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VISUAL-PROPRIOCEPTIVE CUE CONFLICTS IN THE CONTROL OF REMOTELY PILOTED VEHICLES

By

Lawrence E. Reed

ADVANCED SYSTEMS DIVISION
Wright-Patterson Air Force Base, Ohio 45433

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NOTICE

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This technical report has been reviewed and is approved for publication.

GORDON A. ECKSTRAND, Director
Advanced Systems Division

DAN D. FULGHAM, Colonel, USAF
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The purpose of this experiment was to investigate operator performance in an environment which was conducive to visual-proprioceptive conflict. More specifically, the intent was to determine the relative ability of pilot, navigator, and nonrated Air Force officer groups to maneuver a simulated remotely piloted vehicle (RPV) from a simulated airborne control station (i.e., a mother ship). The vehicle and/or the station were given gust-like disturbances on pitch and/or roll. In a between-groups design, the performance of the three groups of subjects was compared under two conditions of conflict (e.g., visual roll right and roll left motion; visual roll right and pitch-up motion), nonconflict, motion only, and no motion. To maintain adequate performance, it was necessary for the subjects to disregard sensations of motion. The results revealed that the two conditions of conflict engendered the

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highest proportion of control errors (i.e., reversal, and axis errors) by all subjects, regardless of experience, but pilots tended to make more errors than nonpilots. The past experience of pilots did not help them overcome the effects of conflict as measured by control errors, but it did help them reduce response latencies. Motion cues appear to play not only an alerting role, but also provide information on the direction of attitude changes. This research indicated no advantage of training pilots, as opposed to nonpilots, to perform airborne control of RPVs as represented by the conditions of this experiment. Such training should be conducted in the presence of motion cues.

PREFACE

This study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio, under project 1710, Training for Advanced Air Force Systems and task 171003, Training Implications of New Military Technology. The work was conducted during the period of July 1973 through April 1977.

The research reported herein extends (and includes portions of) the findings documented by the author in his doctoral dissertation entitled "The Effects of Visual-Proprioceptive Cue Conflicts on Human Tracking Performance" presented to The Ohio State University, March 1977. The author expresses his appreciation to his adviser, Professor H. G. Shulman, for his guidance and support during the course of this study. The author also gratefully acknowledges the invaluable suggestions of Professors D.H. Owen and R.D. Gilson who served as members of his thesis committee, and Professor R.J. Jagacinski who provided advice and stimulating discussions.

Sincere thanks are due Dr. G.A. Eckstrand, Chief, Advanced Systems Division and Dr. R.L. Morgan, the Project Scientist, for their support and review of the manuscript.

The development of the simulation equipment and computer software, and the assistance during the conduct of the study required the support and cooperation of individuals in several disciplines. The author is particularly indebted to Messrs. W. H. Schelker, R.G. Cameron, R.J. Roettele, J.L. Ferguson and Ms. P.A. Knoop for their valuable participation and contribution throughout the experiment. Appreciation is extended also to Dr. T.E. Cotterman, LtCol E.A. Cope, TSgt E.H. Johnson, SSgt G.S. Manoliu, SSgt E.W. Sandelin, Mr. N.H. Kearns, Mr. W.L. Hart, Ms. C. Briggs, and Ms. V.B. Hicks for their support during various periods of the research.

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I. INTRODUCTION

An investigation was made of operator tracking performance under conditions of visual-proprioceptive conflict. (The term *proprioception* as used here refers to sensations arising from the receptors of the nonauditory labyrinth of the inner ear and from muscles, tendons, and joints. Kinesthesis refers to sensations of movement arising from the receptors other than the nonauditory labyrinth.) The experimental scenario is described as follows: An operator is asked to maneuver a remotely piloted vehicle (RPV) from an airborne control station (a mother ship). This station is equipped with a television monitor, control stick, and other controls and displays necessary to maneuver the RPV through a specified course. The RPV, containing a television camera mounted in its nose, relays an image of the terrain to be displayed on the television monitor in the control station. Thus, the visual scene displayed to the operator represents the scene viewed by the camera. The task of the operator is to use the controls and displays to "fly" the RPV in much the same way he would fly a conventional aircraft.

The scenario is complicated by several factors. First, the visual inputs to the operator from the RPV are independent of the motion inputs from the control station. Thus, the operator will experience motion cues that are uncorrelated with the visual inputs received from the RPV. Second, while traditional pilot training programs operate on the philosophy that proprioceptive cues provided by the motion of the aircraft should be disregarded, research has shown that these cues are compelling, not easily ignored, and may improve performance when used in training simulators (see, for example, Borlace, 1967; Cohen, 1970; Douvillier, Turner, McLean, & Heinle, 1960; Fedderson, 1961; Huddleston & Rolfe, 1971; Rathert, Creer, & Douvillier, 1959; Ruocco, Vitale, & Benfari, 1965). The task simulated in the experiment presented here, however, required that the RPV operator disregard sensations of motion in order to maintain adequate performance. Under conditions of visual-proprioceptive conflict (as when the mother ship and/or the RPV are in turbulence) the stereotypic responses of pilots to correct angular accelerations will be inappropriate.

The objectives of the experiment were to obtain data applicable to the following:

1. The relative difficulty of controlling an RPV from an airborne station under different visual-motion combinations (e.g., visual-motion combinations that produce conflict, or no conflict).

2. The relative ability of pilots, navigators, and nonrated Air Force officers to operate an RPV from an airborne station (i.e., the effect of previous experience).

3. The differential effects of experience on the acquisition of skills necessary to operate an RPV.

4. Selection and training of potential RPV operators.

5. The need for motion in RPV training simulators.

II. METHOD

Simulation System

This research utilized the Simulation and Training Advanced Research System (STARS) facility of the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio. The equipment consisted of an operator station mounted on a motion platform, hydraulic pump, terrain model, television camera and optical probe, experimenter station, and a Sigma 5 digital computer. A brief description of the hardware system is presented as follows.

Operator station. The operator station, illustrated in Figure 1, was designed to simulate the environment of an airborne control station. This station contained a television monitor that provided visual images relayed to it from a simulated RPV. These visual images were generated from a television camera and optical probe, which viewed the terrain model. The path followed by the camera and probe over the terrain model was commensurate with the vehicle flight path as determined by control stick inputs provided by the subject. Since the control stick and visual system were independent of the motion platform, the capability existed for the subject to

Figure 1. **Operator station mounted on motion platform.**

maneuver the simulated RPV under various environmental conditions. This arrangement permitted the introduction of conditions in which the RPV alone, the airborne station alone, or both, were under clear air turbulence.

The subject sat in an aircraft-type seat directly facing a 14- by 11-inch (35.6 by 27.9 cm) television monitor, which was mounted in a center sectional panel of the operator console. The distance between the subject's eyes and the center of the television screen was 28 inches (71.1 cm). The viewing angle subtended 28.07° in the lateral plane and 22.23° in the vertical plane of the monitor. An altimeter, altitude warning light, and an attitude director indicator (ADI) were mounted on a flat sectional panel to the left of the subject and at an angle of 45° from the center panel (see Figure 2). The altimeter was a vertical straight-scaled indicator with a moving pointer that provided altitude readings in feet above sea level. An amber altitude warning light flashed whenever the simulated RPV altitude dropped to a level below 180 feet (54.9 m), remained on whenever altitude exceed 1,00 feet (304.8 m), and was off between 180 and 1,000 feet.

A 6-inch (15.2 cm) side-arm rate control stick was mounted on the right-hand side console armrest (see Figure 2). The control was a spring-centered stick with a dual-axis (fee positioning) capability that required 4 ounces (113.4 g) breakout force. The same amount of force was needed to hold the stick at full deflection. The range of deflection on both lateral (right – left) and longitudinal (fore – aft) stick was 0 to 25° (henceforth referred to as 0 to 100 percent deflection).

In addition, the operator station contained a foot switch to allow the subject to communicate with the experimenters. White noise was input to the subject's headset to mask external disturbances. The aircraft seat was equipped with a standard harness and lapbelt to protect the subject. An air conditioner maintained the station temperature at 70° F (21.1° C). Finally, incident illumination was at an average of .37 footcandles at eye level.

Figure 2. **Operator station instruments and control stick.**

Motion system. The operator station was mounted on a motion platform that provided onset cues in two degrees of freedom of angular acceleration. Roll onset cues were provided by tilting the simulator about the longitudinal axis (i.e., the X axis) and pitch onset cues were provided by tilting the simulator about the lateral axis (i.e., the Y axis). Motion was achieved by actuation of hydraulic cylinders mounted under the 9- by 8-feet (2.74 by 2.4 m) simulator platform, as shown in Figure 1.

Visual system. The visual system consisted of a three-dimensional terrain model (a modified SMK-23 Visual Simulator, The Singer Company), television camera and optical probe, and three monochromatic television monitors. The terrain model provided "real-world" ground cues for visual tracking over the surface. The real-world to terrain model scale was 3,000:1 and represented a six- by twelve-mile (9.65 by 19.3 km) area. The model was mounted on an endless belt that was servo-driven to represent visually the continuous changes in scene as the simulated RPV travelled along north-south directions. A television camera viewed the terrain model through an optical probe that contained a servoed mechanical assembly to permit the introduction of heading, roll, and pitch. Both the camera and probe were mounted on a servo-driven carriage system that moved across the terrain model to simulate movement of the RPV along east-west directions, and in and out to simulate altitude changes. The field of view represented on the television monitor subtended a viewing angle of 50° horizontally and 38° vertically over the terrain model. One television monitor was mounted in the operator station and the other two were located in the experimenter station. All three monitors had a 1,000-line resolution vertically.

Experimenter station. The experimenter station contained the equipment necessary to monitor the status of the hardware/software and control activities of the subject, and to set up the various stimulus conditions. This station was manned by two experimenters. The task of the first was to prepare the system for operation, insure that all hardware was operating effectively and reliably prior and during the experiment, and set up the conditions for all experimental trials in accordance with a prepared check list. The task of the second experimenter was to determine the appropriate time for introducing specific stimuli to the subject. When certain criteria were met, the experimenter pressed a discrete hand-held insert button to initiate a stimulus trial.

Computer system and interfaces. A Sigma 5 digital computer was used to drive the peripheral equipment, and to record data during experimental runs. Resident software consisted of a real-time aerodynamic mathematical model, executive routine, and data recording programs. The mathematical model was a six-degree-of-freedom simulation of a fixed-wing aircraft used to represent an RPV. This model received inputs from the subject's control stick and provided outputs to drive the camera and probe to produce the proper visual image, as well as other data necessary to drive the flight-related displays at the experimenter and operator stations. The executive routine served as software interface between the experimenter station and the mathematical model and motion platform by producing stimuli (i.e., inserting forcing functions) when commanded. Depending on switch settings at the experimenter station, visual and/or motion stimuli were produced by emulating a sudden change in roll or pitch similar to that produced by a sharp wind gust. Actual activation of visual stimuli was accomplished by adding a predetermined value to the sampled stick value and sending that sum to the mathematical model in lieu of sending the actual stick position over the fixed number of program cycles. This proved to be a simple and effective method of producing realistic visual stimuli. When a motion stimulus was required, the necessary forcing function, programmed on the analog computer, was triggered under control of the executive routine. Data recording programs recorded all required measures on 9-track magnetic tape, inserted header information used to identify experimental runs and trials, and produced some on-line plots and computed values necessary for the conduct of the experiment.

An analog computer was used primarily to control the motion platform. This included continual generation of low-amplitude inputs on both roll and pitch axes to simulate rough air, thereby adding realism to the task.

Experimental Tasks and Stimuli

The task consisted of maneuvering a simulated RPV through a predetermined tracking course. This was a form of visual contact flying that required the subjects to track ten ground targets, fly the simulated RPV over each, and maintain a level horizon (i.e., wings level). Figure 3 is an illustration of the ground terrain and target as viewed by the subject. Since scaled references were not provided on the television monitor, the task consisted of a subjective form of compensatory tracking.

Figure 3. **Ground terrain and target as viewed by the subject.**

Easily visible ground targets were numbered and placed on the terrain model at intervals representing two statute miles (3.2 km). There were ten targets, five on the right-hand side (east) and five on the left-hand side (west) of the terrain model. The five targets, spaced on the east side of the model, were numbered sequentially toward the northern region of the model. Similarly, the other five targets were numbered sequentially, but spaced at intervals from north to south, down the west side of the model. This arrangement of targets resulted in the most efficient use of the terrain model. In addition, the targets were alternated left and right at distances representing .12 mile (.19 km) from the centerline between targets. Thus, the subject was required to make heading corrections as the simulated RPV was flown toward each target. After a fly-over occurred, the target left the field of view at the bottom of the television screen and the next target appeared over the horizon to the left or right of the current heading. Heading corrections to the target were made at this point. This process was repeated until the subject tracked the RPV over the fifth target, upon which he was instructed to bank to the left to acquire the sixth target. Target tracking continued until the simulated vehicle had been flown over the tenth target. The RPV was flown at an airspeed of 150 knots and at an altitude between 180 and 1,000 feet (54.9 and 304.8 m). The average altitude flown was 500 feet (152.4 m). The average tracking time over the ten targets was 6 minutes 30 seconds.

Since the operator station motion was independent of the visual system, it was possible to simulate conditions in which the vehicle only (i.e., the visual input from the RPV), the operator station only (i.e., the motion input from the mother ship) or both simultaneously were under clear air turbulence. As the subjects maneuvered the simulated RPV over the ten targets, they were presented, at random intervals, with stimuli representing the effects of gusts on the operator station and/or the RPV. The subjects were asked to respond with an appropriate control stick deflection to null the effects of these gusts on the RPV. The visual stimulus duration was one second and the displacement was ±18°/second on roll and pitch during the initial .5 second and ±21°/second on roll and ±14°/second on pitch during the remaining .5 second. Any control stick activity occurring during this period either decreased or increased the rate of error. With no corrective input, the maximum displacement was limited by software control to ±21° on roll and ±14° on pitch.

The motion stimulus was provided by tilting the motion platform about the longitudinal axis (roll) or the lateral axis (pitch). After reaching a maximum excursion of ±8° on roll and ±7° on pitch in a period of one second, the platform was restored to a level position in an equal amount of time. Restoration of the platform did not involve a washout function below sensory threshold. While such functions are used in pilot training simulators to eliminate uncorrelated visual-proprioceptive cues, the environment simulated in this experiment required that motion be independent of the operator's control activities. Thus, it was assumed that a pilot would restore a mother ship immediately following the onset of turbulence.

Subjects

Fifty-nine male volunteers, all uniformed members of the United States Air Force, served as subjects in this experiment. These subjects were assigned to one of three experience groups consisting of twenty pilots, twenty navigators, and nineteen nonrated (inexperienced) officers. The selection of subjects depended upon their prior experience. It was required that the pilots be on current flying status and that they have at least 300 hours of flying experience. It was further required that neither the navigators nor the nonrated participants possess piloting experience and that the nonrated be right-handed.

Questionnaires designed specifically for each of the three experience groups were administered to all subjects. Aside from the demographic characteristics on each subject, it was of interest also to obtain other information relevant to the flying experience of pilots and navigators and any possible informal (i.e., observational, back seat) piloting experience possessed by navigators and nonrated subjects. Also of interest was information relative to the subject's susceptibility to motion sickness. The general characteristics of each experience group are summarized as follows.

Pilots. The average age of pilots was 34.5 (median, 34.5) with a range of 26 to 45 years. All pilots possessed at least four years of higher education (mean, 5.3 years). The mean number of flying hours was 2,953 (median, 2,924), with a range of 350 to 5,100 hours. The mean number of years of flying experience was 9.9 (median, 10.25), with a range of 3 to 32 years. The most recent flying experience had occurred on the average of 6 months (median, 3 months) prior to participation in this experiment. Two pilots reported that they had experienced either car or seasickness, but none reported airsickness.

Navigators. The average age of navigators was 32.5 (median, 33) with a range of 25 to 44 years. All navigators possessed at least four years of higher education (mean, 5.4 years). The mean number of navigation flying hours was 2,206 (median, 2,100), with a range of 550 to 5,700 hours. The mean number of years of experience was 7.1 (median, 7.5) with a range of 1.5 to 19 years. The most recent navigation experience had occurred 8 months (median, 6 months) prior to participation in this experiment. Five navigators reported that they had some presolo piloting experience, but in all cases this had occurred at least seven years prior to the experiment (median, 10 years). Nine navigators had some informal piloting experience. Three reported that they had experienced airsickness and one of these also reported seasickness.

Nonrated. The average age of nonrated subjects was 31.5 (median, 32), with range of 23 to 44 years. All of these subjects had at least four years of higher education (mean 5.8 years). Three subjects reported that they had some presolo piloting experience, but in all cases this experience had occurred at least seven years prior to the experiment and was of short duration. Three subjects reported some informal observational experience and two had minimal experience in a ground simulator. Three subjects reported that they had experienced airsickness and one had experienced seasickness.

Experimental Conditions and Design

Subjects in each experience group were assigned to one of five experimental conditions. As noted earlier, the conditions were selected for their potential to produce visual-propriocepive conflict. The conditions represented various visual-motion stimulus combinations existing between the simulated RPV and control station. As shown in Table 1 the five conditions consisted of: (a) visual only (VO), in which the RPV was represented as being in turbulence, but not the control station, (b) motion only (MO), in which the control station was represented as being in turbulence, but not the RPV, (c) single-axis incompatible (SAI), in which both the control station and the RPV were simultaneously in turbulence, but the

Table 1. **Visual-Motion Stimulus Combinations Used in each Experimental Condition**

Experimental Conditions	Visual Stimulus (Axis and Direction of Displacement)	Motion Stimulus (Axis and Direction of Displacement)
Visual Only (VO)	Pitch-Up	0
	Pitch-Down	0
	Roll Right	0
	Roll Left	0
Motion Only (MO)	0	Pitch-Up
	0	Pitch-Down
	0	Roll Right
	0	Roll Left
Single Axis Incompatible (SAI)	Pitch-Up	Pitch-Down
	Pitch-Down	Pitch-Up
	Roll Right	Roll Left
	Roll Left	Roll Right
Single-Axis Compatible (SAC)	Pitch-Up	Pitch-Up
	Pitch-Down	Pitch-Down
	Roll Right	Roll Right
	Roll Left	Roll Left
Double-Axis Incompatible (DAI)	Pitch-Up	Roll Right
	Pitch-Up	Roll Left
	Pitch-Down	Roll Right
	Pitch-Down	Roll Left
	Roll Right	Pitch-Up
	Roll Right	Pitch-Down
	Roll Left	Pitch-Up
	Roll Left	Pitch-Down

visual-motion combinations were in conflict with respect to direction (e.g., a visual pitch-up was combined with a pitch-down motion), (d) single-axis compatible (SAC), in which both the control station and the RPV were simultaneously in turbulence, but the visual-motion combinations were consistent with normal contact flying conditions, and (e) double-axis incompatible (DAI), in which both the control station and the RPV were simultaneously in turbulence, but the visual-motion combinations were in conflict with respect to axis (e.g., a visual pitch up was combined with a roll right or left motion).

Sixteen subjects in each of the three experience groups (i.e., pilots, navigators, and nonrated) were randomly assigned to one of the first four experimental conditions (i.e., VO MO, SAI, and SAC). An additional four pilots, ar navigators, and three nonrated subjects participated in condition DAI. The ideal design would have required that all subjects be administered all conditions (i.e., a within-groups design). This type of design was not used because the relatively large number of conditions (and combinations within conditions) would create a formidable balancing problem. Also, the possibility of asymmetry due to transfer effects (Poulton & Freeman, 1966) in a within-groups design would require that all combinations of conditions be administered and examined. Constraints on subject availability rendered this approach impractical, if not impossible.

All subjects served for approximately 45 minutes on 5 consecutive days (sessions). The first session was for the purpose of familiarizing the subjects with the equipment and procedures, and for training in the tracking task. The experimental tasks were performed in Sessions 2 through 5. A trial was defined as the introduction of a single stimulus during the experimental sessions. A block of trials consisted of the presentation of ten trials during the simulated flight over the ten targets. The subjects were presented with four blocks of trials in each of the four experimental sessions. The stimulus combinations in each condition were randomized (without replacement) so that each subject experienced the same combinations over the four sessions. The total number of trials by conditions and experience group is presented in Appendix A.

Procedures

Upon arrival at the first session each subject was asked to read a prepared set of instructions. These instructions contained a general overview of the procedures and the task to be performed. The subject then sat in the operator station and the experimenter demonstrated the training task (i.e., one flight over the ten targets) to better acquaint him with the procedures. The subject then completed one flight in the presence of the experimenter. After a brief question-and-answer period, the experimenter assumed his position at the expe menter station and the subject proceeded to complete two additional training flights. No motion was provided in this session, but the subject had use of the ADI. Upon completion of training, the subject was provided with a copy of the questionnaire.

In each of the four experimental sessions, the subjects were escorted to the operator station and were given assistance in adjusting the protective restraints. Instructions were then read to the subject over the communication system. These instructions are presented in Appendix B. The simulated rough air and the television monitor were then activated, the ADI deactivated, and the subject was asked whether he was ready. Upon a "ready" response from the subject, the system was released from freeze status and the subject began maneuvering activities toward the first target.

Experimental trials were initiated from the experimenter station in accordance with pre-established decision criteria. Briefly, it was required that a minimum of ten seconds lapse between trials. Moreover, it was required that the simulated RPV be in a stable and level attitude and that the heading be toward the next target. To insure that the data not be confounded with normal tracking activities, trials were presented only when the subject's control stick input was minimal, if not at zero percent. Finally, to avoid problems of anticipation, the presentation of trials occurred at different locations on the tracking course. Various displays were used to aid the experimenter in making a decision as to whether a trial should be initiated. When all criteria were met, the experimenter pressed the insert button, which caused an output to be made for the pre-selected trial. A 45-second rest period was provided between blocks of trials. The last session was followed with a debriefing, a tour of the simulation facility, and a discussion of the purpose of the experiment.

Performance Measures

Data collected during all sessions (including training) were recorded on 9-track magnetic tape.

The variables, units, and sampling rate on each are presented as follows

Time. Clock time into the tracking task was recorded every .05 second.

Lateral control stick deflection (roll axis). Percent and direction of deflection from center position to full deflection was recorded at a rate of 20 samples/second.

Longitudinal control stick deflection (pitch axis). Percent and direction of deflection from center position to full deflection was recorded at a rate of 20 samples/second.

Longitude. The location of the simulated RPV over the terrain model in an east-west direction was recorded at a rate of 10 samples/second. Data were converted to feet travelled from the left (i.e., west) side of the terrain model.

Latitude. The location of the simulated RPV in a direction running lengthwise over the terrain model was recorded at a rate of 10 samples/second. Data were converted to feet from the lower (i.e., south) end of the terrain model.

Altitude. Altitude of the simulated RPV, measured in feet above sea level, was recorded at a rate of 10 samples/second.

Header information. Recorded prior to the initiation of each tracking task was the subject identification number, experimental condition, and block number. The trial number and the visual and/or motion combination used was recorded whenever a stimulus was presented.

Computer programs were developed to retrieve data from magnetic tape and to compute relevant performance measures. Two principal measures were computed: response time (RT) and error rate. The former was defined as the time interval between the onset of a stimulus and the first point (i.e., time sample) in the tracking record in which control stick deflection exceeded a predetermined limit of allowable tolerance (i.e., a band of tolerance for small control stick deflections regarded as noise rather than responses to trials). The method used to compute these bands, for both lateral and longitudinal stick deflections, is described in Reed (1977).

Response times were computed on three types of responses: correct, reversal errors, and axis errors. Reversal errors were those responses in which stick deflection was in the same axis but different direction as the visual stimulus. This type of response added error by increasing the rate of an already existing stimulus error. Axis errors were those responses in which stick deflections were in the axis other than the one provided by the stimulus. A stick deflection to the left in response to a pitch-up visual stimulus, for example, added roll error to an already existing pitch error. Finally, cross-coupled responses to a stimulus (i.e., responses that combined simultaneously both lateral- and longitudinal-stick deflections) were not submitted to analysis because of their random occurrence, and because they could not be regarded as either correct or error responses.

Error rates on reversal and axis errors were computed from data on all conditions except MO. The primary purpose of this measure was to determine (a) possible effects due to practice, (b) possible differential effects by type of error (reversal vs. axis errors), (c) effects due to experience, and (d) effects due to conditions. All proportions were obtained by dividing the number of errors by the total number of responses. Since all responses to MO were regarded as errors, proportions were obtained by dividing the number of responses by the total number of trials

III. RESULTS AND DISCUSSION

Effects of Visual-Proprioceptive Conflict

The results of this study revealed that the experimental conditions (see Table 1) differed in their potential to engender visual-proprioceptive conflict, as measured by the proportion of reversal and axis errors. An analysis of variance[1] on reversal errors (see Figure 4) revealed that the effect of conditions was significant, $F(3, 35) = 15$, $p < .001$ (.11, .25, .07, .12 in VO, SAI, SAC, and DAI, respectively). A Newman-Keuls (Winer, 1971, p. 191) test of the means revealed further that this effect was due to the large proportion of reversal errors in SAI ($p < .01$) in contrast to the other conditions. Similarly, the proportion of axis errors (see Figure 5) also resulted in an effect due to conditions, $F(3, 35) = 27$, $p < .001$ (.08, .08, .07, .30 in VO, SAI, SAC, and DAI, respectively).

[1] All analyses of variance were performed with the VUL2 – Vanderbilt Statistical Package (1971). The missing data (i.e., unequal n) option supplied with these programs was applied where needed.

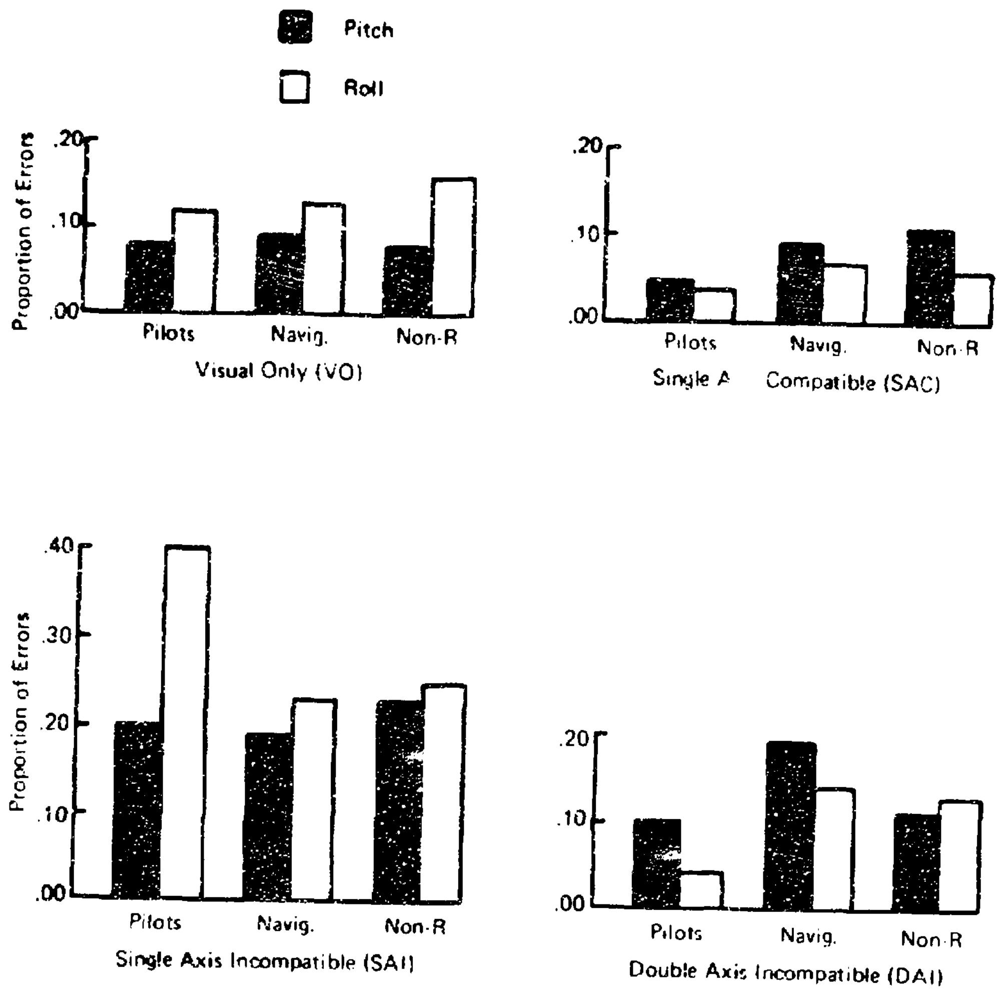

Figure 4. **Proportion of reversal errors as a function of experience groups and axis on each condition.**

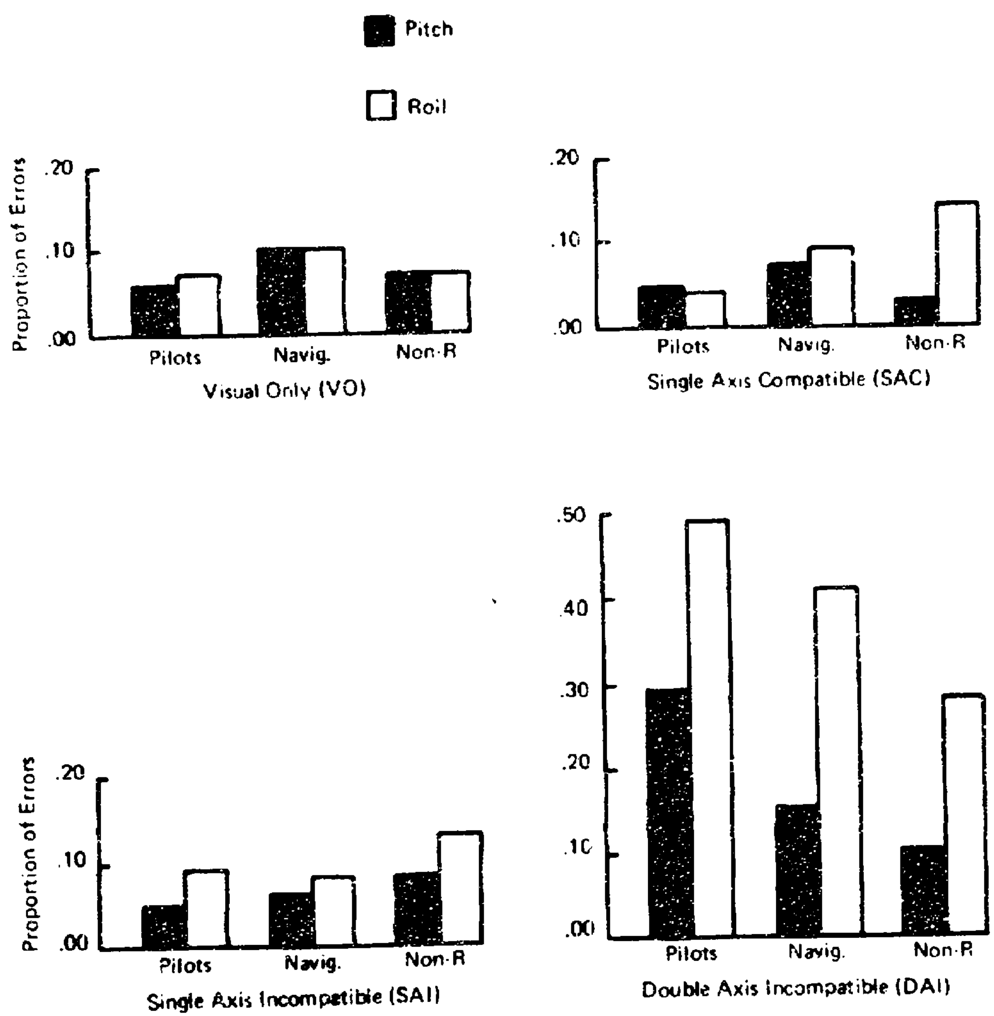

Figure 5. **Proportion of axis errors as a function of experience groups and axis on each condition.**

In contrast to reversal errors, however, the highest proportion of axis errors was made in DAI as revealed by a Newman-Keuls test of the means ($p < .01$).

The DAI condition was included in this study as an added feature to corroborate the predicted effect in SAI and to verify the notion that this effect was produced by visual-proprioceptive conflicts rather than by random control activities. Thus, it had been predicted that the visual-motion relationships in SAI would result in a greater proportion of reversal than axis errors and that the opposite would be the case in DAI. To test this possibility, an analysis of variance was carried out to compare the proportion of reversal errors with the proportion of axis errors made by all subjects in VO, SAI, SAC, and DAI. Of particular interest was a possible Conditions X Type of Error (i.e., reversal and axis errors) interaction. The analysis resulted in a significant interaction in the expected direction on pitch, $F(3, 35) = 6$, $p = .0027$ and roll, $F(3, 35) = 43$, $p < .001$. As shown in Figure 6, the interaction effects were obviously due to a higher proportion of reversal errors in SAI than DAI and a higher proportion of axis errors in DAI than SAI. Thus, the overall results of this analysis confirmed the supposition that the distribution of these two types of control errors would be systematic rather than random. It can be safely concluded that the incompatible conditions (i.e., SAI and DAI) produced visual-proprioceptive conflicts and that these experimental conditions were independent with respect to their effects on the performance of all subjects, regardless of experience (there was no Conditions X Experience Group interaction). Finally, it must be pointed out that only two percent of the axis errors in DAI were inappropriate with respect to direction of motion (e.g., a control stick deflection to the right in response to a right roll motion). These data were not included in the analysis. This latter finding lends further support to the notion that the axis errors in DAI resulted from responses to motion and were not random.

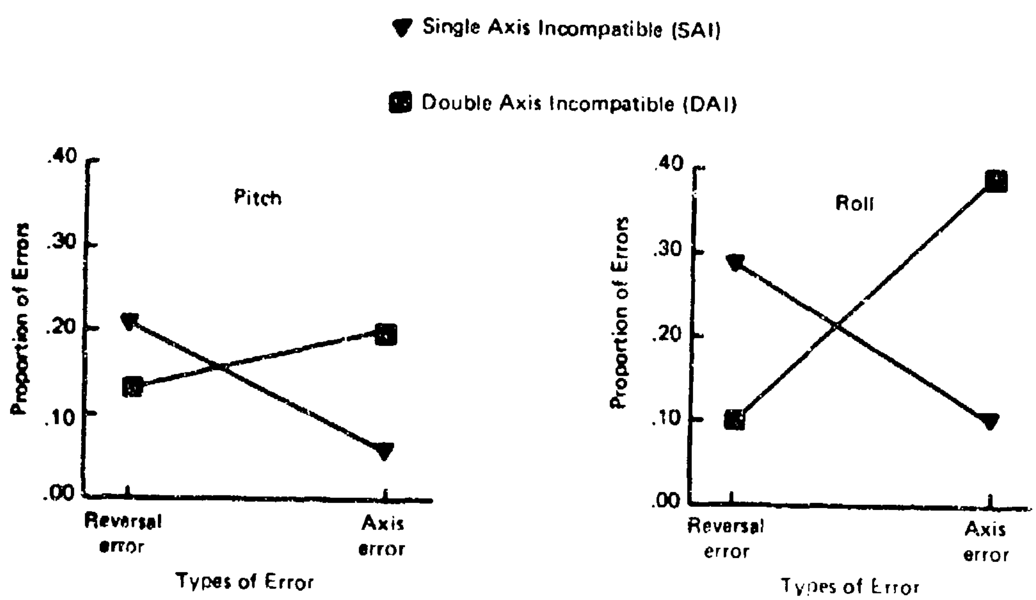

Figure 6. **Proportion of errors as a function of type of error.**

It had been anticipated that VO and SAC (no motion – motion comparisons) would differ in their potential to produce reversal errors. The presence of motion in SAC was thought to aid spatial orientation and result in a very small proportion of inappropriate responses. While the difference between these two conditions was consistently in the expected direction, the Newman-Keuls test failed to reach significance ($p > .05$). Also, the proportion of reversal errors in these two conditions was relatively low (.11 vs. .07 in VO and SAC, respectively) and did not differ from the proportion of axis errors. This latter finding suggests that the errors in VO and SAC were random and non-task related. Although it is tempting to conclude that the visual factors provided the necessary information for spatial orientation and that motion in SAC served no useful role, the effect of motion was obviously present in SAI and DAI. Accordingly, the role of motion in SAC is not dismissed. It must be recalled that VO did result in a strong and consistent tendency to produce more reversal errors than SAC. Detailed interpretation of these results, however, must be carried out in the light of other relevant data.

If motion alerts the subjects to changes in attitude, as claimed by Matheny, Dougherty, and Willis (1963), then the experimental conditions providing motion should result in shorter RTs than those that did not. This assumption was confirmed. Analysis of variance on RTs of correct responses was significant. $F(3, 35) = 6$, $p < .01$ (.75, .67, .57, .74 seconds in VO, SAI, SAC, and DAI, respectively). Newman-Keuls tests of the means by axis (see Table 2), revealed that RTs on correct responses in VO were significantly longer than in SAC ($p < .01$) on both axes, and also longer than SAI on the roll axis ($p < .05$). Response times on correct responses in SAI and SAC did not differ significantly, although there was a consistently strong tendency for SAC to result in shorter RTs on both axes. This tendency is interpreted to mean that compatible visual-motion relationships provide alerting cues that aid performance. That RTs were longer in VO than SAI and the failure to obtain a significant difference between SAI and SAC, however, suggest that motion, even when it is incompatible (i.e., in conflict) with the visual stimulus, alerts the operator to changes in attitude.

Table 2. **Mean Response Times (in seconds) on Correct Responses and on Reversal and Axis Errors**

Conditions	Pitch			Roll		
	Correct	Reversal	Axis	Correct	Reversal	Axis
VO	.63	.37	.35	.86	.57	.51
SAI	.61	.38	.28	.72	.47	.41
SAC	.52	.27	.29	.61	.40	.38
DAI	.67	.43	.44	.81	.53	.58

The assertion that motion provides alerting cues cannot be generalized easily to the incompatible visual-motion relationships in DAI. Response times on correct responses in this condition differed neither from VO and SAI on pitch nor from VO on roll. The relatively long RTs in DAI can be attributed to several factors. First, it will be recalled that the proportion of axis errors in DAI was high relative to SAI. This difference in errors may have been due to the disproportionate number of visual-motion stimulus alternatives in DAI, as compared to SAI (see Table 1). It is assumed that adaptation to the visual-motion relationships in SAI was considerably easier than in DAI. In SAI, the subject merely learned that a stick deflection in the opposite direction from the one provided by the motion cue would result in an appropriate response (i.e., the subject learned to deflect the control stick on the same axis and direction of motion). Similar adaptation would have been difficult, if not impossible, in DAI because the visual-motion combinations were always on different axes and there were two alternative directions of motion displacement within each axis (i.e., a visual pitch up was accompanied with a roll right *or* roll left motion). Taking these factors into consideration, it can be safely concluded that motion in DAI not only interfered with the response tendencies of the subjects, but required that decisions be brought to bear on the task. The subject needed to select an appropriate response among alternatives, a process requiring time.

It is of interest to note that the RT relationships found on correct responses existed also on reversal and axis error RTs. Response time on reversal errors resulted in a significant effect due to conditions, $F(3, 35) = 3$, $p < .05$ (.47, .43, .34, .48 seconds in VO, SAI, SAC, and DAI, respectively) as did axis errors, $F(3, 35) = 10$, $p < .001$ (.43, .35, .33, .51 seconds in VO, SAI, SAC, and DAI, respectively). An examination of Table 2 will show that RTs on errors are generally longer in VO than SAC and that SAI falls between these two conditions. Moreover, RTs on errors in DAI are generally comparable to those in VO. Thus, it is concluded that the variables that have an effect on RTs of correct responses have the same effect on RTs of error responses. Note, however, that the RTs on errors are always shorter than RTs on correct responses. The difference between RTs on correct responses and on reversal errors was statistically significant on both pitch, $F(1, 34) = 144$, $p < .001$ (.61, vs. .37 seconds) and roll, $F(1, 34) = 63$, $p < .001$ (.75 vs. .50 seconds). Similarly, this difference was significant between RTs on correct responses and axis errors on both pitch, $F(1, 33) = 148$, $p < .001$ (.61 vs. .34 seconds) and roll, $F(1, 35) = 233$, $p < .001$ (.75 vs. .47 seconds).

Reed (1977) interpreted the effects, discussed in the preceding paragraph, in terms of the anticipatory behavior occurring prior to the onset of a stimulus event. In some respects, the task of the subjects can be likened to classical reaction time tasks. When the subject awaits the onset of the stimulus event, errors are less likely to occur, but latency is expected to be considerably longer. Anticipation allows the subject to predict when a stimulus is to take place and to select the most probable response among the possible stimulus alternatives. When response selection is initiated prior to the time that anticipatory processes are complete, the subject may likely respond prematurely and make an error. This does not mean that some anticipation does not occur. It simply claims that the process is terminated early. Accordingly, variables that have an effect on correct responses may appear also in the errors because some information processing actually occurs. If this model of anticipatory behavior accounts for the results obtained in this experiment, then it would also predict that some correct responses would have short RT. That is, if the anticipatory process is terminated early, the selection of a response is roughly random, but on occasions may result in the selection of a correct response. Analysis to this level of detail was not carried out on the data from the present experiment.

To summarize, visual-motion relationships that are incompatible interfere with the subject's performance and result in errors and longer RTs. The absence of motion lengthens RT on correct responses, but results in a lower proportion of control errors. The short RTs in SAC on both axes and the short RTs in SAI on roll relative to VO, provide evidence favoring the alerting role of motion. Moreover, since the onset of both the visual and motion stimuli occurred simultaneously, the results are consistent with the assumption (but do not necessarily imply) that proprioceptive cues derived from motion preceded, in time, the visual ones as had been reported by Matheny et al., (1963). A rough estimate of the possible contribution provided by the presence of compatible motion relationships to response time is obtainable by subtracting the average RT in SAC from the average RT in VO. This difference is found to be .11 seconds on pitch and .34 seconds on roll. A similar, but weaker contribution is found when VO is compared to SAI (.06 seconds on pitch and .13 seconds on roll).

The results provide compelling evidence in support of the assumption that motion cues play more than an alerting role in the subject's attempt to cope with visual-proprioceptive conflict. The large proportion of reversal errors in SAI in contrast to DAI and the large proportion of axis errors in DAI relative to SAI suggest that motion also provided directional information. Moreover, that the overwhelming number of axis errors in DAI were commensurate with the direction of motion lends further support to this conclusion.

Effects of Experience

The difference between the experimental conditions was the presence or absence of motion and the axis and direction of motion with respect to visual displacement (see Table 1). The direction of displacement of the visual scene presented on the television monitor, however, remained unaltered with respect to the direction of stick deflection (i.e., the control-display relationship was not varied in this experiment). Accordingly, if a pilot's responses to aircraft attitude changes are dependent on motion cues (i.e., the pilot uses rather than disregards motion), then a motion function which is in conflict with these old and overlearned response habits should interfere with his performance. If performance in SAC is dependent upon learned habits peculiar to pilots, then the performance of nonpilots should be worse than that of pilots in this condition. On the other hand, if pilots are able to ignore motion, then the absence of motion (i.e., VO) or the presence or visual-motion relationships that are in conflict with normal flying operations (i.e., SAI and DAI) should have no effect on their performance. Similarly, the pilots should have no difficulty in the condition in which only motion cues are present (i.e., MO). The extent to which previous experience has an effect on operator responses to motion cues can be obtained by comparing the performance of pilots, navigators, and nonrated subjects on each experimental conditions.

The results revealed that the proportion of errors among the three experience groups was roughly equal. There was no difference in the proportion of reversal errors among experience groups, $F(2, 35) = .24$, $p > .05$ (.13, .14, .14 for pilots, navigators, and nonrated subjects, respectively). Similarly, there was no difference in the proportion of axis errors, $F(2, 35) = .38$, $p > .05$ (.14, .14, .12 for pilots, navigators, and nonrated subjects, respectively). Expected differences, as might have been revealed by a Conditions X Experience Groups interaction, were absent. It must be noted (see Figure 4) that pilots in SAI made more reversal errors on the roll axis than nonpilots (.41 vs. .24). Furthermore, pilots made more axis errors in DAI than nonpilots on both axes (.25 vs. .16 on pitch and .40 vs. .35 on roll), as shown in Figure 5. A descriptive statistic on reversal errors to roll axis stimuli in SAI showed that the visual-motion relationships in this condition had a greater impact on pilots than nonpilots. These results must be interpreted with caution. It can be safely concluded, however, that pilots were unable to ignore the effects of motion and that previous exposure to flight conditions did not aid them in overcoming the effects of cue conflict. In fact, it was surprising to find that the pilots made occasional errors when visual-motion relationships were commensurate with those encountered in contact flying (i.e., SAC). Equally surprising was that the proportion of errors made by nonpilots in SAC were only slightly, but not significantly, higher than those of pilots. Moreover, a similar relationship was found in VO.

Obviously, motion provided compelling cues to subjects in all experience groups, but primarily the pilots. Post-experimental debriefings revealed that pilots were painfully aware that the visual motion relationships in SAI were in conflict with those of normal flying operations. Nonpilots, on the other hand, were unaware that there was something out of the ordinary, yet all of them made more reversal errors in SAI than SAC. Jacobs and Roscoe (1975) obtained similar comments from flight naive subjects. Accordingly, the errors made by the pilots in SAC can be attributed to factors of attention or motivation and those of the nonpilots to their inexperience. If this interpretation is accepted, then it follows that the visual-motion relationships in SAC were compatible with the visual-proprioceptive sensations that engender adequate spatial orientation. Such relationships do not interfere with response tendencies, regardless of the experience of subjects.

Further evidence that motion had a greater effect on pilots than nonpilots comes from the observed tendency for pilots to respond to motion cues even when visual ones were absent (i.e., the motion only condition). An attempt to null the effects of motion in this condition was, by definition, an error response. Two types of responses were possible: those that were "consistent" with the motion function (a roll right motion was responded to with a control stick deflection to the left), and those that were "inconsistent" with the motion function (a roll right motion was responded to with a control stick deflection to the right). Presumably, a legitimate response to motion in the absence of visual stimuli would require that stick deflections be on the axis and direction commensurate with the motion function. If the past experience of pilots influenced their performance in the MO condition, it would be expected that their responses be primarily on the consistent axis and direction, relative to motion. On the other hand, the absence of experience among nonpilots could result in a random distribution of responses between consistent and inconsistent. This prediction was confirmed. Pilots made significantly more consistent than inconsistent responses on both pitch, $F(1, 3) = 21$, $p = .02$ (.13 vs. .01) and roll, $F(1, 3) = 17$, $p = .02$ (.15 vs. .02). In contrast to these results, there was a tendency for navigators to make more consistent responses than inconsistent ones, but the difference failed to reach significance on pitch, $F(1, 3) = 1.9$, $p > .05$

(.11 vs .07) and roll, $F(1, 3) = .9$, $p > .05$ (.09 vs. .05). Similarly, nonrated subjects tended to make more consistent responses but the differences failed to reach significance on pitch, $F(1, 3) = 1$, $p > .05$ (.09 vs. .05) and roll, $F(1, 3) = 3$, $p > .05$ (.09 vs. .03). These results suggest that there was a strong tendency for pilots to respond to motion cues though the expected visual ones were absent. By responding to motion only, the subject provided an input which was fed back to him as pitch or roll error on the visual display. This feedback should have been sufficient to effect learning, and therefore, to result in a strong downward trend of responding. Yet, all subjects, but primarily the pilots, responded to motion throughout all sessions. Obviously, motion provided compelling cues that could not be easily disregarded.

The previous experience of pilots (or factors due to pilot selection) did not aid them to overcome the effects of visual-proprioceptive conflict as measured by the proportion of reversal and axis errors, but it did help them reduce their response latencies. There was a significant effect due to experience, $F(2, 35) = 8$, $p < .05$ and a Newman-Keuls test revealed that pilot RTs on correct responses were considerably, and significantly, shorter than those of nonpilots (.58, .74, .71 seconds for pilots, navigators, and nonrated subjects, respectively). It had been thought that navigator RTs would be shorter than those of inexperienced subjects, but the differences were not significant. Apparently, the types of tasks conducted by navigators did not transfer positively to those in this experiment. It is of interest to note that the differences between pilots and nonpilots was preserved on reversal errors, $F(2, 35) = 4$, $p < .05$ (.36, .43, .49 seconds for pilots, navigators, and nonrated subjects, respectively), but not on axis errors, $F(2, 35) = 1.5$, $p > .05$ (although there was a tendency for pilot RTs to be shorter; .38 .43, .41 seconds for pilots, navigators, and nonrated subjects, respectively).

To summarize, the results present a rather dismal picture of man's capability to function under the conditions simulated in this experiment. All subjects appeared to make use of motion and had difficulty responding appropriately when these cues were in conflict with visual ones. Furthermore, each subject in this experiment was exposed to a single condition in which rate and amplitude of the stimuli did not vary; a rather ideal situation. Isolated instances of the visual-motion relationships as experienced by subjects in this experiment could occur in an operational environment. Nevertheless, an operator of a remotely piloted vehicle would need to adapt to continuous changes in angular acceleration in one or more axes to the vehicle and/or the airborne station. Accordingly, he must learn to restrict his manual activities to visual information rather than to accept some mix of the vehicle status with that of the station. Whether operators can learn to disregard the effects of motion in these environmental conditions is a matter for research.

Effects of Practice

Practice usually improves the performance of motor skills. Thus, it was safe to assume that at least some learning would occur among the subject in this experiment. In view of the conclusions in the preceding paragraphs, the importance of learning factors to the operation of RPVs cannot be overlooked. The primary questions, however, dealt with the specific characteristics of improvement in performance and with the particular dependent variables affected. A related question asked whether motion was necessary for training future operators.

It was expected that the effect of practice should be evidenced primarily in those conditions most conducive to visual-proprioceptive conflict. In view of the results discussed earlier, SAI and DAI were expected to result in the greatest amount of learning. Moreover, since roll creates a severe problem to spatial orientation (a topic to be discussed later), it was anticipated that practice would be most evident on responses to stimuli on that axis. These predictions were confirmed. The proportion of reversal errors made by subjects in all experience groups in SAI declined significantly with practice (see Appendix C). An examination of Figure 7 will show that most of the learning in SAI occurred by the end of the first session on pitch control and by the second session on roll. The latter reveals that acquisition of skills was more difficult when the stimuli were presented on the roll axis than on pitch. It is noteworthy that virtually all subjects continued to make control reversals on the last session. The rate of decline over sessions suggested that considerable learning took place. Had the test continued for additional sessions, the proportion of errors might have declined even further.

Unlike SAI, learning failed to occur in DAI (see Appendix D). As shown in Figure 8, axis errors declined slightly over sessions on pitch control, but the errors were distributed about evenly on roll. Thus, it is impossible to determine from these

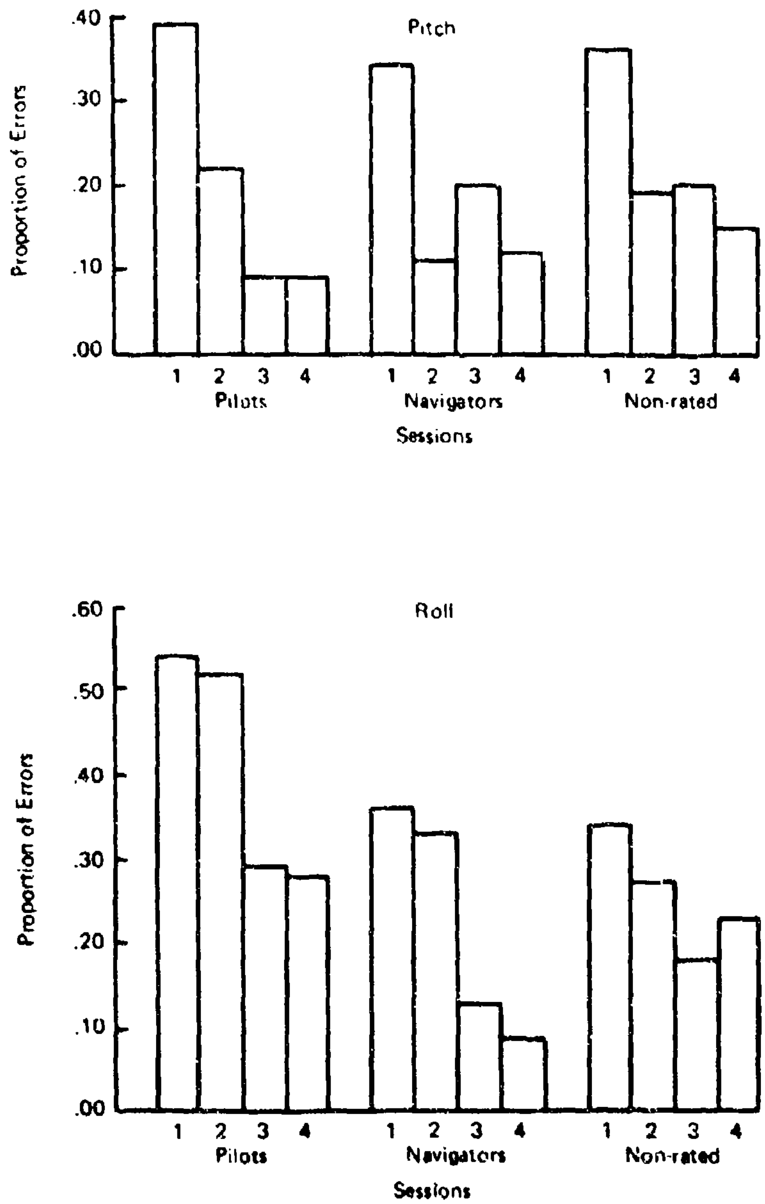

Figure 7. **Proportion of reversal errors as a function of sessions on each experience group.**

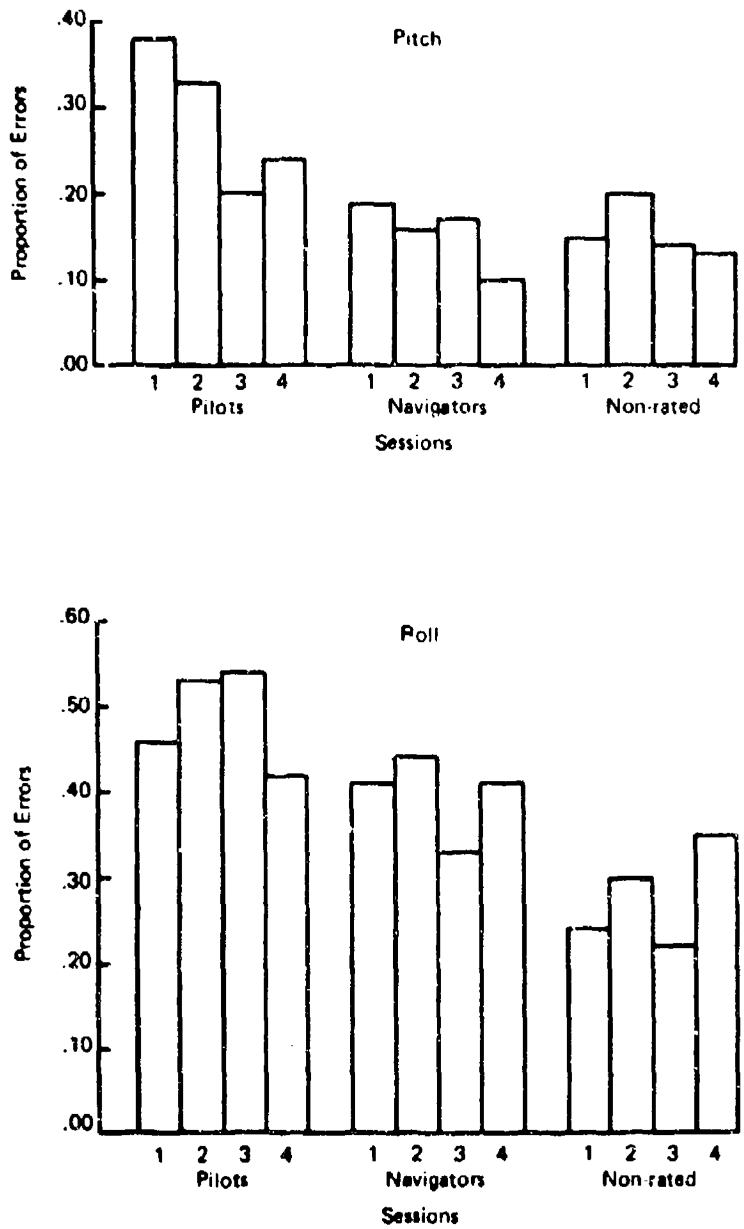

Figure 8. **Proportion of axis errors as a function of sessions on each experience group.**

data whether continued practice in DAI would have aided the subjects. Since faster learning occurred to pitch in SAI and there was a slight decline in axis errors to pitch in DAI, it is assumed that extensive practice would eventually result in learning. As noted earlier, the difference in learning rate between SAI and DAI may have been due to the disproportionate number of visual-motion stimulus combinations between the two conditions, thereby making the task in DAI more difficult.

It was anticipated that the absence of motion in VO would result in more reversal errors than the compatible relationships in SAC. Thus it was assumed that more learning would occur in VO than SAC, at least among the pilots. While there was a strong tendency for all subjects to make more reversals in VO, only navigators showed a significant practice effect in that condition and none showed an effect in SAC (see Appendix C). Apparently, learning occurs only under circumstances of severe spatial disorientation.

While the difference in the proportion of errors made by pilots and nonpilots was not significant in MO, the tendency for pilots to make more consistent responses than inconsistent ones was stronger than for nonpilots. Moreover, there was a tendency for pilots to make more reversal errors in SAI and axis errors in DAI. These results suggested that practice should have a greater effect on pilots than nonpilots in these two conditions. Some evidence for this assumption was revealed by an omega squared index (a descriptive statistic) applied to roll axis data in SAI (see Reed, 1977). The difference between pilots and nonpilots was maintained throughout all sessions, but the difference between navigators and inexperienced subjects (i.e., nonrated) was minimal. Observation of pitch axis data (see Figure 7) reveals that pilots tended to reduce the incidence of reversals at a higher rate than nonpilots. With axis pooled, the reduction of errors from Session 1 to 4 was 28%, 25%, and 16% for pilots, navigators, and nonrated subjects, respectively.

Unlike reversal errors, there was no evidence that RTs on correct responses changed with practice, regardless of experience. That RT remains stable on certain kinds of tracking tasks has been reported earlier by Gottsdanker (1956). Yet pilot RTs were consistently shorter than those of nonpilots in all conditions, but there was no difference between the two nonpilot groups. Either the number of trials in this experiment was insufficient to effect a change or the short RTs made by pilots were due to selective factors.

To summarize, it is apparent that the effects of practice on performance are predicated on the potential of visual-motion relationships to produce conflict. As expected, pilots tended to be affected by the incompatible relationships more than nonpilots and show a greater effect due to practice. The number of test sessions, however, was insufficient to reduce errors in SAI and DAI to the level of SAC.

Personnel Selection and Training

Can nonpilots be assigned to operate RPVs? The answer to this question is a cautious "yes." While the various visual-motion relationships used in this experiment had about the same effect on all experience groups, the nonpilots tended to make less errors in SAI and DAI than pilots despite their lack of experience or familiarity with flight operations. It could be argued that pilots have the advantage of flight experience. Under stress, however, the pilots may revert to old habits and respond to attitude changes of the airborne station. A related question asks whether pilot performance would deteriorate upon return to flying status. The results of this and other experiments have shown that motion is an important factor in pilot performance. If a pilot is trained to disregard the effects of motion in order to operate RPVs from an airborne station, the effect of this training could have dire consequences if he is returned to flying status. While problems in flight usually arise when the aircraft accelerations are below threshold, training to ignore sudden changes in attitude compounds the problem.

This experiment has shown that under the conditions tested, motion provides alerting and directional cues. Yet the operator of an RPV must learn to ignore these cues and place full confidence in the visual display. The extent to which confidence can be instilled in prospective operators might depend on their previous experience with these displays. If a display has caused a pilot to experience conflict (as with artificial horizon displays), there may be a greater possibility that he will experience these same conflicts. Finally, whether pilots or nonpilots are selected, the results of this experiment strongly suggest that the operators be trained in the presence of motion cues (i.e., the cue must be present in order for learning to occur).

Effects of Axis

It has been known for many years that problems in interpreting the direction of atti de shown on aircraft artificial horizon displays are greater on roll than pitch. In their analysis of pilots errors, for example, Fitts and Jones (1947) found that of 22 reversal errors, 19 were due to misinterpreting the direction of bank. Similar findings have been reported elsewhere (e.g., Kelley, 1968; Kelley, de Groot, & Bowen, 1961).

Judging from the studies cited above, it was assumed that differential effects would result from visually displayed pitch versus roll. This assumption was confirmed.

Overall, there was a greater proportion of reversal errors on roll than on pitch (.15 vs. .13), but this difference was attributed to VO (.13 vs. .08) and SAI (.30 vs. .21). No difference was found in SAC (.06 vs. .08). It will be recalled that the effects of practice were observed in VO, but primarily in SAI, and these affects were attributed to roll control. Apparently the effect disappears whenever compatible visual-motion relationships are present as in SAC. (This finding does not mean that the compatible relationships in SAC did not present problems to the subjects. Reversal errors were made by all subjects in all experience groups throughout all experimental sessions.) In a study comparable to VO, Kelley et al. (1961) reported similar findings and noted that it was easier for display content to become the frame of reference for pitch than for roll displacements.

It is of interest to note that the effect produced by visually displayed roll in VO, SAI, SAC, and DAI persisted on axis errors. While the difference was small (.17 vs. .10 on roll and pitch, respectively) it was nevertheless highly significant, $F(1, 35) = 23$, $p < .001$. In DAI the expected axis effect was evident, with a higher proportion of axis errors made to visually displayed roll than pitch (.39 vs. .20). The difference in the proportion of reversal errors in DAI, however, was not systematic (.10 vs. .13 on roll and pitch, respectively). These findings lend support to the assumption that motion in DAI interfered with the subject's response tendencies. Moreover, the results suggest that motion interferes with visually mediated orientation. Had the visual stimulus interfered with the responses to motion in DAI, then more axis errors would have been made to visually displayed pitch in which the motion function was roll. From these results, it is tempting to conclude that spatially oriented behavior is mediated primarily by visual rather than proprioceptive factors. This certainly is not the case here. It must be recalled that the experimental task required that subjects rely on visual cues; control stick deflections were totally independent of motion. Nevertheless, motion cues were extremely compelling. Even when these cues were provided in the absence of visual ones, the pilots responded to motion. Support for this conclusion was found in the differential axis effect on pilot consistent responses to MO. While nonpilots did not show differences (additional evidence that the responses of nonpilots in MO were random, but not those of the pilots), the pilots made a higher proportion of responses to roll motion than to pitch (.15 vs. .12).

Previous investigations have shown that discrimination RT is shorter to horizontal and vertical lines than to oblique ones (Appelle, 1972). This effect is preserved even when the head is tilted 45 degrees right or left (Attneave & Olson, 1967). Thus, it was expected that visually presented roll would result in longer RT than pitch, regardless of conditions or experience. This prediction was overwhelmingly supported in the experimental results. Response times for correct responses were consistently and significantly longer on roll, $F(1, 35) = 110$, $p < .001$ (.61 vs. .75 seconds). This effect was found also on RTs of reversal errors, $F(1, 33) = 19$, $p < .001$ (.36 vs. .49 seconds) and axis errors, $F(1, 33) = 29$, $p < .001$ (.34 vs. .47 seconds).

In summary, it is apparent that visually presented roll presents greater problems to spatial orientation than pitch. Response times are longer and more errors are made on roll control.

IV. SUMMARY AND CONCLUSIONS

The purpose of this experiment was to investigate operator performance in an environment which was conducive to visual-proprioceptive conflict. More specifically, the intent was to determine the relative ability of subjects to maneuver an RPV from an airborne station. To conduct the task adequately, it was necessary for the subject to disregard the effects of motion inputs from the control station. Previous studies, however, have shown that motion is not easily ignored and may be used by pilots as a cue to sudden changes in aircraft attitude. The overlearned responses of pilots to the changes may interfere with their performance under conditions of visual-proprioceptive conflict. Accordingly, it was of interest to compare the performance of pilots with subjects who have not developed these response tendencies.

Several specific experimental objectives were listed in the introduction. The experimental results associated with each are summarized as follows:

1. *The effect of conflict.* It had been anticipated that the experimental conditions would differ in their potential to engender visual-proprioceptive conflict. This prediction was confirmed. Visual-motion combinations that were incompatible with normal contact flying conditions interfered with performance and resulted in a high proportion of errors and longer response times by all subjects, regardless of experience. The absence of motion lengthens response time, but results in a lower proportion of control errors. There was evidence to support the notion that motion not only plays an alerting role, but also provides direction information on attitude changes.

2. *The effect of experience.* The previous experience of pilots did not help them overcome the effects of visual-proprioceptive conflict. While all subjects, regardless of experience, appeared to make use of motion and had difficulty in responding appropriately when these cues were in conflict with visual ones, this effect was evidenced more strongly by pilots. The previous experience of pilots, however, did help them reduce response latencies. These results indicate no advantage in training pilots, as opposed to nonpilots, to perform airborne control of RPVs (as represented by the conditions of this experiment).

3. *Effect of practice.* The effect of practice was primarily in a condition that was conducive to visual-proprioceptive conflict. All subjects reduced the proportion of reversal errors in the single-axis incompatible (SAI) condition, but little evidence of learning was shown when conflict was produced by the double-axis incompatible (DAI) condition. It was concluded that the number of test sessions was insufficient to reduce the proportion of errors in SAI and DAI to the level of the single-axis compatible (SAC) condition.

4. *Selection and training.* The results indicate no advantage in training pilots as opposed to nonpilots to perform airborne control of RPVs. Nonpilots tended to make less errors under conditions of visual-proprioceptive conflict despite their lack of familiarity with flight operat ons. Moreover, if pilots are trained to disregard m on to operate RPVs (under conditions simulated in this experiment), the effect of this training could have dire consequences if they are returned to flying status.

5. *Need for motion in training simulators for RPVs.* The results of this experiment reveal that potential RPV operators should be trained in the presence of motion. There was evidence to support the notion that the subjects can learn to disregard motion; but in order for learning to occur, these cues must be present.

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APPENDIX A: SUMMARY OF TOTAL NUMBER OF TRIALS AND RESPONSES

		Visual stimulus										
		Pitch				Roll						
Conditions	Groups	Correct Responses	Reversal Errors	Axis Errors	Cross Cpld	Correct Responses	Reversal Errors	Axis Errors	Cross Cpld	Total Resp	Data Loss	Total Trials
VO	Pilots	253	22	16	6	230	36	20	21	604	36	640
	Navig.	228	24	28	4	210	34	29	21	578	62	640
	N-R	243	24	20	5	192	46	20	37	587	43	630[a]
SAI	Pilots	220	61	16	2	142	120	26	16	603	37	640
	Navig.	213	56	18	1	194	68	25	19	594	46	640
	N-R	206	66	23	1	184	78	41	6	605	36	640
SAC	Pilots	250	14	14	8	250	10	12	22	580	60	640
	Navig.	210	21	18	6	221	22	26	21	545	95[b]	640
	N-R	240	32	9	8	217	18	39	24	587	53	640
DAI	Pilots	170	25	71	0	126	10	147	10	559	81[c]	640
	Navig.	139	45	37	17	91	36	112	27	504	102[c]	606[a]
	N-R	152	24	35	0	115	29	61	8	424	56[c]	480

		Motion stimulus						
		Pitch		Roll				
Conditions	Groups	Consistent[d]	Inconsistent[e]	Consistent	Inconsistent	Total Resp	Data Loss	Total Trials
MO	Pilots	37	3	45	5	90	40[f]	640
	Navig.	28	21	26	16	91	62	640
	N-R	35	14	28	9	76	50	640

[a]Equipment problems resulted in a lower number of trials presented to subjects.

[b]Twenty trials were not recorded due to equipment problems.

[c]Of these totals, 17 trials given to pilots, 62 to navigators, and 29 to nonrated resulted in axis errors in the wrong direction with respect to motion.

[d]The number of responses in the correct axis with respect to motion.

[e]The number of responses in the incorrect direction, but correct axis, with respect to motion.

[f]Ten trials were not recorded due to equipment problems.

APPENDIX B: INSTRUCTIONS TO SUBJECTS

VO condition. As you fly the remotely piloted vehicle through the same course you have previously (i.e., during training), it will encounter clear air gusts. These gusts will be observed on the television display as pitch or roll. Your task will be to level the remotely piloted vehicle as quickly as possible[2] and continue the flight over the various targets. Do you have any questions?

MO condition. As you fly the remotely piloted vehicle through the same course you have previously (i.e., during training), the airborne control station, but not the remotely piloted vehicle, will encounter clear air gusts. Your task will be to continue to maneuver the remotely piloted vehicle through the prescribed course. Do you have any questions?

SAI, SAC, and DAI conditions. As you fly the remotely piloted vehicle through the same course you have previously (i.e., during training), the remotely piloted vehicle and the airborne control station will encounter clear air gusts occurring simultaneously. These gusts will be observed on the television display as pitch or roll. Your task will be to level the remotely piloted vehicle as quickly as possible and continue the flight over the various targets. Do you have any questions?

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[2]The fundamental issue in this experiment (i.e., visual-proprioceptive conflict) was explored by analyzing the response characteristics immediately following the introduction of a stimulus rather than by measuring overall tracking performance. To avoid possible variability in the data (i.e., response time) that could result from unspecified set for speed or accuracy (Fitts, 1966) the instructions given to the subjects emphasized speed.

APPENDIX C: F RATIOS FROM THE ANALYSES OF VARIANCE ON PROPORTIONS OF REVERSAL ERRORS

Conditions	Experience Groups	Sessions ($df = 3, 9$)	Axis ($df = 1, 3$)	Sessions x Axis ($df = 3, 9$)
VO	Pilots	.93	4.41	1.00
	Navigators	4.12*	20.76*	2.25
	Nonrated	1.01	5.42	.69
SAI	Pilots	6.58*	6.28	1.40
	Navigators	12.84**	1.04	2.65
	Nonrated	6.64*	.61	.56
SAC	Pilots	.44	.67	.17
	Navigators	3.76	.03	.27
	Nonrated	.64	.70	.13
DAI	Pilots	.22	3.51	1.00
	Navigators	.44	2.30	.06
	Nonrated	1.90	.33	.50

*$p < .05$.

**$p < .01$.

APPENDIX D: F RATIOS FROM THE ANALYSES OF VARIANCE ON PROPORTIONS OF AXIS ERRORS

Conditions	Experience Groups	Sessions (df = 3, 9)	Axis (df = 1, 3)	Sessions x Axis (df = 3, 9)
	Pilots	1.22	.33	1.77
VO	Navigators	1.82	.20	1.30
	Nonrated	.25	.01	.14
	Pilots	1.04	.180	2.00
SAI	Navigators	2.12	.60	1.33
	Nonrated	2.61	2.00	2.69
	Pilots	2.35	.50	.50
SAC	Navigators	3.56	.15	.25
	Nonrated	.40	3.68	.20
	Pilots	2.27	4.23	1.54
DAI	Navigators	.38	8.49	.47
	Nonrated	.54	2.87	.60

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