Applied Ergonomics 63 (2017) 62–71

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

I spy with my little eye: Analysis of airline pilots' gaze patterns in a manual instrument flight scenario

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A R T I C L E I N F O

Article history:
Received 17 March 2016
Received in revised form
20 February 2017
Accepted 29 March 2017
Available online 12 April 2017

Keywords:
Gaze pattern
Manual flying
Visual scanning

A B S T R A C T

The aim of this study was to analyze pilots' visual scanning in a manual approach and landing scenario. Manual flying skills suffer from increasing use of automation. In addition, predominantly long-haul pilots with only a few opportunities to practice these skills experience this decline. Airline pilots representing different levels of practice (short-haul vs. long-haul) had to perform a manual raw data precision approach while their visual scanning was recorded by an eye-tracking device. The analysis of gaze patterns, which are based on predominant saccades, revealed one main group of saccades among long-haul pilots. In contrast, short-haul pilots showed more balanced scanning using two different groups of saccades. Short-haul pilots generally demonstrated better manual flight performance and within this group, one type of scan pattern was found to facilitate the manual landing task more. Long-haul pilots tend to utilize visual scanning behaviors that are inappropriate for the manual ILS landing task. This lack of skills needs to be addressed by providing specific training and more practice.

1. Introduction

Since the 1980s, aircraft have been supplied with highly automated flight control systems. These systems have taken over many processes previously performed by pilots including the setting and supervision of flight performance parameters for the engines, the course, and appropriate speed and altitude. In spite of the accrued advantages of modern aircraft with highly automated systems, there is one large disadvantage: the more automation is used, the more manual skills diminish due to an absence of practice opportunities (Wiener and Curry, 1980; Sarter and Woods, 1994; Veillette, 1995; Ebbatson, 2009; Haslbeck and Hörmann, 2016). In an in-depth analysis of 415 commercial aviation accidents, which occurred between 2010 and 2014 by the International Air Transport Association (2015), evidence can be found that manual handling flight crew errors were involved in nearly one third of these accidents. It is therefore of great importance to enhance flight safety by providing pilots with adequate and effective training programs and help them maintaining sufficient manual flying skills, especially during the most vulnerable flight phases such as approach and landing.

The level of practice, strongly associated with the daily flight practice, is assumed to have the biggest influence on manual flight performance (Ebbatson, 2009; Haslbeck and Hörmann, 2016). Airline transport pilots face the same flying tasks and conditions independently from the type of operation. They also perform very similar and predominantly standardized maneuvers in aircraft families (e.g. Airbus A320 family) offering unified cockpit layouts and highly comparable handling qualities (Brière and Traverse, 1993; Favre, 1994; Joint Aviation Authorities, 2004; Bissonnette and Culet, 2013). In spite of these similarities, crews on short-haul routes perform more than five times as many flights as crews on long-haul ones and show better fine-motor flight performance (Haslbeck and Hörmann, 2016) as well as superior visual skills (Haslbeck et al., 2012). If we can identify different instrument scanning patterns in correlation with good or poor performance, it could be beneficial for future cockpit design and training programs.

1.1. Pilot's instrument scanning and analytical methods

Manual flying has been denoted as a closed-loop control problem (Field and Harris, 1998). This is a psycho-motor and highly skilled task where the pilot needs to continuously control and monitor six variables which are usually cross-coupled (Field and

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http://dx.doi.org/10.1016/j.apergo.2017.03.015
0003-6870/

Harris, 1998; Wickens, 2002): pitch, roll, and yaw of the aircraft as well as altitude, lateral, and longitudinal deviation from the desired flight path. Raw data flying specifies the fact when these parameters have to be actively scanned, cognitively processed, and transferred to adequate control inputs by the pilots (instead of the flight computers). Effective instrument scanning strategies can keep the pilots in the loop by continuously updating their memory about the current state of the aircraft. Adequate visual scanning also enables pilots to take effective control in time, which requires adequate cognitive skills and a sophisticated understanding of the relationship between the instruments.

To maintain sufficient spatial awareness, continuous and logical scanning across multiple instruments is required, also known as cross-checking in aviation domain. The two common visual strategies for pilots are the *radial cross-check* technique (Federal Aviation Administration, 2012, pp. 6–24) and the *circular* one (Dick, 1980, p. 12; Jones, 1985, p. 17). In training documentation the FAA describes the *radial cross-check* as a technique where the pilot starts a scan in the center of a primary flight display where the attitude indicator (ATT) is located (Federal Aviation Administration, 2012, pp. 6–24). After that, scans are to be performed left to the airspeed tape (SPD), right to the altitude indicator (ALT), and down to the heading indicator (HDG). However, every scan returns to the center for an intermediate scan – representing a pattern like the spokes of a wheel (Dick, 1980, p. 12; Jones, 1985, p. 17) and comparable to the *basic-T* pattern matching with the instrument layout in conventional cockpits (Fig. 1, left side). A pilot checks control inputs on the control instruments (mainly on attitude) and monitors their effects on the performance instruments such as speed, altitude, and heading (Federal Aviation Administration, 2012, p. 6–18 - 6–19).

Gaze-based metrics such as *mean glance duration*, *glance rate*, and *percent time on areas of interests (AOIs)* are mostly analyzed to gain insight into pilots' visual behavior and attentional allocation, which were standardized for road traffic research by ISO 15007-1 ("*Measurement of driver visual behaviour with respect to transport information and control systems").* Nevertheless, regardless of pilots' attentional switching across the instruments, these metrics alone are inadequate to understand pilots' scanning strategies and reflect complex information acquisition processes.

To take the gaze sequences into account, the term *gaze pattern* describes the order of a person's scanning behavior (Dorr et al., 2010) while *scanpath* refers to vectors, i.e. the geometric characteristics of subsequent glances (Holmqvist et al., 2011, p. 254; Kang and Landry, 2015). Myers (2007) highlights two main influences on sequences of saccades: exogenous and endogenous. Exogenous saccades account for bottom-up (data/sensory-driven) processes being considered as non-deliberate (Einhäuser et al., 2008b; Schütz et al., 2011; Kowler, 2011). Endogenous saccades were described as deliberate top-down (goal-driven) processes, when the successful conduct of a visual task accounts for specific gaze patterns and scanpaths (Noton and Stark, 1971; Holmqvist et al., 2011, p. 253–254). Endogenously initiated saccades can be assumed when an operator fulfills a specific skilled task (Einhäuser et al., 2008a; Schütz et al., 2011; Foulsham et al., 2012) such as continuous flightpath tracking (Allsop and Gray, 2014).

The sequence of how different displays are looked at reveals how this information is cognitively processed by pilots. The comparison of sequences, however, is complex (Foulsham et al., 2012; Anderson et al., 2013), especially when these sequences become extremely long (Kang and Landry, 2015), for example in a continuous flight tracking task. One solution is to break a longer sequence into smaller segments with easily analyzable lengths (Tole et al., 1983; Simon et al., 1993). Hence, the most frequent sequences may reflect the main scanning strategies. Transition matrices are an economic alternative approach indicating the probability of an AOI being next in the sequence based on the current AOI. The highest transition probabilities give a good representation of the overall scanning pattern (Milton et al., 1950; Spady, 1978; Harris et al., 1986). In a very recent study Kang and Landry (2015) introduced the MTAHC algorithm to analyze eye movements during the tracking of multiple moving targets based on unordered transition matrices. This method was developed to find an adequate representation for large and complex gaze patterns when comparing them among several individuals. AOIs with higher transition values were hierarchically clustered and integrated into *visual grouping sets*. In summary, focusing on transition probabilities facilitates the analysis of gaze patterns and reduces complexity of longer sequences.

1.2. Expertise-related differences in visual scanning

Evidence can be found in many transportation studies that expertise levels have a major influence on visual behavior and task performance. One very early study can be dated back to the 1940s when Fitts et al. (1949) investigated the effect of experience on 40 pilots' eye movement measures in a ground control approach flying scenario, suggesting that experienced pilots had more frequent fixation and correspondingly short fixation duration on flight instruments. These findings are fairly consistent with similar studies. For instance, Bellenkes et al. (1997) indicated that expert pilots' scanning strategies differed from those of novices in several aspects

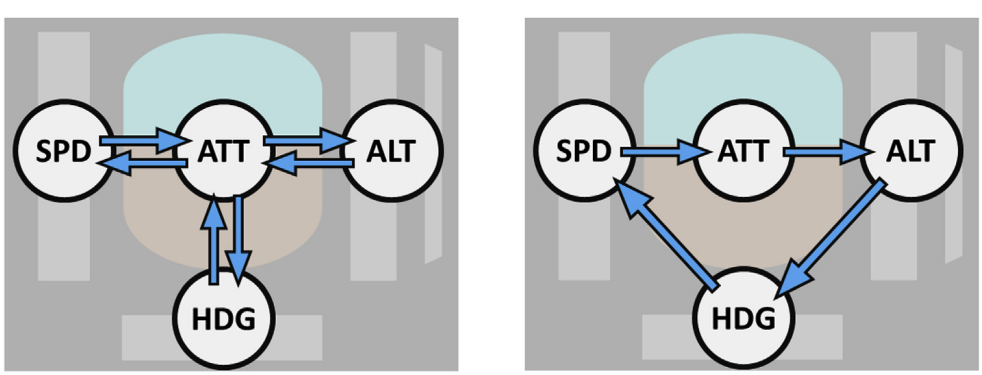

Fig. 1. The radial cross-check technique (spokes-of-a-wheel) showing a center-bound pattern (left side) and the circular scanning technique showing a clockwise pattern (right side). There is no distinct starting point per se, however, a typical starting point is the attitude indicator (ATT), while speed (SPD), altitude (ALT), and heading (HDG) are scanned frequently.