of tiles was a direct function of the observer's hand span. Taken together, these findings add support to the ecological notion that perception and action are inextricably interrelated and that performance should be studied with respect to the person doing the perceiving and acting.

Appendix G: Inventory Of Event And Performance Variables

Table G-1. Inventory of Event and Performance Variables[a]

Event number	1 $\dfrac{\dot{z}_0}{g}$	2 $\dfrac{\dot{z}_{10}}{g}$	3 $\left(\dfrac{\dot{z}}{z}\right)_0$	4 $\left(\dfrac{\dot{z}}{z}\right)_{10}$	5 $\left(\dfrac{\dot{s}}{z}\right)_0$	6 $\left(\dfrac{\dot{s}}{z}\right)_{10}$	7 $\left(\dfrac{\ddot{s}}{z}\right)_t - \left(\dfrac{\dot{s}}{z}\right)_t\left(\dfrac{\dot{z}}{x}\right)_t$ For t=0	8 t=10	9 $\left(\dfrac{\dot{z}}{x}\right)_t$	10 $\dfrac{z_0}{g}$
					Descent trials, accelerating optical flow					
1	.01	.01	.01	.011	.25	.278	.003	.003	.04	1.00
2	.01	.01	.01	.011	.50	.556	.005	.006	.02	1.00
3	.01	.01	.01	.011	1.00	1.111	.010	.012	.01	1.00
4	.01	.01	.02	.025	.25	.313	.005	.008	.08	.50
5	.01	.01	.02	.025	.50	.625	.010	.016	.04	.50
6	.01	.01	.02	.025	1.00	1.250	.020	.031	.02	.50
7	.01	.01	.04	.067	.25	.417	.010	.028	.16	.25
8	.01	.01	.04	.067	.50	.833	.020	.056	.08	.25
9	.01	.01	.04	.067	1.00	1.667	.040	.111	.04	.25
10	.02	.02	.01	.011	.25	.278	.003	.003	.04	2.00
11	.02	.02	.01	.011	.50	.556	.005	.006	.02	2.00
12	.02	.02	.01	.011	1.00	1.111	.010	.012	.01	2.00
13	.02	.02	.02	.025	.25	.313	.005	.008	.08	1.00
14	.02	.02	.02	.025	.50	.625	.010	.016	.04	1.00
15	.02	.02	.02	.025	1.00	1.250	.020	.031	.02	1.00
16	.02	.02	.04	.067	.25	.417	.010	.028	.16	.50
17	.02	.02	.04	.067	.50	.833	.020	.056	.08	.50
18	.02	.02	.04	.067	1.00	1.667	.040	.111	.04	.50
19	.04	.04	.01	.011	.25	.278	.003	.003	.04	4.00
20	.04	.04	.01	.011	.50	.556	.005	.006	.02	4.00
21	.04	.04	.01	.011	1.00	1.111	.010	.012	.01	4.00
22	.04	.04	.02	.025	.25	.313	.005	.008	.08	2.00
23	.04	.04	.02	.025	.50	.625	.010	.016	.04	2.00
24	.04	.04	.02	.025	1.00	1.250	.020	.031	.02	2.00
25	.04	.04	.04	.067	.25	.417	.010	.028	.16	1.00

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Table G-1 (Continued)

$\dfrac{\dot{x}_0}{g}$	g	$\dot{s}_0$	$\dot{s}_{10}$	z_0	z_{10}	$\dot{z}_0$	$\dot{z}_{10}$	Pr err	$\overline{RT}_c$	$\overline{Conf}$	Event number
11	12	13	14	15	16	17	18	19	20	21	
.25	72	18	18	72	64.8	.72	.72	.414	6.16	3.76	1
.50	72	36	36	72	64.8	.72	.72	.448	7.18	3.65	2
1.00	72	72	72	72	64.8	.72	.72	.612	7.48	2.99	3
.125	144	18	18	72	57.6	1.44	1.44	.095	5.42	5.23	4
.25	144	36	36	72	57.6	1.44	1.44	.216	6.62	4.56	5
.50	144	72	72	72	57.6	1.44	1.44	.276	6.82	4.39	6
.0625	288	18 18	18	72	43.2	2.88	2.88	.052	3.84	5.61	7
.125	288	36	36	72	43.2	2.88	2.88	.069	5.07	5.53	8
.25	288	72	72	72	43.2	2.88	2.88	.155	5.55	5.01	9
.50	36	18	18	72	64.8	.72	.72	.216	6.53	4.60	10
1.00	36	36	36	72	64.8	.72	.72	.405	7.13	3.80	11
2.00	36	72	72	72	64.8	.72	.72	.405	7.61	3.64	12
.25	72	18	18	72	57.6	1.44	1.44	.078	5.37	5.34	13
.50	72	36	36	72	57.6	1.44	1.44	.138	5.98	4.97	14
1.00	72	72	72	72	57.6	1.44	1.44	.276	6.42	4.37	15
.125	144	18	18	72	43.2	2.88	2.88	.052	3.19	5.76	16
.25	144	36	36	72	43.2	2.88	2.88	.034	3.55	5.77	17
.50	144	72	72	72	43.2	2.88	2.88	.026	3.81	5.74	18
1.00	18	18	18	72	64.8	.72	.72	.267	6.04	4.39	19
2.00	18	36	36	72	64.8	.72	.72	.379	6.70	3.95	20
4.00	18	72	72	72	64.8	.72	.72	.440	6.57	3.78	21
.50	36	18	18	72	57.6	1.44	1.44	.052	4.70	5.50	22
1.00	36	36	36	72	57.6	1.44	1.44	.138	5.78	5.03	23
2.00	36	72	72	72	57.6	1.44	1.44	.267	6.59	4.35	24
.25	72	18	18	72	43.2	2.88	2.88	.017	2.63	5.90	25

Event number	1 $\frac{\dot{z}_0}{g}$	2 $\frac{\dot{z}_{10}}{g}$	3 $\left(\frac{\dot{z}}{z}\right)_0$	4 $\left(\frac{\dot{z}}{z}\right)_{10}$	5 $\left(\frac{\dot{s}}{z}\right)_0$	6 $\left(\frac{\dot{s}}{z}\right)_{10}$	7 $\left(\frac{\ddot{s}}{z}\right)_t - \left(\frac{\dot{s}}{z}\right)_t\left(\frac{\dot{z}}{x}\right)_t$ For t=0	8 t=10	9 $\left(\frac{\dot{z}}{\dot{x}}\right)_t$	10 $\frac{z_0}{g}$
26	.04	.04	.04	.067	.50	.833	.020	.056	.08	1.00
27	.04	.04	.04	.067	1.00	1.667	.040	.111	.04	1.00

Level trials, accelerating optical flow

Event number	1	2	3	4	5	6	7	8	9	10
28	0	0	0	0	.25	.278	.003	.003	0	1.00
29	0	0	0	0	.50	.556	.005	.006	0	1.00
30	0	0	0	0	1.00	1.111	.010	.012	0	1.00
31	0	0	0	0	.25	.313	.005	.008	0	.50
32	0	0	0	0	.50	.625	.010	.016	0	.50
33	0	0	0	0	1.00	1.250	.020	.031	0	.50
34	0	0	0	0	.25	.417	.010	.028	0	.25
35	0	0	0	0	.50	.833	.020	.056	0	.25
36	0	0	0	0	1.00	1.667	.040	.111	0	.25
37	0	0	0	0	.25	.278	.003	.003	0	2.00
38	0	0	0	0	.50	.556	.005	.006	0	2.00
39	0	0	0	0	1.00	1.111	.010	.012	0	2.00
40	0	0	0	0	.25	.313	.005	.008	0	1.00
41	0	0	0	0	.50	.625	.010	.016	0	1.00
42	0	0	0	0	1.00	1.250	.020	.031	0	1.00
43	0	0	0	0	.25	.417	.010	.028	0	.50
44	0	0	0	0	.50	.833	.020	.056	0	.50
45	0	0	0	0	1.00	1.667	.040	.111	0	.50
46	0	0	0	0	.25	.278	.003	.003	0	4.00
47	0	0	0	0	.50	.556	.005	.006	0	4.00
48	0	0	0	0	1.00	1.111	.010	.012	0	4.00
49	0	0	0	0	.25	.313	.005	.008	0	2.00

Table C-1 (Continued)

$\dfrac{\dot{x}_0}{g}$ 11	g 12	$\dot{s}_0$ 13	$\dot{s}_{10}$ 14	z_0 15	z_{10} 16	$\dot{z}_0$ 17	$\dot{z}_{10}$ 18	Pr err 19	$\overline{RT}_c$ 20	$\overline{Conf}$ 21	Event number
.50	72	36	36	72	43.2	2.88	2.88	.026	2.91	5.84	26
1.00	72	72	72	72	43.2	2.88	2.88	.043	3.62	5.68	27

Level trials, accelerating optical flow

$\dfrac{\dot{x}_0}{g}$	g	$\dot{s}_0$	$\dot{s}_{10}$	z_0	z_{10}	$\dot{z}_0$	$\dot{z}_{10}$	Pr err	$\overline{RT}_c$	$\overline{Conf}$	Event number
.25	72	18	20.0	72	72.0	0	0	.043	6.32	1.58	28
.50	72	36	40.0	72	72.0	0	0	.103	6.35	1.88	29
1.00	72	72	80.0	72	72.0	0	0	.138	5.90	1.96	30
.125	144	18	22.5	72	72.0	0	0	.043	6.47	1.62	31
.25	144	36	45.0	72	72.0	0	0	.069	6.31	1.65	32
.50	144	72	90.0	72	72.0	0	0	.147	6.24	1.93	33
.0625	288	18	30.0	72	72.0	0	0	.069	6.39	1.66	34
.125	288	36	60.0	72	72.0	0	0	.103	6.88	1.78	35
.25	288	72	120.0	72	72.0	0	0	.155	6.40	2.09	36
.50	36	18	20.0	72	72.0	0	0	.095	6.48	1.81	37
1.00	36	36	40.0	72	72.0	0	0	.078	6.21	1.64	38
2.00	36	72	80.0	72	72.0	0	0	.198	5.98	2.03	39
.25	72	18	22.5	72	72.0	0	0	.069	6.24	1.57	40
.50	72	36	45.0	72	72.0	0	0	.086	6.34	1.70	41
1.00	72	72	90.0	72	72.0	0	0	.172	5.49	1.90	42
.125	144	18	30.0	72	72.0	0	0	.069	6.41	1.65	43
.25	144	36	60.0	72	72.0	0	0	.095	6.32	1.71	44
.50	144	72	120.0	72	72.0	0	0	.284	5.62	2.50	45
1.00	18	18	20.0	72	72.0	0	0	.121	6.14	1.73	46
2.00	18	36	40.0	72	72.0	0	0	.095	6.54	1.75	47
4.00	18	72	80.0	72	72.0	0	0	.121	5.92	1.84	48
.50	36	18	22.5	72	72.0	0	0	.026	6.17	1.44	49

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	1	2	3	4	5	6	7	8	9	10
Event number	$\dfrac{\dot{z}_0}{g}$	$\dfrac{\dot{z}_{10}}{g}$	$\left(\dfrac{\dot{z}}{z}\right)_0$	$\left(\dfrac{\dot{z}}{z}\right)_{10}$	$\left(\dfrac{\dot{s}}{z}\right)_0$	$\left(\dfrac{\dot{s}}{z}\right)_{10}$	$\left(\dfrac{\ddot{s}}{z}\right)_t - \left(\dfrac{\dot{s}}{z}\right)_t$ For t=0	$\left(\dfrac{\dot{z}}{x}\right)_t$ t=10	$\left(\dfrac{\dot{z}}{\dot{x}}\right)_t$	$\dfrac{z_0}{g}$
50	0	0	0	0	.50	.625	.010	.016	0	2.00
51	0	0	0	0	1.00	1.250	.020	.031	0	2.00
52	0	0	0	0	.25	.417	.010	.028	0	1.00
53	0	0	0	0	.50	.833	.020	.056	0	1.00
54	0	0	0	0	1.00	1.667	.040	.111	0	1.00

Descent trials, constant optical flow

Event number	1	2	3	4	5	6	7	8	9	10
55	.01	.009	.01	.01	.25	.25	0	0	.04	1.00
56	.01	.009	.01	.01	.50	.50	0	0	.02	1.00
57	.01	.009	.01	.01	1.00	1.00	0	0	.01	1.00
58	.01	.008	.02	.02	.25	.25	0	0	.08	.50
59	.01	.008	.02	.02	.50	.50	0	0	.04	.50
60	.01	.008	.02	.02	1.00	1.00	0	0	.02	.50
61	.01	.007	.04	.04	.25	.25	0	0	.16	.25
62	.01	.007	.04	.04	.50	.50	0	0	.08	.25
63	.01	.007	.04	.04	1.00	1.00	0	0	.04	.25
64	.02	.018	.01	.01	.25	.25	0	0	.04	2.00
65	.02	.018	.01	.01	.50	.50	0	0	.02	2.00
66	.02	.018	.01	.01	1.00	1.00	0	0	.01	2.00
67	.02	.016	.02	.02	.25	.25	0	0	.08	2.00
68	.02	.016	.02	.02	.50	.50	0	0	.04	1.00
69	.02	.016	.02	.02	1.00	1.00	0	0	.02	1.00
70	.02	.013	.04	.04	.25	.25	0	0	.16	.50
71	.02	.013	.04	.04	.50	.50	0	0	.08	.50
72	.02	.013	.04	.04	1.00	1.00	0	0	.04	.50
73	.04	.036	.01	.01	.25	.25	0	0	.04	4.00

11 $\frac{\dot{x}_0}{g}$	12 g	13 $\dot{s}_0$	14 $\dot{s}_{10}$	15 z_0	16 z_{10}	17 $\dot{z}_0$	18 $\dot{z}_{10}$	19 Pr err	20 $\overline{RT}_c$	21 Conf	Event number
1.00	36	36	45.0	72	72.0	0	0	.103	6.47	1.82	50
2.00	36	72	90.0	72	72.0	0	0	.147	6.32	1.85	5▪
.25	72	18	30.0	72	72.0	0	0	.121	6.27	1.79	52
.50	72	36	60.0	72	72.0	0	0	.121	6.52	1.91	53
1.00	72	72	120.0	72	72.0	0	0	.224	5.78	2.27	54

			Descent	trials,	constant	optical	flow				
.25	72	18	16.3	72	65.1	.72	.65	.181	5.70	4.86	55
.50	72	36	32.6	72	65.1	.72	.65	.241	6.18	4.59	56
1.00	72	72	65.1	72	65.1	.72	.65	.345	6.85	3.97	57
.125	144	18	14.7	72	59.0	1.44	1.18	.052	3.70	5.65	58
.25	144	36	29.5	72	59.0	1.44	1.18	.043	4.06	5.66	59
.50	144	72	58.9	72	59.0	1.44	1.18	.069	4.67	5.45	60
.0625	288	18	12.1	72	48.3	2.88	1.93	.069	3.03	5.69	61
.125	288	36	24.1	72	48.3	2.88	1.93	.034	3.34	5.78	62
.25	288	72	48.3	72	48.3	2.88	1.93	.069	3.81	5.59	63
.50	36	18	16.3	72	65.1	.72	.65	.112	5.33	5.09	64
1.00	36	36	32.6	72	65.1	.72	.65	.259	5.67	4.63	65
2.00	36	72	65.1	72	65.1	.72	.65	.310	5.96	4.25	66
.25	72	18	14.7	72	59.0	1.44	1.18	.026	2.95	5.84	67
.50	72	36	29.5	72	59.0	1.44	1.18	.026	3.94	5.76	68
1.00	72	72	58.9	72	59.0	1.44	1.18	.069	4.99	5.40	69
.125	144	18	12.1	72	48.3	288	1.93	.026	2.40	5.88	70
.25	144	36	24.1	72	48.3	2.88	1.93	.026	2.20	5.88	71
.50	144	72	48.3	72	48.3	2.88	1.93	.026	2.49	5.85	72
1.00	18	18	16.3	72	65.1	.72	.65	.086	5.06	5.35	73

Event number	1 $\frac{\dot{z}_0}{g}$	2 $\frac{\dot{z}_{10}}{g}$	3 $\left(\frac{\dot{z}}{z}\right)_0$	4 $\left(\frac{\dot{z}}{z}\right)_{10}$	5 $\left(\frac{\dot{s}}{z}\right)_0$	6 $\left(\frac{\dot{s}}{z}\right)_{10}$	7 $\left(\frac{\ddot{s}}{z}\right)_t - \left(\frac{\dot{s}}{z}\right)_t$ For t=0	8 $\left(\frac{\dot{z}}{x}\right)_t$ t=10	9 $\left(\frac{\dot{z}}{x}\right)_t$	10 $\frac{z_0}{g}$
74	.04	.036	.01	.01	.50	.50	0	0	.02	4.00
75	.04	.036	.01	.01	1.00	1.00	0	0	.01	4.00
76	.04	.033	.02	.02	.25	.25	0	0	.08	2.00
77	.04	.033	.02	.02	.50	.50	0	0	.04	2.00
78	.04	.033	.02	.02	1.00	1.00	0	0	.02	2.00
79	.04	.027	.04	.04	.25	.25	0	0	.16	1.00
80	.04	.027	.04	.04	.50	.50	0	0	.08	1.00
81	.04	.027	.04	.04	1.00	1.00	0	0	.04	1.00
Level trials, constant optical flow										
82	0	0	0	0	.25	.25	0	0	0	1.00
83	0	0	0	0	.50	.50	0	0	0	1.00
84	0	0	0	0	1.00	1.00	0	0	0	1.00
85	0	0	0	0	.25	.25	0	0	0	.50
86	0	0	0	0	.50	.50	0	0	0	.50
87	0	0	0	0	1.00	1.00	0	0	0	.50
88	0	0	0	0	.25	.25	0	0	0	.25
89	0	0	0	0	.50	.50	0	0	0	.25
90	0	0	0	0	1.00	1.00	0	0	0	.25
91	0	0	0	0	.25	.25	0	0	0	2.00
92	0	0	0	0	.50	.50	0	0	0	2.00
93	0	0	0	0	1.00	1.00	0	0	0	2.00
94	0	0	0	0	.25	.25	0	0	0	1.00
95	0	0	0	0	.50	.50	0	0	0	1.00
96	0	0	0	0	1.00	1.00	0	0	0	1.00
97	0	0	0	0	.25	.25	0	0	0	.50

Table G-1 (Continued)

11 $\dfrac{\dot{x}_0}{g}$	12 g	13 $\dot{s}_0$	14 $\dot{s}_{10}$	15 z_0	16 z_{10}	17 $\dot{z}_0$	18 $\dot{z}_{10}$	19 Pr err	20 $\overline{RT}_c$	21 $\overline{Conf}$	Event number
2.00	18	36	32.6	72	65.1	.72	.65	.267	5.57	4.55	74
4.00	18	72	65.1	72	65.1	.72	.65	.440	6.38	3.77	75
.50	36	18	14.7	72	59.0	1.44	1.18	.017	3.20	5.85	76
1.00	36	36	29.5	72	59.0	1.44	1.18	.017	3.86	5.80	77
2.00	36	72	58.9	72	59.0	1.44	1.18	.069	5.11	5.30	78
.25	72	18	12.1	72	48.3	2.88	1.93	.034	2.09	5.83	79
.50	72	36	24.1	72	48.3	2.88	1.93	.017	2.16	5.89	80
1.00	72	72	48.3	72	48.3	2.88	1.93	.017	2.36	5.88	81
Level trials, constant optical flow											
.25	72	18	18.0	72	72.0	0	0	.103	6.24	1.72	82
.50	72	36	36.0	72	72.0	0	0	.086	6.49	1.72	83
1.00	72	72	72.0	72	72.0	0	0	.086	6.20	1.78	84
.125	144	18	18.0	72	72.0	0	0	.052	5.91	1.55	85
.25	144	36	36.0	72	72.0	0	0	.060	6.13	1.65	86
.50	144	72	72.0	72	72.0	0	0	.095	5.92	1.72	87
.0625	288	18	18.0	72	72.0	0	0	.069	5.89	1.58	88
.125	288	36	36.0	72	72.0	0	0	.095	6.31	1.84	89
.25	288	72	72.0	72	72.0	0	0	.086	6.16	1.70	90
.50	36	18	18.0	72	72.0	0	0	.043	6.36	1.62	91
1.00	36	36	36.0	72	72.0	0	0	.129	5.67	1.80	92
2.00	36	72	72.0	72	72.0	0	0	.147	5.67	1.91	93
.25	72	18	18.0	72	72.0	0	0	.095	5.86	1.72	94
.50	72	36	36.0	72	72.0	0	0	.043	6.13	1.58	95
1.00	72	72	72.0	72	72.0	0	0	.095	6.06	1.76	96
.125	144	18	18.0	72	72.0	0	0	.026	6.04	1.44	97

Event number	1 $\frac{\dot{z}_0}{g}$	2 $\frac{\dot{z}_{10}}{g}$	3 $\left(\frac{\dot{z}}{z}\right)_0$	4 $\left(\frac{\dot{z}}{z}\right)_{10}$	5 $\left(\frac{\dot{s}}{z}\right)_0$	6 $\left(\frac{\dot{s}}{z}\right)_{10}$	$\dot{7}$ $\left(\frac{\ddot{g}}{z}\right)_t - \left(\frac{\dot{s}}{z}\right)_t$ For t=0	8 $\left(\frac{\dot{z}}{x}\right)_t$ t=10	9 $\left(\frac{\dot{z}}{\dot{x}}\right)_t$	10 $\frac{z_0}{g}$
98	0	0	0	0	.50	.50	0	0	0	.50
99	0	0	0	0	1.00	1.00	0	0	0	.50
100	0	0	0	0	.25	.25	0	0	0	4.00
101	0	0	0	0	.50	.50	0	0	0	4.00
102 ·	0	0	0	0	1.00	1.00	0	0	0	4.00
103	0	0	0	0	.25	.25	0	0	0	2.00
104	0	0	0	0	.50	.50	0	0	0	2.00
105	0	0	0	0	1.00	1.00	0	0	0	2.00
106	0	0	0	0	.25	.25	0	0	0	1.00
107	0	0	0	0	.50	.50	0	0	0	1.00
108	0	0	0	0	1.00	1.00	0	0	0	1.00

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Table G-1 (Continued)

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | |
$\dfrac{\dot{x}_0}{g}$	g	$\dot{s}_0$	$\dot{s}_{10}$	z_0	z_{10}	$\dot{z}_0$	$\dot{z}_{10}$	Pr err	$\overline{RT}_c$	$\overline{\text{Conf}}$	Event number
.25	144	36	36.0	72	72.0	0	0	.060	6.04	1.59	98
.50	144	72	72.0	72	72.0	0	0	.172	5.99	2.04	99
1.00	18	18	18.0	72	72.0	0	0	.121	6.28	1.85	100
2.00	18	36	36.0	72	72.0	0	0	.095	6.41	1.68	101
4.00	18	72	72.0	72	72.0	0	0	.138	6.11	1.85	102
.50	36	18	18.0	72	72.0	0	0	.034	6.42	1.55	103
1.00	36	36	36.0	72	72.0	0	0	.078	6.26	1.58	104
2.00	36	72	72.0	72	72.0	0	0	.103	5.69	1.75	105
.25	72	18	18.0	72	72.0	0	0	.078	6.09	1.64	106
.50	72	36	36.0	72	72.0	0	0	.095	6.18	1.75	107
1.00	72	72	72.0	72	72.0	0	0	.190	5.57	2.02	108

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Table G-1 (Concluded)

Note. A dot over a symbol indicates a derivative with respect to time. A subscript of zero indicates the value of a variable at the initiation of the test segment of an event; 10, the value at the end of the test segment; and $\underline{t}$, the value at any time during the test segment. The 5-sec preview segment is excluded in all cases.

[a]1. $\dot{z}_0/g$ = initial descent rate scaled in ground units (g/sec).

2. $\dot{z}_{10}/g$ = final descent rate scaled in ground units (g/sec).

3. $(\dot{z}/z)_0$ = initial descent rate scaled in eyeheights (h/sec).

4. $(\dot{z}/z)_{10}$ = final descent rate scaled in eyeheights (h/sec).

5. $(\dot{s}/z)_0$ = initial global optical flow rate (h/sec).

6. $(\dot{s}/z)_{10}$ = final global optical flow rate (h/sec).

7. $(\ddot{s}/z)_0 - (\dot{s}/z)_0(\dot{z}/z)_0$ = initial global optical flow acceleration (h/sec^2).

8. $(\ddot{s}/z)_{10} - (\dot{s}/z)_{10}(\dot{z}/z)_{10}$ = final global optical flow acceleration (h/sec^2).

9. $(\dot{z}/\dot{x})_t$ = path slope (proportion).

10. z_0/g = initial global optical density (g/h).

11. $\dot{x}_0/g$ = initial edge rate (edges/sec).

12. g = ground texture size (m).

13. $\dot{s}_0$ = initial path speed (m/sec).

14. $\dot{s}_{10}$ = final path speed (m/sec).

15. z_0 = initial altitude (m).

16. z_{10} = final altitude (m).

17. $\dot{z}_0$ = initial descent rate (m/sec).

18. $\dot{z}_{10}$ = final descent rate (m/sec).

19. Pr err = proportion error.

20. $\overline{RT}_c$ = mean correct reaction time (sec).

21. $\overline{Conf}$ = mean confidence rating converted to a 6-point scale (1 = "very certain level" to 6 = "very certain descent").

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Appendix H: Instructions

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Instructions

EXPERIMENTER; SEAT THE OBSERVER, THEN READ EXACTLY:

Welcome to the Aviation Psychology Laboratory. In general, we are interested in human performance and perceptual factors in aviation.

In today's experiment, we are interested in your sensitivity to loss in altitude. Specifically, we want to find out how well you can visually detect descent in the absence of motion or kinesthetic cues, for example, the change in gravitational pull in a descending elevator.

You will be shown computer-generated scenes on the screen in front of you which represent travel over open flat fields. Your flightpath will be level in some scenes, and descending in others. Your task will be to press the red button marked "L" if you believe the scene represents level flight, or the green button marked "D" if you detect descent.

The size and number of fields will vary from event to event as will the simulated speed of travel. Regardless of these differences you should base your judgments on whether you see, feel, or experience descent or not.

Sometimes the scenes will appear to scintillate, shimmer, or jitter, especially toward the horizon. These effects are due to limitations of our equipment. Please ignore them.

The specific procedure will go like this:

1. Prior to the beginning of each scene, I will say "Ready." At that time, please turn your full attention to the screen.

2. A scene beginning with 5 seconds of level travel will appear. After the 5 seconds, you will hear a tone. After this signal, the scene will either continue level, or begin to show descent. Each scene will last for 10 seconds after the signal.

3. As soon after the tone as you can distinguish which type of motion is represented, press the button corresponding to your choice ("L" or "D"). You do not have to wait until the end of the scene to press the button, but a judgment must be made for each scene. Please make sure that you press the button only once per scene, and do not press any button between the scenes at all.

4. After you press the button, rate your confidence in the accuracy of

your decision by saying "one" if you guessed, "two" if you are moderately sure, and "three" if you are very sure that you made the correct choice.

We will begin with two practice trials to acquaint you with the scenes and the procedure. The first will descend; the second will remain level. If you have any questions, ask them now or during the practice trials. Following the practice trials, you will judge 108 events with a short break in the middle.

Do you have any questions?

Appendix I: Analysis Of Variance Summary Tables

Table I-1. Analysis of Variance for Descent Events: Proportion Error

Source	df	SS	R^2(%)	F	p < F
Descent in eyeheights (Z)	2	90.760	12.00	131.00	.0000
Descent in ground units (G)	2	3.462	.46	15.10	.0000
Initial flow rate (F)	2	13.632	1.80	37.62	.0000
Flow-rate constancy (K)	1	13.689	1.81	75.28	.0000
ZF	4	7.081	.94	19.06	.0000
GF	4	.679	.09	2.68	.0328
GF x order (O)	12	1.376	.18	1.81	.0483
GFO x session (S)	12	2.056	.27	1.84	.0438
ZGFO	24	4.398	.58	2.28	.0006
ZGFOS	24	5.621	.74	2.78	.0000
ZK	2	5.151	.68	20.90	.0000
GK	2	2.062	.27	12.17	.0000
ZGK	4	1.116	.15	3.27	.0127
FK	2	.561	.07	3.67	.0289
FKO	6	1.401	.19	3.05	.0087
ZFK	4	1.634	.22	4.57	.0015
Total	5939	755.949	100.00	-	-

Note. Each effect was tested using the appropriate error term given by the model. The criterion for inclusion of an effect was p < .05 or better.

Table I-2. Analysis of Variance for Descent Events: Mean Reaction Time

Source	df	SS	R^2(%)	F	p < F
Descent in eyeheights (Z)	2	9089.671	16.53	169.87	.0000
Descent in ground units (G)	2	669.121	1.22	41.69	.0000
Initial flow rate (F)	2	733.411	1.33	65.69	.0000
Flow-rate constancy (K)	1	2462.726	4.48	242.96	.0000
Session (S)	1	570.995	1.04	22.63	.0000
GS x order (O)	6	49.501	.09	3.04	.0088
ZG	4	385.179	.70	23.18	.0000
FS	2	43.644	.08	8.50	.0004
FSO	6	36.444	.07	2.37	.0352
ZF	4	171.335	.31	12.44	.0000
ZFO	12	75.726	.14	1.83	.0450
GF	4	43.067	.08	3.73	.0060
ZGF	8	95.898	.17	4.11	.0001
SZGFO	24	224.838	.41	3.24	.0000
SK	1	19.521	.03	5.66	.0212
ZK	2	399.784	.73	40.47	.0000
ZKO	6	77.433	.14	2.61	.0213
GK	2	47.435	.09	6.66	.0019
ZGK	4	32.202	.06	3.08	.0172
FK	2	42.498	.08	6.17	.0030
ZFK	4	94.446	.17	8.12	.0000
GFK	4	32.412	.06	2.90	.0229
SGFKO	12	48.412	.09	1.92	.0337
Total	5939	54974.125	100.00	–	–

Note. Each effect was tested using the appropriate error term given by the model. The criterion for inclusion of an effect was $p < .05$ or better.
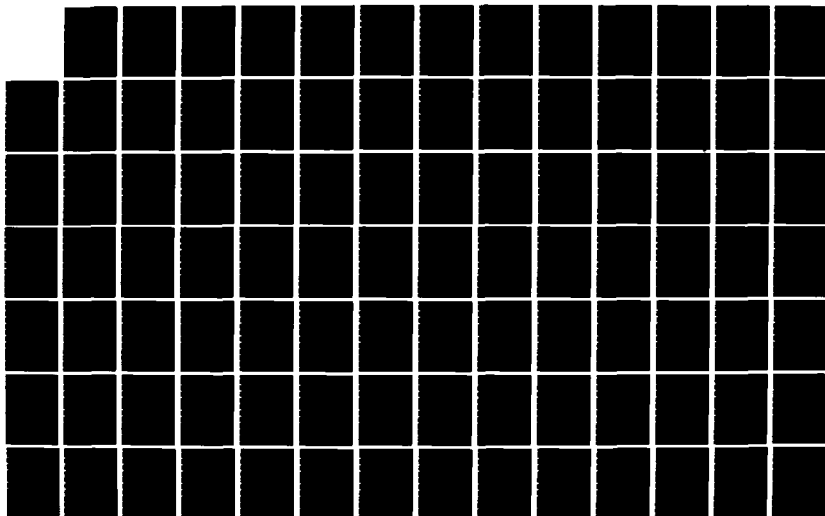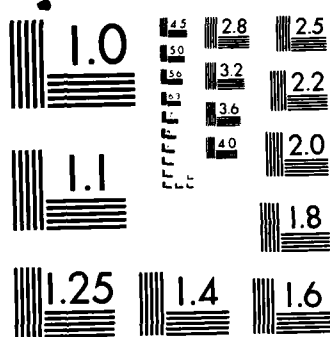
Table I-3. Analysis of Variance for Descent Events: Area Above
the Isosensitivity Curve

Source	df	SS	R^2(%)	F	p < F
Descent in eyeheights (Z)	2	22.944	6.99	125.95	.0000
Descent in ground units (G)	2	.387	.12	3.36	.0385
Initial flow rate (F)	2	6.272	1.91	50.05	.0000
Flow-rate constancy (K)	1	3.260	.99	33.81	.0000
Session (S)	1	1.124	.34	14.65	.0004
SG	2	.382	.12	3.40	.0373
ZF	4	1.997	.61	8.56	.0000
GF x order (O)	12	.831	.25	2.41	.0061
ZGFO	24	1.927	.59	2.28	.0006
SZGFO	24	1.913	.58	1.81	.0115
ZK	2	1.101	.34	11.05	.0000
SZKO	6	.511	.16	2.22	.0467
GK	2	.463	.14	6.19	.0029
ZFK	4	.468	.14	2.66	.0336
Total	5939	328.401	100.00	-	-

Note. Each effect was tested using the appropriate error term given by
the model. The criterion for inclusion of an effect was p < .05 or
better.

THE INFLUENCE OF PREVIEW PERIOD AND GLOBAL OPTICAL FLOW
RATE ON SENSITIVITY TO DECELERATING SELF MOTION

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The experiment to be described investigated the effects of an opportunity to observe a period of level self motion at a constant speed before deciding whether a subsequent segment of the event represents continued constant speed or deceleration. Motivation for the experiment originated from the high "false-alarm" rates observed in a series of previous studies of sensitivity to change in speed or altitude (Owen, 1982, 1983, 1984; Owen & Jensen, 1981). When observers were asked to distinguish events representing constant speed from those representing deceleration, "deceleration" reports were made on over 20% of the constant-speed trials (Owen, Warren, Jensen, Mangold, & Hettinger, 1981). False-alarm rates were higher for events with lower edge rates, and the effect was even stronger for lower flow rates. In a study isolating sensitivity to increase in edge rate and flow rate, "acceleration" reports were made on 20% of the trials when both edge spacing and speed were constant (Warren, Owen, & Hettinger, 1982).

Barring any other influence besides optical flow rate, it seems reasonable to assume that if an observer is trying to detect change in speed, the result of viewing a constant-speed event would always be to report "constant." Obtaining two opposite kinds of false-alarm rates equal in magnitude suggested that the sudden onset of a display representing an ongoing constant-speed self-motion event might initially result in apparent acceleration, followed by apparent deceleration. The apparent deceleration could be due partly to recovery from the initial apparent acceleration and partly to adaptation. Denton (1976) instructed operators of a driving simulator to maintain a constant speed and found that adaptation to a self-motion display revealed a negatively accelerating function over time for a group of participants, each of whom had previously shown evidence of motion aftereffects (see Figure 1). Denton's results indicate that some observers

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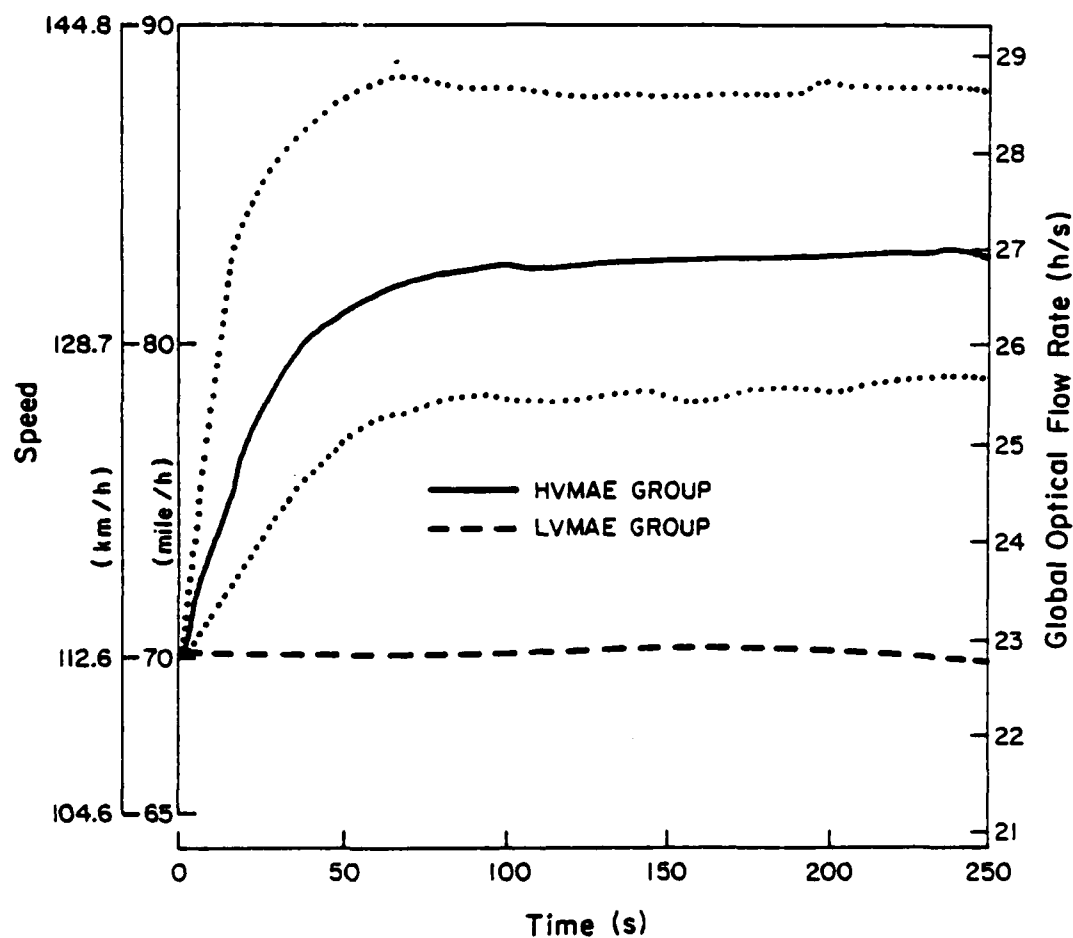
Figure 1. Speed (left ordinate) and global optical flow rate (right ordinate) produced by the High Visual Motion Aftereffect (HVMAE) group and the Low Visual Motion Aftereffect (LVMAE) group to maintain a constant subjective speed, given an initial speed of 70 mi/hr (112.6 km/hr) and an initial flow rate of 22.82 h/s (h = eyeheight). The dotted lines indicate the HVMAE individuals who adapted least and most. Adapted from Figures 3 and 4, p. 414, Denton, 1976.

will experience event-onset effects lasting 50 to 100 s, but reveal nothing about the nature of effects under 10 s because speed was sampled at 10-s intervals.

When observers are instructed to respond as soon as they are ready, as was the case in the experiments described above, their reaction times indicate that their reports are strongly influenced by what they experience during the early part of the 10-s event duration. If so, observers given a choice between "constant" and "acceleration," as in the Warren et al. (1982) study, would be expected to report "acceleration" based on what they experienced when the event was first displayed. Observers given a choice between "constant" and "deceleration," as in the Owen et al. (1981) experiment, would have no category for reporting any initial acceleration experienced. Instead, they would report on the subsequent apparent deceleration. In either task, reporting on event-initiation effects will lead to false alarms on constant-speed trials.

The suspected apparent deceleration effects would parallel those reported by Runeson's (1974) observers in the condition where a bright spot moved across a video screen at a constant velocity. His data show little evidence of initial apparent acceleration, however.

There is a sense in which reports of apparent acceleration are appropriate when the display changes from no motion to constant speed. There is, in fact, an increase in speed from no speed to some ongoing rate. If observers' reports are influenced by event-onset effects, then false alarms should increase with increases in the onset speed, since the step from no speed to the ongoing rate is greater. Just such an effect was found by Owen, Wolpert, & Warren (1984) in a study of flow- and edge-rate influences on self-acceleration perception. Reports of "acceleration" for events representing travel at a constant speed over regularly spaced borders increased from 2% for a global optical flow rate ($\dot{x}/z$) of 1 h/s to 30% for a flow rate of 9 h/s (where $\dot{x}$ = forward speed, z = altitude, and h = observer's eyeheight). Runeson (1974) observed a similar, but opposite, phenomenon for apparent deceleration of a bright spot: the lower the speed (angular velocity), the more frequently observers described constant-speed motion as decelerating. Tobias and Owen (1983) observed the same effect for self-motion events: For

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events with a preview period of 0 s and constant speed and edge spacing, "deceleration" reports increased from 17% for a flow rate of .9 h/s to 33% for a flow rate of .4 h/s.

There are at least two ways to determine whether abrupt display of an ongoing event affects sensitivity to optical information: (a) vary the duration of the event and require the observer to watch the entire event before choosing between the two alternatives, or (b) vary the duration of a preview period during which constant, level self motion is displayed before the test segment during which change in the event represented on some trials must be distinguished from continuation of the preview parameters on other trials. Hettinger, Owen, and Warren (this paper) used event durations of 2, 4, and 8 s in a descent-detection task and found that reports of "descent" for events representing loss in altitude (hits) increased by only 1% for each doubling in duration, while reports of "descent" on level trials (false alarms) showed no change with event duration. Requiring observers to watch the entire event before responding had no advantage over instructing them to respond as soon as they had made a choice. In an experiment investigating flow- and edge-rate influences on self-acceleration perception (Owen, Wolpert, & Warren, 1984), reports of "acceleration" to events representing travel at constant speed over regularly spaced borders dropped from 18 to 6 to 3% for event durations of 3, 6.5, and 10 s, respectively. This reduction in errors may index the dissipation of event-onset effects.

To assess the effects of sudden exposure to an ongoing event, Tobias and Owen (1983) factorially varied the durations of both the preview segment and the test segment. Preview periods of 0 and 5 s were crossed with test-segment durations of 5.0, 7.5, and 10.0 s. Results of the 0%/s (constant-speed) and 9%/s deceleration conditions are most relevant to the present experiment.

The two event-duration variables interacted, and the nature of the interaction differed for error rates and reaction times. The 5-s preview improved accuracy by 8% for the constant-speed events and 11% for the deceleration events. The results for test-segment duration were slightly more complicated: Each 2.5-s increase in duration resulted in about 3.5% improvement in accuracy for events with the 9%/s fractional loss in speed (regardless of preview duration), 2% improvement for the constant-speed events

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with no preview, but no change for the constant-speed events with the 5-s preview (Figure 2).

Reaction times increased 0.9 s with each 2.5-s increment in test-segment duration, indicating that observers used the additional available time in the same way for both event types. By contrast, preview time had a differential effect: The 5-s preview resulted in reaction times that were 2.9 s shorter for deceleration events, but only 1.3 s shorter for constant-speed effects. The Tobias and Owen results indicate that increasing test-segment duration leads to a straightforward improvement in performance, whereas preview-period variation produces complex interactions.

As indicated earlier, Denton (1976, 1977) demonstrated that some observers adapt to the self-motion represented in a driving simulator (Figure 1). The faster the simulated motion, the greater the adaptation and the greater the time before a steady state is reached. In a study conducted subsequently with the same High Visual Motion Aftereffect group, Denton (1973, Experiment 8; 1974, Experiment 7) used 10- and 120-s preview periods to determine whether adaptation to constant speed affected time to detect change in speed. Six initial speeds from 5 to 80 mi/hr were used to test for an interaction between speed and preview period. Observers were told that shortly after a red light was extinguished the flow pattern would either accelerate or decelerate. Before each trial, they were told which type of change would occur. Their task was to press a button as soon as they became aware of the change. (As a consequence, no measure of accuracy was possible.)

Denton's results for the deceleration trials are shown in Figure 3, replotted in terms of global optical flow values. Time to detect deceleration was greater for the longer preview period, and the effect was larger for the three fastest flow rates than for the three slowest. Magnitudes of the negative effect of adaptation correspond to the amounts of adaptation shown in Denton's (1976) active control experiments (Figure 1).

Predictions. Denton's (1973, 1974) results with longer preview periods together with the Tobias and Owen (1983) findings for 0- and 5-s previews suggested that the interaction of preview duration and global optical flow rate might provide some insight concerning the effects of abrupt onset of exposure to an ongoing self-motion event. The best predictions from the

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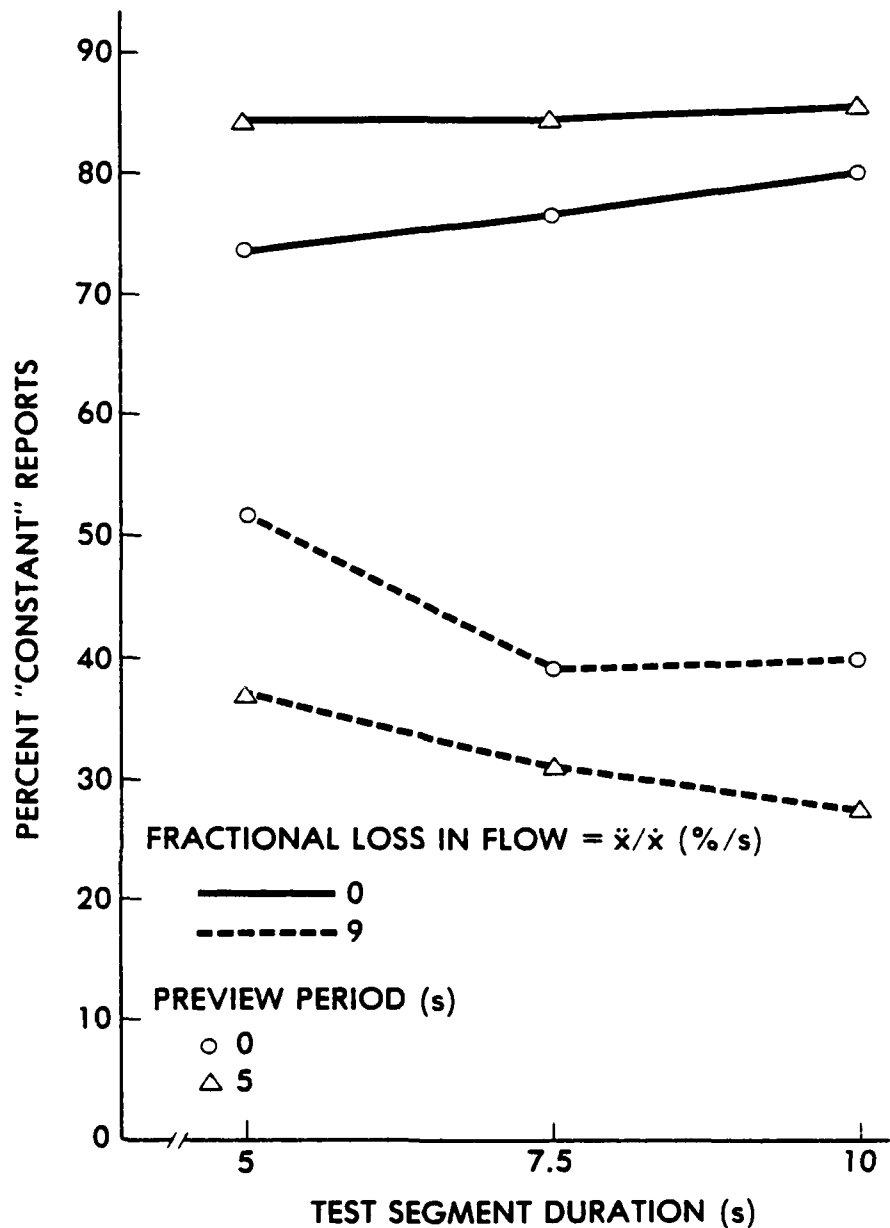
Figure 2. Proportion "constant" reports for events representing constant-speed (0-%/s fractional loss) versus decelerating (9-%/s fractional loss) self motion as a function of preview-period and test-segment duration ($\ddot{x}$ = deceleration rate, $\dot{x}$ = speed, $\ddot{x}/\dot{x}$ was invariant throughout each event). From Tobias (1983, p. 24); Tobias and Owen (1983, p. 45).
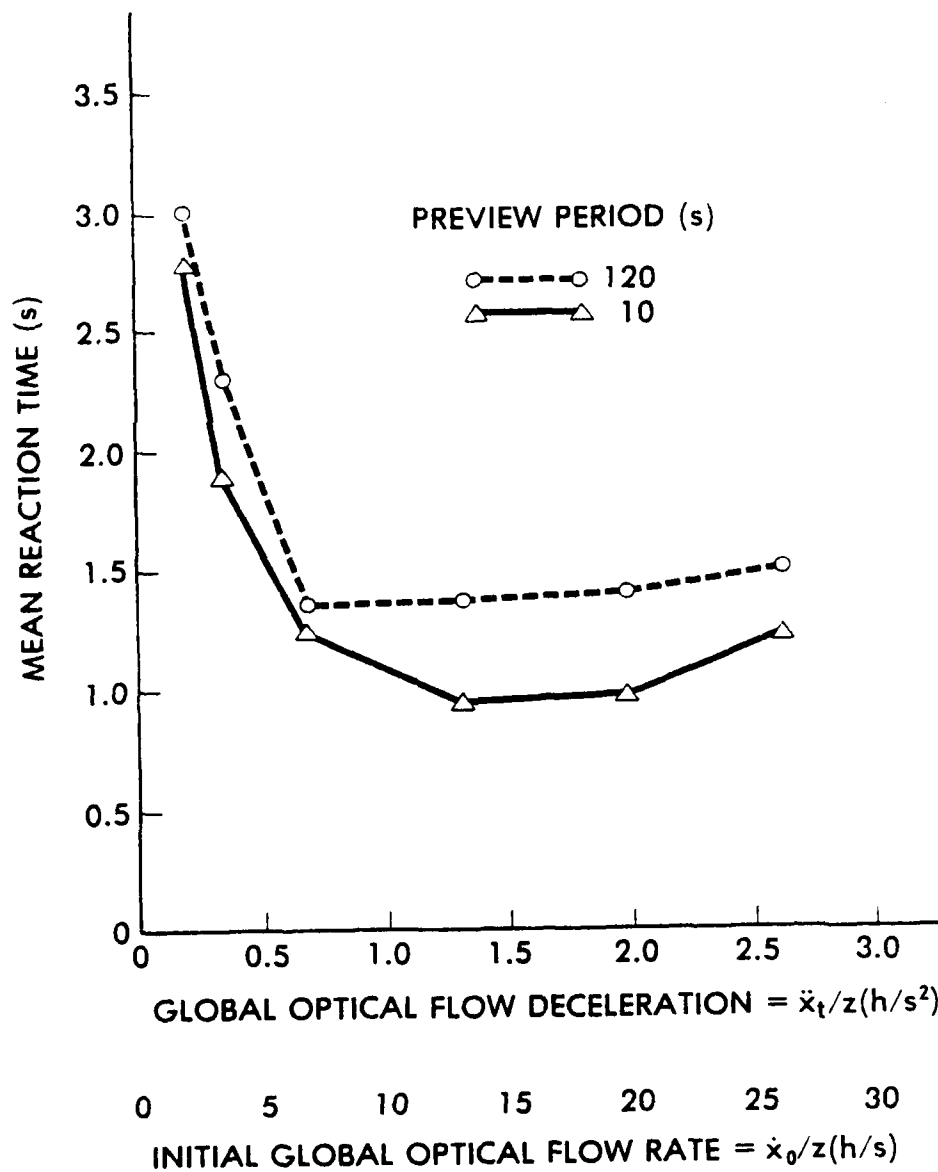
Figure 3. Mean time to detect deceleration as a function of preview period and the combinations of flow deceleration ($\ddot{x}/z$) and flow rate ($\dot{x}/z$) used to produce an initial fractional loss in speed ($\ddot{x}/\dot{x}_o$) of 10%/s ($\ddot{x}$ = deceleration rate, $\dot{x}$ = speed, z = altitude, h = eyeheight, subscript zero indicates initial value, subscript t indictes value throughout an event). Adapted from Denton (1973, Experiment 8; 1974, Experiment 7).

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available literature are that the short preview periods will evidence event-onset effects that have a negative effect on sensitivity to loss in speed, an effect that should dissipate with intermediate preview durations. The improvement should be followed by a second negative effect for the longer preview periods due to adaptation.

Implications. The most pressing goal of investigating event preview periods is methodological: to determine whether selection of a particular preview duration influences sensitivity differentially depending on the levels of other event parameters. In earlier studies, optical and event-duration variables have been factorially crossed to assess their effects and interactions. Two influences of preview period are possible: (a) the overall level of performance varies, but preview period does not interact with other variables of interest, or (b) different preview periods favor different cells in a design, i.e., interactions obtain. Given an experiment in which only a single preview duration is used, the latter result is the more critical, since the relative effects of other event parameters will be erroneously attributed only to the variables in the design, rather than to the selective effect of the particular preview duration. A major reason for conducting highly controlled judgment experiments is to guide the choice of event parameters and their levels for future interactive experiments in which the individual first observes, then takes control of the event. The concern is that results of experiments with no or very short preview periods may not apply to the study of events that allow observation for varying periods of time before a control adjustment is made.

A combination of the above two alternatives is also possible. No or brief preview periods may have differential effects that merge to a common effect (or the effects may disappear altogether) by some longer duration. If not too long, this duration would be acceptable for initiating interactive trials.

The manipulation of preview period may also have theoretical implications. Runeson (1974, 1975, 1983) found that the constant velocity of an ongoing event was not initially perceived as constant. In comparison with the results from other types of events, he interpreted his findings as indicating that the visual system presupposes natural motions. According to

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this view, the system expects events that start from stop and can be extrapolated according to a natural motion function that takes environmental dynamics, e.g., mass, force, resistance, into account. Regardless of the explanation, a complete theory of self-motion perception will have to deal with event-initiation effects.

Practical implications are also of interest. If short preview periods have disruptive effects on sensitivity to change in heading or speed, pilots could be given instruction about minimum periods of observation following breakout from cloud cover or looking up from instruments and controls before an adjustment in flight path or speed is initiated. Denton's (1973, 1974) results suggest that following long preview periods, sensitivity to certain optical transformations is enhanced while sensitivity to complementary changes is reduced. Pilots could be trained to avoid the negative influences of adaptation by breaking up long periods of exposure to the flow pattern by fixating inside the aircraft.

Method

The study consisted of two separate, but overlapping, experiments. In most essential respects Experiment 2 represents a replication of Experiment 1. The changes instituted in Experiment 2 will be described at the appropriate places in this section.

Apparatus and General Scene and Event Parameters

The simulated self-motion events were generated by a PDP11/34 computer and a special purpose scene generator (see Yoshi, 1980). In Experiment 1, 27 observers viewed events displayed via a Sony KP-5040 video projection unit, which had a screen 1.20 m wide and 0.765 m high, producing a field of view of 34.3 deg by 21.9 deg when viewed from a distance of 2.005 m. Forty-three observers in Experiment 1, and all observers in Experiment 2 viewed events displayed via a Sony Model KP-7240 video projection unit, which had a screen 1.5 m wide and 1.125 m in height, producing a field of view of 34.3 deg by 26.1 deg when viewed from a distance of 2.43 m. The sampling rate of 30 frames/s for scene generation matched the scanning rate of the video projectors. The observer was seated in an elevated chair, with a viewpoint at the level of the simulated horizon.

Use of the smaller screen size was a result of using a replacement video

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projection unit while the large-screen unit was being repaired. The first 27 observers tested with the large screen were used in the analyses comparing screen size, which was linked to viewing distance in order to control optical size. Since the two screens did not have the same width/height ratio, the scenes were matched in horizontal and vertical optical angles for the textured terrain area below the horizon. Hence, the mismatch was in vertical extent of the display area devoted to sky. The ratio of the horizon height (from the bottom of the screen) to the screen width was fixed at 0.375, which resulted in a horizon height of 45 cm on the KP-5040 and 56.25 cm on the KP-7240. The resulting fields of view of terrain area were 34.3 deg by 12.9 deg for the KP-5040, and 34.3 deg by 13.1 deg for the KP-7240. (The slight difference in vertical optical extent is due to discrepancies introduced by adjusting the horizon in discrete steps.)

All events represented level self motion at an altitude (z) of 6 m over a flat, rectangular island extending 30.72 km parallel to the direction of travel (x dimension) and 114 m perpendicular to the direction of travel (y dimension). The texture blocks representing fields on the island were 12 m in length (x dimension). The number of edges along the y dimension was fixed at 20, and all texture blocks were 6 m wide. Four earth colors (light green, dark green, light brown, and dark brown) were randomly assigned to the texture blocks with the constraint that no two texture blocks of the same color were adjacent in the x dimension, and no more than two were adjacent in the y dimension. The area above the horizon was pale blue-gray, and the nontextured area surrounding the island was dark gray.

An earlier experiment (Tobias, 1983; Tobias & Owen, 1983), contrasted constant-speed preview segments of 0 and 5 s on sensitivity to detection of deceleration, and found that accuracy increased in the 5-s condition (see Figure 2). Denton (1973, Experiment 8; 1974, Experiment 7) used constant-speed periods of 10 and 120 s. Since 80% of the adaptation effect in Denton's (1976) study was complete by 40 s (see Figure 1), and since this interval fit a doubling series of preview durations that included the 5- and 10-s segments previously used, it was selected as the maximum preview period in the current study.

Therefore, an event consisted of a 0-, 1.25-, 2.5-, 5.0-, 10.0-, 20.0-,

or 40.0-s preview segment of constant speed followed by a 10-s test segment of either continued constant speed or deceleration at a constant rate. As a result, total event duration was 10.0, 11.25, 12.5, 15.0, 30.0, or 50.0 s.

Design

In an earlier experiment (Tobias, 1983; Tobias & Owen, 1983), global optical flow rate affected performance for constant-flow events only. After that experiment was initiated, Denton's experiments on time to detect decelerating and accelerating self motion were discovered (Denton, 1973, Experiment 8; 1974, Experiment 7). Denton used a much wider range of flow rates and found that reaction time dropped sharply to 13 h/s, then rose slightly between 13 and 26 h/s (see Figure 3). For the range of flow rates employed in the Tobias and Owen (1983) study (.4, .6, and .9 h/s), Denton (1973,1974) observed reaction times that were nearly three times longer than the shortest at 13 h/s. Since finding an optimal level was of some interest, the present experiments were conducted with initial global optical flow rates of 1.63, 3.26, 6.53, 13.05, 19.58, and 26.1 h/s to match the rates explored by Denton. Global optical flow deceleration was constant throughout each deceleration event at a value one-tenth the initial flow rate for the event, as in Denton's experiment. The complete inventory of event variables is shown in Appendix K.

In order that there be no uncertainty on the part of the observer with regard to the preview time, the seven preview-segment durations were blocked using a 7x7 Latin-square design (Winer, 1971). Within each block there were six events with constant speed and six with deceleration.

Each block began with two practice events, one representing deceleration and the other representing constant speed, that were matched in terms of initial flow rate (19.58 h/s). The initial flow rate for the practice events matched Denton's (1973, Experiment 8; 1974, Experiment 7) 60-mi/hr condition. This was the only condition in his design which did not fit in a doubling series of initial speeds. The remaining 10 events were rerandomized for each block, with the constraint that no more than 4 events of one type (constant speed or deceleration) could occur in sequence. In addition, a block could not begin or end with more than 2 events of the same type. A second set of event orders was generated by reversing the order within each block of the

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first set.

The crossing of seven block orders by two within-block random orders required groups of 14 observers to produce a complete counterbalancing. The crossing of seven levels of preview-segment duration, by six levels of initial flow rate, by two event types (constant speed versus deceleration) produced 84 unique events. Observers in Experiment 1 were randomly assigned to one of the 14 block orders by within-block randomly ordered combinations and were tested with each of the 84 unique events once.

Examination of the one-session results from 54 observers comparing the large and small screens indicated unexpected structure for specific combinations of flow rate and preview period. Possible explanations of the deviations were that the events presented were not correct because the values fed to the scene generator were not correct or there were nonlinearities in the event simulation system. Since the system is calibrated before each experiment with standard scenes (i.e., eyeheight equal to ground-unit size, so that global optical density = 1 g/h) and events (i.e., speed equal to ground-unit size, so that edge rate = 1 edge/s), nonlinearities could go undetected. For these reasons, each of the events showing deviant structure were calibrated individually. No errors were found relative to the inventory values, and scene and event parameters were within normal tolerances.

Even though better structure had resulted from previous experiments with comparable numbers of observers, increased error variance due to the higher flow rates and/or longer preview periods was also a possibility. For this reason, five replications of the 14 counterbalancing orders were completed for a total of 70 observers. Examination of the one-session data at this point revealed that unusual structure still remained.

In the meantime, an experiment on descent detection was completed by Hettinger and Owen (1985) revealing a great deal of variation in the first-session data, followed by well-structured patterns of results over the subsequent three sessions. To test whether more practice would produce less variable performance, a group of 42 observers was tested for four replications of the original constant-speed and deceleration test trials. The design allowed for a test of improvement with practice and pooling of the sessions which have common structure to better stabilize the results. These four-

session observers were also randomly assigned to one of the 14 unique within-block randomly ordered combinations. Random-order assignments for the first session in Experiment 2 were carried out in a manner identical to that used in Experiment 1, but the remaining three sessions were determined by the random order of the first. The 14 possible random-order assignments were as follows; A1B2C1D2, B1F2G1A2, B1C2D1E2, F1G2A'B2, C1D2E1F2, G1A2B1C2, D1E2F1G2, A2B1C2D1, E2F1G2A1, B2C1D2E1, F2G1A2B1, C2D1E2F1, G2A1B2C1, and D2E1F2G1 (where A through G corresponds to the seven preview-period block orders, and 1 versus 2 corresponds to the two within-block random event orders. Odd-numbered observers received within-block orders over the four sessions according the sequence 1-2-1-2; even-numbered observers received the sequence 2-1-2-1. Fourteen observers were required for complete counterbalancing, and the design was repeated three times for a total of 42 observers.

Procedure

The ongoing development of testing equipment overlapped the execution of the study, resulting in minor procedural differences between the two experiments. In Experiment 1, a verbal "ready" signal from the experimenter instructed the observer to turn full attention to the screen. In Experiment 2, an acoustic tone served the same purpose.

The constant-speed preview segment was separated from the 10-s test segment by an acoustic tone. The observer was instructed to indicate whether the 10-s test segment represented decelerating or constant speed by pressing one of two buttons on a hand-held response box as soon as the decision was made. In both experiments, reaction time from initiation of the 10-s test segment to the button press was surreptitiously recorded. The response was also recorded by the computer.

Following each choice response in Experiment 1, the observer verbally indicated a rating of confidence in the accuracy of the decision ("1" = not very certain, "2" = moderately certain, "3" = very certain) which was keyed into the computer by the experimenter. In Experiment 2 the observer indicated a rating of confidence by pressing one of three buttons, so that the rating was recorded automatically by the computer. No performance feedback was provided during the testing. (See Appendix L for the complete instructions.)

Observers

All observers were undergraduates at the Ohio State University, who participated in order to fulfill an extra-credit option of an introductory psychology course. Sixty-five males and five females served in Experiment 1; 42 males served in Experiment 2. Each claimed no previous simulator or piloting experience.

Results

The following summary scores were computed for each cell in the experimental design for both the one- and four-session data sets: proportion error, mean reaction time for all events (correct plus error), mean reaction time for error-free events only, and confidence ratings for all events (converted to a 6-point scale). Proportion error scores and correct reaction times together comprise data from the entire set of events. A comparison of analyses of variance performed for mean reaction time for all events versus correct reaction time showed negligible differences. Thus, in later analyses of variance total reaction times were used because of the number of missing values involved in using only correct reaction times. Differences in frequency of using the two report categories, for whatever reason, can distort the structure of accuracy data, particularly if the bias varies with level of an independent variable. Therefore, area under the isosensitivity curve (A_g), a nonparametric bias-free measure of sensitivity, was also computed and analyzed.

Analyses of variance revealed no main effect for screen size as a between-observers variable for either error rate ($F = 1.03$, $p > .31$) or reaction time ($F < 1.00$, $p > .35$). Of the 26 possible interaction effects involving screen size (from the analyses of error rate and reaction time for all events, decelerating events only, and level events only), just two exceeded the $p < .05$ level. For deceleration-only error rates, the Screen Size by Flow Rate interaction was significant ($F = 2.89$, $p < .02$). Observers of the small screen made 3% fewer errors when the flow rate was 13.1 h/s, but averaged 5% more errors over all other flow rates. The Screen Size by Flow Rate by Preview Period interaction was significant for constant-speed errors ($F = 1.60$, $p < .03$), but no interpretable pattern was in evidence. Since neither interaction appeared to be a result of other than chance, the one-

session data were pooled over screen size for all further analyses.

Data for the two highest flow rates presented problems for the analyses by being nonrepresentative in two different ways. As shown in Figure 4, the highest flow rate (26.1 h/s) revealed anomalously high error rates for preview periods of 2.5 and 5.0 s, a pattern not in evidence for the flow rate of 19.6 h/s used for the practice trials. This unexpected result dominated the analyses to a degree that the interactions were not characteristic of the five lower flow rates. The practice trials, on the other hand, were not included in the counterbalancing scheme used for the other five flow rates. As a result, reaction times for the 19.6-h/s flow rate were uncharacteristically low, indicating that early in a block of trials the observers did not wait as long for the event to unfold. Error rates were slightly elevated, more so for the one-session than for the four-session data (Figure 4). Taking both of these distorting factors into account, it appeared more representative to include data for the 19.6-h/s flow rate (minus the first two trials in each session for which the correct response was given in advance) in the analyses. Therefore, means for the 26.1-h/s flow rate are shown in the figures for each preview period, but are excluded from the means plotted over preview periods in favor of the 19.6-h/s flow rate in all subsequent figures.

In addition to a complete repeated-measures analysis of variance, an analysis for decelerating events only was performed for each of the dependent variables for both the one- and four-session designs. The one-session analyses included the first session for all observers in the four-session design. Counterbalancing order was treated as a grouping factor.

Due to the large number of observations, many of the effects reached traditional levels of statistical significance and yet accounted for only a negligible part of the total variance. Therefore, an effect was considered to merit discussion only if it accounted for at least 1.5% of the total variance in the data. Main effects and interactions reaching this criterion for any of the four dependent variables are presented in Table 1.

Interactions

The fact that the Flow Rate by Preview Period and the Event Type by Flow Rate by Preview Period interactions were large effects for errors in every case strongly influenced the decision to make a detailed presentation of the

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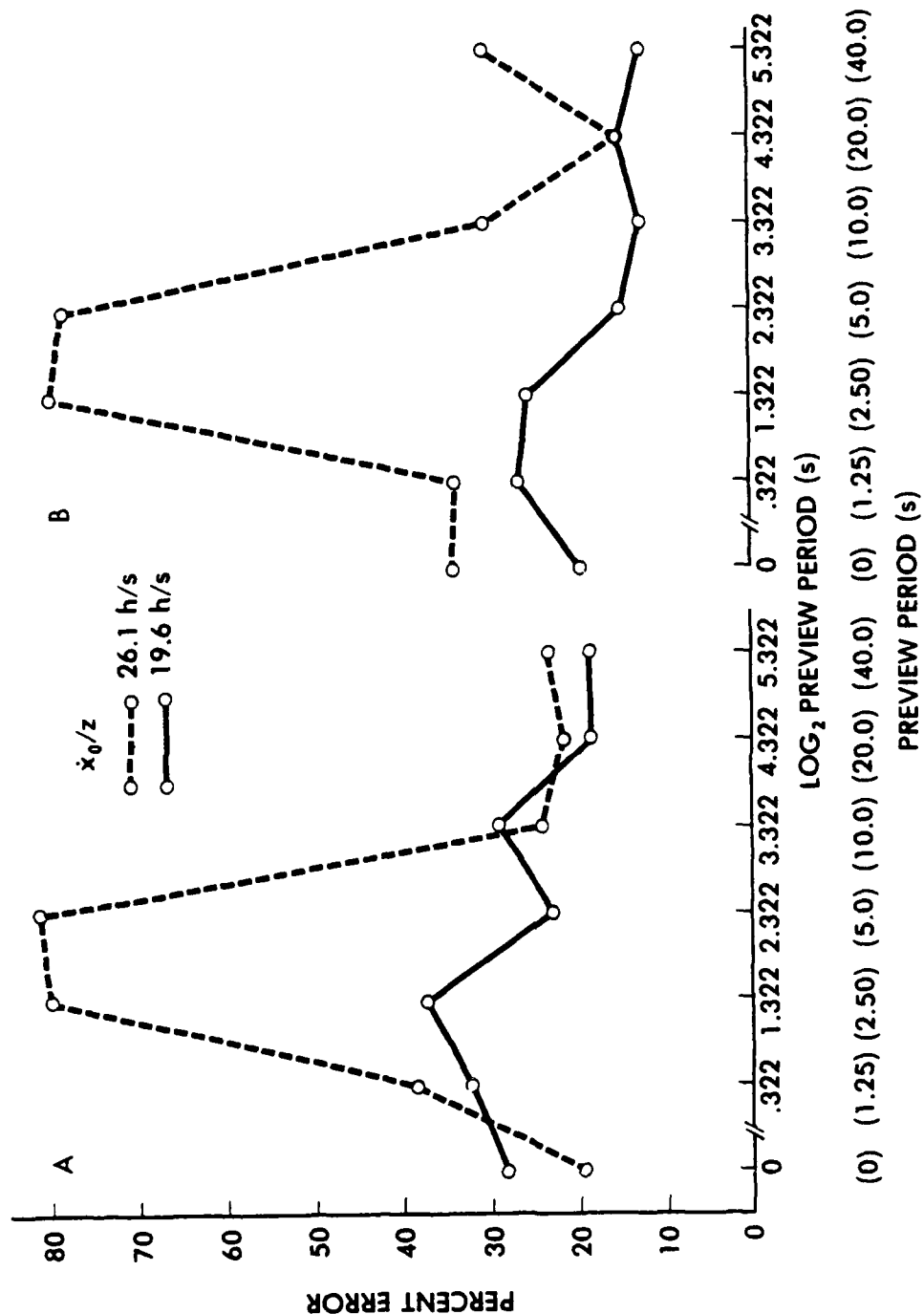
Figure 4. Percent error for the one-session data (N = 112, 112 observations per point) (A) and for the four-session data (N = 42, 168 observations per point) (B) as a function of preview period for events representing decelerating self motion with initial global optical flow rates ($\dot{x}_o/z$) of 19.6 and 26.1 h/s.

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results in graphic format. The other influence was the similarity of the one-session and four-session results, indicating that the complex nature of the interactions is reliable. For these reasons, means for the one-session and four-session data are summarized for each preview period separately in Figures 5 to 18. Percent error scores are presented in Panel A at the top of each page, and mean correct reaction times are presented in Panel B at the bottom.

Table 1. Percent of Variance Accounted for by Sources Which
Accounted for 1.5% or More of the Variance

	Dependent variable			
Source	Error	Correct RT	Confidence	A_g
All events, one session				
Order (O)	–	9.4	–	–
Event type (E)	2.2	2.0	91.3	N/A
Flow rate (F)	–	3.7	–	–
Preview period (P)	–	2.7	–	1.7
OP	–	1.7	–	–
FP	1.6	–	–	3.1
OFP	3.4	–	–	6.8
EFP	1.5	–	–	N/A
OEFP	3.7	–	–	N/A
Decelerating events, one session				
Order (O)	–	8.4	–	N/A
Flow rate (F)	2.2	4.0	–	N/A
Preview period (P)	2.7	3.1	–	N/A
OP	–	2.9	–	N/A
FP	4.6	–	–	N/A
OFP	6.6	–	–	N/A

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Table 1. (Concluded)

| | Dependent variable | | | |
Source	Error	Correct RT	Confidence	A_g
All events, four sessions				
Order (O)	-	-	-	-
Event type (E)	2.0	1.5	91.7	N/A
Flow rate (F)	1.6	3.7	-	2.5
Preview period (P)	-	2.2	-	-
Session (S)	-	-	-	-
FP	1.6	-	-	3.3
EFP	1.8	-	-	N/A
OPS	-	1.9	-	-
OFPS	-	2.9	-	-
OEFPS	6.4	-	-	N/A
Decelerating events, four sessions				
Order (O)	-	18.7	-	N/A
Flow rate (F)	3.2	3.4	-	N/A
Preview period (P)	2.1	3.0	-	N/A
Session (S)	-	-	-	N/A
OF	-	1.5	-	N/A
OS	-	3.4	-	N/A
FP	4.2	-	-	N/A
OFP	-	2.9	-	N/A
OPS	-	2.6	-	N/A
OFPS	11.2	-	9.9	N/A

One-session Data. The great increase in error rates (27%) at the highest flow rate for both the 2.5-s and 5-s preview periods (Figure 4) was a major contributor to the Flow Rate by Preview Period interaction. For the 0-s preview period, error rates peaked at 3.3 h/s and decreased a total of 13% for

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Figure 5. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 0 s (one-session data, N = 112, 112 observations per point).

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Figure 6. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 0 s (four-session data, N = 42, 168 observations per point).

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Figure 7. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 1.25 s (one-session data, $N = 112$, 112 observations per point).

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Figure 8. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 1.25 s (four-session data, N = 42, 168 observations per point).

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Figure 9. Percent error (A) and mean correct reaction time
(B) as a function of global optical flow rate for events
representing constant-speed and decelerating self motion
with a preview period of 2.5 s (one-session data, N = 112,
112 observations per point).

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Figure 10. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 2.5 s (four-session data, N = 42, 168 observations per point).

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Figure 11. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 5 s (one-session data, $N = 112$, 112 observations per point).

Figure 12. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 5 s (four-session data, N = 42, 168 observations per point).

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Figure 13. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 10 s (one-session data, N = 112, 112 observations per point).
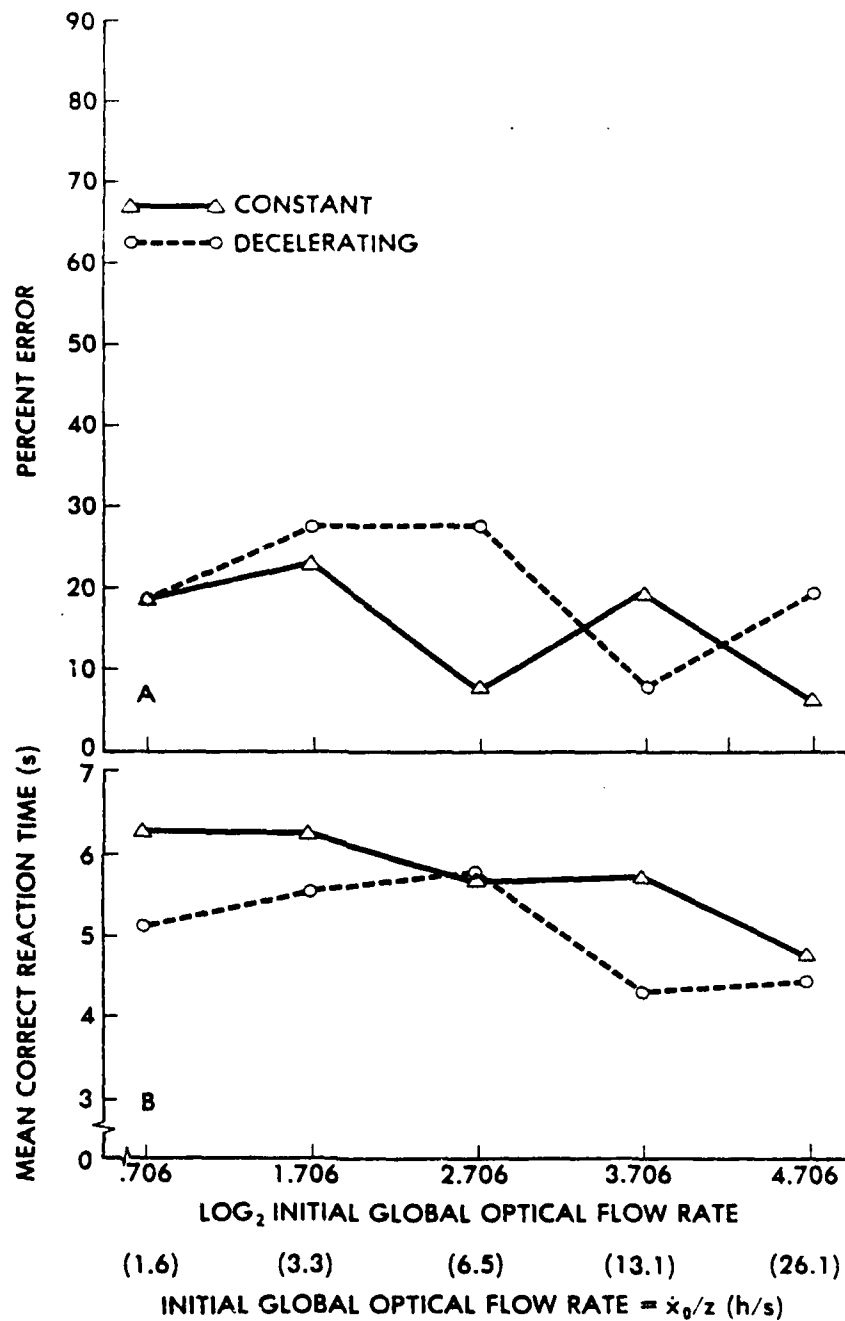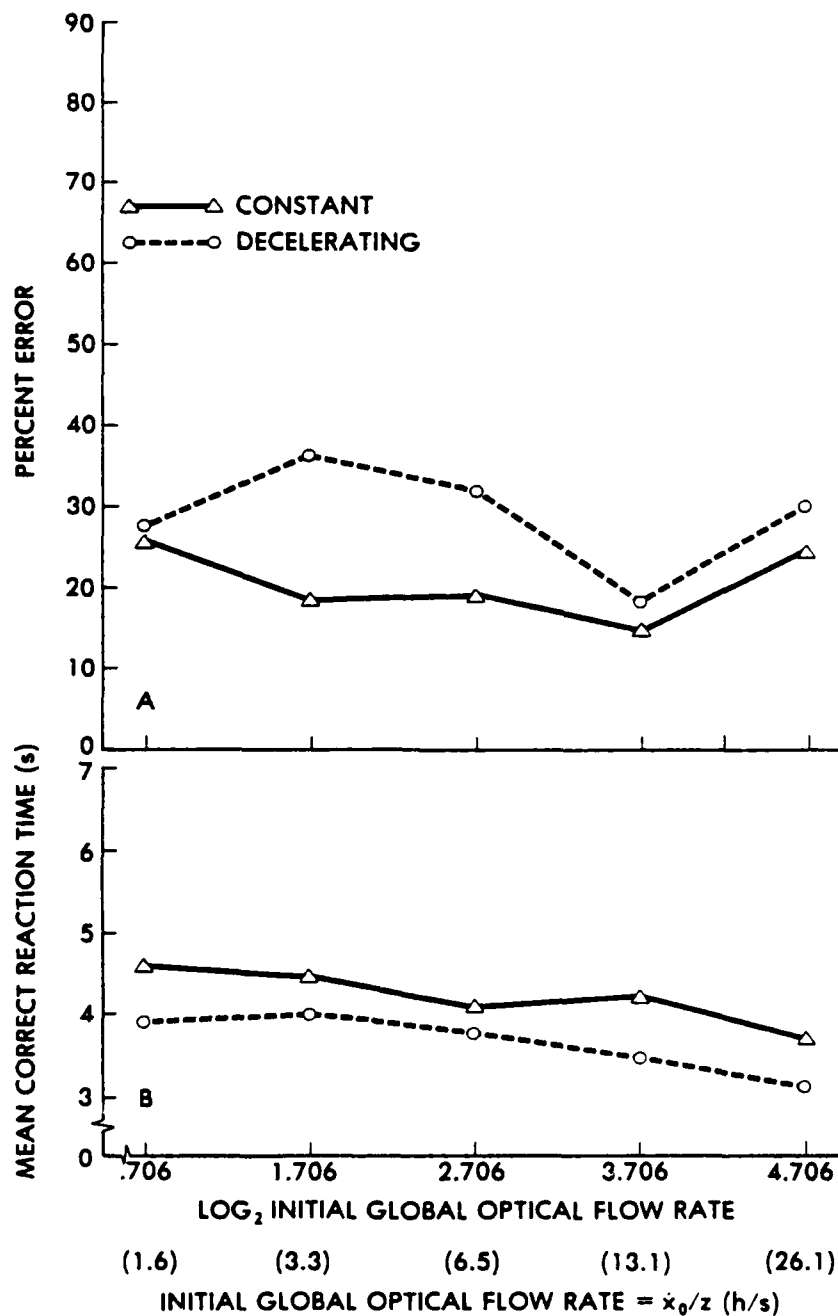
Figure 14. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 10 s (four-session data, N = 42, 168 observations per point).

110
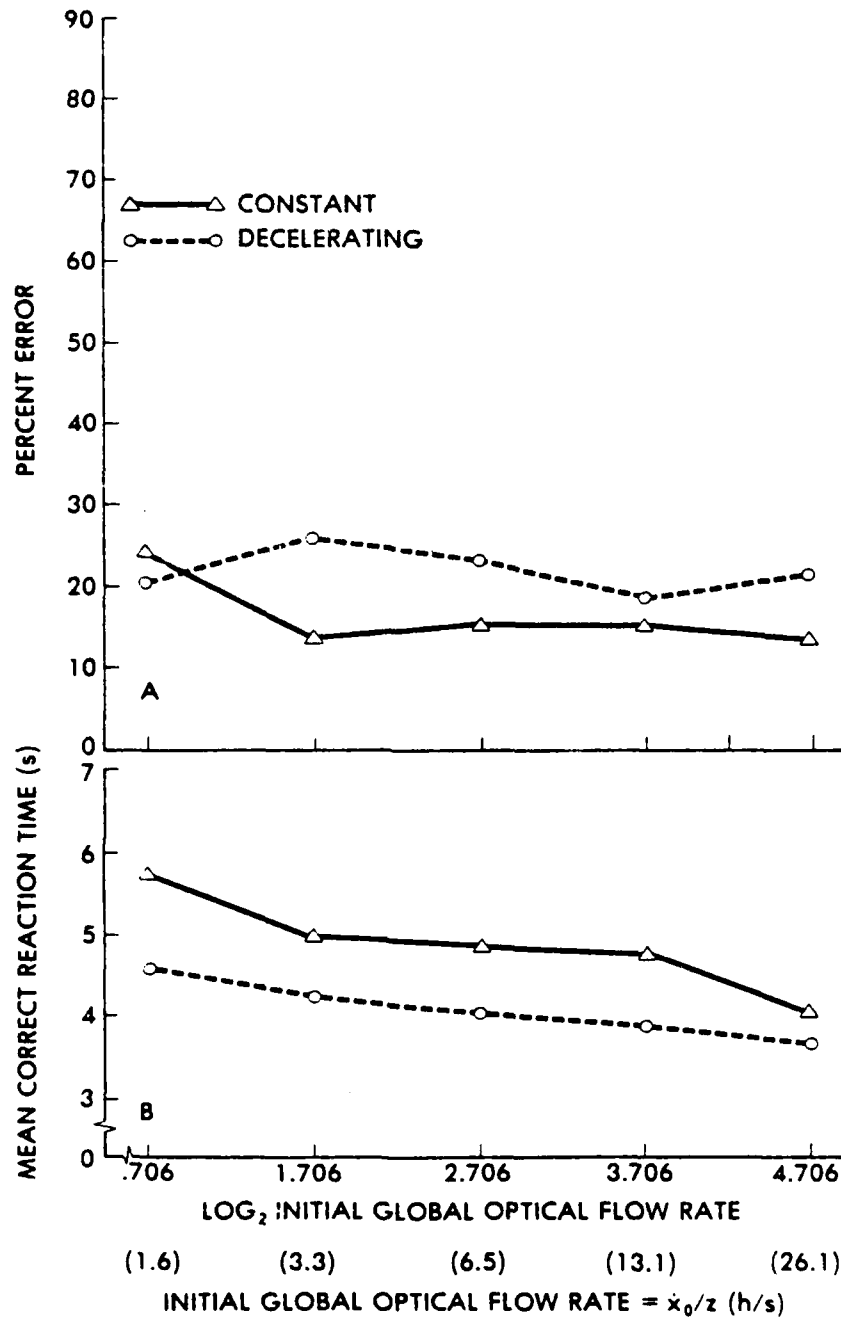
Figure 15. Percent error (A) and mean correct reaction time
(B) as a function of global optical flow rate for events
representing constant-speed and decelerating self motion
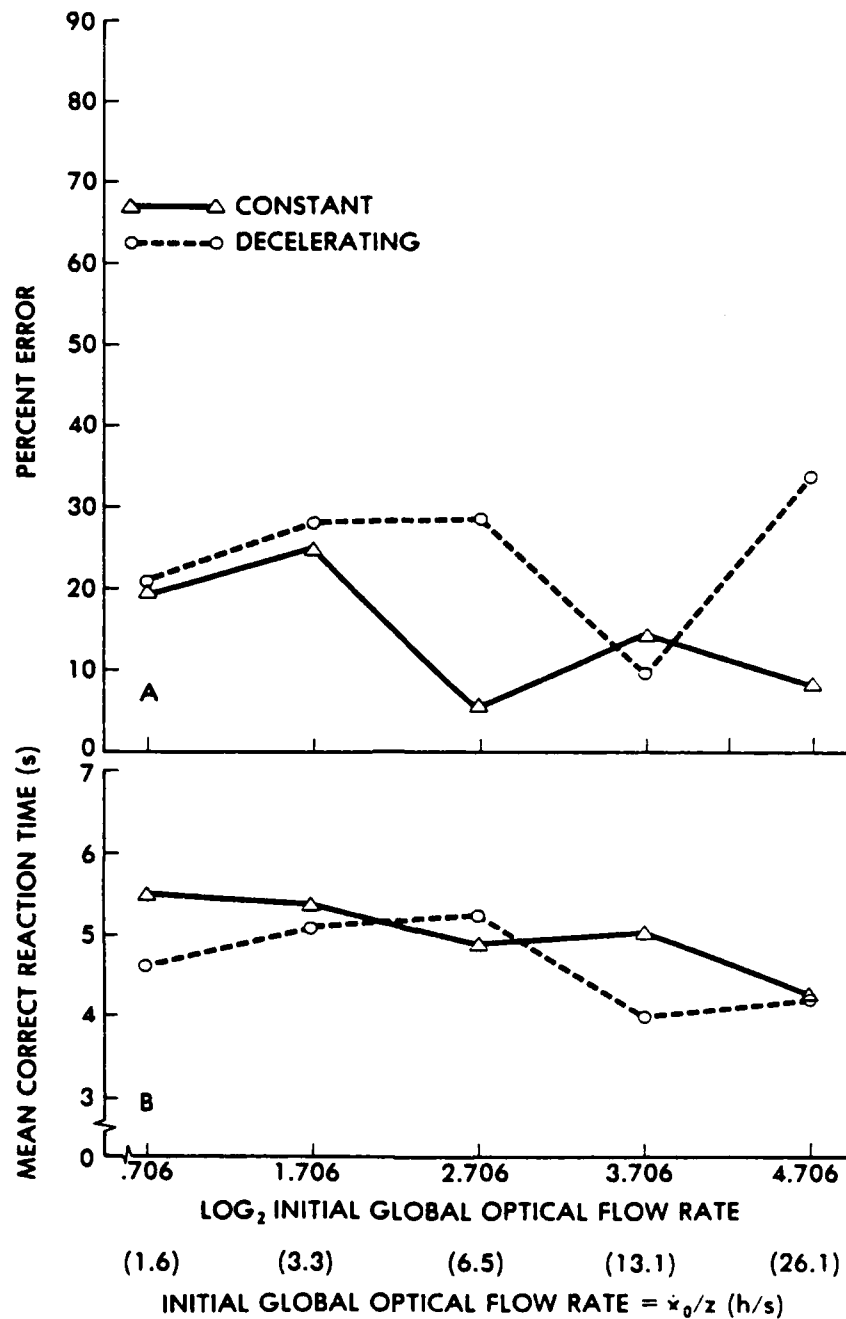with a preview period of 20 s (one-session data, N = 112,
112 observations per point).

111
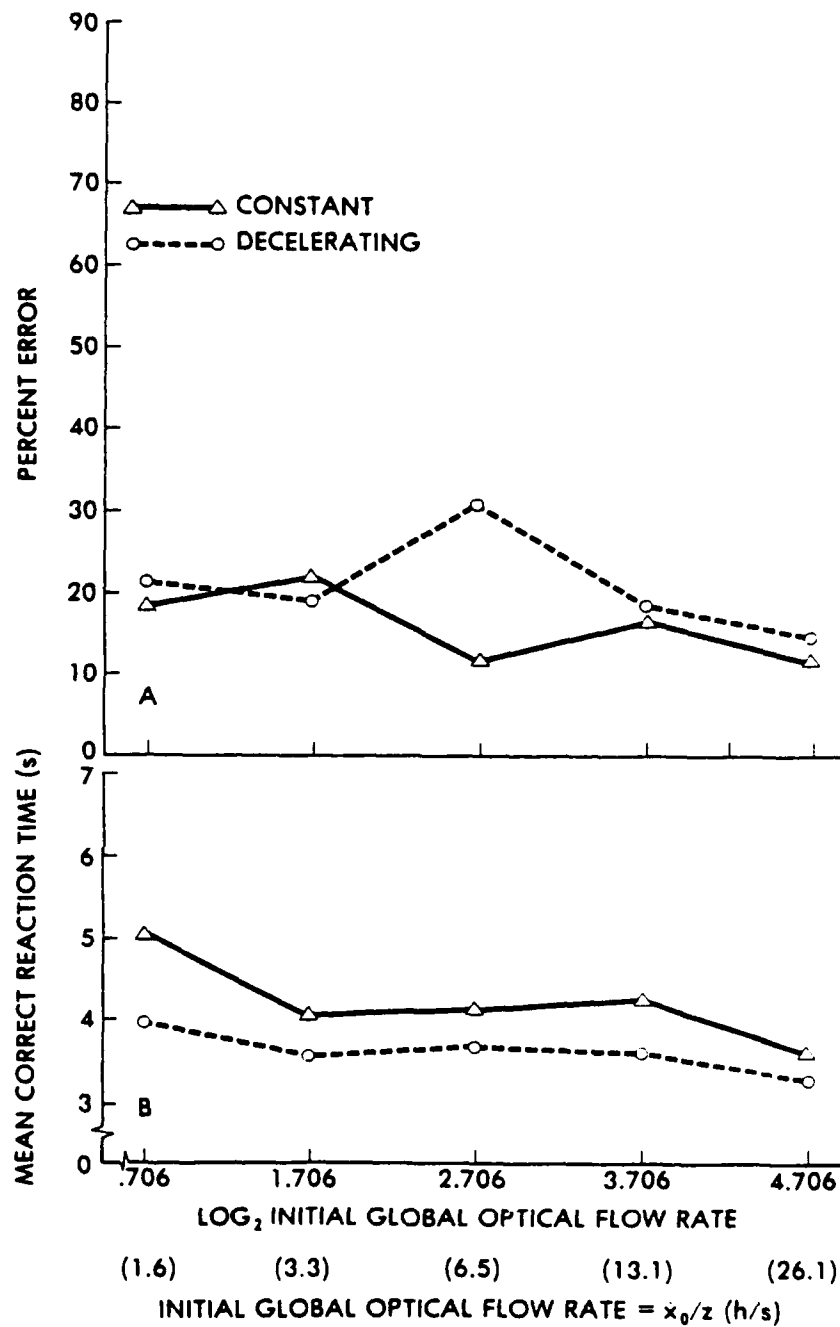
Figure 16. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 20 s (four-session data, N = 42, 168 observations per point).
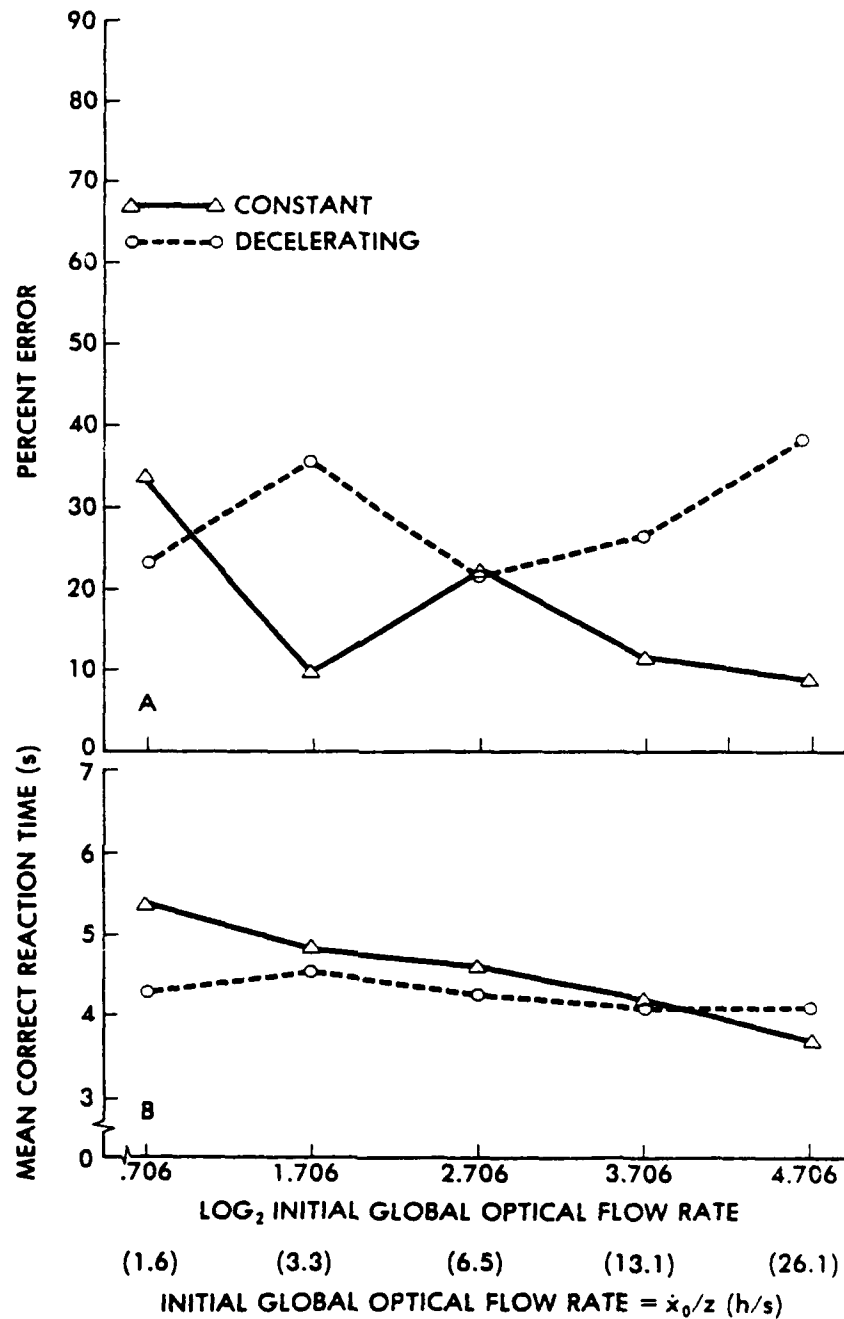
112
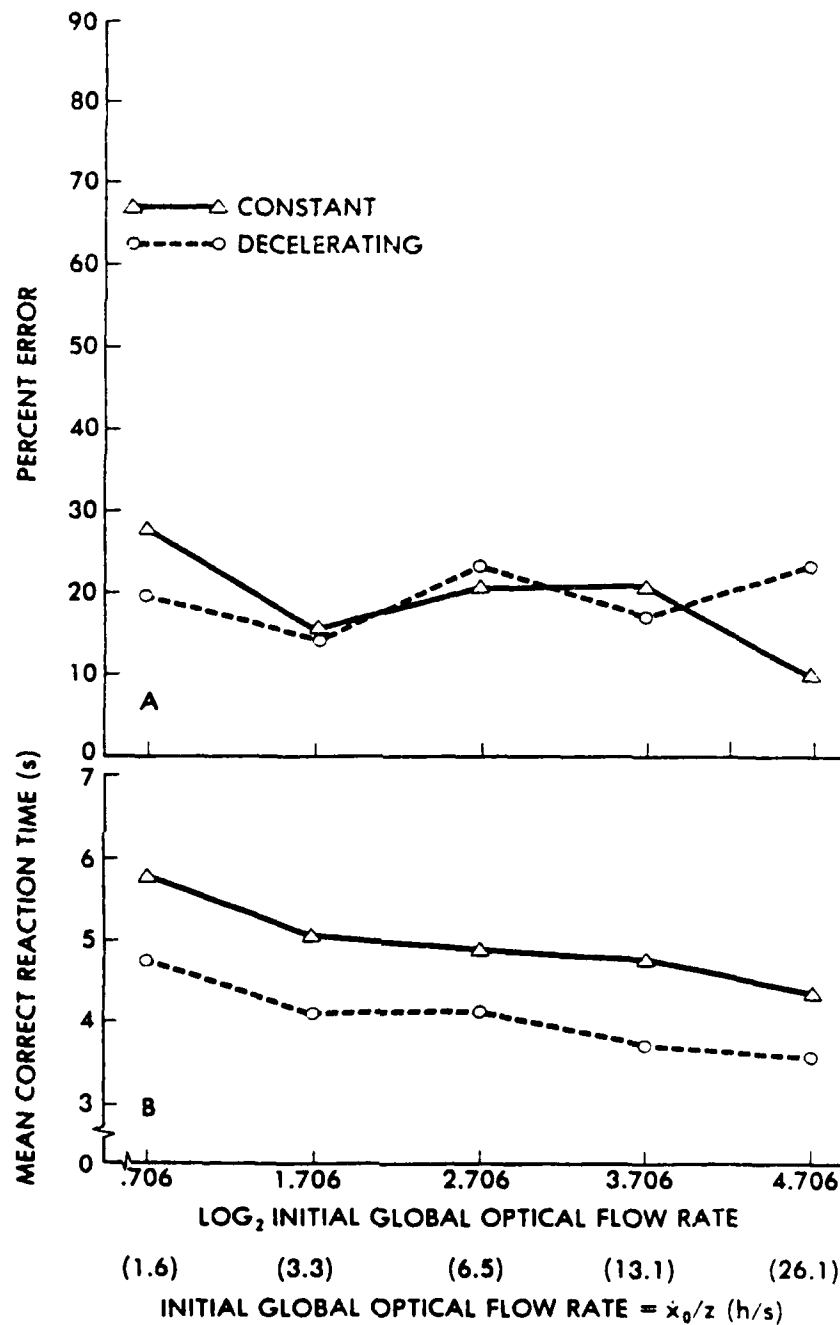
Figure 17. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 40 s (one-session data, N = 112, 112 observations per point).
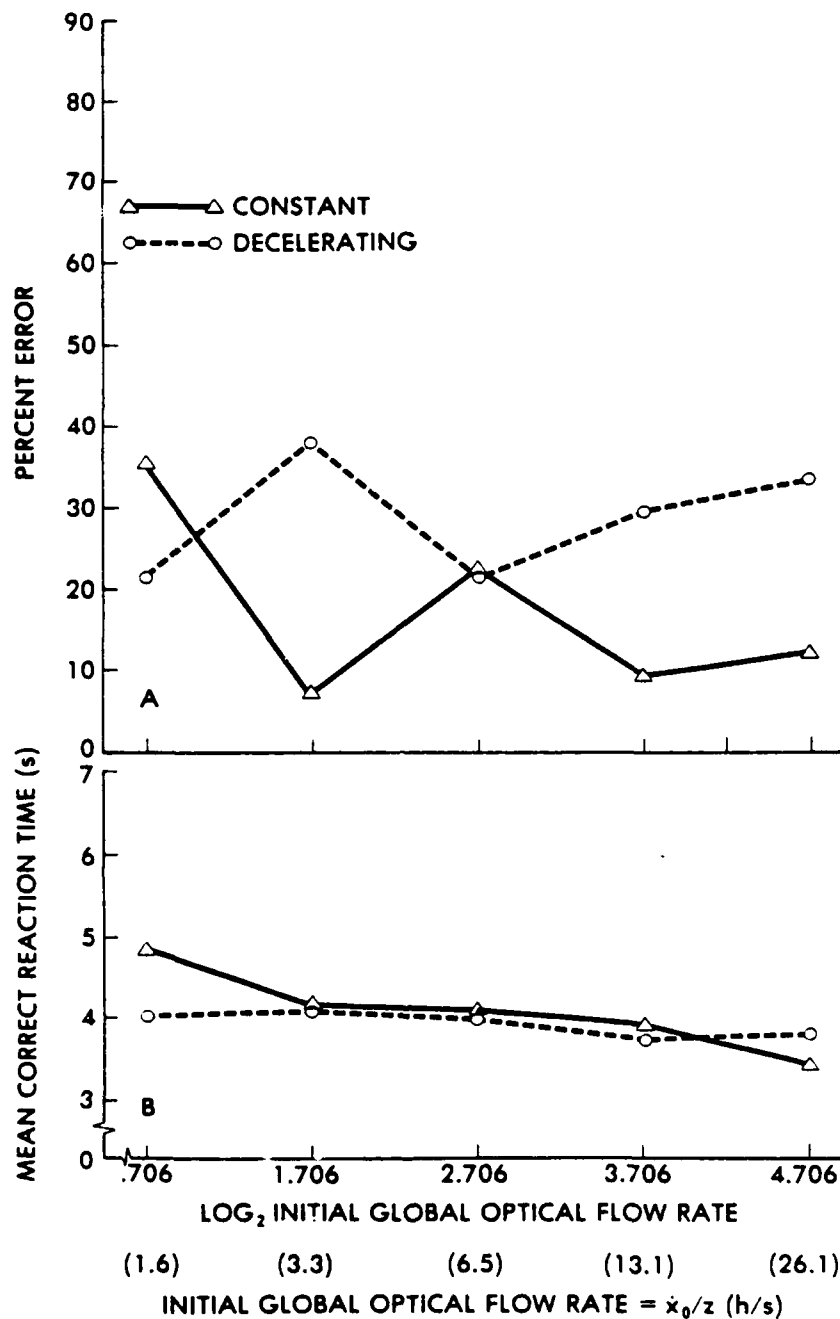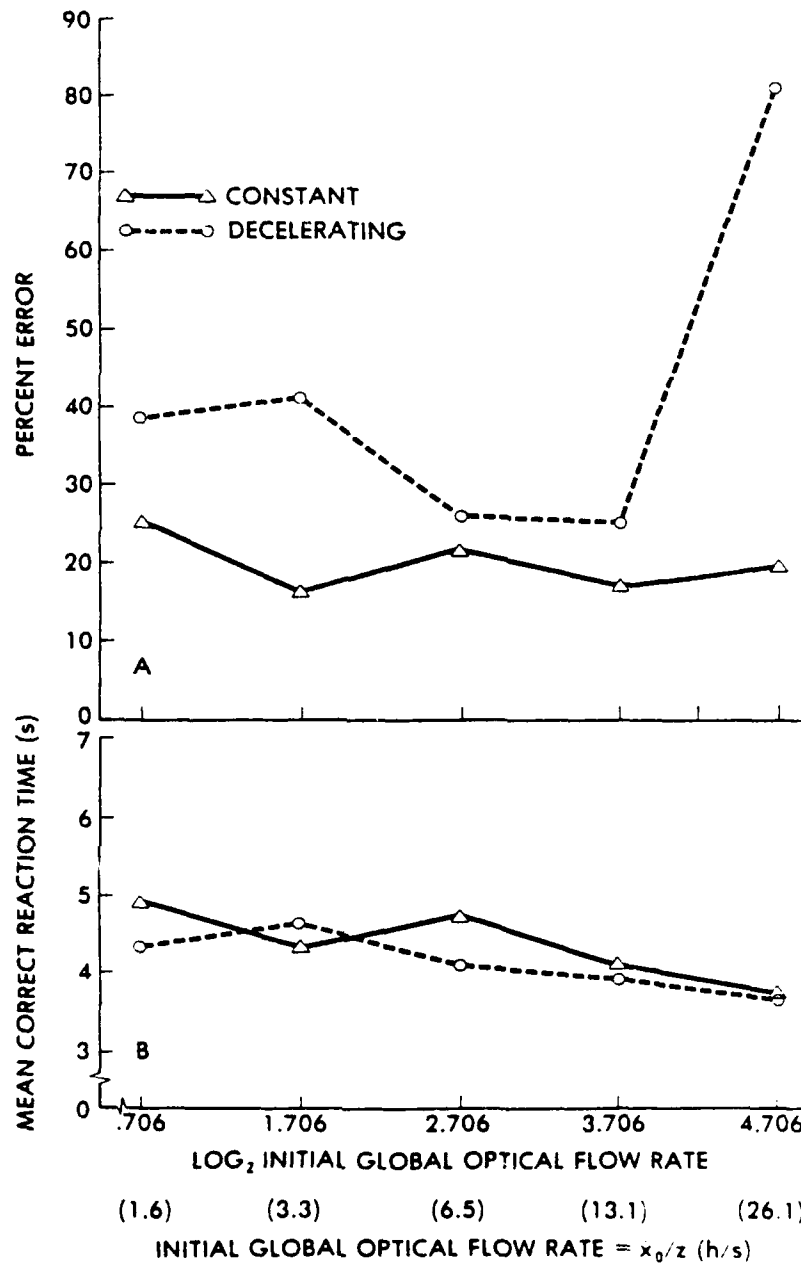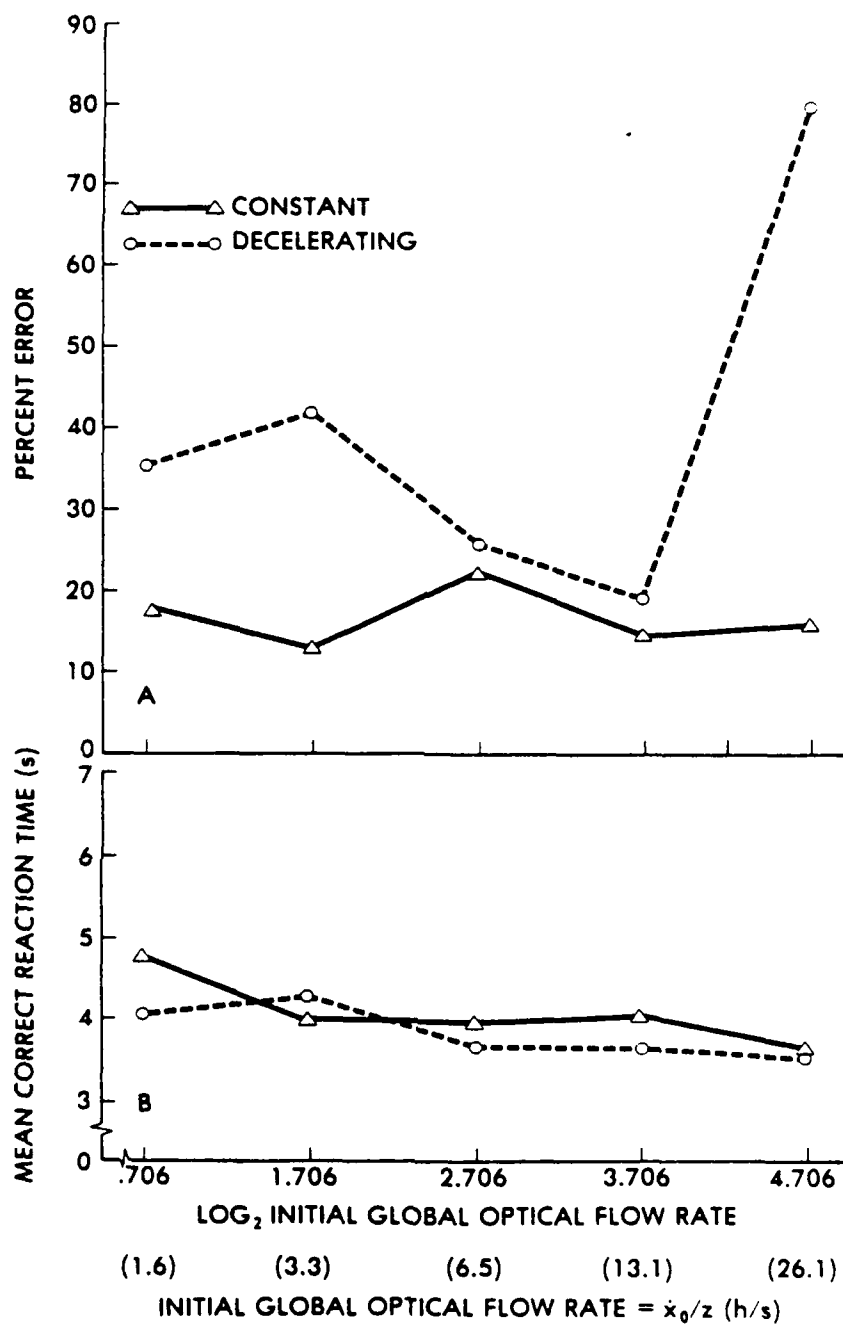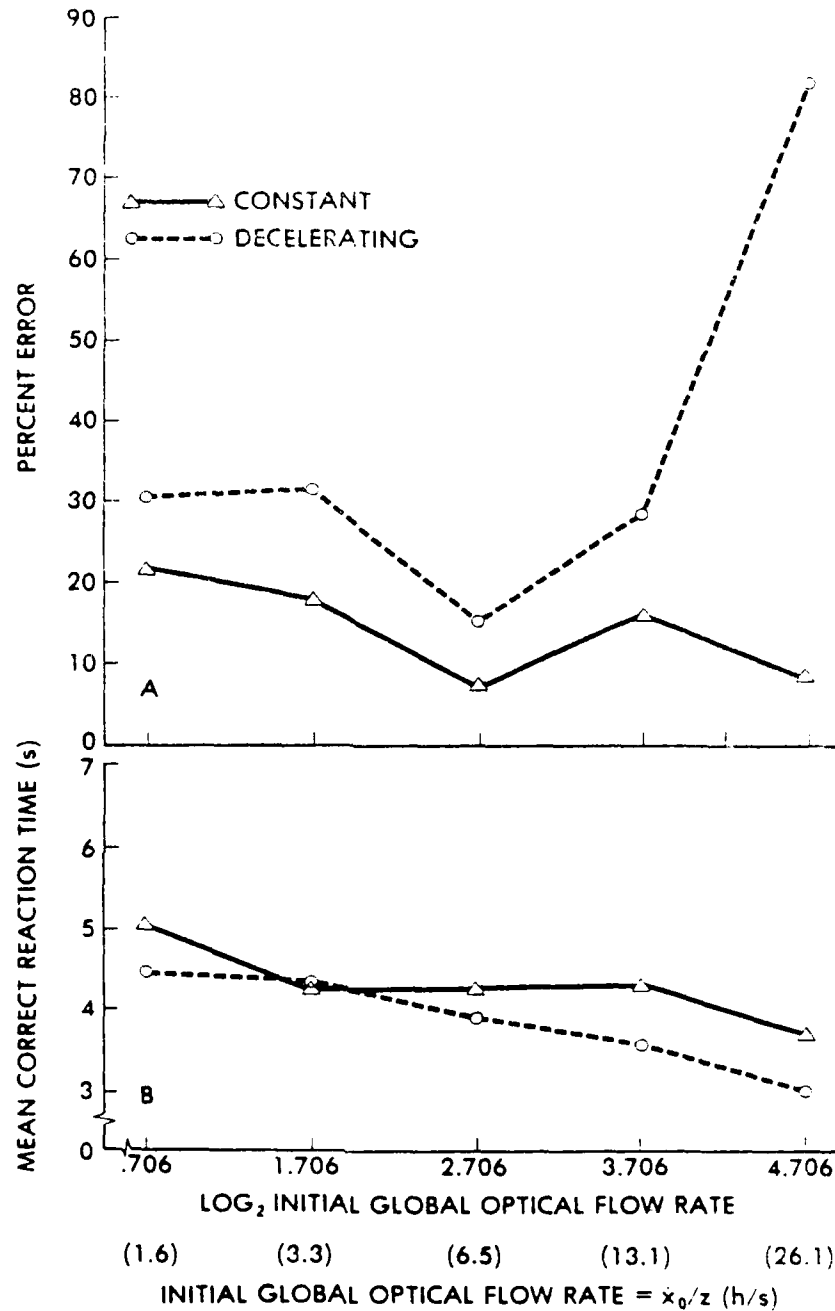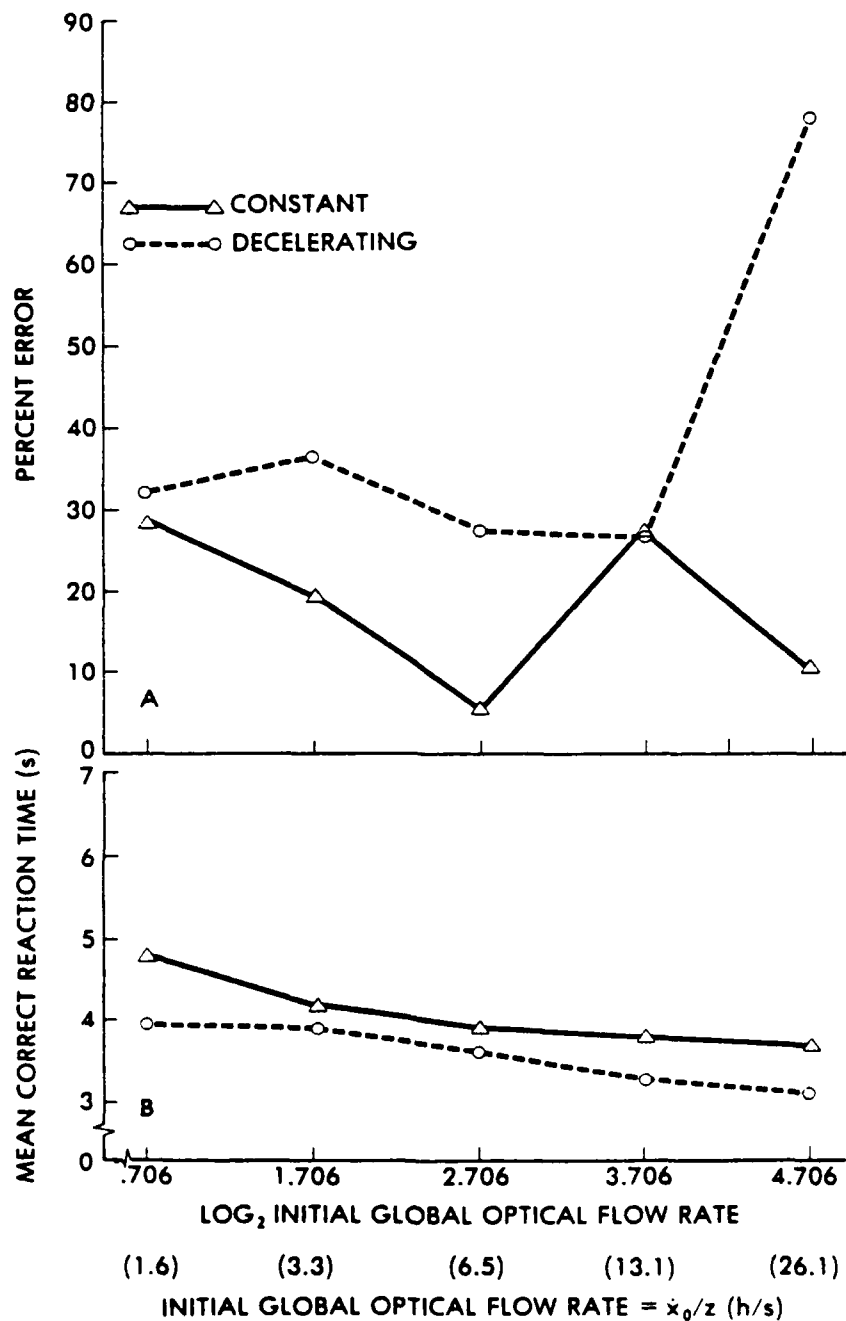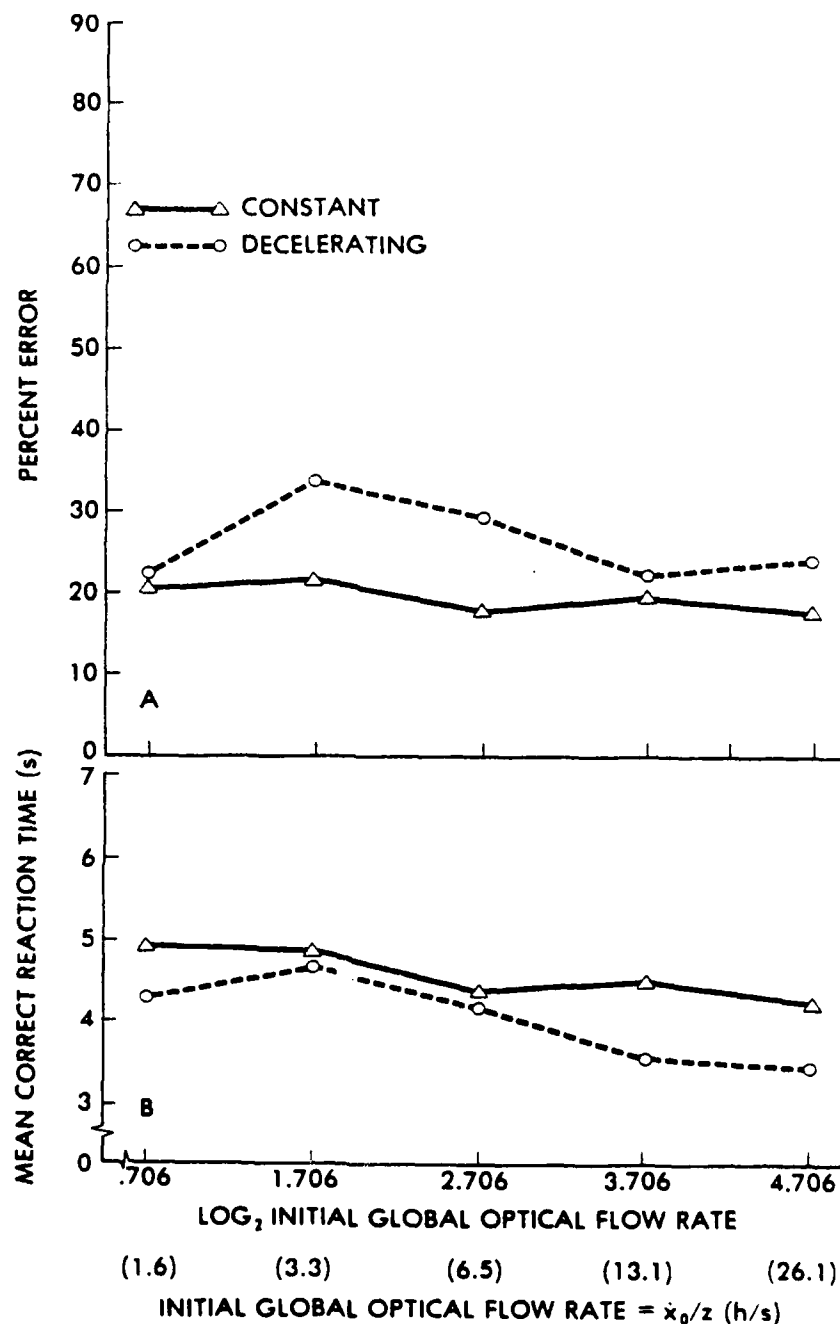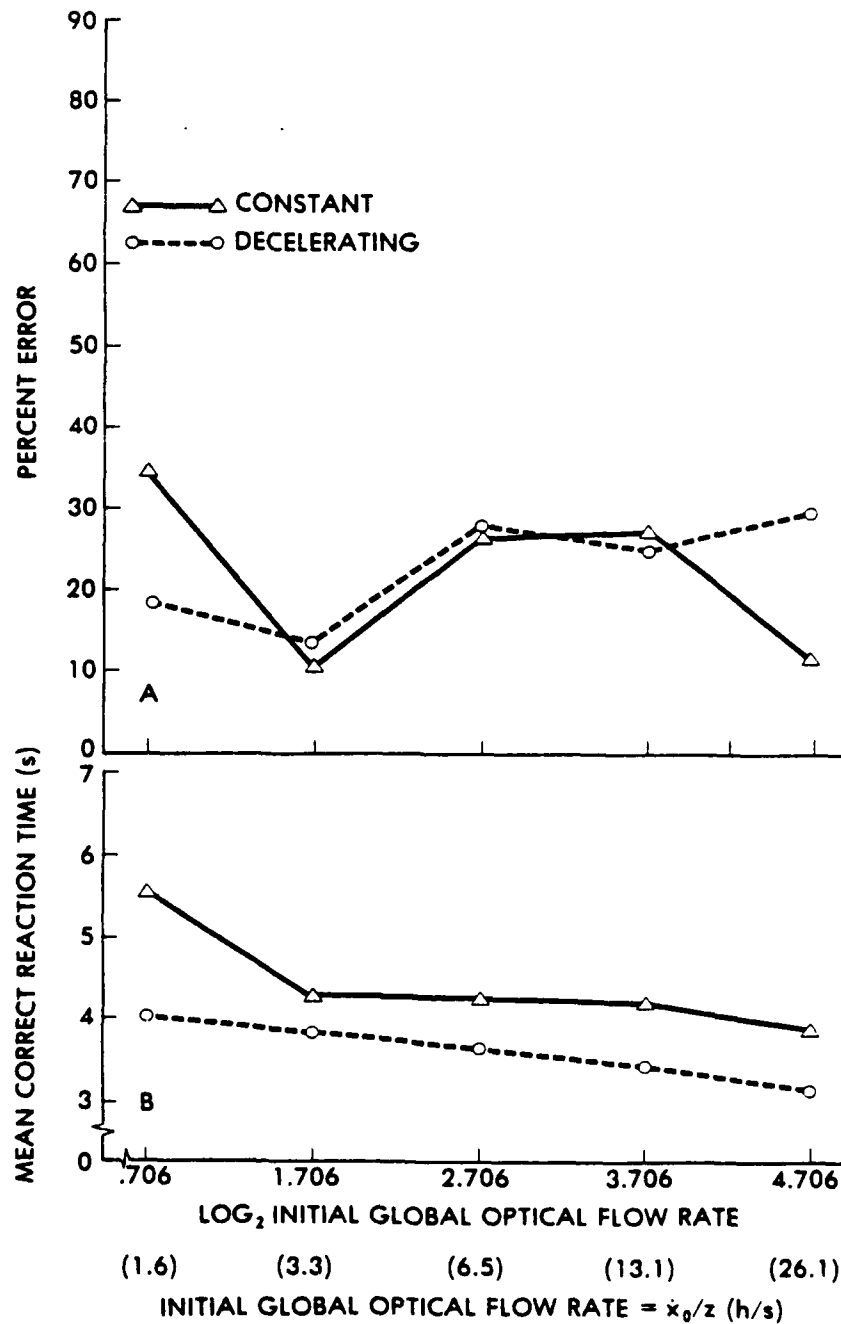
Figure 18. Percent error (A) and mean correct reaction time (B) as a function of global optical flow rate for events representing constant-speed and decelerating self motion with a preview period of 40 s (four-session data, N = 42, 168 observations per point).

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the higher flow rates. This was also the largest difference, excluding the 5- and 2.5-s preview periods. Lowest error rates were also at 3.3 h/s for the 40- s preview period, at 6.5 h/s for the 5-s preview period, and at 13.1 h/s for the 1.25-, 2.5-, 10- and 20-s preview periods. The breakdown of initial flow rate by preview period by event type shows that the increases in error rate at the highest flow rate for the 2.5- and 5-s preview periods are found in the decelerating events, 44 and 59%, respectively. In general, the decelerating events had higher error rates than the constant-speed events, except for a crossover at 13.1 h/s for the 0-s preview period. There, error rates jumped by 12% for the constant-speed events, then decreased again by 13% for the highest flow rate. Conversely, the decelerating event error rate first decreased by 20% then increased by 12%. There was also a crossover for the 1.25- and 20-s preview periods, where error rates were initially lower for the decelerating events at the lowest initial flow rate. Differences in error rates between constant-speed and decelerating events were highest for the 1.25- and 2.5-s preview periods, decreasing with increasing preview period so that they were virtually the same for the two event types for the 40-s preview period.

In the analysis of decelerating events for the one-session data, error rates remained fairly constant with increase in flow rate except for the highest flow rate, where errors jumped by 21%. There was a general decrease in correct reaction time, however, with increase in initial flow rate (1.12-s decrease from slowest to fastest flow). Error rates increased by 20% from the 0-s to the 2.5-s preview period, then decreased steadily to the 40-s preview period by a total of 22%. Correct reaction times, in contrast, decreased by 0.94 s from the 0-s to 5-s preview period, then increased from the 5-s to the 40-s preview period by 0.13 s. As mentioned before, much of the variance in error rate producing the Flow Rate by Preview Period interaction is due to the high error rates at the highest flow rate for the 2.5- and 5-s preview periods. The three longest preview periods (10, 20 and 40 s) consistently had the lowest error rates, only exceeding 30% at 3.3 h/s for the 10-s preview period. Error rates were low at 3.3 h/s for the shorter preview periods also, dropping by at least 15% for the next highest flow rate for the preview

periods of 1.25, 2.5 and 5 s, staying constant for 6.5 h/s and then dropping by 20% at the flow rate of 13.1 h/s for the 0-s preview period. Error rate increased at the highest flow rates for all the preview periods.

Analysis of the area above the isosensitivity curve (1-A_g) showed a general decrease in sensitivity of 12% from the 0-s to the 2.5-s preview period, with an increase of 11% in sensitivity from the 2.5-s to the 40-s preview period. Sensitivity increased by less than 5% with increase in flow rate from 1.6 to 13.1 h/s, then decreased by 8% for the highest flow rate. There was a drastic decrease in sensitivity at the highest flow rate for the 2.5-s and 5-s preview periods (35% and 26%, respectively); for the 2.5-s preview period, highest sensitivity was at 13.1 h/s; for the 5-s preview period, there was an increase in sensitivity of 8% at 6.5 h/s compared to the higher and lower flow rates. There was a general increase in sensitivity from 1.6 to 13.1 h/s for all preview periods except for the 0-s and 10-s durations, where sensitivity decreased by 7% from 1.6 to 3.3 h/s; the 40-s duration, where a decrease of 4% from 3.3 to 6.5 h/s was observed; and the 5-s duration where a decrease of 8% from 6.5 to 13.1 h/s occurred.

Four-session data. The Flow Rate by Preview Period interaction also showed a pattern of effects for error rates similar to that in the one-session data. Again, the error rates increased for the highest flow rate for the 2.5- and 5-s preview periods, and the lowest error rates were found in general for the flow rate of 13.1 h/s except for the 5-s preview period. A major difference is that in the one-session data, the 2.5-s preview period had the highest error rates in general across flow rates (except for 13.1 h/s), whereas in the four-session data, the 5-s preview period had the highest error rates (except for 6.5 h/s).

The three-way interaction of intial flow rate by event type by preview period showed only a few deviations from the one-session data for error rates. Specifically, there was a 21% increase in error rates from 6.5 h/s to 13.1 h/s for the 5-s preview period for constant-speed events versus only 9% in the one-session data. The pattern of error rates was fairly dissimilar for the 20-s preview period, however (see Figures 15 and 16). There was a 12% increase in error rates at 6.5 h/s for the decelerating events, whereas accuracy stayed fairly constant across flow rates in the one-session data.

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Also, there was a corresponding increase of 10% in error rates for the constant-speed events at the 6.5-h/s flow rate in the four-session data. In the one-session data, the error rates decreased by 10% at 3.3 h/s and then remained fairly constant across the higher flow rates. For the 40-s preview period, as shown in Figures 17 and 18, the pattern of error rates was the same for the two data sets, though the increase in error rates from 3.3 to 6.5 h/s for both constant and decelerating events was much larger in the four-session data (16 and 15.5%, respectively) than for the one-session data (5.5 and 9%).

Main Effects

One-session data. Error rates for decelerating events were 12% higher than for constant speed (Figure 19), while correct reaction times were 0.67 s shorter (Figure 20). Correct reaction times decreased steadily by a total of 1.04 s from the lowest to highest initial flow rate. Correct reaction times were highest for the 0-s preview period, dropping by 1 s at the 1.25-s preview period, and rising by 0.2 s by the 20-s preview period (Figure 20). Changing the confidence ratings to a 6-point scale resulted, as would be expected, in event type accounting for a large amount of variance in this variable in both the one- and four-session data.

Four-session data. Testing observers for four sessions did not have an effect on any of the dependent variables, either as a main effect or in any interaction. Error rate dropped by only 1%/session. The main effect of even type was the same as for the one-session data: Error rates were 12% lower for constant speed than for decelerating events (Figure 21), and correct reaction times were higher by 0.41 s (Figure 22). The same pattern was found in correct reaction times for the main effect of initial flow rate. There was a general decrease in correct reaction times of 1.34 s with increase in initial flow rate, except for an increase of 0.44 s for the highest flow rate. Initial flow rate also had an effect on error rates for the four-session experiment. Error rates decreased a total of 14% with increase in flow rate, except, again, for the highest flow rate, where error rate increased by 3%.

Error rate for decelerating events increased from the 0-s to the 2.5-s preview duration, then declined to the 40.0-s period, showing a more order quadratic function than did the one-session means (compare Figure 19 with 21). Constant-speed error rates were fairly constant through the 20-s preview
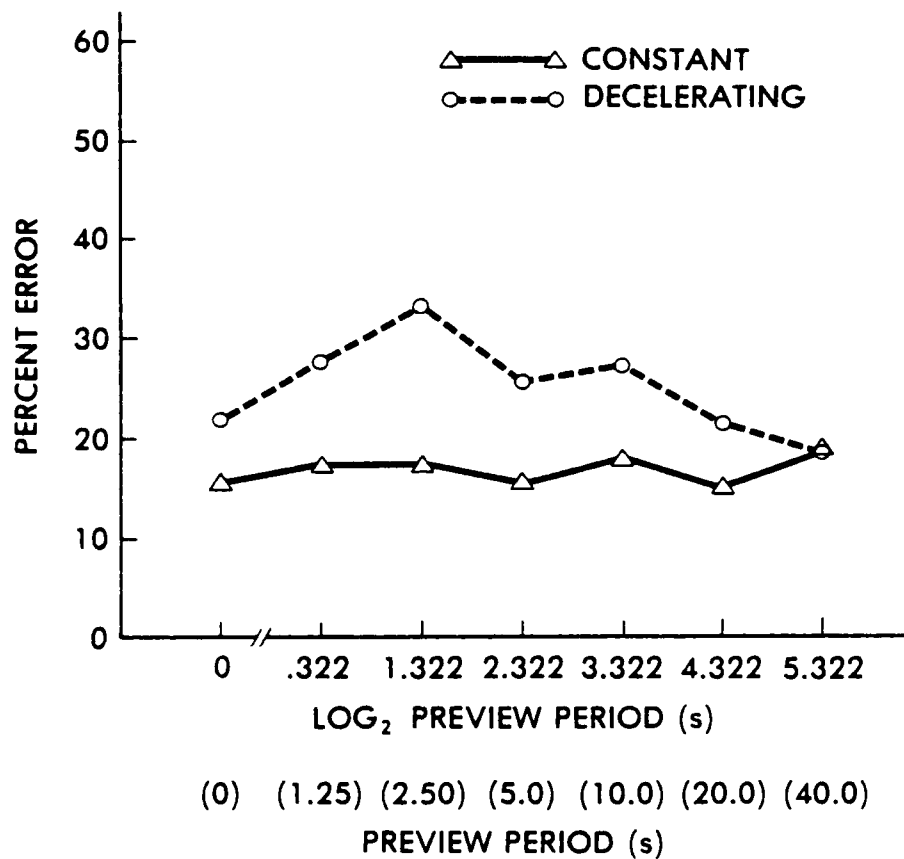
Figure 19. Percent error as a function of preview period for events representing constant-speed and decelerating self motion. The data are pooled over five flow rates including the practice trials, but excluding the fastest flow rate (one-session data, N = 112, 560 observations per point).

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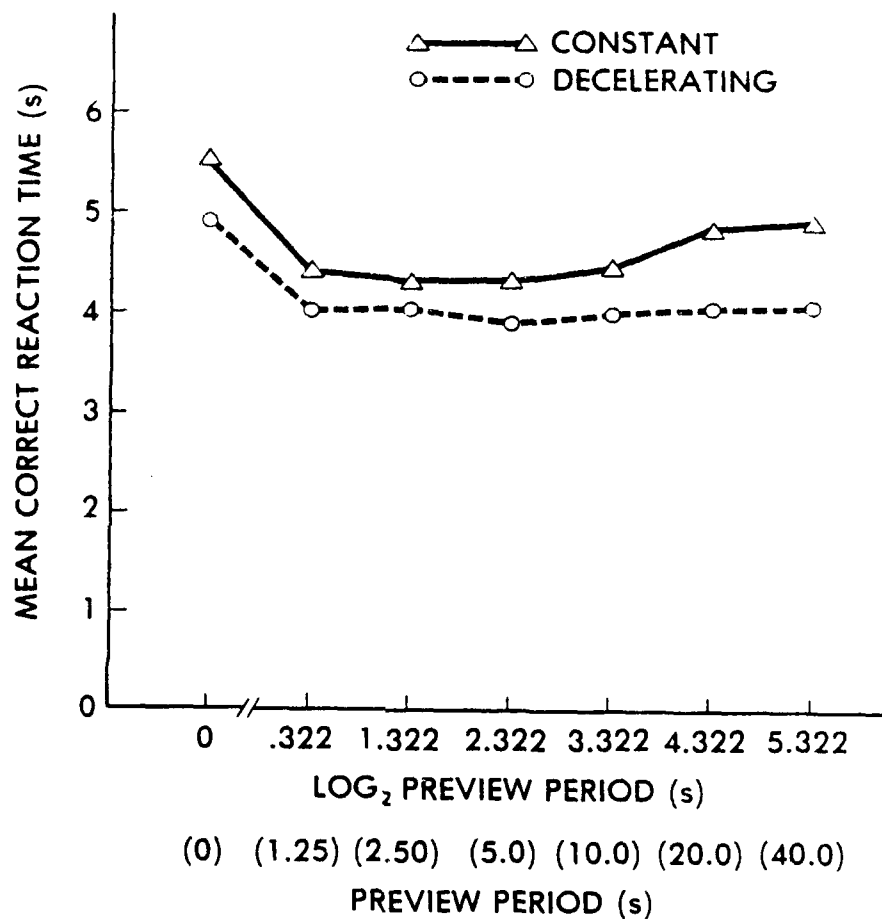
Figure 20. Mean correct reaction time as a function of preview period for events representing constant-speed and decelerating self motion. The data are pooled over five flow rates including the practice trials, but excluding the fastest flow rate (one-session data, N = 112, 560 observations per point).

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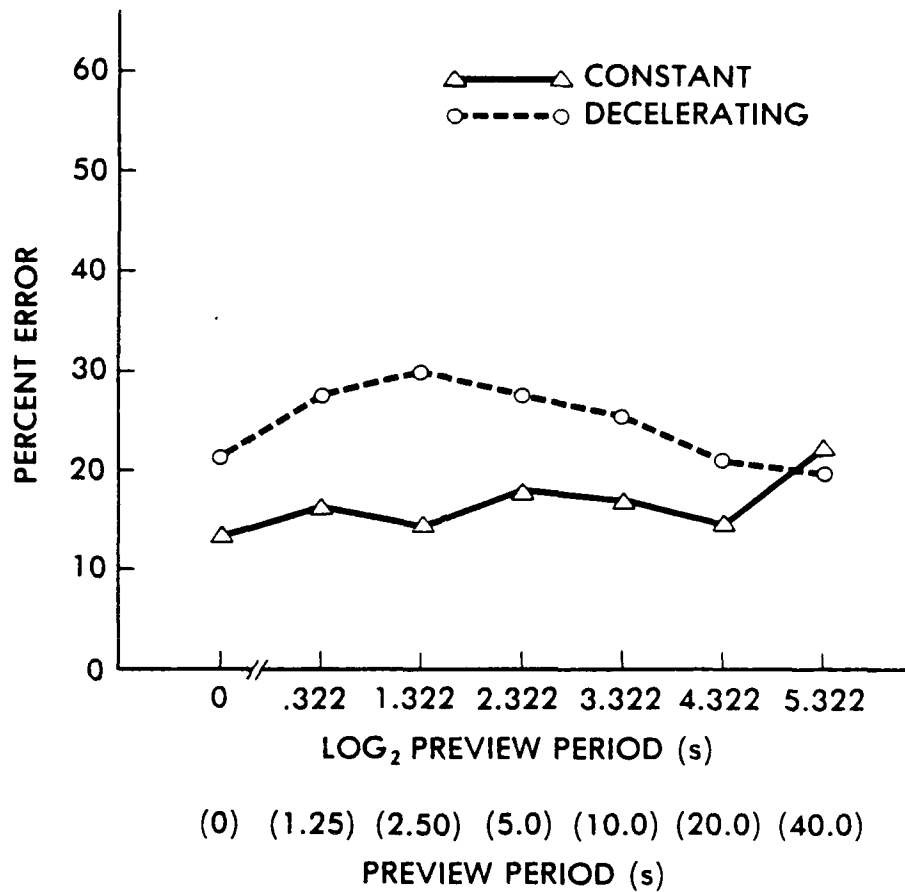
Figure 21. Percent error as a function of preview period for events representing constant-speed and decelerating self motion. The data are pooled over five flow rates including the practice trials, but excluding the fastest flow rate (four-session data, N = 42, 840 observations per point).
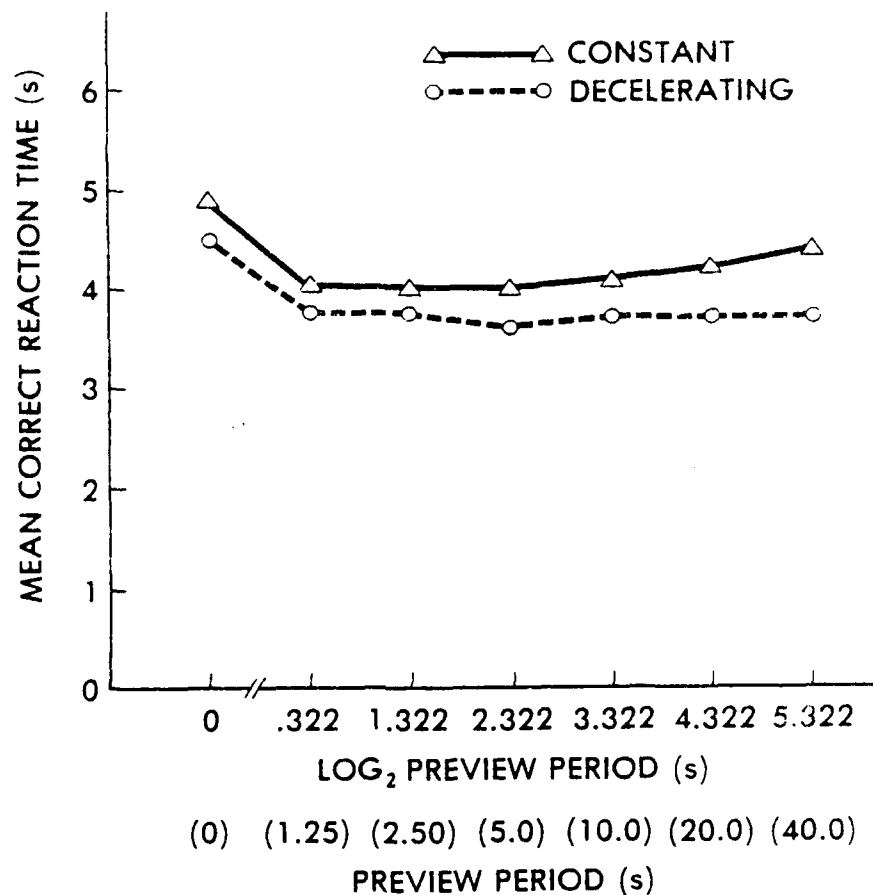
Figure 22. Mean correct reaction time as a function of preview period for events representing constant-speed and decelerating self motion. The data are pooled over five flow rates including the practice trials, but excluding the fastest flow rate (four-session data, N = 42, 840 observations per point).

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period, then increased markedly at the 40-s duration (Figure 21). The main effect of preview period on correct reaction time seemed to be due mainly to longer reaction times for the 0-s preview period. There was a 0.77-s decrease in reaction time from the 0-s to the 1.25-s preview period; reaction time then increased slightly for the constant-speed events, but remained fairly constant over the longer preview periods (Figure 22). This trend is similar to that found in the one-session data.

Bias-free sensitivity. Area under the isosensitivity curve (A_g) was computed as a measure of sensitivity in distinguishing deceleration and constant speed unbiased by differential use of the two report categories. Area above the curve ($1-A_g$) is presented to be comparable with error rates, i.e., lower scores represent better performance. Figure 23 allows an examination of the main effect for flow rate, ignoring the complex interaction between flow rate and preview period. From 1.6 to 13.1 h/s, increasing flow rate results in an essentially log-linear, though small, improvement in sensitivity. Sensitivity becomes much poorer with a flow rate of 26.1 h/s. The practice trials (19.6 h/s) produced an abnormally low value for the four-session data, an effect that can also be seen in Figure 4 for deceleration trials. The reaction times pooled over both event types also indicate that practice-trial performance was deviant. Over all other flow rates, reaction time decreased in a remarkably log-linear fashion as flow rate increased.

Figure 24 shows bias-free change in sensitivity over preview periods. The effect is clearly quadratic, with poorest sensitivity for the middle range of preview durations. The four-session data show that sensitivity becomes much poorer as the preview duration increases from 20 to 40 s. Reaction time pooled over both event types also revealed a quadratic pattern, with the shortest time at 5.0 s for both data sets.

Discussion

Obtaining a three-way interaction among preview period, flow rate, and event type means that the results must first be considered at the finest level of grain in the design. Following that, subtleties of the three-way interaction will be ignored to examine main effects and two-way interactions. Last, the anomalous results for the fastest flow rate following previews of 2.5 and 5 s will be discussed.

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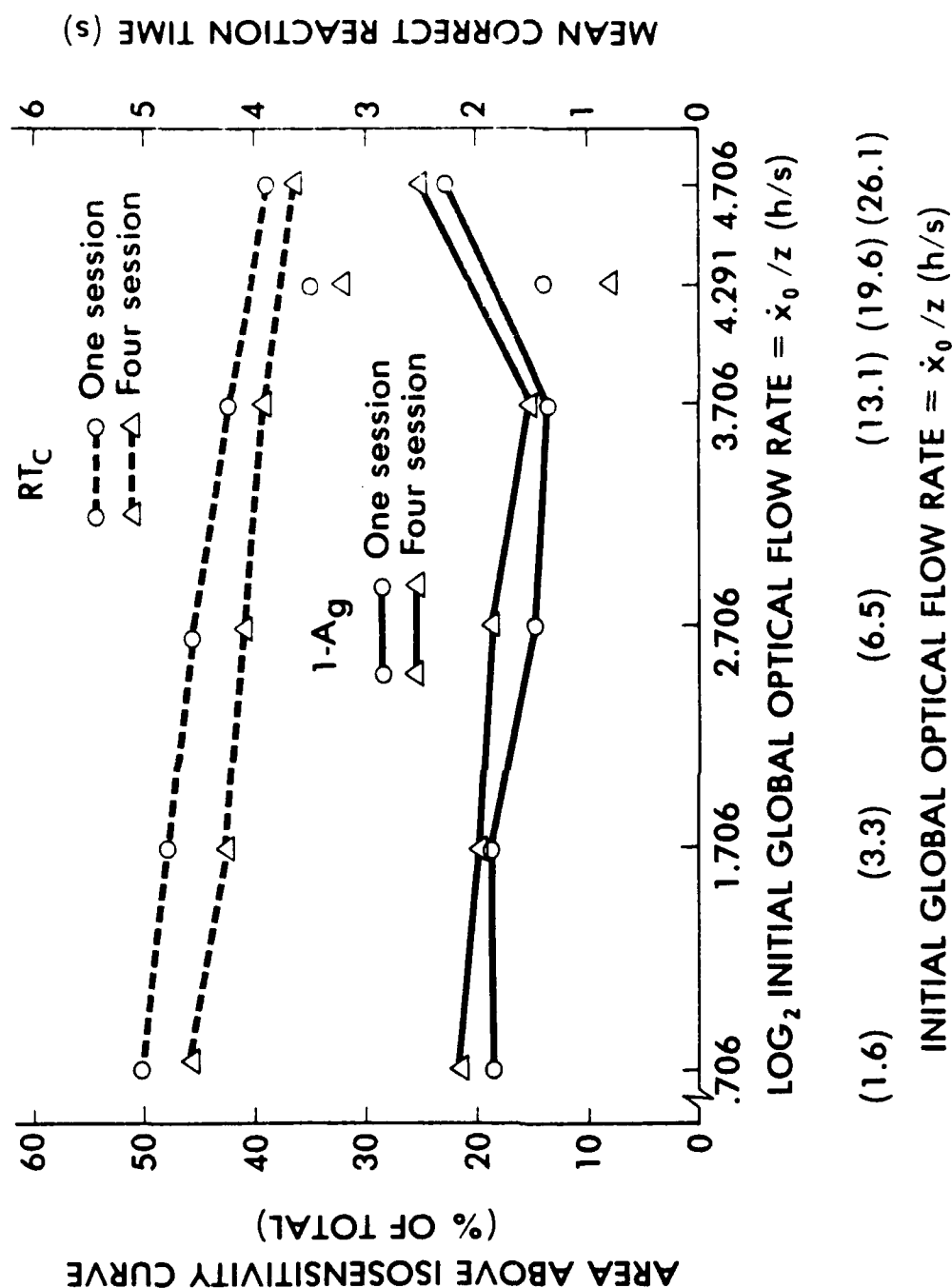
Figure 23. Mean area above the isosensitivity curve $(1-A_g)$ and mean correct reaction time (RT_c) as a function of global optical flow rate. The data are pooled over seven preview periods (one-session data, N = 112, 784 observations per point; four-session data, N = 42, 1176 observations per point.

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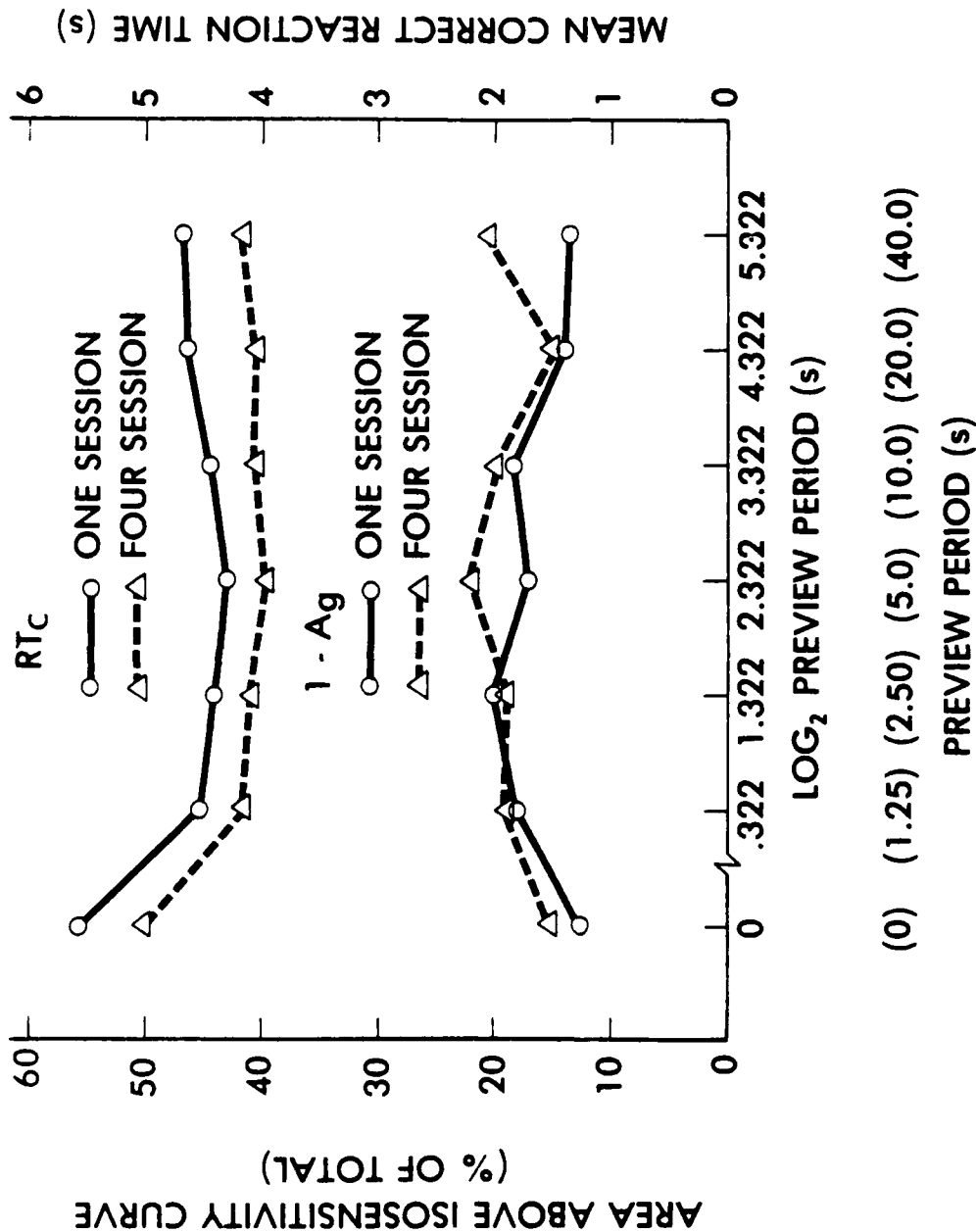
Figure 24. Mean area above the isosensitivity curve $(1-A_g)$ and mean correct reaction time (RT_c) as a function of preview period. The data are pooled over five flow rates including the practice trials, but excluding the fastest flow rate (one-session data, $N = 112$, 560 observations per point; four-session data, $N = 42$, 840 observations per point).

Interaction of Preview Period and Flow Rate

Examination of Figures 5 to 18 reveals a complex error-rate pattern that involves largely inexplicable reversals with event type. This pattern is damped considerably when the A_g scores are computed over both event types. For example, in the four-session results mean correct reaction time is lowest for the 10-s preview for the slowest flow rate (1.63 h/s), then lowest for the 5-s preview period for every flow rate above that. Sensitivity (A_g) has a slightly more complex quadratic relationship, being worst for the 5-s preview for flow rates of 1.6 and 3.26 h/s, worst at the 40-s preview for 6.53 and 13.05 h/s, and at the 2.5-s preview for the two highest flow rates. It is clear that the intermediate preview durations have a deleterious effect on sensitivity, primarily by reducing information pickup time by about a second on the average relative to the 0-s preview. It is possible that the tones used to delineate the beginning and end of the preview period (in order to eliminate uncertainty about when the test segment began) rushed the judgements. If that were the only factor, however, the shortest previews should have rushed observers the most. Some effect of event-onset on the perceptual system seems to be implicated as well.

Speed-Accuracy Tradeoffs

There are two indications of speed-accuracy tradeoffs in the data: (a) As preview period increases, error rates increase then decrease, whereas reaction times become shorter then longer (compare Figures 21 and 22). Varying the duration of the test segment had a similar effect in the Tobias and Owen (1983) experiment: Decreasing the duration resulted in increased error rates, moreso for deceleration events than constant speed. It appears that the briefer preview periods may have the effect of rushing the observer. (b) Error rates for deceleration events tend to be higher than constant-speed error rates, whereas reaction times tend to be shorter for deceleration events (again, compare Figures 21 and 22). These tradeoffs are complicated by the fact that for preview periods from 2.5 s through 40 s, deceleration error rates drop to the level of constant-speed error rates, while deceleration reaction times drop further below constant-speed reaction times. Neither dependent variable shows much change for the constant-speed events over this range of preview periods. The net effect is that for the longer preview

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periods deceleration detection becomes less difficult by both criteria.

Observers are probably attempting to detect deceleration, and if it is not detected, they default to a report of "constant" speed. When deceleration is constant throughout an event, as in this study and Denton's (1973, 1974) experiment, fractional loss in speed and flow rate increase exponentially. If fractional loss in flow is the functional information for detecting deceleration, as indicated by Owen et al. (1981), then the longer an observer waits, the more salient the relevant optical variable becomes. Not waiting for loss in speed to become apparent will result in a "constant" response. This would account for the fact that error rates are higher for deceleration events, whereas deceleration reaction times are shorter than those for constant speed. The effect of the 1.25-s preview period is to reduce reaction times for both event types by about 1 s relative to the 0-s condition. Supporting the speed–accuracy argument, error rates increase, with the loss in accuracy being greater for deceleration events. Thus, the shorter preview periods appear to "pace" the observer. The negative pacing effect does not dissipate until the preview segment reaches a duration of 20 s. After that, adaptation to flow appears to have a detrimental effect on constant-speed trials.

Denton (1976) demonstrated that when observers are told to maintain a constant speed, they will increase speed in a positively decelerating fashion, asymptoting after a period which increases in duration with initial speed. For this to occur, the observers must have been compensating for apparent deceleration due to adaptation (Figure 1). Likewise in the present experiment, observers would continue to experience deceleration due to adaptation during the 10-s test segment following a 40-s preview, leading to an increase in errors on constant trials (Figure 21). The same adaptation will occur on deceleration trials, summing, as Denton (1977) demonstrated, with the actual effect of deceleration during the test segment to reduce errors on deceleration trials. Adaptation is evidenced from the 5-s preview on for deceleration events. The overall effect, as evidenced by the bias-free A_g scores, is to markedly reduce sensitivity following the 40-s preview period, as compared with the 20-s preview.

One comparison of the present results can be made with events having the

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same segment durations in the Tobias and Owen (1983) experiment, i.e., 0- and 5-s preview segments followed by a 10-s test segment. For these conditions and a comparable fractional loss in speed of 9%/s, Tobias and Owen found 2.8-s improvement on deceleration trials and 1.7-s improvement on constant trials from 0- to 5-s preview. Since the Tobias and Owen flow rates were slower (0.4, 0.6, and 0.9 h/s), the most comparable condition in the present experiment is the slowest flow rate of 1.67 h/s. For the one-session data, increasing the preview period from 0 to 5 s resulted in a 0.6-s improvement on deceleration trials and 1.2-s improvement on constant trials. For the four-session data, the improvement was 0.7 s for both event types. Comparisons of Figure 5B with 11B and Figure 6B with 12B reveal that the direction and magnitude of the effect hold across all flow rates. Thus, the reaction-time effect is in the same direction as in the Tobias and Owen study, but the advantage for the 5-s preview was smaller, perhaps because the reaction times were 1.5 to 3.0 s shorter in the present study.

Changes in error rate with the addition of the 5-s preview, although comparable in magnitude in the two studies, were opposite in direction. For the condition with a 10-s test segment and 9%/s loss in speed, Tobias and Owen (1983) found 12.5% fewer errors on deceleration trials, and 6% fewer errors on constant-speed trials as preview duration increased from 0 to 5 s. For the 1.67-h/s flow rate in the present experiment, the 5-s preview resulted in 12% more errors for deceleration and 3% more errors for constant speed for the one-session data; 11% more errors for deceleration and 8% more errors for constant speed for the four-session data. Since Denton (1973, 1974) could not score his observers' performance, no comparison with error rates from the longer preview periods in the present experiment is possible.

Reaction times have a consistent relationship with preview period over the three studies, but the errors suggest different interpretations. The Tobias and Owen (1983) preview-period results indicate that both errors and reaction times index detection difficulty, a finding in common with the effects of optical variables in many studies. In contrast, the present data indicate a tradeoff in that shorter reaction times are accompanied by more errors, indicating insufficient information pick-up time. Given the complexity of the Flow Rate by Preview Period interaction, it is possible that

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different explanations apply to different combinations of the two variables.

It is apparent from Figure 23 that accuracy varies as a function of flow rate in a fashion that parallels Denton's (1973, 1974) finding for reaction time (Figure 3). Comparison of the mean correct reaction times shown in Figure 23 with the accuracy scores indicates that both variables index detection difficulty when performance is considered as a function of flow rate. This is a marked contrast with the speed/accuracy tradeoff observed for the effect of preview period. Accuracy improves less over the three slowest flow rates, then more rapidly than Denton's reaction times up to the 19.6-h/s flow rate used for practice trials. The highest flow rate is problematic because of the extremely high error rates for the 2.5- and 5-s preview durations. Even without those data included, however, sensitivity is poorer than at 19.6 h/s, indicating the same increase in difficulty as did Denton's reaction times at 26.1 h/s.

Interpretation of the flow-rate main effect, then, hinges critically on the data from the two highest flow rates. Including the two highest rates requires interpretation of a quadratic effect, a result meeting the criterion for a contextual variable which optimizes at intermediate levels. Excluding the two highest rates leaves an effect that meets the log-linear criterion for a functional variable, i.e., equal-ratio increments in magnitude result in equal-interval improvements in performance. For the first four flow rates, both accuracy and reaction time meet the functional criterion.

Of particular interest is the task specificity of the flow-rate effect. For the five flow rates below 26.1 h/s, performance in the deceleration-detection task improves as flow rate increases. By contrast, descent-detection performance deteriorates with increase in flow rate, by both accuracy and reaction-time criteria (Hettinger, Owen, & Warren, this paper; Wolpert & Owen, this paper). The same fractional loss in speed becomes easier to detect in the context of higher flow rates in the range encountered during driving and low-altitude flying, whereas higher flow rates increasingly interfere with descent detection when fractional loss in altitude is the same over events. This interaction between functional and contextual classes of optical variables is suggestive with regard to attention and/or selectivity of the mechanisms responsible for the two types of sensitivity to self-motion

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information.

A particularly curious aspect of the data is the radical increase in
error rate on deceleration trials for the fastest flow rate (26.1 h/s) with
preview periods of 2.5 and 5 s (Figure 4). Given that a parallel effect is
not evidenced at all by the reaction times (Panel B of Figures 9 to 12), the
result does not seem to index difficulty of detecting deceleration, i.e., the
observers show little uncertainty. Rather, it would seem that these events
appear to represent constant speed most of the time. The phenomenon is
relatively specific, since there is no evidence of it at preview periods of
1.25 or 10 s, or at the practice-trial flow rate of 19.6 h/s.

The effect may be a result of some interaction between the human visual
system and characteristics of the video system used to simulate optical
motion. If so, there does not appear to be any other evidence of the
phenomenon in the literature. Video simulation depends upon discrete
displacement from one "frame" to the next, rather than the continuous optical
displacement that occurs during real-world self motion, and the displacement
of a horizontal edge at a flow rate of 26.1 h/s is quite extensive from one
thirtieth of a second to the next. Although preview periods of comparable
durations have not been studied in actual driving, drivers do not seem to have
difficulty detecting flow-pattern transformations at 26.1 h/s (80 mi/hr).

From the standpoint of guiding further investigation, it would seem best
to isolate the phenomenon. Researchers interested in visual-video
interactions now have a set of event-duration and optical parameters and
levels thereof which identify a problem area. Researchers interested in
studying events which result in veridical self-motion perception outside the
simulation environment may want to avoid combinations of event-initiation and
flow-rate values which frequently result in misperception. Other than for
demonstration purposes, users of video simulation systems for training will
certainly want to avoid values which result in perceptual aberrations only
during simulation.

Conclusions

Under the conditions of this study, preview time has an effect on
sensitivity and reaction time that suggests a speed-accuracy tradeoff. The
tradeoff could be due to total event duration or to the spacing of the tones

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defining the preview segment. The two explanations could be separated by eliminating the second tone on half the trials. If the spacing of the tones is inducing a time stress which reduces observation time, the results do not bode well for situations in which pilots are time stressed by demands of a far more critical nature. On the other hand, if eliminating the second tone eliminates the speed-accuracy tradeoff, the resulting events would better mimic real-world situations. Varying the preview period would simply increase the uncertainty of onset of the changes in self motion, but the effect on difficulty in detecting change would have to be reassessed.

Only one level of fractional loss in speed (10%/s) was used, and it was hoped that a subsequent experiment would test the interaction of preview period and fractional change in speed. That experiment will have to be postponed until the complexity of the interaction with flow rate is worked out.

To be certain that the structure of the Flow Rate by Preview Period interaction was stable, both the one- and four-session data sets were somewhat "overpowered." In this application, the one-session design produced essentially the same structure as the four-session design, except for the emergence of an adaptation effect by the 40-s preview duration in the four-session data (Figures 21 and 24). Given the same amount of experimental effort, the possibility that the structure of the results will change with practice may be sufficient reason to use a multisession design with fewer observers, however. The disappearance of the interfering effect of high flow rates on descent detection as a result of training and practice is a case in point (Hetting : & Owen, 1985).

Appendix J: Inventory Of Event Variables

Table J-1. Inventory of Event Variables[a]

Event number	1 $\dot{x}_o/z$	2 $\ddot{x}/z$	3 $\dot{x}_o/g$	4 $\ddot{x}/g$	5 $\dot{x}_o$	6 $\ddot{x}$	7 $(\ddot{x}/\dot{x})_o$	8 z	9 g_x	10 g_y
1	1.63	0	.815	0	9.78	0	0	6	12	6
2	3.26	0	1.630	0	19.56	0	0	6	12	6
3	6.53	0	3.265	0	39.18	0	0	6	12	6
4	13.05	0	6.525	0	78.30	0	0	6	12	6
5	19.58	0	9.79?	0	117.48	0	0	6	12	6
6	26.10	0	13.050	0	156.60	0	0	6	12	6
7	1.63	-.163	.815	-.0815	9.78	-.978	-.10	6	12	6
8	3.26	-.326	1.630	-.163	19.56	-1.956	-.10	6	12	6
9	6.53	-.653	3.265	-.3265	39.18	-3.918	-.10	6	12	6
10	13.05	-1.305	6.525	-.6525	78.30	-7.830	-.10	6	12	6
11	19.58	-1.958	9.790	-1.305	117.48	-11.748	-.10	6	12	6
12	26.10	-2.610	13.050	-1.305	156.60	-15.660	-.10	6	12	6

Note. A dot over a symbol indicates a derivative with respect to time. A subscript of zero indicates the value of a variable at the initiation of an event, while a subscript of t indicates the value of a variable at any time during the event. Events 5 and 11 were used in the practice trials.

[a]
1. $\dot{x}_o/z$ = initial global optical flow rate (in eyeheights/s).
2. $\ddot{x}/z$ = global optical flow deceleration (in eyeheights/s^2).
3. $\dot{x}_o/g$ = initial edge rate (in edges/s).

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Table J-1 (Concluded)

4. $\ddot{x}/g$ = edge-rate deceleration (in edges/s^2).

5. $\dot{x}_o$ = initial forward velocity (m/sec).

6. $\ddot{x}$ = deceleration (m/s^2).

7. $(\ddot{x}/\dot{x})_o$ = initial fractional loss in flow rate, edge rate, and speed (in %/s).

8. z = altitude (in m).

9. g_x = ground-texture-unit size in the dimension parallel to the direction of travel (in m).

10. g_y = ground-texture-unit size in the dimension perpendicular to the direction of travel (in m).

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Appendix K: Inventory Of Performance Variables

Table K-1. Inventory of Performance Variables[a]

1 Preview period	2 $\dot{x}_o/z$	3 Event number	4 Percent error	5 Mean $1-A_g$	6 Mean RT_c	7 Mean cont.
One session (N = 112 observers)						
0	1.63	1	18.8		6.28	1.77
0	3.26	2	23.2		6.26	1.5e
0	6.53	3	8.0		5.66	1.38
0	13.05	4	19.6		5.71	1.54
0	19.58	5	5.3		4.25	1.42
0	26.10	6	6.2		4.73	1.30
0	1.63	7	18.8	12.5	5.12	5.39
0	3.26	8	27.7	19.2	5.55	5.53
0	6.53	9	27.7	11.6	5.78	5.47
0	13.05	10	8.0	7.1	4.29	5.75
0	19.58	11	28.4	14.3	3.71	5.46
0	26.10	12	19.6	8.9	4.43	5.69
1.25	1.63	1	33.9		5.35	1.82
1.25	3.26	2	9.8		4.83	1.53
1.25	6.53	3	22.3		4.59	1.55
1.25	13.05	4	11.6		4.20	1.40
1.25	19.58	5	8.3		3.01	1.34
1.25	26.10	6	8.9		3.57	1.31
1.25	1.63	7	23.2	22.3	4.28	5.51
1.25	3.26	8	35.7	20.1	4.56	5.50
1.25	6.53	9	21.4	15.2	4.27	5.58
1.25	13.05	10	26.8	15.2	4.09	5.55
1.25	19.58	11	32.3	14.7	2.84	5.38
1.25	26.10	12	38.4	16.5	4.12	5.53
2.50	1.63	1	25.0		4.91	1.80
2.50	3.26	2	16.1		4.36	1.71
2.50	6.53	3	21.4		4.71	1.54

Table K-1 (Continued)

1 Preview period	2 $\dot{x}_o/z$	3 Event number	4 Percent error	5 Mean $1-A_g$	6 Mean RT_c	7 Mean conf.
2.50	13.05	4	17.0		4.20	1.46
2.50	19.58	5	6.2		3.30	1.27
2.50	26.70	6	19.6		3.76	1.41
2.50	1.63	7	38.4	25.0	4.34	5.47
2.50	3.26	8	41.1	22.3	4.67	5.41
2.50	6.53	9	25.9	17.9	4.10	5.58
2.50	13.05	10	25.0	15.2	3.93	5.56
2.50	19.58	11	37.5	15.6	3.25	5.53
2.50	26.10	12	81.2	49.6	3.56	5.65
5.0	1.63	1	21.4		5.08	1.70
5.0	3.26	2	17.9		4.30	1.55
5.0	6.53	3	7.1		4.29	1.43
5.0	13.05	4	16.1		4.38	1.40
5.0	19.58	5	13.5		3.59	1.40
5.0	26.10	6	8.9		3.75	1.31
5.0	1.63	7	30.4	22.3	4.49	5.46
5.0	3.26	8	31.2	19.6	4.37	5.54
5.0	6.53	9	15.2	9.4	3.94	5.63
5.0	13.05	10	28.6	17.0	3.62	5.56
5.0	19.58	11	22.9	16.5	3.15	5.75
5.0	26.10	12	82.1	42.9	3.04	5.58
10.0	1.63	1	20.5		4.96	1.63
10.0	3.26	2	21.4		4.87	1.66
10.0	6.53	3	17.9		4.38	1.47
10.0	13.05	4	19.6		4.50	1.43
10.0	19.58	5	8.3		3.64	1.33
10.0	26.10	6	17.9		4.23	1.31
10.0	1.63	7	22.3	16.5	4.31	5.51

Table K-1 (Continued)

1 Preview period	2 $\dot{x}_o/z$	3 Event number	4 Percent error	5 Mean $1-A_g$	6 Mean RT_c	7 Mean conf.
10.0	3.26	8	33.9	24.1	4.68	5.46
10.0	6.53	9	29.5	20.1	4.18	5.59
10.0	13.05	10	22.3	13.4	3.57	5.64
10.0	19.58	11	29.2	15.2	3.29	5.66
10.0	26.10	12	24.1	16.5	3.46	5.71
20.0	1.63	1	24.1		5.75	1.62
20.0	3.26	2	13.4		5.00	1.45
20.0	6.54	3	15.2		4.86	1.48
20.0	13.05	4	15.2		4.77	1.41
20.0	19.58	5	6.2		3.94	1.31
20.0	26.10	6	13.4		4.03	1.39
20.0	1.63	7	20.5	14.3	4.60	5.58
20.0	3.26	8	25.9	15.6	4.25	5.62
20.0	6.53	9	23.2	13.4	4.05	5.66
20.0	13.05	10	18.8	12.5	3.90	5.65
20.0	19.58	11	18.6	12.1	3.45	5.66
20.0	26.10	12	21.4	10.7	3.67	5.73
40.0	1.63	1	27.7		5.79	1.56
40.0	3.26	2	15.1		5.07	1.58
40.0	6.53	3	20.5		4.91	1.46
40.0	13.05	4	20.5		4.78	1.49
40.0	19.58	5	9.4		3.98	1.33
40.0	26.10	6	9.8		4.40	1.29
40.0	1.63	7	19.6	15.6	4.77	5.50
40.0	3.26	8	14.3	10.7	4.13	5.60
40.0	6.53	9	23.2	14.7	4.15	5.64
40.0	13.05	10	17.0	13.8	3.75	5.62
40.0	19.58	11	18.8	11.2	3.61	5.72

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1 Preview period	2 $\dot{x}_o/z$	3 Event number	4 Percent error	5 Mean $1-A_g$	6 Mean RT_c	7 Mean conf.
40.0	26.10	12	23.2	12.5	3.61	5.69

		Four sessions (N = 42 observers)				
0	1.63	1	19.6		5.49	1.70
0	3.26	2	25.0		5.40	1.56
0	6.53	3	5.4		4.88	1.32
0	13.05	4	14.3		5.03	1.54
0	19.58	5	1.2		3.81	1.36
0	26.10	6	8.3		4.29	1.33
0	1.63	7	20.8	15.2	4.62	5.38
0	3.26	8	28.0	23.2	5.11	5.43
0	6.53	9	28.6	11.9	5.26	5.48
0	13.05	10	9.5	9.2	4.01	5.65
0	19.58	11	19.8	6.8	3.63	5.54
0	26.10	12	33.9	17.6	4.22	5.60
1.25	1.63	1	35.1		4.86	1.69
1.25	3.26	2	7.1		4.23	1.45
1.25	6.53	3	22.6		4.13	1.46
1.25	13.05	4	9.5		3.94	1.48
1.25	19.58	5	5.6		3.02	1.29
1.25	26.10	6	12.5		3.48	1.31
1.25	1.63	7	21.4	22.3	4.04	5.44
1.25	3.26	8	38.1	18.2	4.12	5.54
1.25	6.53	9	21.4	19.0	4.02	5.51
1.25	13.05	10	29.8	17.3	3.78	5.56
1.25	19.58	11	26.5	11.3	2.92	5.54
1.25	26.10	12	33.9	19.6	3.85	5.57
2.50	1.63	1	17.8		4.79	1.61

Table $\underline{K-1}$ (Continued)

1 Preview period	2 $\dot{x}_o/z$	3 Event number	4 Percent error	5 Mean $1-A_g$	6 Mean RT_c	7 Mean conf.
2.50	3.26	2	13.1		4.00	1.49
2.50	6.53	3	22.6		3.97	1.52
2.50	13.05	4	14.9		4.04	1.42
2.50	19.58	5	2.5		3.15	1.28
2.50	26.10	6	16.1		3.67	1.37
2.50	1.63	7	35.7	23.2	4.10	5.52
2.50	3.26	8	42.3	22.6	4.30	5.46
2.50	6.53	9	26.2	18.5	3.68	5.55
2.50	13.05	10	19.6	12.2	3.66	5.62
2.50	19.58	11	25.3	12.5	3.07	5.64
2.50	26.10	12	79.8	46.1	3.53	5.64
5.0	1.63	1	28.6		4.80	1.70
5.0	3.26	2	19.6		4.20	1.49
5.0	6.53	3	5.4		3.93	1.33
5.0	13.05	4	27.4		3.82	1.45
5.0	19.58	5	7.4		3.25	1.33
5.0	26.10	6	10.7		3.71	1.33
5.0	1.63	7	32.1	27.1	3.98	5.45
5.0	3.26	8	36.3	24.7	3.92	5.54
5.0	6.53	9	27.4	14.6	3.63	5.61
5.0	13.05	10	26.2	22.0	3.30	5.70
5.0	19.58	11	14.8	6.0	2.83	5.69
5.0	26.10	12	80.0	43.5	3.13	5.66
10.0	1.63	1	25.6		4.60	1.59
10.0	3.26	2	18.4		4.45	1.57
10.0	6.53	3	19.0		4.08	1.36
10.0	13.05	4	14.9		4.21	1.43
10.0	19.58	5	4.9		3.27	1.23

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Table K-1 (Continued)

1	2	3	4	5	6	7
Preview period	$\dot{x}_o/z$	Event number	Percent error	Mean $1-A_g$	Mean RT_c	Mean conf.
10.0	26.10	6	24.4		3.73	1.29
10.0	1.63	7	27.4	20.8	3.91	5.51
10.0	3.26	8	36.3	23.8	4.00	5.54
10.0	6.53	9	32.1	24.4	3.77	5.62
10.0	13.05	10	18.4	10.7	3.48	5.61
10.0	19.58	11	12.3	6.8	2.84	5.72
10.0	26.10	12	30.4	24.1	3.13	5.71
20.0	1.63	1	18.5		5.07	1.52
20.0	3.26	2	22.0		4.09	1.47
20.0	6.53	3	11.9		4.16	1.36
20.0	13.05	4	16.7		4.27	1.43
20.0	19.58	5	4.3		3.46	1.24
20.0	26.10	6	11.9		3.61	1.36
20.0	1.63	7	21.4	17.6	3.99	5.58
20.0	3.26	8	19.0	14.9	3.59	5.62
20.0	6.53	9	31.0	15.5	3.69	5.65
20.0	13.05	10	18.5	12.5	3.61	5.61
20.0	19.58	11	14.8	7.7	3.07	5.74
20.0	26.10	12	14.9	7.4	3.31	5.74
40.0	1.63	1	34.5		5.56	1.55
40.0	3.26	2	10.7		4.31	1.48
40.0	6.53	3	26.2		4.28	1.32
40.0	13.05	4	27.4		4.22	1.37
40.0	19.58	5	11.1		3.61	1.29
40.0	26.10	6	11.9		3.90	1.35
40.0	1.63	7	18.5	21.7	4.05	5.51
40.0	3.26	8	13.7	9.5	3.84	5.64
40.0	6.53	9	28.0	27.1	3.65	5.65

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Table K-1 (Concluded)

1	2	3	4	5	6	7
Preview period	$\dot{x}_o/z$	Event number	Percent error	Mean $1-A_g$	Mean RT_c	Mean conf.
40.0	13.05	10	25.0	23.5	3.46	5.59
40.0	19.58	11	12.3	8.9	2.99	5.76
40.0	26.10	12	30.0	16.1	3.15	5.67

[a]1. Preview period = Initial event-segment duration (s).

2. $\dot{x}_o/z$ = initial global optical flow rate (eyeheights/s).

3. Event number = identifies a row in Table J-1, Inventory of Event Variables.

4. Percent error.

5. Mean $1-A_g$ = mean area above isosensitivity curve, where total area = 100.

6. Mean RT_c = Mean reaction time for correct responses (s).

7. Mean conf. = Mean confidence rating converted to a 6-point scale (1 = "Very certain constant" to 6 = "Very certain decelerating").

Appendix L: Instructions

EXPERIMENTER; SEAT THE OBSERVER, THEN READ EXACTLY:

Welcome to the Aviation Psychology Laboratory. We conduct research which deals with perceptual factors in aviation. In this experiment, we are interested in your sensitivity to decrease in traveling speed. We want to find out how well you can visually detect deceleration in the absence of motion cues, such as the feeling of being pushed forward in your seat as the car in which you are riding decelerates.

You will be shown computer-generated scenes on the screen which represent forward travel in an airplane over open, flat fields. The displayed speed will be constant in some events, and will decelerate in others. Your task will be to press the button labeled "C" if you believe the event represents constant speed, or press the button labeled "D" if you believe the speed is slowing down, or decelerating.

The size of the simulated fields will be the same for every event, but the simulated speed will vary. No matter how fast or slow the speed or how long or short the entire event, you should base your judgment only on whether you see deceleration or constant speed over the course of the event.

Sometimes you may notice scintillation or shimmering near the horizon. Please ignore this effect; it is due to limitations of our equipment.

The specific procedure is as follows:

1. Before the beginning of each event, I will say "ready." Turn your full attention to the screen at that time.

2. Most events will begin with a period of constant travel, after which you will hear a tone. After the tone, the event may continue at a constant speed, or begin to decelerate. Each event will continue for 10 seconds after the tone. In one block, each of the 12 events will begin with the tone immediately. These events will be called "zero-second preview." If the event represents constant speed, it will remain constant. If deceleration is represented, the speed will begin to decrease immediately in the zero-second block. All of the events within a given block of 12 will have the same preview or constant-speed period. Preceding each block, I will tell you how many seconds the preview period will last

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before the tone sounds. It is important that you watch the screen during the entire event.

3. As soon _after the tone_ as you can distinguish which type of motion is represented, press the button corresponding to your choice ("D" for deceleration or "C" for constant). You do _not_ have to wait until the end of the event to press the button, but a judgment must be made for each event. Indicate your choice _as quickly as possible, without guessing_. Please be certain that you press the button only _once_ per event, and do not press either button between events.

4. After you press one of the buttons, please rate your confidence in the accuracy of your decision by saying "one" if you are not very certain, "two" if you are moderately certain, or "three" if you are very certain that you made the correct choice.

5. EXPERIMENTER; FIRST SESSION ONLY: We will begin with two practice events to acquaint you with the procedure. Including the practice events, you will judge a total of 84 events.
Do you have any questions?

6. EXPERIMENTER; EXPLANATION OF THE PRACTICE SCENES:
Scene #1 represents descent, i.e., loss in speed.
Scene #2 represents travel at a constant speed, i.e., level travel.

7. EXPERIMENTER; READ AT THE BEGINNING OF _BLOCK A_ ONLY: For this block of 12 trials, there will be no preview period. Therefore, you will hear only one tone. As soon after the tone as you can distinguish which type of event is represented, press the button corresponding to your choice.

Appendix M: Analysis Of Variance Summary Tables

Table M-1. Analysis of Variance for All Events with Screen Size
as a Grouping Factor

Source	df	SS	R^2(%)	F	p > F
Error					
Screen size (S)	1	1.29	0.1	1.03	.3145
Event type (E)	1	11.27	1.2	20.29	.0000
Initial flow rate (F)	5	5.51	0.6	9.09	.0000
Preview period (P)	6	11.32	1.3	15.04	.0000
FS	5	1.36	0.2	2.24	.0495
EF	5	16.59	1.8	18.28	.0000
EP	6	7.70	0.9	11.87	.0000
FP	30	27.49	3.0	8.60	.0000
FPS	30	4.81	0.5	1.51	.0387
EFP	30	22.96	2.5	7.70	.0000
Pooled error	6097	793.35	88.0	–	–
Total	6215	902.36	100.0	–	–
Reaction time					
Screen size (S)	1	203.50	0.5	0.86	.3561
Event type (E)	1	1106.37	2.5	33.21	.0000
Inital flow rate (F)	5	1307.38	2.9	65.49	.0000
Preview period (P)	6	634.53	1.4	10.23	.0000
EF	5	88.31	0.2	3.97	.0016
EP	6	48.98	0.1	2.54	.0200
FP	30	129.75	0.3	1.59	.0220
Pooled error	6162	41312.81	92.6	–	–
Total	6215	44628.13	100.0	–	–

Note. Each effect was tested using the appropriate error term given by the model and is significant at the $p < .05$ level or better, except Screen size.

Table M-2. Analysis of Variance for Decelerating Events with
Screen Size as a Grouping Factor

Source	df	S	R^2(%)	F	p > F
Error					
Screen size (S)	1	1.59	0.3	1.27	.2626
Initial flow rate (F)	5	13.77	2.6	13.36	.0000
Preview period (P)	6	15.47	2.9	20.21	.0000
FP	30	46.92	8.7	13.57	.0000
FS	5	2.43	0.5	2.89	.0142
Pooled error	3061	459.22	85.3	–	–
Total	3107	537.81	100.0	–	–
Reaction time					
Screen size	1	138.09	0.9	1.83	.1807
Initial flow rate (F)	5	607.68	4.1	33.60	.0000
Preview period (P)	6	246.68	1.7	8.99	.0000
FP	30	143.71	1.0	2.13	.0004
Pooled error	3066	13836.56	93.2	–	–
Total	3107	14834.21	100.0	–	–

Note. Each effect was tested using the appropriate error term given by
the model and is significant at the $p < .05$ level or better.

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Table M-3. Analysis of Variance for All Events

Source	df	S	R^2(%)	F	p > F
Event type (E)	1	35.02	2.2	60.96	.0000
Initial flow rate (F)	5	9.57	0.6	13.21	.0000
Preview period (P)	6	14.59	0.9	15.95	.0000
EF	5	22.46	1.4	22.00	.0000
EP	6	11.89	0.7	17.64	.0000
FP	30	26.22	1.6	7.16	.0000
FP x order (O)	390	54.83	3.4	1.15	.0288
EFP	30	24.65	1.5	6.87	.0000
EFPO	390	60.02	3.7	1.29	.0003
Pooled error	8544	1351.93	84.0	–	–
Total	9407	1611.18	100.0	–	–
	Reaction time				
Order (O)	13	4554.64	9.4	1.97	.0315
Event type (E)	1	981.14	2.0	47.40	.0000
Initial flow rate (F)	5	1814.21	3.7	123.23	.0000
Preview period (P)	6	1285.72	2.7	27.49	.0000
⁻F	5	87.03	0.2	8.54	.0000
PO	78	823.56	1.7	1.35	.0292
EP	6	656.80	0.1	4.53	.0002
EPO	78	217.65	0.4	1.33	.0361
FP	30	160.61	0.3	3.56	.0000
EFP	30	84.27	0.2	1.91	.0021
Pooled error	9155	38390.56	79.3	–	–
Total	9407	48456.19	100.0	–	–

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Source	df	S	R^2(%)	F	p > F
Confidence rating					
Event type (E)	1	39625.73	91.3	4558.64	.0000
Initial flow rate (F)	5	13.49	0.0	8.73	.0000
EF	5	73.56	0.2	36.38	.0000
E x preview period (P)	6	9.21	0.0	3.55	.0018
FP	30	19.92	0.0	2.62	.0000
FP x order	390	112.35	0.3	1.14	.0438
EFP	30	11.60	0.0	1.51	.0376
Pooled error	8940	3531.93	8.2	–	–
Total	9407	43397.79	100.0	–	–
Area above the isosensitivity curve					
Preview period (P)	6	8.35	1.7	15.43	.0001
Initial flow rate (F)	5	4.83	1.0	10.82	.0001
PF	30	14.69	3.1	6.65	.0001
PF x order	390	32.65	6.8	1.14	.0415

Note. Each effect was tested using the appropriate error term given by the model and is significant at the $p < .05$ level or better.

Table M-4. Analysis of Variance for Decelerating Events

Source	df	S	R^2(%)	F	p > F
Error				
Initial flow rate (F)	5	20.72	2.2	20.51	.0000
Preview period (P)	6	25.33	2.7	27.23	.0000
FP	30	43.45	4.6	10.62	.0000
FP x order	390	62.22	6.6	1.17	.0168
Pooled error	4272	797.43	83.9	-	-
Total	4703	949.15	100.0	-	-
Reaction time				
Order (O)	13	1407.72	8.4	1.86	.0446
Initial flow rate (F)	5	665.02	4.0	66.85	.0000
Preview period (P)	6	524.23	3.1	24.49	.0000
FO	65	203.35	1.2	1.57	.0045
PO	78	479.21	2.9	1.72	.0003
FP	30	127.39	0.8	3.16	.0000
Pooled error	4506	13328.33	79.6	-	-
Total	4703	16735.25	100.0	-	-
Confidence rating				
Initial flow rate (F)	5	14.75	0.8	9.07	.0000
Preview period (P)	6	8.41	0.5	3.73	.0012
FP	30	15.71	0.8	1.98	.0011
Pooled error	4662	1809.62	97.9	-	-
Total	4703	1848.49	100.0	-	-

Note. Each effect was tested using the appropriate error term given by the model and is significant at the $p < .05$ level.

Table M-5. Analysis of Variance for All Events

Source	df	S	$R^2(\%)$	F	p > F
Error					
Event type (E)	1	48.82	2.0	23.23	.0000
Initial flow rate (F)	5	39.51	1.6	26.04	.0000
Preview period (P)	6	15.87	0.7	13.44	.0000
EF	5	31.32	1.3	17.19	.0000
EP	6	18.26	0.8	23.92	.0000
FP	30	38.03	1.6	8.16	.0000
EFP	30	43.36	1.8	8.45	.0000
E x session (S)	3	2.03	0.1	2.92	.0389
EFS	15	4.23	0.2	2.05	.0112
PS	18	4.05	0.2	1.88	.0154
EFPS x order	1170	154.40	6.4	1.22	.0000
Pooled error	12822	2001.13	83.3	-	-
Total	14111	2401.01	100.0	-	-

Source	df	S	$R^2(\%)$	F	p > F
Reaction time					
Event type (E)	1	742.01	1.5	20.22	.0001
Initial flow rate (F)	5	1860.66	3.7	69.93	.0000
Preview period (P)	6	1103.66	2.2	52.96	.0000
Session (S)	3	194.99	0.4	2.84	.0427
EF	5	97.13	0.2	10.92	.0000
P x order (O)	78	419.52	0.8	1.55	.0099
EP	6	59.63	0.1	6.82	.0000
FP	30	128.04	0.3	3.22	.0000
EFP	30	85.00	0.2	2.31	.0001
EFPO	390	551.31	1.1	1.15	.0465
PS	18	116.96	0.2	2.10	.0051
PSO	234	949.50	1.9	1.31	.0063
FPS	90	136.29	0.3	1.33	.0208

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Source	df	S	$R^2(\%)$	F	p > F
FPSO	11170	1444.86	2.9	1.09	.0438
Pooled error	2045	42786.72	84.2	-	-
Total	14111	50676.28	100.0	-	-

Confidence rating					
Event type (E)	1	61021.05	91.7	1440.42	.0000
Initial flow rate (F)	5	12.22	0.0	6.79	.0000
EF	5	103.01	0.2	29.29	.0000
EF x order (O)	65	64.95	0.1	1.42	.0439
E x preview period (P)	6	21.17	0.0	6.63	.0000
FP	30	12.14	0.0	1.64	.0168
EFP	30	13.89	0.0	1.89	.0028
FO x session (S)	195	53.69	0.1	1.29	.0164
EPS	18	11.65	0.0	1.86	.0172
FPSO	1170	284.77	0.4	1.13	.0_84
Pooled error	12586	4924.21	7.5	-	-
Total	14111	66522.75	100.0	-	-

Area above the isosensitivity curve					
Preview period (P)	6	9.13	1.3	11.76	.0001
Initial flow rate (F)	5	19.36	2.5	21.52	.0001
PF	30	23.57	3.3	8.97	.0001
F x session	15	2.32	0.3	1.91	.0208
Pooled error	6999	668.95	92.6	-	-
Total	7055	722.33	100.0	-	-

Note. Each effect was tested using the appropriate error term given by the model and is significant at the $p < .05$ level or better.

Table M-6. Analysis of Variance for Decelerating Events

Source	df	S	$R^2(\%)$	F	p > F
Error					
Initial flow rate (F)	5	45.00	3.2	23.48	.0000
Preview period (P)	6	30.01	2.1	28.30	.0000
FP	30	59.92	4.2	11.15	.0000
F x session (S)	15	6.25	0.4	2.60	.0010
FPS	90	13.67	1.0	1.27	.0476
FPS x order	1170	157.30	11.2	1.12	.0103
Pooled error	5739	1098.50	77.9	–	–
Total	7055	1410.65	100.0	–	–
Reaction time					
Order (O)	13	3658.24	18.7	2.14	.0448
Initial flow rate (F)	5	672.68	3.4	45.92	.0000
Preview period (P)	6	587.28	3.0	38.48	.0000
FO	65	292.64	1.5	1.54	.0182
FP	30	149.03	0.8	4.37	.0000
FPO	390	570.69	2.9	1.29	.0015
O x session (S)	39	656.89	3.4	1.62	.0328
FS	15	41.30	0.2	1.99	.0151
PSO	234	505.75	2.6	1.21	.0407
Pooled error	6258	12419.23	63.5	–	–
Total	7055	19553.74	100.0	–	–

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Table M-6 (Concluded)

Source	df	S	R^2(%)	F	p > F
Confidence rating					
Initial flow rate (F)	5	27.23	1.0	10.73	.0000
Preview period (P)	6	18.22	0.7	7.55	.0000
FP	30	11.27	0.4	1.56	.0290
Session (S)	3	14.73	0.5	3.07	.0322
FPS x order	1170	276.40	9.9	1.12	.0090
Pooled error	5841	2440.43	87.5	–	–
Total	7055	2788.28	100.0	–	–

Note. Each effect was tested using the appropriate error term given by the model and is significant at the p < .05 level or better.

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THE INFLUENCE OF PREVIEW PERIOD ON SENSITIVITY TO LOSS IN ALTITUDE

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Gibson (1958a) noted that loss in altitude is accompanied by optical magnification of surface texture elements and acceleration in the flow of optical texture discontinuities. He proposed that such transformations in the optical flow pattern are potential sources of information for detecting and guiding self motion, since optical variables are specific to the relationship between an observer's self motion and surfaces of the environment.

Hettinger, Owen, and Warren (this paper) isolated three global optical variables which might serve as information for detecting loss in altitude: (a) global optical flow acceleration, (b) decrease in global optical texture density, and (c) increase in optical (perspectival) splay angle. They noted that holding optical flow constant during descent also holds fractional loss in altitude constant within an event. Consequently, rate of increase in optical splay angle becomes a within-event invariant.

Owen, Warren, and Mangold (in press) found that fractional loss in altitude ($\dot{z}/z$, where $\dot{z}$ = sink rate, and z = altitude) was the functional variable for detecting descent. Hettinger et al. (this paper) found that fractional loss in altitude accounted for more variance in performance than did any of the other variables.

Previous research contrasting 0- and 5-s constant-speed preview segments of events representing level self motion indicated that the duration of constant speed preceding a change in the event is important for detecting deceleration (Tobias, 1983; Tobias & Owen, 1983). Results showed that the 5-s preview segment resulted in increased accuracy and shorter reaction times.

Denton (1973, Experiment 8; 1974, Experiment 7) contrasted 10- and 120-s constant-speed preview segments to study adaptation effects on time to detect change in speed in a driving simulator. Deceleration performance worsened as preview-period duration increased. Additionally, 80% of the adaptation effect present in an another experiment was completed by 40 s (Denton, 1976).

Owen, Hettinger, Pallòs, and Fogt (this paper) crossed seven preview

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periods with Denton's (1973, 1974) six flow rates to test for an interaction. Observers viewed computer-generated events which represented either constant speed or deceleration, with instructions to respond as soon as they could determine whether the event represented constant speed or deceleration. For preview durations from 0 through 2.5 s, the results showed a classic speed/accuracy tradeoff. As preview period increased, mean correct reaction time for decelerating events decreased while percent error increased. In addition, reaction times for decelerating events were shorter than for constant speed, whereas error rates were higher for events representing deceleration. As preview period increased to 40 s, constant-speed reaction times and errors increased, showing the negative effects of adaptation to forward speed.

Maintaining constant altitude is important during low-altitude high-speed flight. Tests of loss in sensitivity to loss in altitude may provide measures important in assessing possible detrimental event-onset effects, as well as effects and aftereffects of adaptation.

The current study is a preliminary experiment to aid in selecting levels of optical and event-duration variables for subsequent experiments investigating the influence of preview period and global optical flow rate on the detection and control of loss in altitude. The present experiment crossed an extensive range of values of fractional loss in altitude with several preview periods in order to assess the influence of viewing events which begin with a period of constant altitude on sensitivity to information distinguishing descent from continued level flight. The values of fractional loss in altitude and preview period used in this study extended the range of values employed by Owen et al. (this paper), Tobias & Owen (1983), and Wolpert, Owen, & Warren (1983). Additionally, this experiment utilized a single value of global optical flow rate between the values used by Tobias and Owen (1983) and Denton (1973, Experiment 8; 1974, Experiment 7). A low value of flow rate was chosen because previous studies (Hettinger, Owen, & Warren, this paper; Wolpert, Owen, & Warren, 1983) revealed that sensitivity to descent decreases as flow rate is increased.

The experiment was designed to assess any interaction occurring between preview period and fractional loss over broad ranges of both variables. If

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sensitivity to loss in altitude varies with both parameters, then the results of experiments with a particular preview period and a given set of fractional-loss values cannot be generalized to events with other values of either variable. Future experiments would have to include several levels of each. If no interaction results, then one or more preview-period durations can be selected without concern for any differential influence that preview period might have on sensitivity to loss in altitude.

Method

Apparatus and General Scene Parameters

The simulated flight events were generated by a PDP 11/34 computer and a special purpose scene generator in real time (see Yoshi, 1980). The 30 frames/s scene-generator sampling rate matched the video projector scanning rate. Each event was displayed via two Sony KP-7240 video projection units having screens 1.5 m wide and 1.125 m high. This arrangement resulted in a 34.3 deg x 26.1 deg field of view when the observer was seated on an elevated chair 2.43 m in front of the screen. The height of the simulated horizon was fixed at 56.25 cm above the bottom edge of the screen. The viewpoint of the observer was at the level of the horizon 1.95 m above the floor.

All scenes represented either level flight or descent beginning at an initial altitude of 72 m (z dimension) over a flat, rectangular island extending 30.72 km parallel to the direction of travel (x dimension) and 114 m perpendicular to the direction of travel (y dimension). Square ground-surface texture blocks were used throughout the experiment. The texture blocks, which were 72 m long (x dimension) and 72 m wide (y dimension), represented fields on the island. Four earth colors (light green, dark green, light brown, and dark brown) were randomly assigned to the texture blocks so that no two blocks of the same color were adjacent in the x or y dimensions. The area above the horizon was a pale blue-gray, and the non-textured area surrounding the island was dark gray.

Design

Two event types (level flight and descent) were crossed with six levels of fractional loss in altitude ($\dot{z}/z$ = .625, 1.25, 2.50, 5.0, 7.0, and 10.0%/s) and seven preview periods (0, 1.25, 2.50, 5.0, 10.0, 20.0, and 40.0 s) to create 84 unique events in each of two sessions. An inventory of the

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displayed events is presented in Table 1.

Table 1. Inventory of Event and Performance Variables[a]

	1	2	3	4	5	6	7	8
Event number	$(\dot{z}/z)_t$	$(\dot{z}/\dot{x})_t$	$\dot{z}_0$	$r_{\dot{z}}$	% err	$\overline{1-A}_g$	$\overline{RT}_c$	$\overline{Conf}$
1	0	0	0	1.000	12.1	–	4.39	1.49
2	−0.625	−0.625	−0.45	.994	71.7	38.4	5.80	5.30
3	−1.25	−1.25	−0.90	.988	52.6	31.9	5.22	5.29
4	−2.5	−2.5	−1.80	.975	22.4	12.5	4.08	5.47
5	−5.0	−5.0	−3.60	.951	5.4	3.7	2.54	5.83
6	−7.0	−7.0	−5.04	.932	9.7	5.7	2.18	5.83
7	−10.0	−10.0	−7.20	.905	4.3	2.9	1.80	5.86

Note. A dot over a symbol indicates a derivative with respect to time. A subscript of zero indicates the value of a variable at the initiation of an event, while a subscript of t indicates the value of a variable at any time during the event.

[a]
1. $(\dot{z}/z)_t$ = fractional loss in altitude (%/s).

2. $(\dot{z}/\dot{x})_t$ = path slope (%).

3. $\dot{z}_0$ = initial descent rate (m/s).

4. $r_{\dot{z}}$ = rate of change in loss in altitude.

5. % err = percent error.

6. $\overline{1-A}_g$ = area above the isosensitivity curve, where total area = 100.

7. $\overline{RT}_c$ = mean correct reaction time (s).

8. $\overline{Conf}$ = mean confidence rating converted to a 6-point scale (1 = "very certain level" to 6 = "very certain descent").

Each event consisted of a 0-, 1.25-, 2.5-, 5.0-, 10.0-, 20.0-, or 40.0-s preview segment of level flight followed by a 10.0-s test segment of either

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continued level flight or descent, with initial path speed of 72 m/s. Therefore, an event lasted 10.0, 11.25, 12.5, 15.0, 20.0, 30.0, or 50.0 s. Fractional loss in altitude ($\dot{z}/z$) and path slope ($\dot{z}/\dot{x}$, where $\dot{x}$ = forward speed) were invariant and equal in value throughout an event, resulting in an invariant global optical flow rate ($\dot{s}/z$, where $\dot{s}$ = path speed) of 1 eyeheights/s. (See Hettinger, Owen, & Warren, this paper, for the necessary formulae.) Constant flow was used because previous research has shown that observers do not use optical flow acceleration for detecting loss in altitude (Hettinger, Owen, & Warren, this paper; Hettinger, Warren, & Owen, 1982) and because optical flow acceleration may actually interfere with descent detection (Wolpert & Owen, this paper; Wolpert, Owen, & Warren, 1983). The conditions are ecologically valid, as deceleration occurs along the path slope for the typical landing approach of rotary-wing and many Vertical/Short Take-off and Landing (V/STOL) aircraft (Armstrong, Hofmann, Sanders, Stone, & Bowen, 1975; Hennessy, Sullivan, & Cooles, 1980).

The resulting 42 descent events were matched by 42 level events in preview period and event duration. Each block of 12 events consisted of 6 descent events and 6 level events (one level event replicated six times) within each preview period.

The seven preview periods were blocked using a 7 x 7 Latin-square design (Winer, 1971) so that observers would have no uncertainty with regard to the preview period within a block. Each block began with two practice events, one representing level flight ($\dot{z}/z$ = 0%/s) and one representing descent ($\dot{z}/z$ = 1.0%/s). For Session 1, the 10 subsequent events within each block were randomly presented with the constraint that no more than four events of one type (level or descent) would occur in sequence. Additionally, no block began or ended with more than two events of the same type. For Session 2, the set of event orders were generated by reversing the order within each block of events used in Session 1. Two sessions were used to provide more observations per event type and to test for improvement over sessions.

The crossing of seven block orders with two within-block orders (original and reverse) required 14 observers to produce complete counterbalancing. The design was repeated twice for a total of 28 observers. Observers were assigned to one of the 14 block-order combinations during Session 1 when they appeared

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for testing, and were tested with each of the 84 unique events during both sessions.

Procedure

Whenever possible, two observers were tested simultaneously. Both observers received identical block-order combinations of events during both testing sessions. The testing procedure for a single observer was identical to that of two observers.

An accoustic tone signaled each observer to give full attention to the screen. For all preview periods except the 0-s condition, a second tone separated the level flight preview segment from the 10-s test segment. The observer was instructed to view each computer-generated event and to indicate as soon as he decided whether the displayed event represented level flight or descent. The observer responded by pressing one of two buttons on a hand-held response box as soon as the decision was made. One button was labeled "L" for level; the other, "D" for descent. The observer also pressed one of three buttons to indicate the level of confidence in the decision ("1" = not very certain, "2" = moderately certain, "3" = very certain). (Appendix N contains the complete instructions.) The computer recorded the observer's response, confidence level, and reaction time. No performance feedback was provided during the experiment.

Observers

Twenty-eight male undergraduate students from The Ohio State University served as observers in order to fulfill an extra-credit option of an introductory psychology course. All observers claimed no previous experience in flight simulators or in piloting actual aircraft.

Results

Repeated-measures analyses of variance were performed for error, reaction time, mean confidence rating, and area above the isosensitivity curve (A_g) data. All effects discussed reached at least the $p < .05$ level of significance and accounted for at least 1.5% of the total variance, unless noted otherwise. (Appendix O contains the analysis of variance summary tables.) Percent error, area above the isosensitivity curve, mean correct reaction time, and mean confidence ratings for each event type are given in the last four columns of Table 1. Table 2 presents the mean correct and

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incorrect reaction times by preview period. It is clear that reaction times are shortest when the preview period is 1.25 or 2.50 s. The fact that error reaction times are longer than correct times is because more errors were made on trials where fractional loss was lower and descent was more difficult to detect.

Table 2. Mean Reaction Time by Preview Period[a]

	2	3	4	5
	Descent		Level	
Preview period	$\overline{RT}_c$	$\overline{RT}_1$	$\overline{RT}_c$	$\overline{RT}_i$
	3.39	4.60	4.71	6.08
1.25	2.72	3.87	4.17	4.89
	2.80	4.05	3.83	5.55
	2.72	4.33	4.15	5.39
	3.09	4.20	4.41	6.02
	3.11	4.76	4.57	5.67
	3.47	4.74	4.92	6.38

Note. Mean reaction times for descent were obtained by pooling across the levels of fractional loss within each preview period.

[a] Preview period = initial event-segment duration (s).

[b] $\overline{RT}_c$ = mean correct reaction time (s).

[c] $\overline{RT}_i$ = mean incorrect reaction time (s).

For descent events, fractional loss in altitude ($\dot{z}/z$) accounted for the variance in error rate and 20.65% of the variance in reaction time. Columns 1, 2, and 3 show that increasing the rate of fractional loss in altitude resulted in lower error rates (percent "level" reports on descent trials) and reaction times.

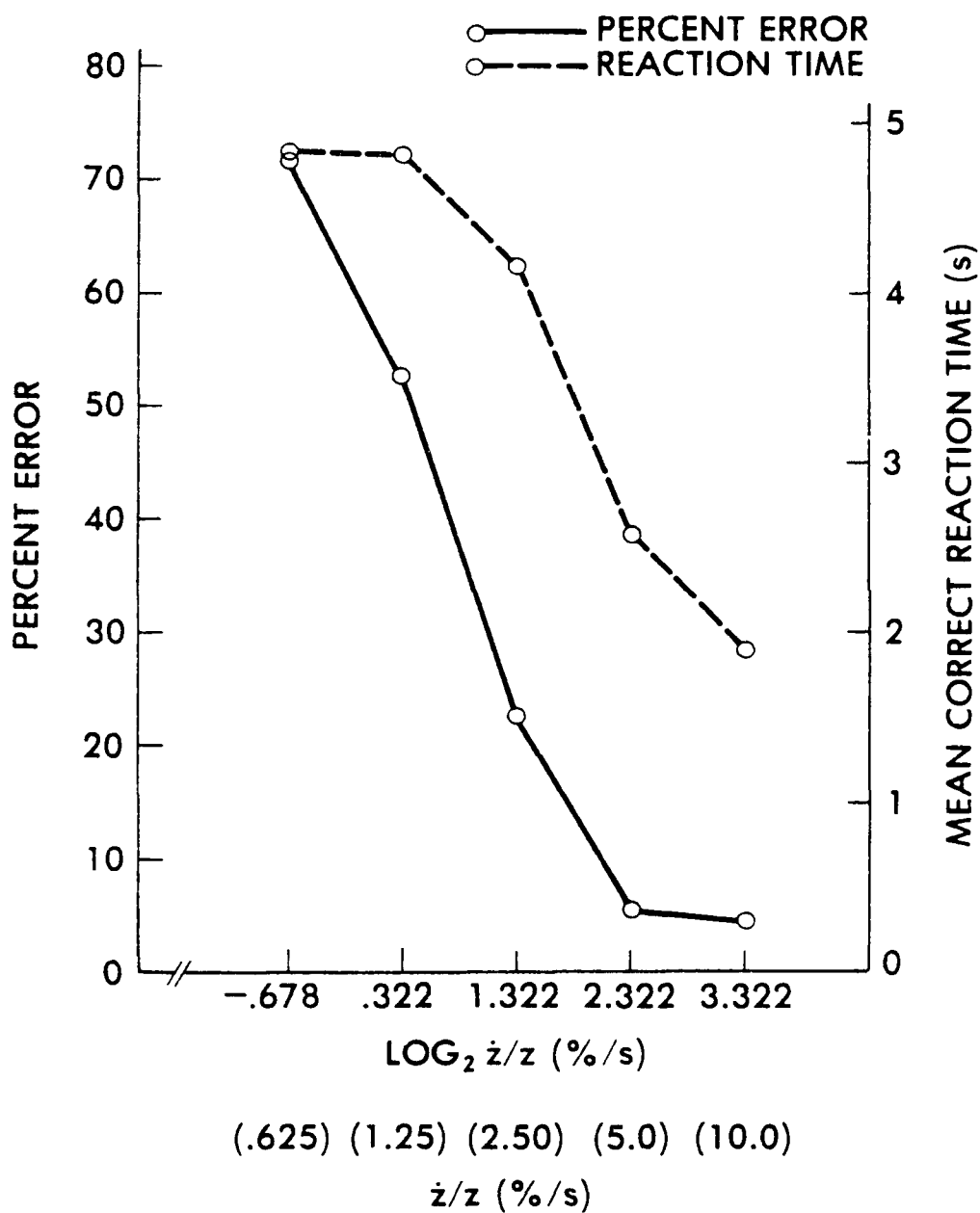The Location x Preview Period x Order interaction accounted for 2.68% of

Figure 1. Percent error and mean correct reaction time pooled across sessions and preview periods for the five non-practice levels of initial fractional loss in altitude ($\dot{z}/z$) (392 observations per point).
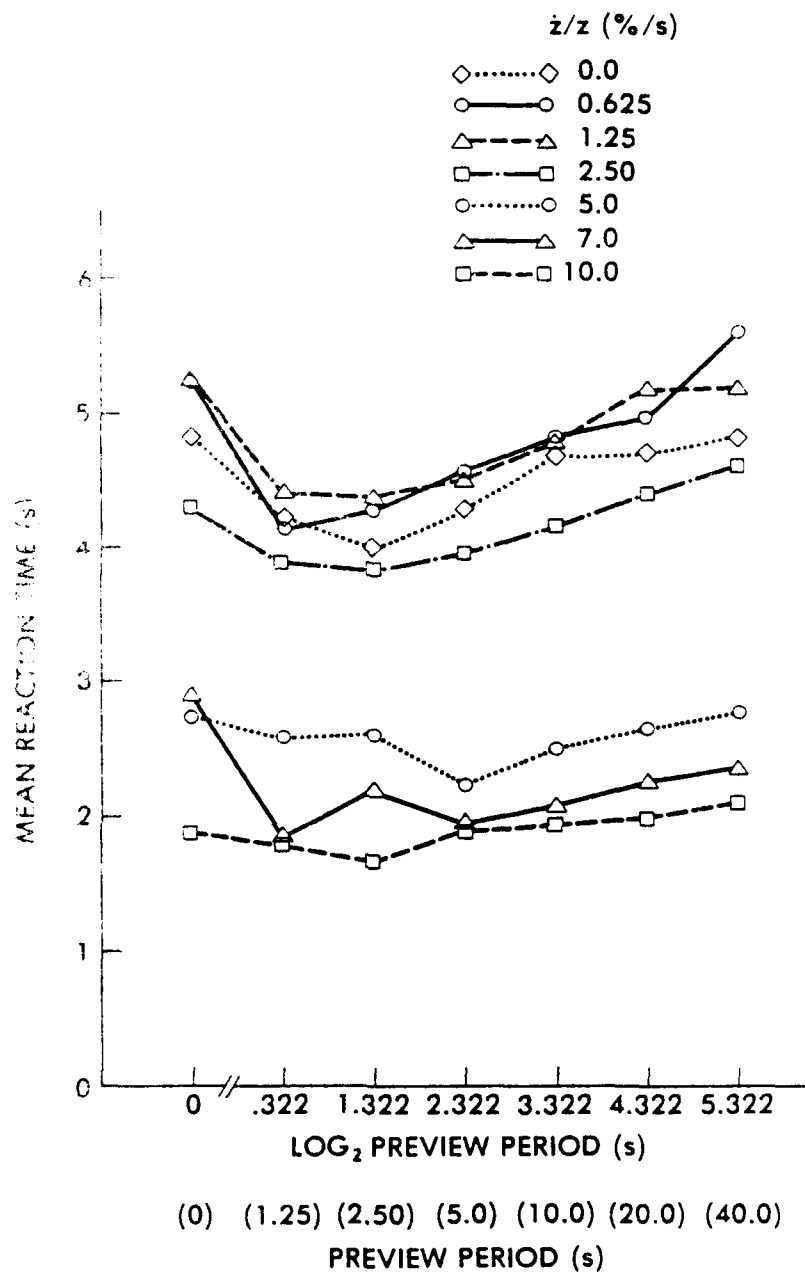
Figure 2. Mean reaction time pooled across sessions for the seven levels of preview period crossed with the seven levels of initial fractional loss in altitude ($\dot{z}/z$) (336 observations per point for $\dot{z}/z = 0\%/s$, 56 observations per point for all other levels).
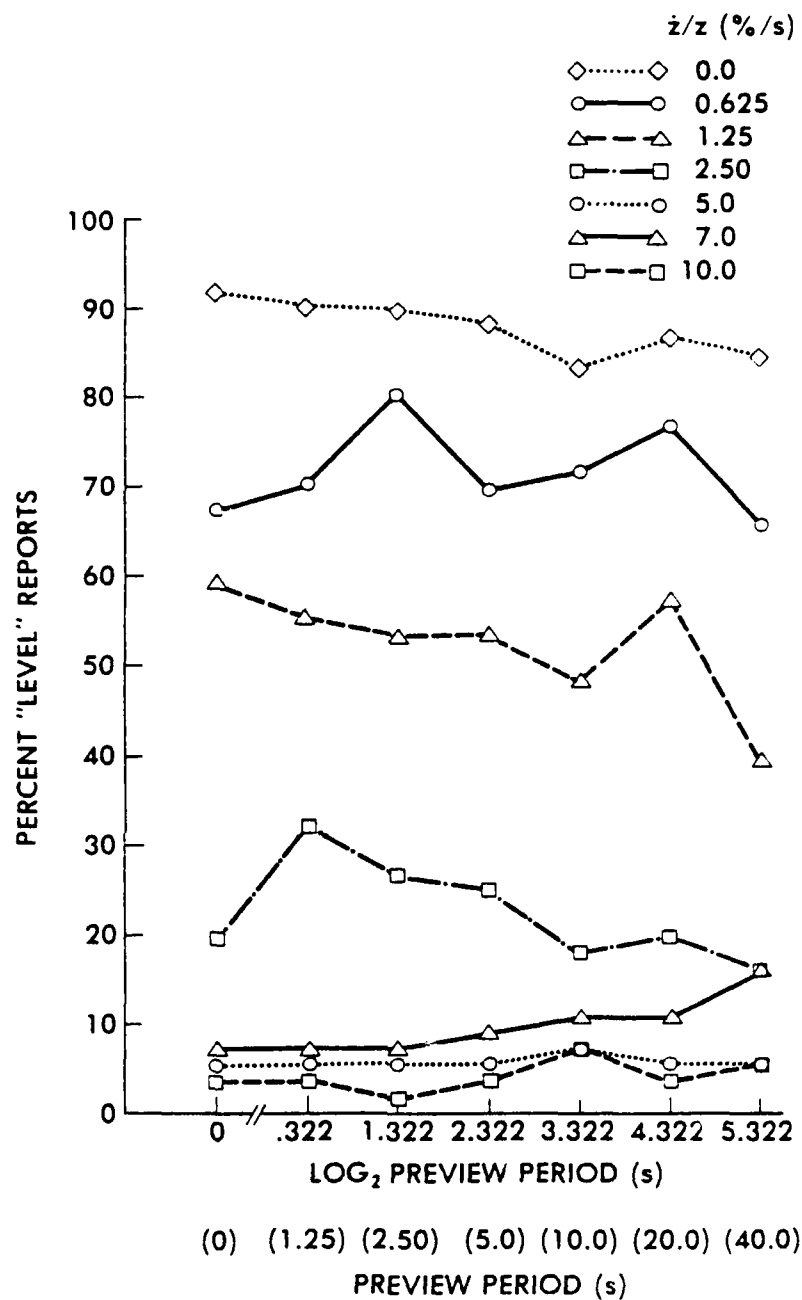
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Figure 3. Percent "level" reports pooled across sessions for the seven levels of preview period crossed with the seven levels of initial fractional loss in altitude ($\dot{z}/z$) (336 observations per point for $\dot{z}/z = 0\%/s$, 56 observations per point for all other levels).

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the variance in error rate and 1.86% of the variance in reaction time. The Session x Fractional Loss x Preview Period x Order interaction and the Session x Fractional Loss x Order interaction accounted for 9.49% and 1.82% of the variance in error rate, respectively (Appendix O, Table O-1). (In general, there was an incerptable structure to the effects involving order.)

For level events, error rate dropped from the first to the second session for every preview period, with a mean improvement of 8.7%, accounting for 1.77% of the variance. The Preview Period main effect (coded as $\dot{z}/z = 0.0\%/s$ in Figure 2) accounted for 1.93% of the variance in reaction time. The Session x Preview Period x Order interaction and the Replication x Order interaction accounted for 4.73% and 2.85% of the variance in error rate, respectively (Appendix O, Table O-1).

The observers differed considerably in how confident they were that events represented level flight or descent. For descent events, fractional loss in altitude accounted for 12.57% of the total variance. For level events, however, only the Replication x Order x Session x Preview Period interaction was significant, accounting for 9.54% of the variance. An overall mean increase in confidence of 3.9% on the three-point scale resulted in a main effect for sessions accounting for 1.54% of the total variance in confidence ratings.

The analysis of variance of A_g scores yielded results similar to the analysis of variance of the error data for descent events for the Fractional Loss in Altitude main effect (21.6% of the variance), the Session x Fractional Loss x Order interaction, and the Session x Preview Period x Order interaction. However, the A_g analysis also showed that the Fractional Loss x Order and the Preview Period x Order interactions accounted for 3.52% and 3.23% of the variance in sensitivity, respectively. The order in which observers viewed the events accounted for 2.80% of the variance in sensitivity. Also, the Session x Order interaction accounted for 1.60% of the variance in sensitivity.

Discussion

Several major points can be made concerning the significance of these results. First, for all four mean performance variables listed in Table 1, the three highest rates of fractional loss in altitude (5, 7, and 10%/s)

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produced the lowest error rates, the least area above the isosensitivity curve,the shortest mean correct reaction times, and the greatest confidence that the event shown represented descent. The longest mean correct reaction time for the easiest rates of fractional loss in altitude was 62% shorter than the shortest mean correct reaction time for the three lowest rates of fractional loss in altitude (2.54 s versus 4.08 s). Second, observers may have experienced adaptation to altitude. For preview periods greater than 5 s, and for each rate of fractional loss in altitude, the mean reaction time increased for observers to decide whether the event shown represented level flight or descent. These results are in line with Denton's adaptation findings (Denton, 1973, Experiment 8; 1974, Experiment 7). Also, for the three highest rates of fractional loss in altitude (5, 7, and 10%/s), preview periods beyond 2.5 s resulted in an increased tendency of observers to report descent events as representing level flight. Third, optimum performance in terms of mean reaction time was found for the midrange of preview periods (1.25, 2.5, and 5.0 s). For all rates of fractional loss in altitude except 5.0 and 7.0%/s, mean reaction time was lowest for the 2.5-s preview period.

No one preview period was best in terms of error rate, however. For the highest rates of fractional loss in altitude, preview periods of 5 s or less resulted in less than 10% "level" reports, with increases in errors occurring after the 5-s preview period. For the lowest rates of fractional loss (0.625, 1.25, and 2.5%/s), however, preview periods greater than 5 s resulted in somewhat quixotic error rates. The trend is toward decreased errors, except for the marked increase for the 20-s preview period. The pattern of results for the 2.5%/s fractional loss is somewhat problematic. Error rate increased from 20% for the 0-s preview period to approximately 30% for the 1.25-, 2.50-, and 5.0-s preview periods, then decreased to the initial rate when preview period increased beyond 5.0 s.

The current findings are equivocal in terms of speed/accuracy tradeoffs. For a speed/accuracy macrotradeoff to have occurred, long mean correct reaction times should be associated with low percent "level" reports for descending events, if observers emphasized accuracy. If the observers emphasized speed, then short reaction times should be associated with high percent "level" reports for descending events. Figures 2 and 3 show that, in

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general, a macrotradeoff did not occur. However, two within-condition speed/accuracy microtradeoffs (Pachella, 1974) for fractional losses of 1.25 and 2.5%/s may have occurred.

For a fractional loss of 1.25%/s, as preview segment increased, slow reaction times are associated with decreasing errors. For a fractional loss of 2.5%/s, the microtradeoff seems more apparent. Initially, as preview period increases, reaction times become faster and accuracy worsens. However, this trend reverses for preview periods of 5 s or longer; accuracy increases and reaction times get slower.

The 2.50%/s fractional loss is problematic. The mean correct reaction times for this condition resemble those of the three lowest fractional losses (0.5, 1.25, and 1.25%/s). However, the error rates more closely resemble those associated with the three highest fractional losses (5, 7, and 10%/s).

Conclusions

This experiment examined the effects of different levels of fractional loss in altitude crossed with several preview periods, with global optical flow rate constant at 1 eyeheight/s. The results suggest that optimum performance results from utilizing short preview periods (1.25 to 5.0 s). These results provide a logical starting point for future experiments designed to investigate the interrelationships among preview period, global optical flow rate, and fractional loss in altitude in the detection of descent.

Owen et al. (this paper) found a complex interaction between preview period and flow rate when observers were asked to distinguish constant speed from decelerating self motion. Two studies have shown that the higher the flow rate, the more difficult it is to detect loss in altitude (Hettinger, Owen, & Warren, this paper; Wolpert & Owen, this paper). Therefore it is reasonable to expect an interaction between preview period and flow rate in a descent detection task. Since both contextual variables can interfere with the detection of change in self motion, there may be combinations which are particularly degrading high-speed, low-altitude flight.

Owen, Warren, Jensen, Mangold, and Hettinger (1981) demonstrated the system responsible for self-motion perception is sensitive to fractional rates of change in altitude, rather than absolute rates of change. One advantage of this sensitivity is that when approaching a surface, the inverse of fractional

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change specifies time to collision (Gibson, 1958b). This is useful information to a pilot attempting to maintain a margin of safety between an aircraft and the ground or between the aircraft and another plane (Schiff & Detwiler, 1979). Indeed, insensitivity to or not attending to fractional loss in altitude may be a contributing factor in aviation mishaps (Owen & Warren, in press). Therefore, the interaction of the functional variable, fractional loss, with the two contextual variables, preview period and flow rate, is of both practical and methodological interest. Also, future research with fractional change as a variable should better define the effects of preview period and guide the development of theory explaining preview-period effects.

Since piloting an aircraft involves controlling optical variables, the study of passive sensitivity is only the first step in isolating preview effects. During altitude control, for example, pilots may benefit from a preview period in order to properly control the aircraft after breaking out of clouds or after prolonged instrument viewing. The preview-period effects noted suggest that pilots should delay making control actions for a brief period until an event unfolds, or risk misperceiving the event and making incorrect control actions. Further research utilizing an active control paradigm is needed to determine how critical preview period is and how long the preview period should be to optimize pilot performance.

Appendix N: Instructions

Instructions

EXPERIMENTER; SEAT THE OBSERVER, THEN READ EXACTLY:

In this experiment we are interested in investigating how well you can visually detect loss in altitude. You will be shown computer generated scenes on the screen which represent travel in an airplane over open, flat fields. Your flightpath will be level in some scenes, and descending in others. Your task will be to press the lighted button marked "L" if you believe the scene represents constant altitude, i.e., level flight, or the "D" button if you detect descent, i.e., loss in altitude.

Sometimes you will see a shimmering or flicker of the fields along the horizon. Please ignore this effect. It is due to limitations in our equipment.

The specific procedure is as follows:

1. Before the beginning of each event, you will hear a tone. Turn your full attention to the screen at that time.

2. Most events will begin with a period of level travel called the "preview period." After the preview period, you will hear a second tone. After the tone, the event may continue to represent travel at a constant altitude, or it may represent descent. Each event will continue for 10 seconds after the tone. Remember that although you are to observe the entire event, you will be making a judgement only about what occurs after the second tone during the event.

All of the events within a given block of 12 will have the same preview period. Preceding each block, I will tell you how many seconds the preview period will last before the second tone sounds.

3. As soon after the second tone as you can distinguish which type of motion is represented, press the button corresponding to your choice. Indicate your choice as quickly as possible, but without guessing. Please be certain that you press the button only once per event, and do not press either button between events.

4. After you press one of the buttons, please rate your confidence in the accuracy of your decision by pressing "one" if you are not very certain, "two" if you are moderately certain, or "three" if you are very certain that

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you made the correct choice.

5. EXPERIMENTER; FIRST SESSION ONLY: We will begin with two practice events to acquaint you with the procedure. Including the practice events, you will judge a total of 84 events.

Do you have any questions?

6. EXPERIMENTER; EXPLANATION OF THE PRACTICE SCENES:

Scene #1 represents descent, i.e., loss in altitude.

Scene #2 represents travel at a constant altitude, i.e., level travel.

7. EXPERIMENTER; READ AT THE BEGINNING OF <u>BLOCK A ONLY</u>: For this block of 12 trials, there will be no preview period. Therefore, you will hear only one tone. As soon after the tone as you can distinguish which type of event is represented, press the button corresponding to your choice.

Appendix O: Analysis Of Variance Summary Tables

Table O-1. Analysis of Variance for Descent Events

Source	df	SS	R^2(%)	F	p : F
Error					
Preview period (P)	6	0.98	0.23	1.37	.2344
Fractional loss (Z)	4	139.58	33.13	107.20	.0000
PZ	24	2.74	0.65	1.20	.2400
Session (S) x order (O)	13	3.34	0.79	2.69	.0387
SZP	24	4.27	1.01	1.98	.0045
SZO	52	7.66	1.82	1.63	.0368
SPO	78	11.28	2.68	1.48	.0397
SZPO	312	39.96	9.49	1.43	.0007
Pooled error	1446	212.47	50.20	-	-
Total	1959	422.3	100.00	-	-
Reaction time					
Preview period (P)	6	136.69	1.01	4.80	.0003
Fractional loss (Z)	4	2808.44	20.65	61.26	.0000
Session (S)	1	77.80	0.57	16.33	.0012
PZ	24	59.35	0.44	1.23	.2132
SZ	4	28.10	0.21	3.24	.0185
SP	6	41.12	0.30	3.11	.0085
SZP	24	71.64	0.53	1.96	.0051
S x order (O)	78	253.64	1.86	1.47	.0408
Pooled error	1812	10126.93	74.43	-	-
Total	1959	13603.71	100.00	-	-

Note. Each effect was tested using the appropriate error term given by the model and is significant at least at the $p < .05$ level, unless otherwise noted.

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Table O-2. Analysis of Variance for Level Events

Source	df	SS	R^2(%)	F	p < F
Error					
Preview period (P)	6	2.12	0.85	3.67	.0028
Session (S)	1	4.42	1.77	30.78	.0001
Replication (R)	5	1.15	0.46	3.14	.0129
R x order (O)	65	7.13	2.85	1.50	.0477
SPO	78	11.81	4.73	1.47	.0420
Pooled error	2196	223.07	89.34	–	–
Total	2351	249.70	100.00	–	–
Reaction time					
Preview period (P)	6	315.41	1.93	6.44	.0000
Replication (R)	5	189.46	1.16	19.39	.0000
Session (S) x R	5	16.44	0.10	3.01	.0161
SP	6	88.49	0.54	3.03	.0099
PR	30	110.45	0.68	2.55	.0000
SR x Order (O)	65	123.35	0.76	1.74	.0119
Pooled error	2234	15486.74	94.83	–	–
Total	2351	16330.34	100.00	–	–

Note. Each effect was tested using the appropriate error term given by the model and is significant at least at the p < .05 level, unless otherwise noted.

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Table O-3. Analysis of Variance for Confidence Ratings

Source	df	SS	R^2(%)	F	p < F
Descent events					
Preview period (P)	6	0.41	0.04	0.24	.9637
Fractional loss (Z)	4	122.99	12.57	29.70	.0000
PZ	24	4.18	0.43	0.78	.7637
Session x P	6	3.14	0.32	2.38	.0357
Pooled error	1919	847.55	86.64	–	–
Total	1959	978.27	100.00	–	–
Level events					
Preview period (P)	6	2.83	0.28	1.34	.2497
Session (S)	1	15.63	1.54	19.82	.0005
SP x replication x order	312	96.71	9.54	1.24	.0257
Pooled error	1640	898.73	88.64	–	–
Total	1959	1013.90	100.00	–	–

Note. Each effect was tested using the appropriate error term given by the model and is significant at least at the p < .05 level, unless otherwise noted.

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Table O-4. Analysis of Variance for Area Above the Isosensitivity Curve

Source	df	SS	R^2(%)	F	p < F
Preview period (P)	6	0.21	0.09	0.52	.7905
Fractional loss (Z)	5	46.78	21.57	143.35	.0001
Session (S)	1	0.00	0.03	0.00	.8700
Order (O)	13	6.07	2.80	7.15	.0001
SP	6	1.05	0.48	2.67	.0139
SO	13	3.47	1.60	4.09	.0001
ZO	65	7.64	3.52	1.80	.0001
PO	78	7.09	3.27	1.39	.0157
SZO	65	5.74	2.65	1.35	.0355
SPO	78	7.04	3.25	1.38	.0177
Pooled error	2021	131.76	60.74	–	–
Total	2351	216.85	100.00	–	–

Note. Each effect was tested using the appropriate error term given by the model and is significant at least at the $p < .05$ level, unless otherwise noted.

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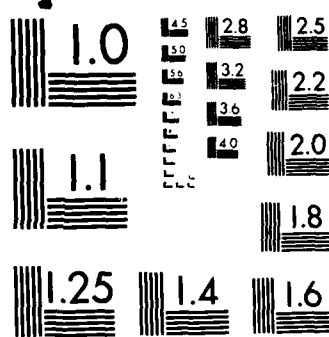MICROCOPY RESOLUTION TEST CHART

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