2009

How Differences in Spatial Ability Influence Inexperienced Users in a Visual Perceptual Aviation Task

Michael T. Curtis

Florian G. Jentsch

Crystal Maraj

HOW DIFFERENCES IN SPATIAL ABILITY INFLUENCE INEXPERIENCED USERS IN A VISUAL PERCEPTUAL AVIATION TASK

Michael T. Curtis
University of Central Florida
Orlando, FL

Florian G. Jentsch
University of Central Florida
Orlando, FL

Crystal Maraj
University of Central Florida
Orlando, FL

The approach and landing phase of flight is widely recognized as one of the most difficult phases of flight. More specifically, professionals in aviation training report difficulty in training inexperienced pilots on execution of visual approaches. The current paper focuses on our efforts to develop a perceptual skill trainer using a static image discrimination task. From a perceptual standpoint there are a number of documented visual environmental cues that have been found to impact one's ability to judge distances. These distracting cues can cause individuals to misjudge distance to landing surfaces, and subsequently result in an unstable or unsafe approach. For this study we chose to examine how individual differences in spatial orientation ability predict performance in a visual approach static image discrimination task. As expected, individuals high in spatial orientation ability outperformed those with low spatial orientation ability. More importantly we examine how distracter cues have a differing effect on low and high spatial orientation ability individuals. The results from this study have implications for development of tailored training in aviation training.

The words "clear for visual approach" usually signify favorable conditions for the approach and landing phase of flight. Based on the clear conditions that coincide with visual approach, flight safety would seem to be at its most optimal. Controlled flight into terrain (CFIT), however, remains one of the most prevalent causes of aviation accident (Darby, 2006). CFIT accidents are those in which the pilot unknowingly maneuvers the aircraft into the terrain below (e.g. ground, water, or obstacles). In some cases, this can be attributed to degraded conditions or unexpected events that challenge even the most experienced pilot. Surprisingly, accidents and incidents also occur in clear conditions where visual flight rules (VFR) prevail (Shappell & Weigmann, 2003). Despite technological advancement in training, aircraft instrumentation, and external visual flight aids (e.g., visual approach slope indicator) visual approach still remains one of the most challenging phases of flight. Overall, our research focuses on the investigation of critical skills in visual approach, and the development of supplemental training tools to improve these skills.

Our research efforts are geared toward the investigation of both cognitive and perceptual skills that are involved during the visual approach phase of flight. The current study represents one part of a larger study in which we examine visual perceptual factors that influence distance estimation in a visual approach. Here, we examine how one measure of individual difference might predict performance on a visual aviation task intended to train perceptual performance when conducting a visual approach.

Visual Approach

Visual approach is a flight maneuver that is conducted when pilots have unobstructed visual contact with the landing surface. When cleared by air traffic control for visual approach, pilots rely on their view outside of the cockpit to establish and maintain flight path, while judging ground proximity for final approach and landing flare (Robson, 2001). Distance and altitude regulation are critical to effective maintenance of safe flight conditions. The angle generated by the distance and altitude from the landing surface, or glide slope, is usually recommended at 3° for optimal approach. Anything that deviates too far from the recommended glide slope can result in dangerously steep or shallow approaches. In fact, pilot workload increases as the glide slope angle gets steeper (Boehm-Davis, Casali, Kleiner, Lancaster, Saleem, & Wochinger, 2007). The issues associated with inefficient glide slope maintenance may, as a result, be compounded by additional workload.

Perceptually, the estimation of distance on both the vertical and horizontal plane, known as slant distance, is a key contributor to maintaining a safe flight path. The visual environment at times contains information that may mislead distance judgment. Unfortunately, this can lead to inappropriate flight path alterations, leading to unstable visual approach conditions. Human adaptation to terrestrial viewpoints may have something to do with this. Given that the world is oriented with a bias toward vertical and horizontal orientations (Baddeley & Hancock, 1991), the oblique viewpoint associated with aerial perspective is less familiar. In fact, oblique aerial viewpoints contribute to a number of illusory effects that may cause incorrect judgment of distance in relation to terrain or other obstacles (Leibowitz, 1988). These effects can result from lack of visual information (i.e. black hole effect; Gibb, 2007; Mertens, 1981), variation in runway dimensions (i.e. form ratio, Mertens, 1981; Mertens & Lewis, 1982), or even the relative heading at which an aircraft approaches the runway (Curtis, Schuster, Jentsch, Harper-Sciarini, & Swanson, 2008). Since the geometric principles for approach angle are rigid, the judgment of distance should be relatively straight forward. However, there is a wide variation in visual information that a pilot may experience. Depending on the circumstances, environmental visual cues can act to distract pilot perception. Since visual perception continues to play an important role in aviation, it is important to investigate measures that accurately assess perceptual skill as it relates to the visual approach task. Carefully selected measures of individual difference may provide this accuracy. Ultimately individual difference measures found to predict performance can be a valuable guide in training development.

Individual Differences

Spatial ability is a widely studied individual difference factor that has been investigated in a broad range of domains. Spatial ability consists of a number of widely disputed dimensions (Carroll, 1993; Lohman, 1988; McGee, 1979; Michael, Guilford, Fruchter & Zimmerman, 1957) that are best defined as a representation of an individual's capacity to cope with object relations in space. Spatial ability encompasses skills such as wayfinding, navigation, and object recognition. It has been found to predict task ability and used for selection purposes within the context of numerous domains (Gibbons, Baker, & Skinner, 1986; Ghiselli, 1973; Humphreys & Lubinski,, 1996).

In aviation, spatial ability has been found to predict success in general piloting skill, and for many years in the mid 20th century was used for selection of military pilots (Hegarty & Waller, 2005; Humphreys & Lubinski, 1996). In fact, through a series of spatial measures Dror, Kosslyn and Waag (1993) found that pilots tend to be better than non-pilots in mental rotation and precise distance judgments. The ability to make precise distance judgments is a critical flight skill that has implications especially for execution of visual approaches. Despite the findings by Dror and colleagues (1993), there are still reports of instances where pilots, who should have good distance judgment skill, experience difficulty executing visual approach. So distance judgment skill alone does not guarantee that pilots are impervious to distracting features in the environment.

Many studies of spatial ability of pilots focus on comparing pilot and non-pilot populations. This is informative in distinguishing that experienced pilots have spatial skill advantages to non-pilots, but does little to identify application of spatial skill to specific aviation tasks. Instead of using spatial measures for blanket piloting performance selection criteria (Humphreys & Lubinski, 1996), perhaps spatial measures can serve more to diagnose areas where additional training may benefit.

In visual approach, a pilot's understanding of their location relative to the runway is critical. Unlike the distance judgment task used by Dror and colleagues (1993), visual approach involves accurately judging distance in an environment with a plethora of visual information in the environment. Approach to the same runway from the same distance can have vastly different appearances due to variations in terrain, time of day, and orientation of the aircraft. Measures of spatial orientation, address an individual's ability to recognize how change in viewpoint orientation alters the appearance of the surrounding environment (McGee, 1979). In aviation a spatial orientation measure such as the Guilford-Zimmerman (1948) measure could provide a more meaningful prediction of specific orientation related tasks such as visual approach. Although there is debate over whether spatial orientation and another separately proposed dimension, spatial visualization, measure different constructs (Carroll, 1993); the Guilford-Zimmerman spatial orientation measure more closely resembles an aviation task specifically.

Table 1. ***Manipulated Variables for Visual Approach Discrimination Task***

Manipulated variables	Description
Target variable:	
Slant distance	Combination altitude/distance measure from the focal point of the image (the end of the runway)
Distracter variable:	
Terrain	Quantity and density of environmental features (i.e. buildings, trees, etc.)
Relative approach angle	Heading angle at which the aircraft is facing the runway
Visibility	Meteorological measure of distance at which environmental features can be viewed due to atmospheric conditions
Form ratio	Length width ratio of the runway

Hypothesis

For this study, we sought to investigate how a measure of spatial ability could predict performance on a visual approach task. Using a perceptual discrimination training module geared to improve visual approach skills (Curtis, Schuster, Jentsch, Harper-Sciarini & Swanson 2008), we looked to decipher the predictive nature of a spatial orientation measure. Based on our assertion that the parallels between spatial orientation ability and similar visuo-spatial requirements when flying a visual approach, we hypothesize that individuals with high spatial orientation ability will perform better on the visual approach discrimination task (Hypothesis 1).

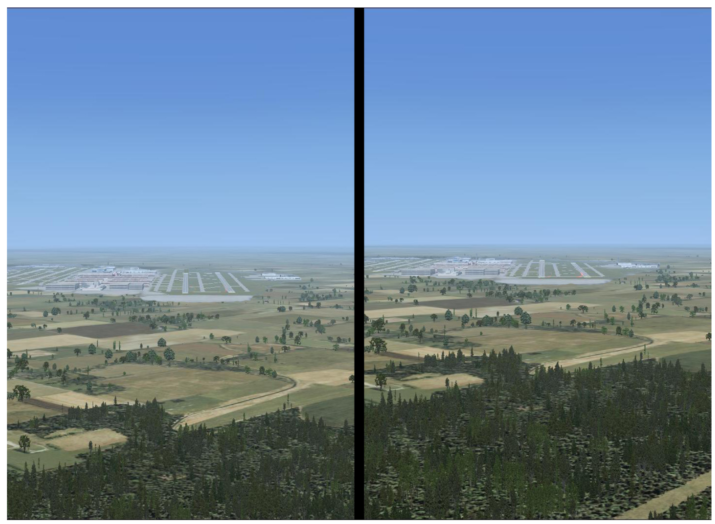

Figure 1. **Sample discrimination task image pair.**

In addition to our primary hypothesis we sought to investigate how those individuals who scored high and low on the spatial orientation measure differed on their responses to the discrimination task. That is, we examined their responses influenced by the distracting environmental cues manipulated in the performance task. Based on our previous hypothesis that individuals scoring high on the spatial orientation measure will score better on the discrimination task, we also hypothesized that individuals in the low spatial orientation group are more susceptible to influence from distracting visual cues (Hypothesis 2).

Method

Participants. For this study participants consisted of 97 undergraduate students recruited from the University of Central Florida. The population was selected due to the assertion that many of the perceptual influences that a non-pilot would experience can be equated to that experienced by a novice pilot trainee.

Measures

Spatial Orientation. For our study we selected the Guilford-Zimmerman (Guilford & Zimmerman, 1948) spatial orientation test. Given the similarity of this test to a pilots experience in the course of an approach and landing task, the Guilford-Zimmerman spatial orientation measure was proposed to predict performance. The test was administered using an electronic format.

Discrimination Task. The performance measure for this study was a discrimination task. The task consists of 270 static image pairs that the participant (Figure 1) was asked to determine if the images are same or different based only on their judgment of slant distance from the end of the runway. In addition to varying the slant distance from the end of the runway, we systematically manipulated a series of distracter variables (Table 1). Accuracy is determined as the number of correct comparison judgments made based on the judgment of slant distance from the end of each runway.

Procedure.

Upon arrival participants were asked to complete an informed consent form, following completion, participants were seated in front of a laptop computer and asked to begin the study. All questionnaires and testing material were presented using MediaLab and Direct RT software. Participants were presented with a timed spatial orientation test. Upon completion of this, the perceptual discrimination task began. A brief tutorial on how to perform the task was provided prior to beginning the session. For the discrimination task, participants were presented with comparisons comprised of two visual approach images presented side by side on the display. Each comparison was presented for a maximum of 10 seconds. Participants were asked to categorize the pair of images as same or different by pressing designated keys on the keyboard. Failure to respond within 10 seconds resulted in an incorrect response. After completion of the discrimination accuracy test, participants were debriefed and dismissed.

Results

All analyses were performed using SPSS 12.0; the alpha level was set at .05, unless otherwise specified. Although data were found to be mildly positively skewed, we decided to forgo transformations to preserve the directional relationship of the variables. Scores from the spatial orientation measure were split at the median to create a high and low spatial orientation score group.

An independent samples *t* test was performed to compare mean discrimination task scores for the high spatial orientation group (M = 160.28, SD = 24.30) and low spatial orientation group (M = 150.82, SD = 18.03). Results indicate a significant difference, t (95) = -2.19, p < .05. This indicates that individuals who scored high on the spatial orientation test did better on the discrimination task than those with lower spatial orientation scores.

Each item on the discrimination task varied on one target variable (glide slope) and four distracter variables (relative approach heading, terrain, visibility and form ratio). An item analysis was performed to investigate whether specific environmental cues were further predictive of performance in either the high spatial orientation group or the low spatial orientation group. We performed a multiple regression to determine if the target variable or any distracter variables predicted performance using backwards removal. For the high spatial ability group there were no variables that significantly predicted performance. In the low spatial orientation score group, form ratio was found to significantly predict performance on the discrimination task, F (1, 268) = 5.377, p < .05. Counter to what we expected, this significant effect suggests that participants did worse in the absence of form ratio manipulation (R^2 =.02; Adjusted R^2 = .02). In order to address this conflicting result we further investigated the low spatial orientation group.

Based on findings from Jentsch, Curtis, Schuster and Swanson, (2008) that response predictors differ on same item pairs and different item pairs in the same visual approach aviation discrimination task, we chose to investigate whether a similar pattern exists in the low spatial ability group. We performed two multiple regressions to investigate same image pairs and different image pair responses. Terrain difference was found to significantly predict performance for the low spatial orientation group on same image pairs F (1, 89) = 6.756, p < .05 (R^2 =.07; Adjusted R^2 = .06). Furthermore, terrain difference and form ratio were found to significantly predict on different image pairs F (2, 179) = 4.889, p < .05 (R^2 =.05; Adjusted R^2 = .04).

Discussion

The purpose of this study was to investigate the predictive capabilities that an individual difference measure has on a visual approach task. Our primary hypothesis was supported in that spatial orientation scores positively predicted performance on the visual approach discrimination task. Given this, it is reasonable to deduce that spatial orientation may provide an accurate prediction of initial individual ability on visual aviation tasks. It is interesting to note that in our second hypothesis there was a lone predictor of performance, form ratio, in the low spatial orientation ability group. At first glance this seems logical, given that form ratio is a known cause of visual misperception in the cockpit (Mertens, 1979; Mertens & Lewis, 1982). However our findings were counter to what one would expect. Individuals were significantly worse at discriminating between items where the form ratio was the same than those where form ratio was manipulated.

Our further investigation on response predictors for same and different discrimination tasks helped to clarify this confusing outcome. Form ratio was found to predict response on different discrimination pairs, but not same discrimination pairs. Participants used form ratio as a criteria for making image pair discriminations. As such, they would correctly respond to different image pairs based on the difference in form ratio instead of the target variable. It is also interesting to note that those in the low spatial orientation group also used terrain for both same and different image pairs. Both this and the form ratio finding suggest that individuals lower on spatial ability may be more prone to distraction from visual features that are known to influence distance estimations. Given this, it is reasonable to suggest that individuals scoring low on spatial orientation should receive additional training geared toward their tendency for distraction by known visual distracters such as terrain and form ratio.

If a number of measures, like the spatial orientation test, can be identified to accurately predict performance for specific aviation based tasks, training could be tailored for each trainee. By adjusting training to individual's strengths and weaknesses, tailored training programs would provide increased efficiency. Individuals who master a skill set will be able to focus on topics in which they are less proficient. Meanwhile, individuals who take more time to grasp topics will be provided additional training to ensure coverage of the topic area.

Most practically, our findings have implications for a very specific skill on a specific perceptual aviation task. Given the wide range of tasks that must be trained to safely operate an aircraft, it is too soon to coronate the tailored approach as the end-all cost saving solution for aviation training. In spite of this, our findings support the notion that individual difference measures can provide prediction of both general skill (i.e., visual discrimination task performance) and more specific performance indicators (i.e., terrain and form ratio variation). Given the promise that this and similar training based research have provided (Curtis, Harper-Sciarini, Jentsch, Schuster & Swanson, 2007), further research and development in tailored training could lead to both cost and efficiency gains in aviation training.

References

Baddeley, R. J., & Hancock, P. J. B. (1991). A statistical analysis of natural images matches psychophysically derived orientation tuning curves. *Proceedings of the Royal Society of London B*, *246*, 219-223.

Boehm-Davis, D.A., Casali, J.G., Kleiner, B.M., Lancaster, J.A., Saleem, J.J. & Wochinger, K. (2007). Pilot performance, strategy, and workload while executing approaches at steep angles and with lower landing minima. *Human Factors,* 49(5), 759-772.

Carroll, J. (1993). *Human cognitive abilities: A survey of factor-analytical studies.* New York: Cambridge University Press.

Curtis, M.T., Harper-Sciarini, M., Jentsch, F.G., Schuster, D. & Swanson, R. (2007). Filling the gaps: An investigation of the knowledge needed for effective human-automation interaction. *Proceedings of the 14th International Symposium on Aviation Psychology*, Dayton, OH: Wright State University.

Curtis, M.T., Schuster, D., Jentsch, F., Harper-Sciarini, M. & Swanson, R. (2008). Perceptual cue effects on distance estimation from different angles of approach. Proceedings for the 52nd Annual Meeting of the Human Factors and Ergonomics Society, New York, NY: HFES.

Darby, R. (2006). Commercial jet hull losses, fatalities rose sharply in 2005. *Aviation Safety World,* 1(2), 51-53.

Dror, I.E., Kosslyn, S.M., & Waag, W.L. (1993). Visual-spatial abilities of pilots. *Journal of Applied Psychology, 78(5),* 763-773.

Gibb, R. W. (2007). *Visual spatial disorientation: Re-visiting the black hole illusion* (Tech Rep No. CI07-0009). Wright Patterson Air Force Base, OH: Department of the Air Force.

Gibbons, R., Baker, R., & Skinner, D. (1986). Field articulation testing: A predictor of technical skills in surgical residents. *Journal of the American Podiatric Medical Association, 73,* 12-16.

Ghiselli, E.E. (1973). The validity of aptitude tests in personnel selection. *Personnel Psychology, 26,* 461-477.

Guilford, J.P. & Zimmerman, W.S. (1948). The Guilford-Zimmerman aptitude survey. *Journal of Applied Psychology, 32,* 24-34.

Hegarty, M. & Waller, D. (2004). A dissociation between mental rotation and perspective-taking abilitites. *Intelligence, 32,* 175-191.

Humphreys, L.G. & Lubinski, D. (1996). Assessing spatial visualization: An underappreciated ability for many school and work settings. In C.P. Benbow & D. Lubinski (Eds.), *Intellectual talent: Psychometric and social issues,* (pp. 116-146), Baltimore, MD: John Hopkins Press.

Jentsch, F., Curtis, M., Schuster, D. & Swanson, R. (2008). Visual approaches : A continuing training challenge among pilots. Poster presented at *Human Factors and NextGen : The Future of Aviation*, Arlington, TX.

Leibowitz, H.W. (1988). The human senses in flight. In E.L. Weiner & D.C. Nagel (Eds.) *Human Factors in Aviation,* (pp.125-133) Academic Press, San Diego, CA.

Lohman, D.F. (1988). Spatial abilities as traits, processes and knowledge. In R.J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (pp. 181-248). Hillsdale, NJ: Erlbaum.

McGee, M.G. (1979). Human spatial abilitites: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin, 86,* 889-918.

Mertens, H. W. (1979). *Runway image shape as a cue for judgment of approach angle* (Tech. Rep. FAA-AM 79/25). Alexandria, VA: Federal Aviation Administration, Office of Aviation Medicine. Retrieved May 5, 2008, from http://www.faa.gov/library/reports /medical/oamtechreports/1970s/media/AM79-25.pdf

Mertens, H.W. (1981). Perception of runway image shape and approach angle magnitude by pilots in simulated night landing approaches. *Aviation, Space, and Environmental Medicine,* 52(7), 373-386.

Mertens, H. W., & Lewis, M. F. (1982). Effect of different runway sizes on pilot performance during simulated night landing approaches. *Aviation, Space, and Environmental Medicine, 53,* 463–471.

Michael, W.B., Guilford, J.P., Fruchter, B., & Zimmerman, W.S. (1957). The description of spatial-visualization abilities. *Education and Psychological Measurement, 17,* 185-199.

Robson, D. (2001). *Human Factors for the Professional Pilot.* South Melbourne, Australia: Aviation Theory Centre.

Shappell, S.A. & Wiegmann, D.A. (2003). *A human error analysis of general aviation controlled flight into terrain accidents occurring between 1990-1998* (DOT Report No. DOT/FAA/AM-03/4). Springfield, VA: National Technical Information Service