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COMPARISON OF EXPERT AND NOVICE SCAN BEHAVIORS DURING VFR FLIGHT

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ABSTRACT

Seven expert and ten novice pilots flew several simulated approaches and landings while their scanning behavior was recorded. We found that experts had significantly shorter dwells, more total fixations, more aimpoint and airspeed fixations and fewer altimeter fixations than novices. Experts were also found to have better defined eye-scanning patterns. Pilots also had more total fixations and shorter dwells on trials with more precise landing, regardless of expertise. Implications for pilot training are discussed.

INTRODUCTION

Landing has always seemed to be one of the most dangerous parts of flight. Khatwa and Helmreich (1999) report that 287 out of 621 (46%) fatal accidents between 1980 and 1996 occurred during the approach and landing phases of flight. According to Baker, Lamb, Li, & Dodd (1996) instructional flights experience more than 300 crashes annually (statistics cover period between 1989 and 1992), that 51% of the accidents were during student solo flights. Of those accidents, 193 of 360 students on solo (54%) foundered due to loss of control on landing or takeoff.

With such a large number of accidents occurring during landing, it is important to enhance training methods for pilots during this vulnerable phase of flight. In flying, as with many other skills, experts (those with more flight experience) are expected to perform better landings than novices, a natural improvement that comes with practice. However, it is not clear what strategies improve with practice. For instance, do expert pilots simply demonstrate more precise control or do they do things in a qualitatively different way, by perhaps sampling different sources of information.

<u>Eye scanning as a performance metric</u>. One may assume that pilots extract information from where they are directly looking. Presumably, pilots pay attention to only the instruments that provide the needed information at that given time. The questions we examine in this experiment are (a) to what extent are the various sources of information visually sampled during effective landings, including flight instruments and the visual world as seen through the windshield, and (b) what are the differences in these scanning strategies between novices and experts? If we are able to conclude that there are significant differences between expert and novice visual scanning patterns, the findings could impact flight training methods in general aviation and in the United States Air Force. Upon characterizing expert patterns of visual scanning, these patterns may be taught to student pilots. Hence, the student pilots may learn more efficient and advanced scanning patterns earlier in their training, leading to increases in pilot training effectiveness and efficiency, as well as to decreases in student training accidents**.**

Shapiro and Raymond (1989) found a correlation between efficient oculomotor strategies and skill acquisition while playing video games. Shapiro and Raymond trained their subjects to use either efficient or inefficient eye scanning practices. Those in the efficient groups received training designed to minimize eye movements and optimize scan paths. In contrast, the inefficient subjects were encouraged to increase the frequency of eye movements without any established pattern. Those trained to use efficient methods exhibited significantly superior performance in the video game with fewer foveations. The inefficient group performed at the same level as the control group that did not receive any training. It was also discovered that after several trials the inefficient group adopted the efficient scanning patterns on their own.

In the aviation domain, Katoh (1997) found that, pilots exhibited the shortest dwell times of all flight phases during landing. Katoh also found that the saccade amplitude was the smallest during the landing phase. This finding suggests that visual scanning patterns during landing are distinctly different than during other periods of flight. Katoh also proposed landings require attention of both instruments and the outside view. Hence, the pilots must have more active visual scan patterns, especially as the runway is approached. Similarly, Bellenkes, Wickens, and Kramer (1997) found differences in visual scanning during various phases of instrument flight. Their research indicated that pilots exhibited different scanning patterns when turning than when climbing or descending. For example, the pilot viewed the altimeter more during stages where heading was changing, and while heading and altitude were changing, the airspeed indicator was visited more frequently. While descent and landings share features in common (loss of altitude), it is important to understand that visual scanning during landings may differ even from the scanning during descents, because of the greater flight precision needed and the importance of scanning the outside world. Additionally, the most important conclusion reached by Bellenkes et al. (1997) is that scanning differences between novice and experts are correlated with better performance (as measured by reduced flight path error on all axes) by experts. Since the pilots will be descending during landing, we expect similar results. Generally speaking, experts should have shorter dwells and more fixations than novices on all instruments. In particular, experts should demonstrate more frequent fixations with shorter dwells on the airspeed indicator, altimeter and vertical velocity indicator.

One possible explanation as to why experts do not need excessive dwell times is experts are able to extract information from their peripheral vision while novices do not. Mourant and Rockwell (1972) found that expert drivers looked farther down the road and gained more lane information from their peripheral vision. This allowed experts to stay in their lane better than novices. In contrast, novices demonstrated a behavior in which they glanced slightly ahead and to the right of the car gathering lane position information directly from seeing the distance from the curb. Not only did this prevent them from looking forward, but it also hindered their ability to stay within their lane. Wikman, Nieminin & Summala (1998) also found that novices' in-car dwells hindered their ability to maintain lateral stability. Perhaps experts were able to gain peripheral information about the outside position of the car, even when their fixations were inside. In support of this hypothesis, Fox, Merwin, Marsh, McConkie, and Kramer (1996) found that performance for expert pilots suffered more than for students when flight relevant information was removed from the instruments in the pilots' peripheral vision. Therefore, they concluded that experts are more likely than novices to use peripheral vision and hence, process a broader range of visual cues, thereby reducing the need to make a conscious fixation on an instrument and allowing the experts to vary their scanning pattern while still obtaining the needed information.

The literature just described offers many conclusions. First, we know that efficient visual scanning patterns yield better performance (Shapiro & Raymond, 1989). Also, experts demonstrate that an increased use of the ADI and a higher frequency of fixations with shorter dwell time on all instruments leads to increased performance (Bellenkes, et al., 1997) and (Kramer, et al., 1994). Furthermore, Mourant and Rockwell (1972) found that experts tend to look more outside and farther away than novices while driving. Mourant and Rockwell's study together with Fox et al. (1996) suggests that experts also gain information from their peripheral vision. Therefore, in flying tasks, we may predict that those who demonstrate frequent fixations with short dwell times and maximize the use of the peripheral vision will demonstrate better landings.

Unfortunately, the previously mentioned studies only concentrated on scanning patterns during the low stress maneuvers during cruise flight under instrument flight rules (IFR) conditions. So far, the research has yet to address expert and novice comparisons during landings under VFR flight conditions, when an important channel of information is the forward view above the instrument panel (i.e., the runway).

We have three hypotheses to examine. First, we hypothesize that experts will make more frequent fixations than novices, and will have shorter dwells overall. A second hypothesis is that experts will spend more time looking outside the cockpit at the runway during landing because they have more time available given their shorter dwells (than novices) on the instrument panel. Finally, we predict that landing performance will correlate with more total fixations and less average dwell time per fixation.

EXPERIMENTAL METHODS

Ten novice and six expert pilots participated in the study. The novice pilots were all USAF Academy cadets who had completed the Introductory Flight Training (IFT) program. Each subject had logged between 40 and 70 hours of VFR flight time, with an average of 46.8 hours. The expert pilots were rated Air Force pilots. The experts had logged between 1500 hours and 2150 hours of flight time, with an average of 1980 hours.

The simulation equipment consisted of a 700 MHz IBM compatible PC running Windows 98 and 21-inch monitor. The program **Fly!** by Terminal Reality® was used to simulate VFR approaches. Subjects used a flight yoke to control pitch, roll, and airspeed during the simulation. The eye tracker was an Applied Science Laboratories (ASL) 5000 control unit, one pan/tilt optics eye camera, one scene camera, a magnetic head tracker and a PC used as an eye tracker interface.

Our independent variables were the level of experience of the aviator (expert/novice) and the quality of landing flown (good/poor), which was based on a predetermined scoring algorithm designed by the experimenters (described in detail below).

Each participant performed 15 landing trials. Each landing trial started at 1000ft above ground level on a 45° turn to final and consisted of a 2-3 minute approach that ended after the participant had touched down and rolled out of the landing. Each participant was given 3 practice and 12 experimental trials. They were then evaluated on their ability to land on the runway and their scanning behavior was recorded.

DATA ANALYSIS

The formula used for scoring landing performance was 28 times the lateral distance from centerline plus the longitudinal difference.

Score=28*(latdev)+(longdev)

This 28-1 weighting assigned by the experimenters was based on the length and width of the experimental runway and the relative importance of a lateral or longitudinal deviation. In our case, we established a +/- 25 ft. lateral deviation from centerline and a 1400 ft. landing zone, starting from 300 ft. down the runway (1000 ft. down was the desired landing point). Based on this criteria, we established that a one foot of lateral deviation was 28 times more important that a longitudinal one. After each landing was scored, all expert and novice landings were combined and the median of all landings was found. Any score below the median, whether achieved by an expert or a novice, was considered to be a good landing (small deviations from the touchdown point) and any score above the median was considered to be a poor landing (greater deviations). A second measure of landing performance was derived from AF standards of a satisfactory landing of a T-1 aircraft during Air Force Undergraduate Pilot Training. The minimum criteria for a “satisfactory” landing were if the plane lands within 10 feet of the centerline and within the first 1500 feet of the runway. Using these criteria, we evaluated pilots as to whether they made a satisfactory landing.

The pilot’s fixations were classified into four visual areas of interest (AOI) on the **Fly!** computer screen using an analysis program provided with the eye tracker. The first AOI consisted of the upper two-thirds of the computer screen, excluding the instrument panel (where the runway was also located). As each trial progressed, the runway would also move within the AOI. The remaining three AOIs were located on the instrument panel. They were the airspeed indicator, the altimeter, and ‘other’ instruments that consisted of the far right side of the instrument panel that contained a directional gyroscope and radio equipment

Each dwell was located in one of these four AOIs. These AOIs then provided information concerning whether the pilot was looking inside or outside the cockpit, and if inside, which instrument was fixated on. The attitude indicator was not included as a separate AOI because we found it did not provide any useful information to a pilot performing a visual landing. Preliminary examination also revealed very few fixations for the ADI.

RESULTS

Not surprisingly, as figures 1 and 2 show, there was a difference in landing performance between experts and novices using both standards of performance (our score t(199)=4.675; p<.001 and AF standards t(199)=5.848; p<.001). Novice landings were more varied and they tended to land short of the optimal point. Experts demonstrated a tighter grouping of landings and they tended to land past the optimal point.

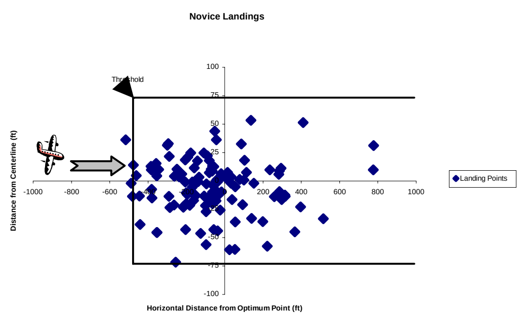

Figure 1: Plot of novice landings (Optimal touchdown point is the intersection of the x and y axes)

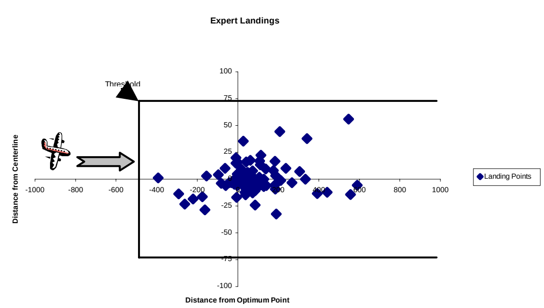

Figure 2: Plot of expert landings (Optimal touchdown point is the intersection of the x and y axes)

As figures 3 and 4 below indicate, expert pilots had significantly more fixations $t(193)=2.793$; $p=.006$ (and lower avg. dwell $t(193)=2.579$; $p=.011$), more runway aimpoint $t(193)=2.147$; $p=.033$, and airspeed fixations $t(193)=3.874$; $p<.001$, and although not statistically significant, slightly fewer fixations on "other" instruments, including the altimeter.

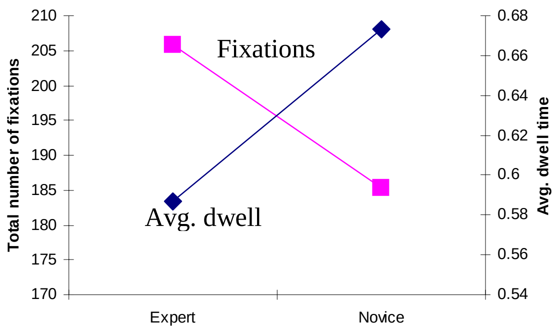

Figure 3: Fixations and avg. dwell times for Novices and Experts

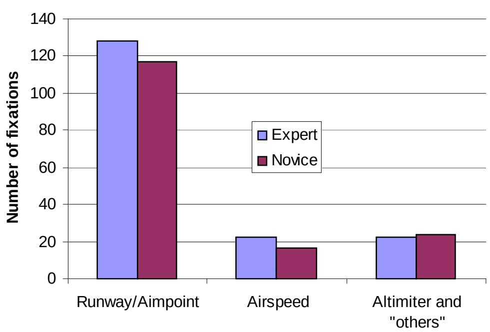

Figure 4: Numbers of Novice and Expert fixations on particular Areas of Interest (AOI)

Figures 5 and 6 portray the eye movements for one novice and one expert trial. These figures clearly demonstrate the importance of how the pilot transitions between the runway and the airspeed indicator. The novice plot (Figure 5) shows a more complicated pattern that exhibits several instances of horizontal movement within the runway area. These data suggest that the novice makes several consecutive fixations in the vicinity of the runway. There does seem to be a weak pattern of transitions between the runway and the airspeed indicator and visa versa. However this pattern is less evident than in the expert's data.

Figure 5: Novice Scan patterns (Circle = Fixation, Line = Path the eye took during the saccade.)

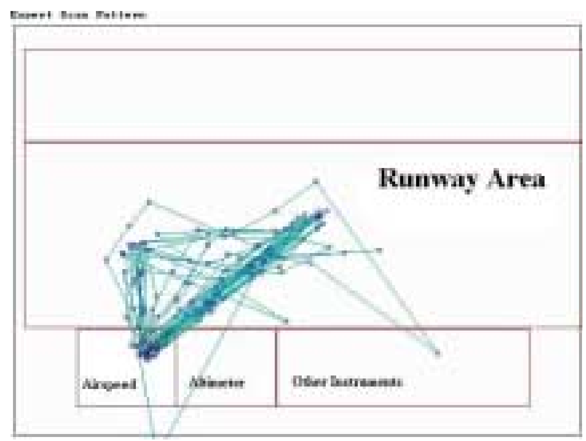

Figure 6: Expert Scan Paths (Circle = Fixation, Line = Path the eye took during the saccade.)

In contrast, the expert plot (Figure 6) shows that experts tended to exhibit a clearly defined pattern of visual scanning between the runway and the airspeed indicator. The vertical saccades in this plot represent transitions between the runway at the beginning of the scenario (the scenario started with the runway to the left of the screen – 45 degree approach to final). The diagonal saccades occurred later in the scenario when the pilot rolled out on final approach with runway in the middle of the screen. This particular expert pilot only looked at the runway and the airspeed indicator and made many transitions between the two. In contrast to the novice, the expert did not fixate on the altimeter at all. The visible transitions differences seen in Figures 5 and 6 were also found to be statistically significant when all expert trials were compared to all novice trials.

As revealed by the data in figure 7, Results of a 2X2 ANOVA indicate that experts had more total fixations than novices (a marginally significant effect--F(1,191)=2.816, (p=.095)), and within each group, better landings were characterized by more fixations than poorer ones, as defined by the experimenter's criterion. F(1,191)=4.187, (p=.048). Expertise level played a nominal factor in this.

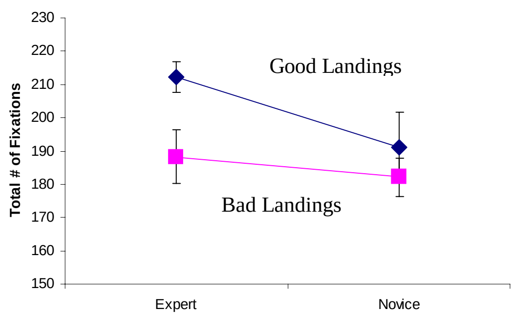

Figure **7**: ANOVA results from type of landing and expertise level (DV is number of fixations)

DISCUSSION

The purpose of the current experiment was to examine the visual scanning characteristics of novice and expert pilots during landings. Bellenkes et al. (1997) had studied the eye scanning differences in expert and novice pilots but only during IFR cruise flight. The current study provided many significant results about how eye scanning patterns differs as a function of expertise, particularly during the landing phase of flight. In the following, we examine three general aspects of the data: (1) how, in general, can we characterize the scanning performance during landing, an issue that has not been addressed before. (2) how do novices differ from expert pilots in this scanning; and (3) what scanning characteristics differentiate high quality from low quality landings, and how are these related to differences in expertise.

First, we observed two important characteristics of visual scanning during landing, which differentiates it from the general characteristics of scanning in cruise flight (Bellenkes et al, 1997; Wickens, Xu, Helleberg & Marsh, 2001). One important characteristic is that, during landing, pilots use the ADI far less than during cruise flight, where this instrument had been found to be the most important (Bellenkes et al., 1997). In fact, during landing, it is hardly fixated on at all. In hindsight, this lack of attention to the ADI is not surprising, because all necessary attitude information is directly obtainable from the true horizon outside the cockpit.

Another characteristic, again not altogether surprising, is that pilots spend far more time looking out the window than in cruise flight. In the latter conditions, Wickens et al, found that roughly 60% of the time was spent on the instrument panel (and 40% outside). In our study, the instrument panel scan dropped to approximately 13% of the total dwell time. This finding is again not surprising, since the forward view not only contains the necessary horizon for attitude control, but, of course, the most critical information for the pilots task, the runway.

Secondly, we did find that our expert pilots differed substantially in both performance and scanning from the novices. It was clear from the data presented in figures 1 and 2 that experts landed more precisely than novices. In addition, they tended to land past the aimpoint while novices tended to land before the aimpoint. The analysis of the visual scanning data provided some insight as to how this better performance was obtained, a difference that appeared to be attributable to several factors: the experts paid relatively more attention to airspeed and less to the altimeter; they had relatively more fixations outside, and their outside fixations tended to be at a more distant point on the runway; and the experts had shorter dwells (and therefore more frequent fixations) on nearly all instruments and the runway. It is therefore likely that this difference in airspeed concern is a strategic factor, which allows airspeed to be more closely monitored and controlled, and, as a consequence, allows for a more precise touch down. Bellenkes et al. (1997) also found that experts visited the airspeed indicator more frequently than novices. This pattern was especially evident during segments where altitude was changing (Bellenkes et al.) Therefore, as with Bellenkes et al. we too observed more airspeed fixations by experts during a time which altitude was changing (approach to landing). In order to look more at airspeed, the expert pilots needed to "borrow" their attention from somewhere, and they apparently did this by looking less frequently than novices at the altimeter.

The number of transitions between the runway and the airspeed indicator in expert pilots is no accident. Air Force pilots are trained to repeatedly look at the runway and then the airspeed during their final approach. This behavior is taught even to beginning glider students at USAFA (Soar for All Manual, 1996). Our data indicate that expert pilots are indeed following their training and making more of the runway – airspeed saccade transitions, and vice versa during approach to landings. This finding suggests that the Air Force (and other flight training agencies) continue to teach this scan pattern.

The second major difference between experts and novices was in terms of the expert's shorter dwells on everything. As found in the study by Bellenkes et al (with the ADI), the observation that experts can extract information in a shorter period of time is consistent with views of expertise, that many aspects of their performance is simply more rapid and automated. It is unlikely that this difference may be thought of as a STRATEGIC one, in the same way that describes the greater airspeed interest of the expert. However the shorter dwells certainly allow the expert to have more time available to scan other locations. In particular, they allow the expert to stay "head down" for a shorter duration, and thus return their gaze to the runway more rapidly, correcting any errors that might have appeared. With more rapid head down scans, they are presumably not penalized for being head down slightly longer than novices, a finding that appears to contradict the typical scan patterns of drivers (Mourant & Rockwell, 1972; Wikman et al, 1998)

While the above data has revealed that experts (a) land better than novices and (b) have different scanning strategies than novices, these two findings do not in themselves indicate that the scanning difference was the source or cause of the better landings. However further evidence that this is the case is provided by the distinction between "good" and "bad" landings. Our data suggest that those scanning factors that discriminate experts from novices are the same as those that discriminate good from poor landings. For example, good landings were associated with more fixations and shorter dwell times.

Conclusion

In conclusion, expert pilots demonstrated more frequent fixations with shorter dwell times than novice pilots. In addition, expert pilots revealed a stronger and more defined scan pattern than novice pilots. This type of active scan pattern corresponds to better maintenance of airspeed and better landing performance. Hence, the more active the eyes, in a consistent, efficient pattern, the better a pilot performs

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