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The Relationship Among Eye Movements, Head Movements, and Manual Responses in a Simulated Air Traffic Control Task

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16. Abstract

Performance of operators in aviation systems is highly dependent on their ability to visually scan information sources, identify problematic situations, and respond appropriately. Scanning behavior has often been mentioned as a contributing factor in the performance of air traffic controllers. An investigation was initiated to identify how alterations in various gaze measures could serve as indices of changes in alertness. As part of that larger investigation, a subset of the complete data base was used to investigate the nature of changes in eye and head movements within a session, between days, and among event types. Ten subjects were chosen for their propensity to make head movements when shifting gaze from the CRT display to the keypad for a manual response. The task consisted of 44 infrequently occurring events for which manual responses were required. There were 4 types of events; Unidentified Aircraft , Loss of Altitude, Conflict (2 aircraft at the same altitude flying toward each other), No Conflict (2 aircraft at the same altitude flying away from each other). The 2-hour session was divided into 3 approximately equal time blocks. The dependent measures were: eye movement latency, head movement latency, and the eye movement following the manual response that returned the eye to the visual display (return saccades). Eye and head movement latencies were measured from the manual response. The following conclusions were made: There were no significant eye-head movement differences among the event types. The relationship between the initiation of head movements and the initiation of eye movements appears to be a stable characteristic of the individual; it was consistent between days, as well as within the session. Return saccades were task dependent; events requiring 2 manual responses showed different return saccade patterns. The return saccade associated with the first response occurred prior to making the manual response, whereas the return saccade associated with the second response occurred after the manual response.

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The Relationship Among Eye Movements, Head Movements, and Manual Responses in a Simulated Air Traffic Control Task

Performance in aviation systems requires a high level of visual attention. The ability of an operator to maintain attention or alertness while on position (air traffic control) or during an aircraft flight (pilot) can be a critical factor in aviation safety. A study was designed to evaluate several gaze measures as possible indicators of changes in alertness of subjects who performed on a visually demanding air traffic control (ATC) simulation task (Stern, Boyer, Schroeder, Touchstone, and Stoliarov, 1994). A portion of the data base from that study was used to identify additional aspects of both eye and head movements that may be effected by aspects of the task itself and the length of the monitoring session.

Bizzi, Kalil & Morasso (1972) observed that for large amplitude gaze shifts, shifts accomplished by both eye and head, eye movements generally precede head movements by approximately 30 msec. The head, however, tends to precede the eye when the target's time and location are predictable. The movements where the head precedes the eye movement were called "predictive." Head movements that followed the eye movement were referred to as "classical movements." Mourant and Grimson (1977) found that the eye precedes the head by 45 msec in the classical eye-head movement; under predictive conditions the eye movement follows the head movement by 90 msec.

Zangemeister and Stark (1982) classified eye-head synchronicities into 4 types. Type I corresponds to the classical movement, with the eye preceding the head; about 35% of the time. Type I movements, also referred to as "Synchronous eye- and head-controller signals," are more likely to occur when the subject's vigilance is low or when the target's brightness is high. Type I movements are unaffected by the predictability of the target. In the Type II movement, identified as late head movements, the head and eyes are not synchronized. The eye movement occurs well before the onset of the head movement and is usually not seen in normal human subjects. The head moves prior to the eye in the Type III movements, also referred to as early head movements. Type III movements are identical to Bizzi's predictive head movement. Zangemeister and Stark found Type III movements more likely to occur when the target location is predictable and the subject is making a conscious effort to move to the target as rapidly as possible. Type III movements occur 43% of the time. They are also more likely to occur when the amplitude of the gaze shift is large. Type IV movements are early head movements with a final independent eye saccade; they are not synchronous. In the case of Type IV movements, the head movement is complete before the onset of the saccade. These movements are most likely to occur when the subject is required to make a rapid, large amplitude gaze shift.

There is considerable variation among individuals in both the pattern of eye-head movements and in the propensity to use the head to acquire targets that require a large gaze shift. Guitton and Volle (1987) found that the classical head movement pattern (Type I) is most likely to occur. The latency of the head movement from the eye movement is dependent on target predictability; unpredictable targets have a mean latency of 42 msec, while predictable targets have a mean latency of 17 msec. Some subjects demonstrated a tendency for the head to precede the eye in all conditions. One condition tested was a self-paced, unrestrained head condition; 1 subject was tested in this condition, and the head preceded the eye by an average of 65 msec.

The purpose of the present study was to gather data on subject head movements and eye movements made while performing a demanding visual information processing task. Analyses were conducted to identify the presence of any systematic changes that occurred in the head and eye movements subjects made between the display and the response keypad. Consistent with earlier published studies, it was thought that head movements would be predictive; namely, that head movements would precede eye movements made to the target. The location of the target (the keypad) was known, although the occurrence of stimuli requiring a response was infrequent and unpredictable. Further, it was thought that there would be a change in the relationship between head movements and eye movements, over time, to correspond with the increased familiarity of the target location. Changes in the nature of the eye movement were expected to take place over the course of the session. There were 2 opposing reasons for the belief that a change in the nature of the eye movement would occur. On the one hand, subjects might be expected to demonstrate improvements in gaze efficiency over time. On the other hand, because the task was long (2 hours), subjects might demonstrate an increase in gaze inefficiencies over time. Data were collected for each subject on 3 occasions, separated by approximately 1 week.

METHODS

Subjects

A subset of 10 subjects (9 men and 1 woman) were chosen from a pool of 20 subjects used in the primary study (Stern, Boyer, Schroeder, Touchstone, and Stoliarov, 1994) on the basis of their propensity to make head movements. All subjects performed the Thackray-Touchstone ATC task on 3 separate occasions. Each session lasted 2 hours and subjects were paid for their participation.

Materials

Display. Stimuli were presented on a 19-inch graphic display terminal controlled by a VAX 11/730 computer. A keyboard, utilized for manual responses, was attached to the lower right edge of the terminal.

Task. The ATC task consisted of 2 lines of nonintersecting vectors of air traffic, 8 aircraft each, running from the lower right to the upper left of the display. Subjects were required to continuously monitor these flight paths, which were updated by quadrant every 6 seconds. The location of an aircraft was denoted by a small rectangle. Information about each aircraft, its identification number — altitude and ground speed — were given in an adjacent data box.

Stimuli. The stimuli were 44 events that occurred infrequently throughout the 2-hour course of the session. The minimum inter-event time was 1.5 minutes, and the maximum 4 minutes. There were 4 event types, each requiring the subject to identify the event, make a response, and take action to correct the situation. The 4 event types included 2 that required 1 response and 2 that required 2 responses. Those stimuli that required only a single keyboard response were the loss of altitude event (LOA) and the event representing the presence of an unidentified aircraft (UAC). The other 2 events, involving 2 aircraft at the same altitude, required subjects to make the initial identification response and then further evaluate the nature of the event. In the No Conflict condition, aircraft would be flying away from each other. In the Conflict condition, the aircraft were flying toward each other. If the subject did not identify the event within 26 seconds, both a visual and auditory alert occurred. The auditory alert consisted of a 600 hz, 65 dB tone pulsed at 2 per second. The visual alert was a flashing of the 2 aircraft at the same altitude.

Procedure

Subjects were prepared for the recording of both horizontal and vertical electro-oculography by attaching AgAgCl electrodes on the outer canthi of the 2 eyes for the recording of horizontal eye movements, and above and below the right eye for the recording of vertical eye movements and blinks. Inter-electrode impedance was generally below 10,000 ohms. Signals were amplified with special purpose amplifiers with high common mode rejection. Amplifier output was linear from DC to 100 hz. The output of these amplifiers was fed into a Kyowa data logger. Head movements were recorded by placing the inner liner from a construction worker's helmet on the subject's head. A strip of balsa wood was attached to the liner extending from the back of the head, approximately 90 degrees from the subject's shoulders. At the tip of the strip and oriented downward and sideways were 4 LEDs, 2 on each side. Photocell receptors were attached to the left and right shoulder. The sensors were positioned equidistant from the light source, with the subject looking straight ahead. The output of the photocells was appropriately amplified and then combined to allow for the recording of head movements in the horizontal

Table 1. Frequencies and Percentages of manual responses from onset of head movements within each 500 msec time period for Days 1 and 3.

	Before response				After response			
	0 - 500 ms		501 - 1000 ms		1001 - 1500 ms		1501 - 2000 ms	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Day 1	4	1	115	33	176	51	50	15
Day 3	13	5	162	55	95	32	24	8

plane. The output of the head movement amplifier was also fed into the Kyowa data logger. Stimulus and response data were coded by assigning different voltage levels and also recorded on the data logger.

The taped data were digitized at 200 samples per second. For each of the 3 test days a 1-minute sample (commencing at stimulus onset) of eye-head movement data was obtained for each of the 44 infrequently occurring events.

Three types of data events were identified; 1) head movements, the initiation and termination of the head movement made to the target, 2) horizontal eye movements which included the initiation of saccades made to the target, and the initiation of eye movements that returned the eye to the display (return saccades), 3) stimuli and manual keyboard responses. Head movements and saccades were identified automatically by the computer program, WUPDRS (Washington University Physiological Data Reduction System, Brown, 1990). Stimulus and response timing was manually abstracted.

RESULTS

The results are organized to answer 3 major questions: 1) Are there differences between the dependent measures in responding to alerted (cued) events, as compared to events that were responded to within the 28 seconds allotted for an uncued response; 2) Are there differences in the nature of either to-target head movements or eye movements over the course of the 2 hours; and 3) Did the nature of head movements and eye movements differ from Day 1 to Day 3?

The dependent measures were 1) to-target head movements, 2) to-target eye movements, 3) return eye movements, and 4) timing of manual responses.

Head movement–manual response relationship

When subjects made a gaze shift that included a head movement, the majority (86%) of the manual responses was made between 501 msec and 1500 msec following that head movement. Table 1 shows the percentages of response latencies from the initiation of the head movement in each time block for both Day 1 and Day 3.

As shown in Figure 1, manual response latencies from the onset of head movements were significantly shorter on Day 3 than on Day 1 ($x^2_{(3)} = 42.01$, $p < .001$).

This pattern of shorter response latencies on Day 3 can be seen across all time periods and is fairly consistent across time within days as well, as shown in Figure 2. Seven of 10 subjects (4, 13, 16, 17, 21, 24, and 25) showed this pattern. The remaining 3 subjects showed no change from Day 1 to Day 3 .

There was no difference between the pattern of head movements for cued events and uncued events. The frequency of head movements did, however, decline significantly from Day 1 to Day 3 ($t_{(9)} = 2.27$, $p = .05$).

Figure 1.
Percentage of to-target head movements occurring in each 500 msec time block for Day 1 and Day 3.

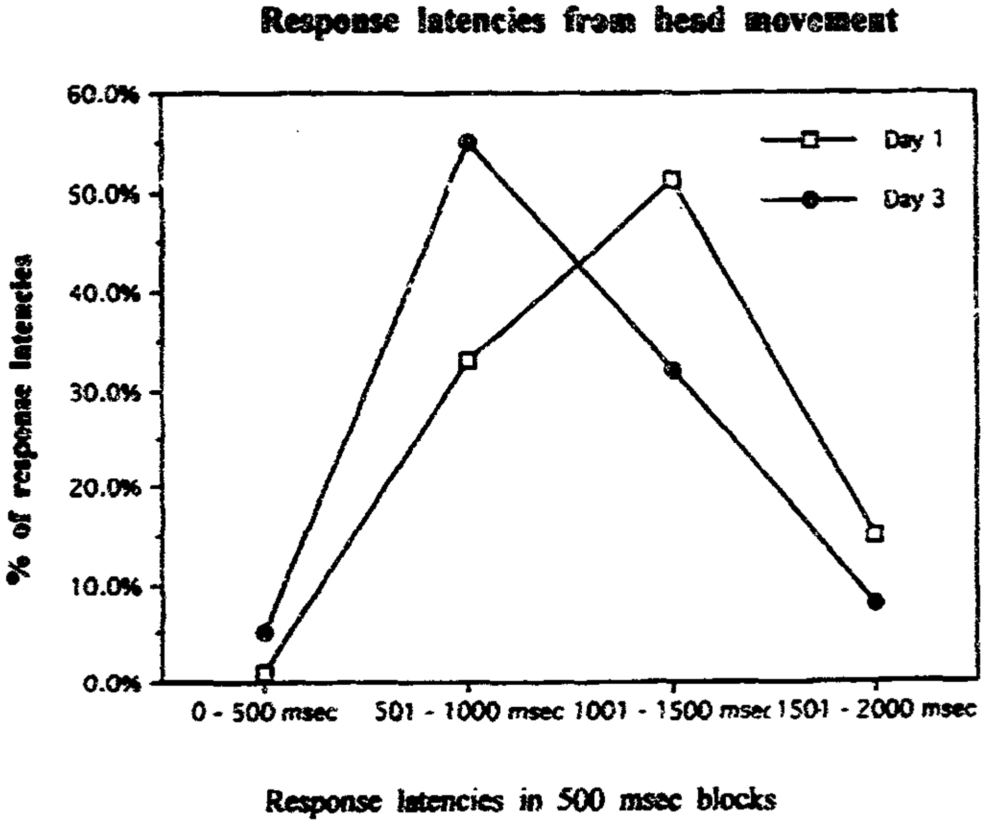


Figure 2.
Percentages of to-target head movements initiated in each 500 msec time block for Day 1 and Day 3 (plotted by time). Time is broken down into early (the first 15 events), middle (the middle 14 events), and late (the last 15 events).

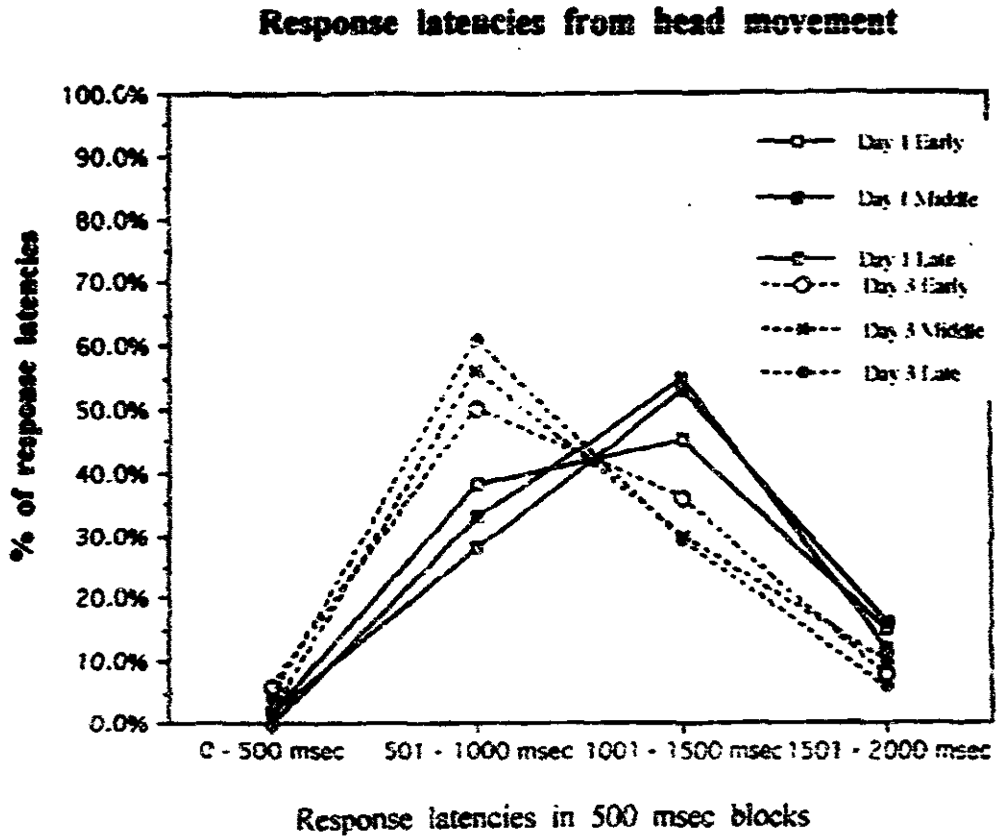


Figure 3.
Percentage of to-target saccades initiated in each 500 msec time block for Day 1 and Day 3.

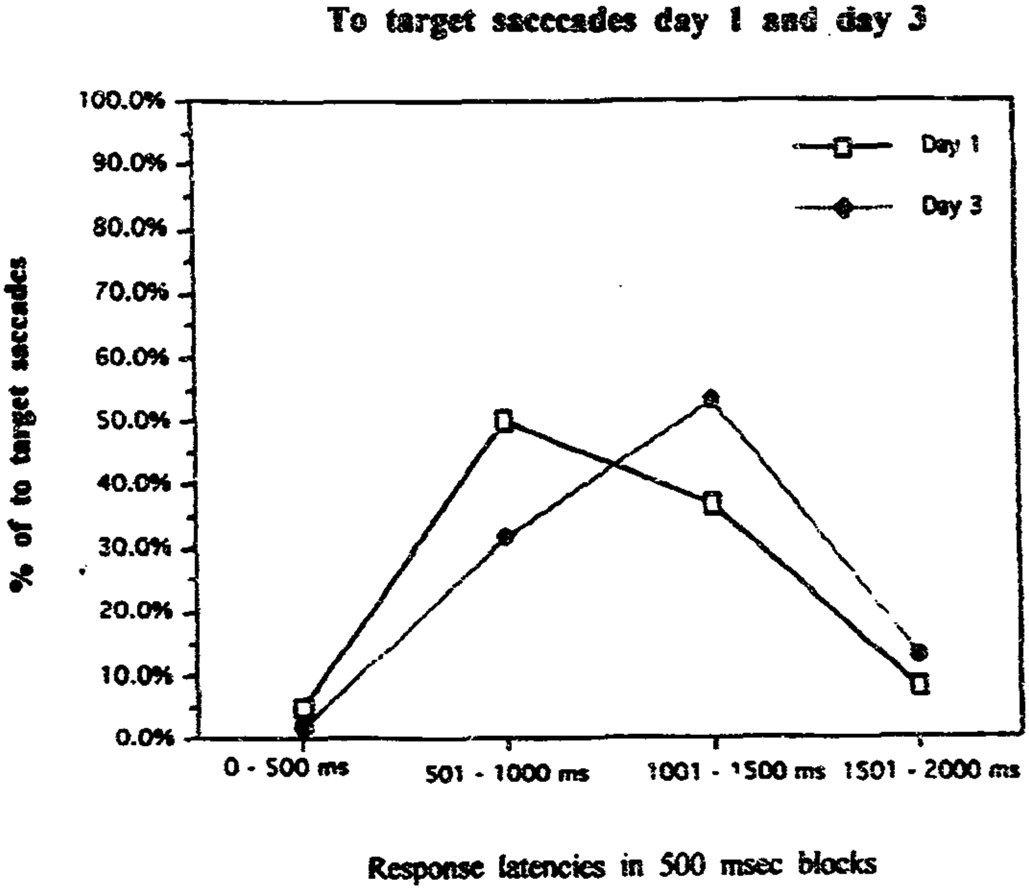


Table 2. Frequencies and percentages of manual responses from initiation of eye movements within each 500 msec time period for Days 1 and 3.

	TIME							
	0 - 500 ms		501 - 1000 ms		1001 - 1500 ms		1501 - 2000 ms	
	FREQUENCY	%	FREQUENCY	%	FREQUENCY	%	FREQUENCY	%
Day 1	21	5	188	50	137	37	29	8
Day 3	7	2	115	32	187	53	47	13

Saccadic eye movement – response relationship

The eye movement made to-target showed an opposite pattern than that of the head movements. There was a shift to longer response latencies, from Day 1 to Day 3, as shown in Figure 3. The difference between days in the pattern of response latency from the initiation of the saccade was significant ($x^2_{(3)} = 36.09$, $p < .001$.).

On Day 1, 50% of responses were made between 501 msec and 1000 msec following the eye movements made to the target. On Day 3, however, the majority of manual responses occurred between 1001 msec and 1500 msec after the eye began to move to the keypad. Table 2 shows, in frequency and percentages, the latencies from eye movement initiation to manual response within each 500 msec. block for both days.

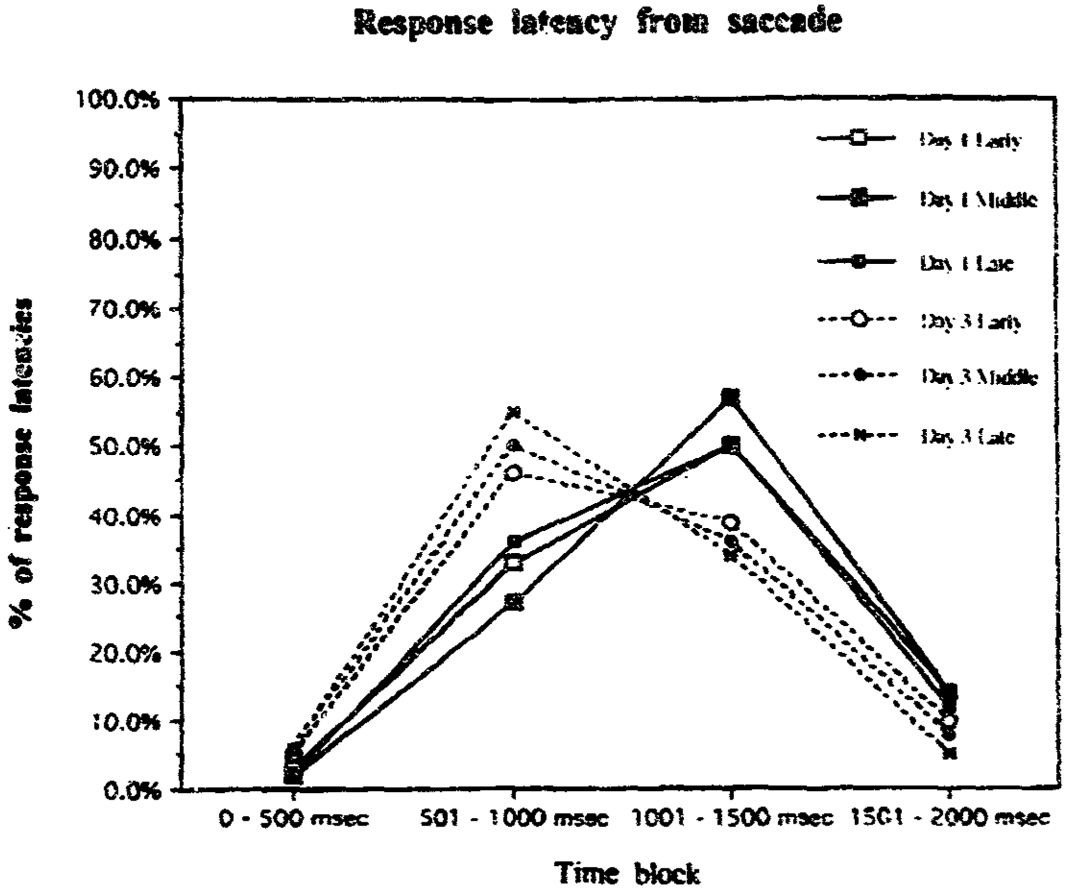


Figure 4. Percentages of response latencies from to-target saccades initiated in each 500 msec time block for Day 1 and Day 3, broken down into 3 periods: early (the first 15 events), middle (the middle 14 events), and late (the last 15 events).

This pattern of eye movements and manual responses was consistent across time as well, as seen in Figure 4.

The pattern of eye movements to the target, faster responses on Day 3 than on Day 1 following saccade initiation, was demonstrated by 6 out of the 10 subjects (4, 13, 17, 21, 24, and 25). Three subjects (16, 18, and 3) demonstrated no change from Day 1 to Day 3. They made the majority of manual responses between 501 msec and 1000 msec following the eye movement on both Day 1 and Day 3 . Subject 29 was the only subject having longer response latencies from saccade initiation on Day 1 than on Day 3.

As with head movements, there was no difference between the cued or uncued events with respect to the eye movement/manual response relationship.

Coordinated eye and head movements associated with gaze shift to the keyboard.

If the head movement consistently preceded the eye movement, the head movement was considered predictive. If the eye movement preceded the head movement, the movement was considered a classical movement. Overall, 46% of head movements preceded eye movements. The percentages of eye movements preceding head movements were fairly consistent over time on Day 1, but there was a slight tendency for the eye movements to precede the head movements over time on Day 3, as shown in Figure 5.

The mean latency from the initiation of the head movement and initiation of the saccadic eye movement for predictive head movements was longer on Day 3 than on Day 1; 49 msec on Day 1, and 55 msec on Day 3. The mean latency from initiation of the eye movement and initiation of the head movement for the classical head movements was longer on Day 1 than on Day 3, 59.5 msec on Day 1 and 52.5 msec on Day 3.

Figure 5.
The percentages of head movements that precede the eye movements for all subjects on Day 1 and Day 3.

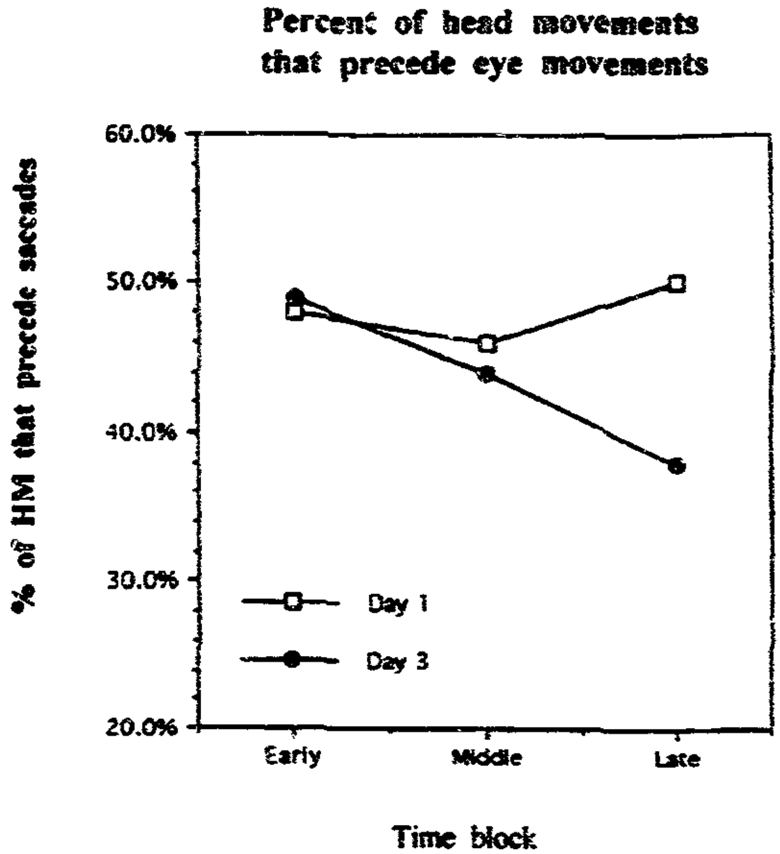


Figure 6.
The 6 subjects with predictive head movements on Day 1 and Day 3.

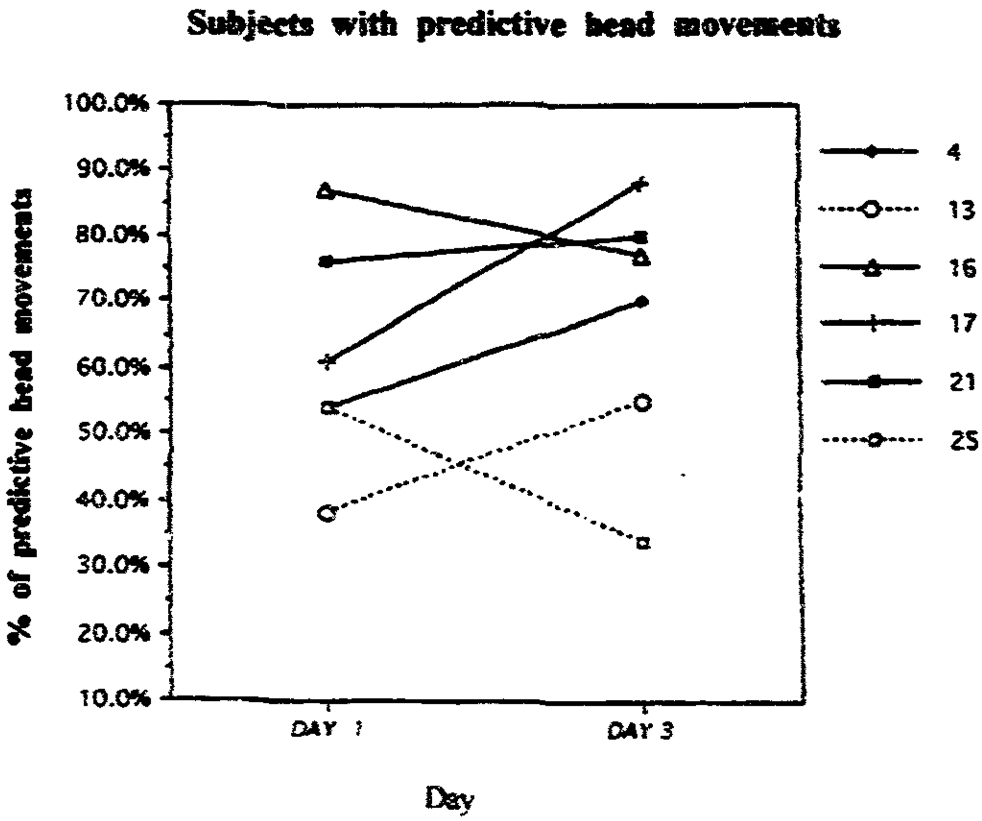
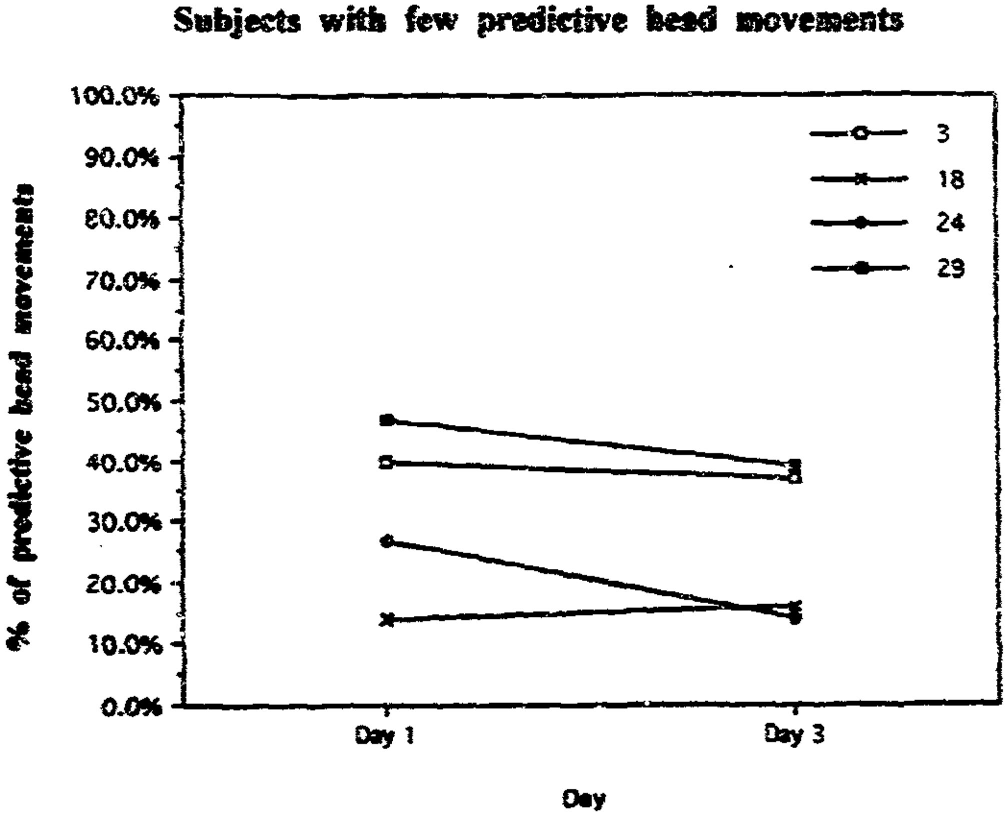


Figure 7.
The 4 subjects with few predictive head movements on Day 1 and Day 3.



For 6 of the 10 subjects, head movements preceded eye movements on at least one day for more than 50% of the trials on which both a head movement and eye movement could be measured. As seen in Figure 6, 5 of these 6 subjects showed a majority of predictive head movements on Day 1. Five subjects also showed a majority of predictive head movements on Day 3. Four of the 6 showed more than 50% predictive head movements on both days. Two subjects, 13 and 25, showed a change in eye-head patterns from Day 1 to Day 3; subject 25 showed a decline in the percentage of predictive head movements from 54% on Day 1 to 32% on Day 3, while subject 13 showed an increase in predictive head movements from Day 1 (37.5%) to Day 3 (58%).

Subjects with few predictive head movements showed less change from Day 1 to Day 3 than is true of those who had a large percentage of predictive head movements on Day 1, as seen in Figure 7. Whether or not the subjects moved the head first or the eye first appeared to be a stable subject characteristic, as seen in Figures 6 and 7.

The relationship between head and eye movements did not differ for cued and uncued events.

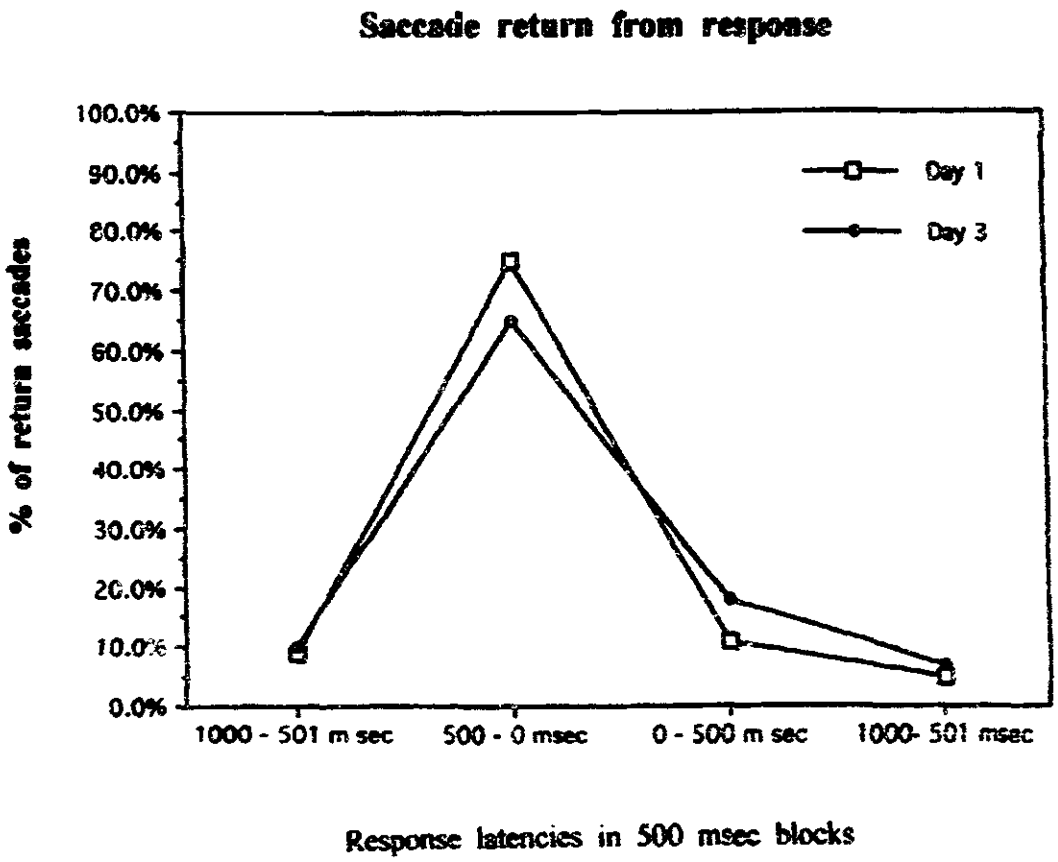
Return Saccades

Return saccades are the eye movements that returned the eye from the response panel to the display. This return was necessary for the operator to determine whether 2 aircraft, flying at the same altitude, were flying away from or toward each other. Overall, return saccades were more likely to be made prior to making the manual response (80%) than following the response. Table 3 shows the frequencies and percentages of return saccades occurring on each day for each of the 500 msec time periods.

Table 3. Frequencies and percentages of the return saccades occurring on each day for each 500 msec time period.

	Before response				After Response			
	1000 - 501 ms		500 - 0 ms		0 - 500 ms		501 - 1000 ms	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Day 1	32	9	255	75	38	11	14	5
Day 3	37	10	228	65	63	18	25	7

Figure 8.
The percentage of return saccades in each 500 msec block, preceding and following the manual responses for Day 1 and Day 3.



As seen in Figure 8., the pattern of the return saccades was quite consistent between Day 1 and Day 3. All 10 subjects showed this pattern of eye movements, that is, returning the eye to the display prior to making the manual response.

Figure 9.
The percentages of return saccades in each 500 msec block, preceding and following the manual response for Day 1 and Day 3, broken down into 3 periods; early (the first 15 events); middle (the middle 14 events), and late (the last 15 events). Return saccades for the first of 2 responses for conflict/ no conflict events and for the remaining events (the sole response).

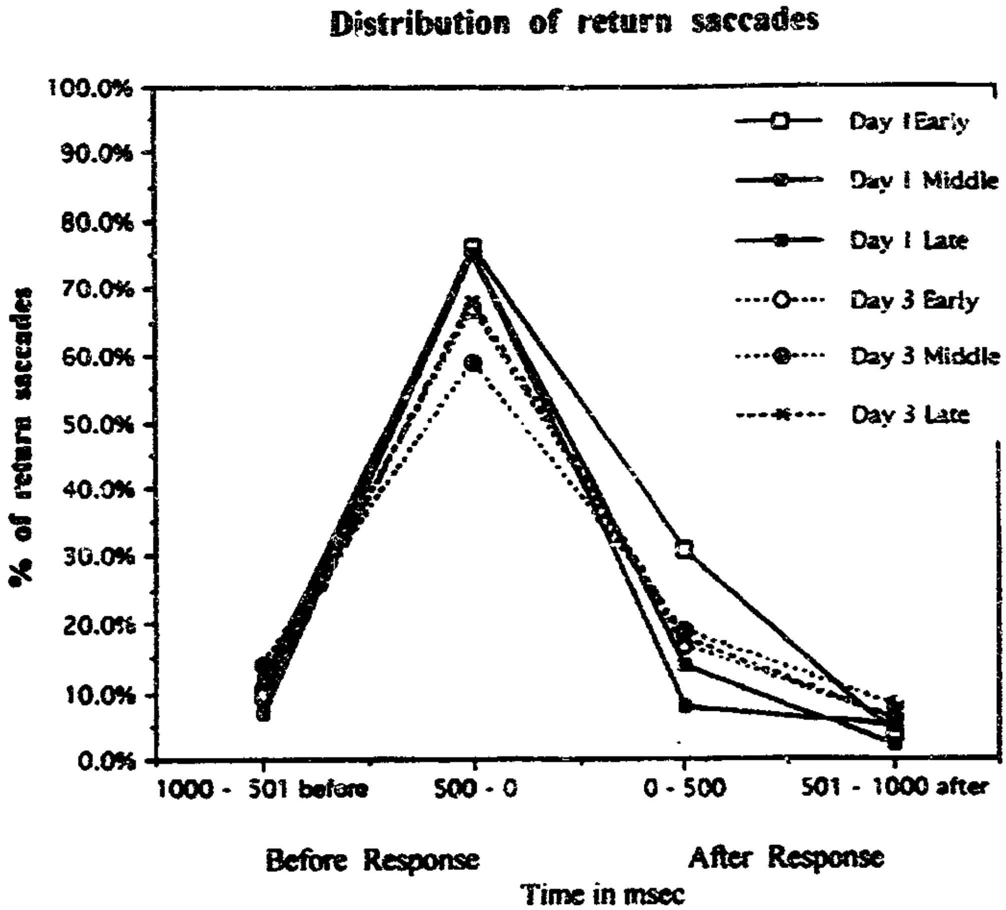
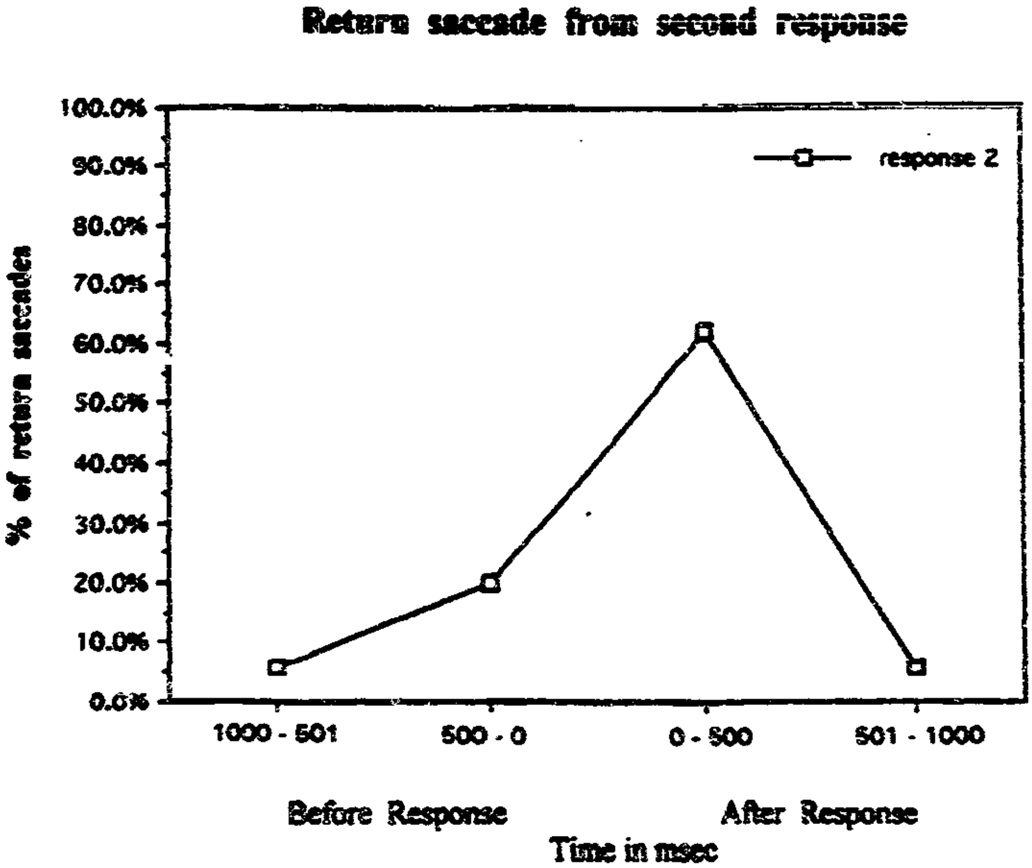


Figure 10.
The percentage of return saccades in each 500 msec block for the second manual response.



This pattern was consistent across time blocks on both days as well, as seen in Figure 9.

There was no difference in the pattern of return saccades for cued and uncued events.

For 2 of the event types, conflict and no conflict, a second response was required. There were 32 such events where a second return saccade could have occurred. Unlike the first return saccade, where the eye moved back to the display before the response was made, the second return saccade did not usually occur prior to the manual response. As shown in Figure. 10, the second return saccade followed the response on 68% of events requiring a second response.

As seen in Figure 11, the return eye movement pattern was consistent from Day 1 to Day 3. Seven of the 10 subjects showed the pattern of return saccades following the second manual response.

The 2 event types, conflict and no conflict, did not differ in overall second return saccade distributions, as shown in Figure 12.

The relationship between to-target saccades and return saccades

Dwell time, the amount of time the gaze is fixed at the keypad, was derived by subtracting the target saccade initiation from the return saccade initiation. The mean dwell time across all subjects decreased from Day 1 (M= 1040 msec) to Day 3 (M= 940 msec) by 85 msec. Six of the 10 subjects showed a decline in dwell time between Day 1 and Day 3 in average keypad dwell time. The difference, however, was not statistically significant.

Figure 11.
The distribution, in percentages, of return saccades in each 500 msec block for the Conflict and No Conflict events. Days 1 and 3 are combined.

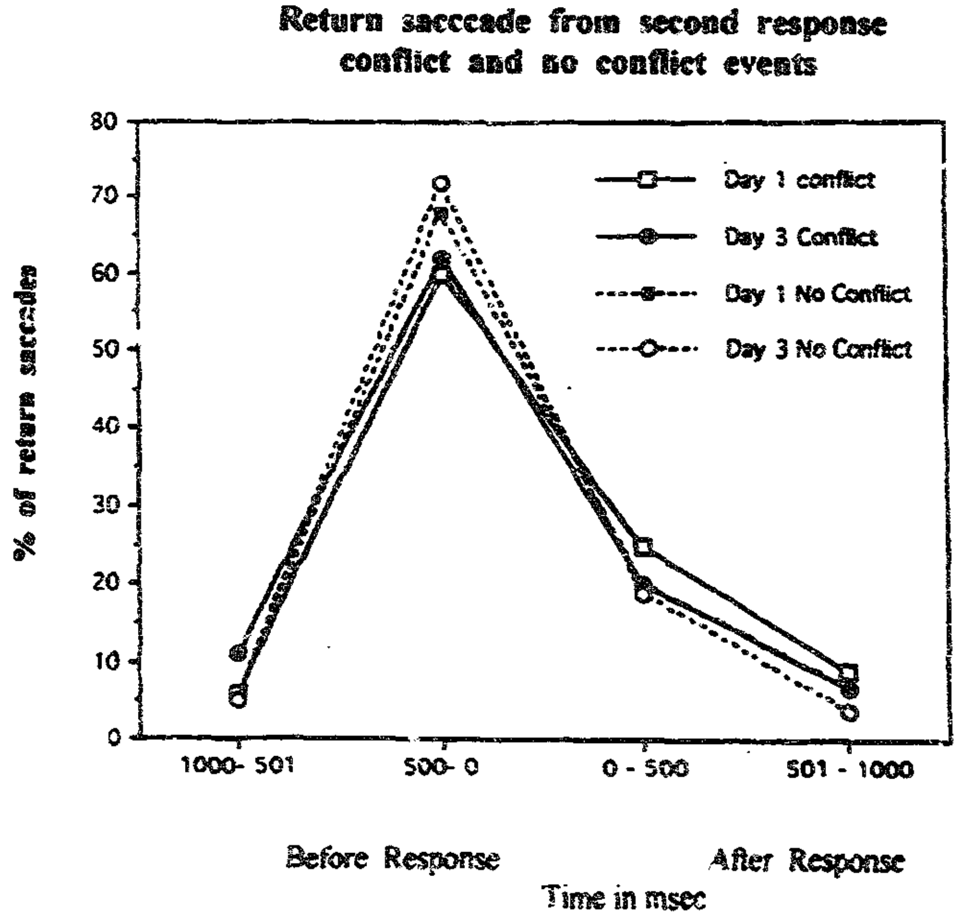
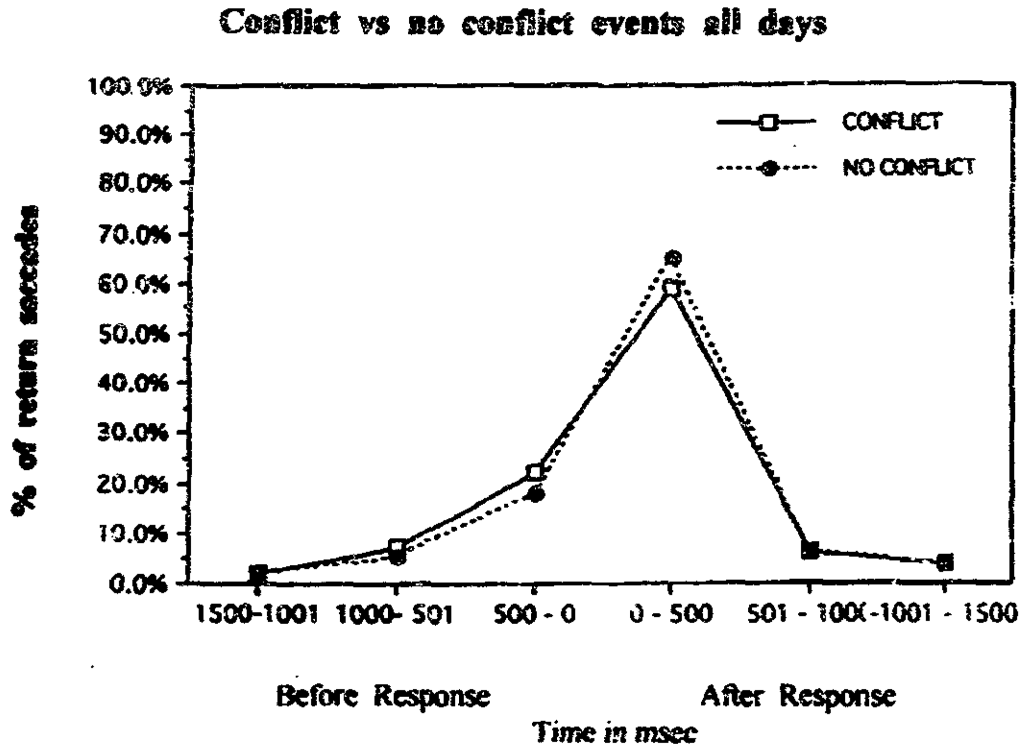


Figure 12. The distribution of second return saccades for the Conflict and No Conflict events.



DISCUSSION

Cued vs. Noncued Events

No differences were found between cued and uncued events for any of the measures. Our results suggest that regardless of whether the subject detects the unusual event or is alerted to its presence, eye movement and head movement patterns to the response pad are indistinguishable. One possible reason for this unexpected lack of difference may be that all events are "cued" events in the sense that the subject is alerted to their presence on the display. It apparently makes no difference whether the operator identifies the event, or whether it is done by a visual warning plus an auditory warning signal. Once the event is identified by, or for, the operator, the sequence of events leading to the manual response is the same.

Time on task effects

Time-on-task (TOT) effects are reflected in changes across days (between days) and across time during each session (within days). The first and third day were chosen for the analysis of between days effects. On each day, the 2-hour session was divided into 3 blocks representing early, middle, and late occurring events. We had expected, over the course of the task, decreases in gaze efficiency that would manifest themselves as changes in either eye-head coordination or increased response latencies and longer fixation periods (keypad dwell time).

To determine if TOT differences in gaze shifts strategies occur, it is important to look at the components of the response. The response required in our task consisted of 3 segments. The first was visual acquisition, the second was to move the eye to the keypad, and the third was to identify the appropriate key and make the manual response. The TOT findings for between days and across time within days will be discussed separately.

Within days. There did not appear to be any significant TOT effect for head movement or saccade initiation. Within days the response latencies for eye and head movement initiations were quite consistent. Between days, however, there were a number of differences.

Between Days. There was a shift toward shorter response latencies on Day 3 than are found on Day 1 for head movements, but the opposite was true for the eye movements. For head movements, we found 3 changes between days; 1) there were fewer head movements made to acquire the target on Day 3 than were made on Day 1; 2) the percentage of head movements preceding the eye movement decreased only slightly from Day 1 to Day 3; and 3) response latencies from the initiation of the head movement were shorter on Day 3 than on Day 1. There was 1 related finding for gaze shift over the 2 days. The average keypad dwell time declined from Day 1 to Day 3 by 85 ms, although this was not statistically significant. One possible reason for these changes is that by Day 3, subjects were likely to have become much more familiar with the task and required less time to complete the third segment of the response; these 4 related changes from Day 1 to Day 3 point to a possible change in scanning strategy on Day 3.

There are 2 assumptions that follow from increased gaze efficiencies on Day 3. First, if head movements are more likely to occur when the subject knows that gaze has to be held at the keypad for an extended period of time, it follows that there might be fewer head movements on Day 3 than on Day 1. This decrease is likely because as subjects become more familiar with the response procedure, they require less time to find the appropriate keys. Second, the percentage of predictive head movements should increase from Day 1 to Day 3. If dwell time decreased over time, it should follow that as the location and function of the keypad becomes more familiar to the subject, it is more predictable. It is usually found that if the gaze shift is made to a predictable location, the head precedes the eye. This decrease is not what happened for the majority of our subjects. We found the relationship between head movements and eye movements to be consistent between days.

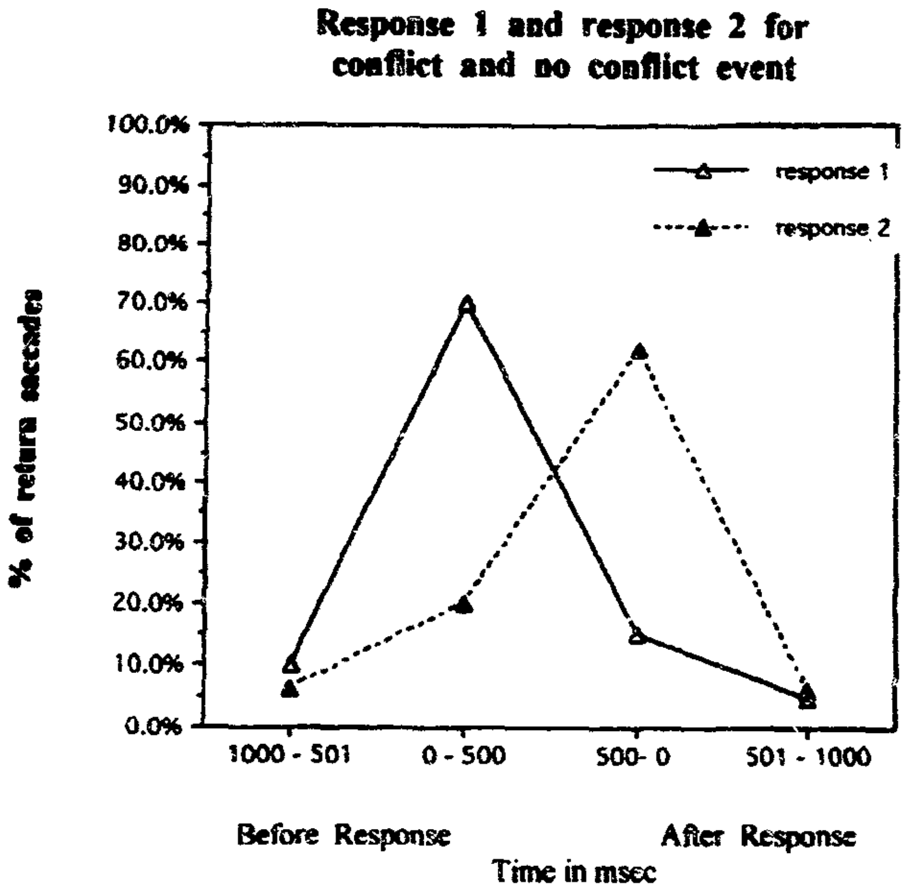
We believe that 2 distinctive factors affected the likelihood of eye-head movements; 1) individual differences, and 2) the cognitive processing demands of the task. There were 2 distinct groups of subjects, 1 with a fairly high level of predictive head movements, and the other with a fairly low percentage of predictive head movements. Subject variability, such as we have found in the present study, was consistent with Guitton and Volle (1987) who noted subject differences in predictive head movements. Likewise, Funk and Anderson (1977) observed considerable eye-head movement variability in children. They report only 1 of 9 subjects had a pattern of eye movements that could be considered classical, while the others showed a predictive pattern. They also reported a wide variation in the latency between head movement and eye movement onset. Funk and Anderson attributed this large variability to "a lack of structured motivational forces and a lack of familiarity with the equipment and the test situation" (p. 608). Our results do not support this explanation. There is considerable variability among subjects within days for both the latency between the initiation of the eye movements and the initiation of head movements. Between days, however, subjects are internally consistent in their overall pattern of coordinated eye-head movements. The subjects in our study had 4 hours of practice with the ATC task by the beginning of Day 3 and they, for the most part, displayed a pattern of coordinated eye-head movement patterns on Day 3 that was consistent with their eye-head movement pattern on Day 1. Additionally, the movement of the eye back to the display *prior to* the first response and the movement of the eye back to the display *following* the second response for the Conflict/No Conflict events provides evidence for highly motivated responding. If the subjects were not concerned with rapid and accurate performance, it is unlikely that the present pattern of responding would be found. If subjects were not motivated to move as rapidly as possible to collect the second piece of information necessary for the decision process in the Conflict/No Conflict condition, it is likely that the return saccades would have followed, rather than preceded, manual response initiation as they did in the first response.

Bizzi (1974) noted that "motor output subserving the coordinated output of eye-head movements is not fixed, but instead exhibits distinctive patterns depending on the specific behavioral situation" (p 105). These behavioral situations may account for the differences between movements to memorized locations in both monkeys (Bizzi, Kalil and Morasso, 1972) and cats (Guitton and Volle, 1987). There were also differences found in children among the 3 variations of Funk and Anderson's (1977) task. Dunham (1992) found differences in the likelihood of head movements in subjects performing either a mathematical task or a counting task. When the cognitive demand was low, i.e., the counting task, the subjects were less likely to move their heads than when the task was difficult, i.e., the math task. Rahimi, Briggs, and Thom (1990) found that when the driving situation was more demanding, for example, in a busy intersection, drivers made more head movements than when the situation was less demanding (a quiet intersection). According to Rahimi, Briggs, and Thom (1990), head turning is desirable when the amount of information to be abstracted from the scene is great. It appears the gaze system is under considerable voluntary control when the task demands greater attention be paid to the visual scene for the abstraction or the processing of information.

Return Saccades

The most reliable finding was that the eye movements returning gaze to the display were sensitive to task demands. When making the first of 2 responses, the eye returns to the display prior to making the manual response 80% of the time. In the 32 events that required a second response, additional information had to be abstracted from the display to make the second response. It was, therefore, important to shift gaze quickly. This task demand was reflected in the pattern of eye movements. The quick return of the eye to the display *in this case differed from that of the second* manual response where, after making the second manual response, no further visual information was required. The eyes returned to the display *after* making the manual response. Subjects on days 2 and 3 knew the next unusual event would not occur for some time, consequently, their eyes did not return to the display until after the response was made on 68% of such events. Figure 13 shows the difference between the return saccades associated with the first response and the return saccades associated with the second response.

Figure 13.
The distribution, in percentages, of the first return saccade and second return saccade for the Conflict and No conflict events combined. Days 1 and 3 are combined.



Due to the complex nature of the response required in our task, measured from stimulus onset to manual response, there was an inadequate measure of efficiency. Because the subject must scan 2 vectors of air traffic; finding the "event" depended, not only on their level of alertness, but where they are looking when the "event" presented itself. Mackworth & Kaplan (1964) found that the more elements one must monitor, the more likely an infrequently occurring event will be missed. Interestingly, Mackworth and Kaplan found about 40% of the two-dial targets were fully fixated when they were missed; subjects were often "looking" at the event when they failed to detect it. The task required of subjects in our study was more complex than Mackworth and Kaplan's simple detection task, therefore, subjects would be expected to "miss" even more of the infrequently occurring events. Thackray & Touchstone (1989) found the ability to detect targets in a more complex environment manifested itself, not only as an increase in detection time, but also as increased errors. Errors, in their study, included missed signals (as in *our study) and also incorrect decision responses concerning* the event types. They concluded that the additional demands of a decision regarding the direction of flight in the Conflict/No Conflict events added to the complexity of an already demanding visual environment, resulting in more errors and longer reaction times over the course of the session. They found no such increase for less demanding tasks, tasks which only required a single keyboard response, such as an unidentified aircraft entering the air space (UAC) or loss of altitude warnings (LOA) events. The first return saccades for these less-demanding tasks (UACs and LOAs) were similar to the first response for the Conflict/ No Conflict events: they required only an identification. The second response for the Conflict/No Conflict events, in addition to the identification, required the subject to make a decision. Therefore, additional information needed to be gathered, processed, and a gaze shift back to the keypad had to be made. This process *required a quick return to the display following* identification of the event, which is not present in the less demanding task of merely identifying. The second return saccade for the Conflict/No Conflict events, on the other hand, was much more like that of the first response in the less demanding events. Because the subject was not required to abstract any additional information, he could return to the display with little time pressure.

Eye-Head Coordination

The coordination of the target to eye-head movements was found to be consistent with previous studies, both in frequency and variability of predictive and classical movements. There may be consistent individual differences in the eye-head movement patterns employed by subjects to shift their gaze to the keypad before making a manual response. Four subjects demonstrated consistent predictive eye-head movement patterns, and another group of 4 demonstrated consistent classical eye-head movement patterns. It was impossible for subjects to know which events would require additional processing, so the initial eye-head movements are the same for all 4 *event types. Because there is no difference in the* first response, it is difficult to determine if the difficulty of the task influences the eye-head movement pattern. The easier event types, LOA and UAC, required only 1 manual response, so no comparison can be made between easy and difficult event types. There were also fewer of these events in the task, only 8 LOAs and 4 UACs. If all events required a second response, it would be possible to compare easy and difficult event types for the second responses.

We suggest that head movements are a likely indicator of processing demand. In other words, subjects making large numbers of head movements find the task to demand more cognitive effort. Analyses of the 10 subjects (Stern, Boyer, Schroeder, Touchstone, and Stoliarov, 1994) who did not make head movements to acquire the keypad target could provide comparison data that would provide additional evidence regarding the relationship between task *demands and head movements.*

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