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National Aerospace Laboratory NLR

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Summary

Displaying multiple information sources on the same location reduces scanning but increases clutter and the chance of attentional tunnelling. This paper describes an experiment in a flight simulator applying a display with flight instruments and tunnel-in-the-sky symbology superimposed on the world. The primary task was flight path following, with the colour of the tunnel-in-the-sky either the same or deviating from the instrument symbology. Attention and workload were manipulated by adding a manual speed control task and/or a detection task. The main result was that flight path control improved when the colour of the tunnel-in-the-sky deviated. However, performance on the concurrent speed tracking task was worse, indicating an influence of colour on the switching of attention. This result can have important implications for display design (for example, when using colour on a head-up display).

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1 Introduction

One important objective in critical flight phases is to effectively divide attention between relevant information domains, including the out-the-window view, instruments, and the flight path. The distance between the information sources (in terms of visual angle) can lead to serious costs of scanning, especially when going from head up to head down and vice versa. It is expected that more and more interfaces will be used which superimpose instrument symbology on the out-the-window scene, which has the advantage that attention can be distributed between the information domains with minimal scanning costs. A popular example is the head-up display (HUD), which employs a semitransparent screen. Another example where scanning costs are reduced is a synthetic vision system (SVS), where instrument symbology is presented on top of computer-generated imagery representing the out-the-window scene.

Two types of theories try to describe the allocation of attentional resources over space (Duncan, 1984). According to *space-based* theories, attention is directed at all elements within a spatially defined region. According to *object-based theories*, complex scenes are parsed into groups of objects, with attention focused on only one object at a time. Objects can be defined by contours, rigidity of motion, colour equality etc. The two theories probably describe different mechanisms (Kramer and Jacobson, 1991).

A disadvantage of interfaces applying superimposed symbology is that the display gets increasingly cluttered so that focused attention tasks ('read-out') are harder to perform, although it is suggested that selective attention tasks ('search') are most influenced (Wickens, 1997). Another drawback is that it can become more difficult to switch attention between objects. This effect is called *attentional tunnelling*. With HUDs, this implies that the compelling nature of the HUD images inhibits the detection of other critical events (especially when the event is unexpected and/or the bottom-up signal quality is degraded), which might lead to unsafe situations like unnoticed runway incursions (Fischer, Haines and Price, 1980; Larish and Wickens, 1991; Weintraub and Ensing, 1992). This is recognized as the most prominent cost of using a head-up display.

Additional factors influence the efficiency with which attention is switched between information domains. Foyle, McCann, Sanford and Schwirzke (1993) presented digital altitude information on a HUD at different locations relative to terrain path information, and found that simultaneous processing of both the HUD and the outside world only occurs in those conditions where visual scanning is required. Close proximity of both information sources encouraged the use of inefficient attentional switching strategies, resulting in attentional tunnelling. McCann, Lynch, Foyle and Johnston (1993) found that the differential motion between the superimposed HUD symbology and the out-the-window scene led to increased attentional switching time, indicating that this differential motion may be the primary driver behind attentional tunnelling. This problem was solved in a study by Foyle, McCann and Sheldon (1995), who linked altitude information to the flight path in the out-the-window scene (so that the altitude information appeared to be physically part of the world), thereby removing the differential motion. This linkage improved both altitude maintenance and flight path control, and did not lead to a trade-off. A study by Wickens and Long (1995) suggested that attention is more efficiently switched between symbology and the out-of-window scene when conformal symbology is used, which overlies its far domain counterpart and moves in synchrony and equal amplitude with that counterpart (e.g., a runway or a horizon).

The current study

The current study focuses on attentional phenomena in situations where both flight path tracking and instrument information are superimposed on the out-the-window scene (or imagery representing that view). The flight path is presented by means of a perspective flight path display, in this case a *tunnel-in-the-sky*. Several studies have found that perspective flight path displays lead to better position tracking and aircraft control when compared to more conventional types of guidance displays (e.g., Haskell and Wickens, 1993; Flohr and Huisman, 1997). Few studies have yet examined the head-up presentation of a perspective flight path display, with the flight path symbology superimposed on the outside world. Fadden and Wickens (1997) compared a head-up and a head-down positioning of a perspective flight path and found no negative clutter effect of a head-up presentation.

This paper describes an experiment in which the effects were studied of superimposing flight instrument and tunnel-in-the-sky symbology on the out-the-window scene while performing a flight path tracking task in combination with a speed tracking task and/or a detection task. The main manipulation was the colour of the tunnel-in-the-sky, which was either the same or deviating from the colour of the instrument symbology.

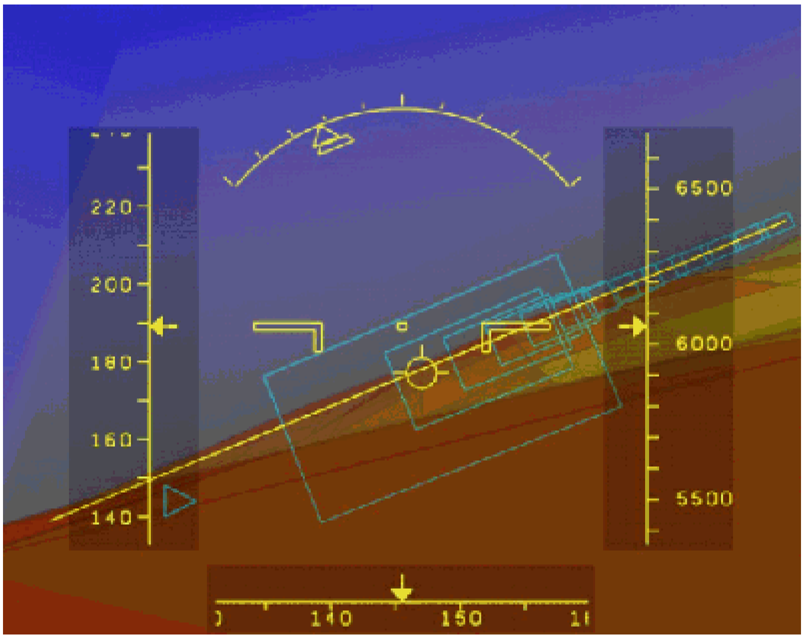

Fig. 1 Example of the display used in the experiment

2 Method

Eight trainee pilots participated in the experiment (mean age 26.6 years, mean flight experience 78 hours).

The experiment was conducted on a civil cockpit mock-up, recreating the flight dynamics of an unloaded Fokker 100. The pilot was seated in an authentic aircraft chair, with the eyes positioned at a distance of 95 cm from a 21 inch screen. Control inputs were made via a steering column, a trim, and a throttle. A button on the steering column, near the left thumb, was used for giving responses as required in the detection task (see further).

A virtual out-the-window scene was presented on the screen. Several depth cues were provided, like atmospheric perspective and texture. Instrument symbology was superimposed on the world, consisting of speed, altitude, roll, and heading indicators, as well as a fixed aircraft symbol, a flight path vector, and an artificial horizon. The speed and altitude tapes also contained trend indicators. Flight path information was provided by a tunnel-in-the-sky, consisting of rectangular gates of 100 metres high and 200 metres wide, with an interspacing of 400 metres. The screen was also used to present instructions with regard to the experimental flights. In figure 1, the three layers - instruments, tunnel, and world - are illustrated.

Flights started in the air (speed 200 knots), and ended at final approach, about 7 miles before the runway. Each route consisted of four flight segments: straight & level/descent, and curved & level/descent (order depended on the route). The primary task in all experimental conditions was to fly accurately through the tunnel-in-the-sky. The main experimental manipulation was the colour of the tunnel through which the pilots had to fly: this was either the same or a different colour than the instrument symbology.

Attention and workload were manipulated by adding tasks. In half of the conditions speed had to be controlled manually (and be maintained at 200 knots). In the other half, speed was controlled by the autothrottle.

The last variation was the addition of a detection task. Subjects had to respond to triangles pointing to the left (half of the triangles pointed to the right). Figure 1 displays an example of a triangle (in the lower-left corner). Triangles stayed visible for 5 seconds. Triangles were presented at intervals ranging randomly from 10 to 20 seconds. Triangles could appear randomly at eight positions (four central and four peripheral), and randomly in three equiluminant colours: the colour of the instrument symbology or the tunnel-in-the-sky, or a neutral colour. Triangles could also randomly appear in two different layers: the 2D instrument symbology layer or the 3D world layer. In the 2D-layer, triangles were fixed with regard to the symbology. In the 3D-layer, triangles were fixed with regard to the world, and as a consequence of airplane movement, their x,y-location and size varied during presentation (these effects were kept small, however).

The three manipulations (tunnel colour, speed control, and detection task) led to 2x2x2=8 experimental conditions. The eight conditions were coupled to eight different routes according to a Greek-Latin square.

Control inputs and resulting location and speed were recorded, and deviations from the required location and speed were used for analysis.

In the conditions with the detection task, speed and accuracy of task performance were analyzed. The reaction time (RT) to targets, and the percentage of incorrect responses were calculated.

For eye-point-of-gaze (EPOG) measurement areas were defined on the display, and for each area the percentage dwell time (the total time spent fixating on that area), the percentage fixations, and the mean fixation duration was calculated. In addition, scanning entropy was calculated.

The following cardiovascular measures were used: inter-beat-interval (IBI, in msec), and heart rate variability (HRV) in the mid-frequency band, also known as the 0.10 Hz component.

After each flight, the *perceived* amount of mental effort was measured by using the Rating Scale Mental Effort (RSME). At the end of the experiment subjects received general questions on the experiment.

3 Results

In the following, emphasis is on the main effects of tunnel colour, and the interaction of tunnel colour with speed control and/or the detection task.

Lateral control (indicated as the standard deviation of aileron deflection) was better when the colour of the tunnel deviated from the colour of the instrument symbology (F(1,7)=5.12, p=.058). This effect was maximal when concurrent tasks had to be performed (interaction: F(1,7)=15.22, p=.006). For vertical control (indicated as the standard deviation of elevator deflection), no effects of tunnel colour were found. Considering only flights during which speed had to be controlled manually, lateral deviation was about 15% less with a deviating tunnel colour (F(1,7)=12.29, p=.010). However, deviation from the required speed was about 17% *greater* with a deviating tunnel colour. Though the latter effect did not reach significance, a trade-off could be suspected. This is illustrated in figure 2.

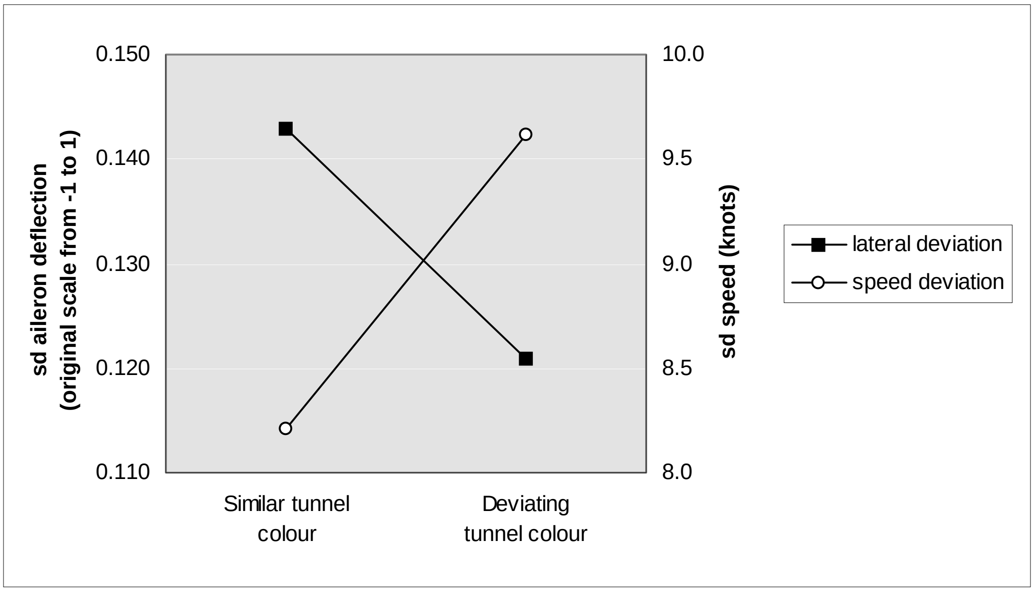

Fig. 2 Deviation from the required (lateral) flight path and the required speed (conditions with manual speed control only)

No effects of tunnel colour were found on dwell time, fixation frequency, nor scanning entropy. A trend though was found on mean fixation duration, especially when concurrent tasks had to be performed: in the centre of the screen the mean fixation duration was 1.02 instead of 0.89 sec. when the tunnel colour deviated (F(1,7)=2.84, p=.136).

With regard to cardiovascular measures, no effect of tunnel colour was found on IBI nor the 0.10 Hz component.

No effect of tunnel colour was found on perceived effort. With regard to the colour of the tunnel-in-the-sky, six subjects preferred the tunnel with a deviating colour, one when the colour was the same, and one none. The tunnel in a deviating colour was considered more ‘restful’, creating better contrast. The one subject preferring the tunnel in the similar colour liked it because it was *less* contrasting with the instrument symbology.

Overall, the percentage of incorrect responses was lower when the tunnel colour deviated from the instrument symbology colour (6.2 against 8.7 per cent ($F(1,7)=6.55$, $p=.038$)). In addition, reaction time was faster, but only when speed was controlled by the autothrottle; with speed controlled manually, the effect was the reverse (interaction effect: $F(1,7)=6.67$, $p=.036$). In other words, when attention had to be divided over more tasks, the response time advantage with a deviating tunnel colour disappeared. This was especially the case for peripherally presented stimuli ($F(1,7)=15.34$, $p=.006$). Looking at centrally presented stimuli, a clear effect of tunnel colour could be found. The deviating colour conditions produced the fastest *as well as* the slowest reaction times, while the similar colour conditions produced reaction times of about the same value. This effect was caused by the 2D-3D difference: with a deviating tunnel colour, 2D stimuli were responded to much faster than 3D stimuli (582 and 711 msec. respectively). This effect was not present in the similar tunnel colour conditions (680 and 660 msec. respectively).

4 Discussion

The accuracy of flying through the tunnel is higher when the tunnel colour deviates from the instrument symbology colour, especially when workload is high. A possible explanation is that it is easier to attend to the guidance task because the tunnel can be more easily distinguished from the environment. This is confirmed by subjective statements: most subjects claimed a tunnel with a deviating colour created more contrast and was more ‘restful’. When the same colour is used for the instrument and the tunnel-in-the-sky symbology, it might be possible that (in terms of object-based theories of attention) they are ‘forced’ into one object, while at the same time other characteristics (especially movement) are forcing *two* objects to appear. This ‘unrestfulness’ might be prevented by a deviating colour.

There is a risk that the tunnel-in-the-sky in a deviating colour might actually become too compelling, with the risk of attentional tunnelling. If this were true, subjects would be less successful in switching attention between the flying task through the tunnel (in the deviating colour) and other tasks. A first indication in that direction might be the fact that the mean fixation duration in the centre of the screen is longer with a deviating tunnel colour. In the case that speed had to be controlled manually, a higher speed deviation was found, especially when also a detection task was present. Performance on the detection task produced less clear results: some types of stimuli clearly benefit, whereas others are put at a disadvantage with a deviating tunnel colour. This observation can have important implications for display design.

In summary, a tunnel-in-the-sky with a deviating colour seems to have both advantages and disadvantages. It can improve flight path control, but there is a serious risk that it attracts too much attention, leading to inefficient attention-switching strategies when other task are involved.

5 References

Duncan, J. (1984). ‘Selective attention and the organization of visual information’. *Journal of Experimental Psychology: General*, *113,* 501-517.

Fadden, S. & Wickens, C.D. (1997). ‘Improving traffic awareness with a head-up flight path highway display’. In: R.S. Jensen & L.A. Rakovan (eds.), *Proceedings of the 9th International Symposium on Aviation Psychology* (pp.329-335). Columbus, OH: Ohio State University.

Fisher, E., Haines, R. & Price, T. (1980). *Cognitive issues in head-up displays* (NASA Technical Paper 1711). Washington, DC: NASA.

Flohr, E.L. & Huisman, H. (1997). ‘Perspective Primary Flight Displays in the 4D ATM Environment’. In: R.S. Jensen & L.A. Rakovan (eds.), *Proceedings of the 9th International Symposium on Aviation Psychology* (pp. 882-886) , Columbus, OH: Ohio State University.

Foyle, D.C., McCann, R.S., Sanford, B.D. & Schwirzke, M.F.J. (1993). ‘Attentional effects with superimposed symbology: Implications for head-up displays (HUD)’. *Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society* (pp.1340-1344). Santa Monica, CA: Human Factors and Ergonomics Society.

Foyle, D.C., McCann, R.S. & Shelden, S.G. (1995). ‘Attentional issues with superimposed symbology: Formats for scene-linked displays’. In R.S. Jensen (ed.), *Proceedings of the 8th International Symposium on Aviation Psychology* (pp. 98-103). Columbus, OH: Ohio State University.

Haskell, I. D. & Wickens, C.D. (1993). ‘Two- and three-dimensional displays for aviation: A theoretical and empirical comparison’. *The International Journal of Aviation Psychology*, *3(2)* , 87-109.

Kramer, A.F. & Jacobson, A. (1991). ‘Perceptual organization and focused attention: The role of objects and proximity in visual processing’. *Perception & Psychology*, *50*, 267-284.

Larish, I. & Wickens, C.D. (1991). ‘Divided attention with superimposed and separate imagery: Implications for head-up displays’ (TR ARL-91-4 / NASA HUD-91-1). Savoy: University of Illinois, Aviation Research Lab.

McCann, R.S., Lynch, J.M., Foyle, D.C. & Johnston, J.C. (1993). 'Modeling attentional effects with Head-Up Displays'. *Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society* (pp.1345-1349). Santa Monica, CA: Human Factors and Ergonomics Society.

Weintraub, D.J. & Ensing, M. (1992). *Human factors issues in head-up display design: The book of HUD*. SOAR 92-2. CSERIAC, Wright-Patterson AFB, OH.

Wickens, C.D. (1997). 'Attentional issues in head-up displays'. In Don Harris (ed.), *Engineering psychology and cognitive ergonomics (Volume one): Transportation systems* (pp.3-21). Aldershot: Ashgate Publishing Company.

Wickens, C.D. & Long, J. (1995). 'Object vs space-based models of visual attention: Implications for the design of head-up displays'. *Journal of Experimental Psychology: Applied*, 1, 179-194.

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