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Traffic and Flight Guidance Depiction on a Synthetic Vision System Display: The Effects of Clutter on Performance and Visual Attention Allocation

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TRAFFIC AND FLIGHT GUIDANCE DEPICTION ON A SYNTHETIC VISION SYSTEM DISPLAY: THE EFFECTS OF CLUTTER ON PERFORMANCE AND VISUAL ATTENTION ALLOCATION

ABSTRACT

Fourteen pilots flew a synthetic vision system (SVS) display through a terrain and traffic-rich environment in a high fidelity flight simulator. Traffic information was hosted on the SVS display. In a 2x2 factorial design, the SVS display hosted a highway-in-the-sky in half the conditions, while instrument panel information and a flight path velocity vector was the sole means for guidance in the other conditions. In half the trials the instrument panel overlaid the SVS display, and in the other half it was separate, allowing us to examine the effects of the resulting clutter. Tunnel guidance, and clutter effects were examined as they influenced routine flight performance, SVS traffic detection and change awareness, and the pilots' response to off-normal events, as these were mediated by visual scanning measures of attention allocation. The tunnel greatly improved flight path tracking and detection of traffic on the SVS display, and did not hurt the detection of traffic changes present on a CDTI. However the tunnel disrupted the detection of the two off-normal events: unexpected outside world traffic, and of a runway offset. The instrument panel overlay provided no benefits to tracking and a clutter-related time cost to SVS traffic detection. Scanning analysis on 8 of the pilots revealed that visual attention was focused on the SVS display over half the time, and rarely on the outside world, even in visual meteorological conditions (VMC). This scanning pattern indicated a source of possible cognitive tunneling. However in general, scanning was not tightly linked to performance. The final section of this report describes our efforts to apply a computational model to predict the visual scanning data.

INTRODUCTION

Synthetic Vision Systems provide pilots with a realistic 3D image of the terrain in front of the aircraft, with a primary objective of increasing terrain awareness, and reducing the likelihood of CFIT accidents (Prinzel Comstock, Glaab, Kramer, Arthur, & Barry, 2004; Schnell, Kwon, Merchant, & Etherington, 2004). As shown in Figure 1 (upper left panel), within the 3D ego-referenced SVS pictorial display, it is reasonable to consider designs that might also host three additional forms of information: (1) 3D information regarding the forward flightpath, in the form of a pathway, tunnel, or "highway-in-the-sky" (Alexander, Wickens, & Hardy, 2003; Beringer, 2000; Fadden, Ververs & Wickens, 2001; Williams, 2002), (2) information about traffic near the forward flightpath (Merwin, 1998), and (3) other aspects of the primary flight display, represented as a head-up display (HUD) -like overlay (Fadden et al., 2001, Merwin, 1998).

All three of these design decisions--to implement a tunnel for guidance, to overlay traffic, and to overlay instruments--have implications for the pilots' allocation of attention and multi-task performance. At the one extreme, if all three elements are overlaid (tunnel, instrument panel, traffic depiction), a compact, but cluttered display will result. This should minimize the scanning and information access effort required to monitor all displays, but may inhibit the processing of fine detail because of the inhibitory effects of overlay clutter (Fadden et al., 2001; Kroft & Wickens, 2003; Wickens, 2000). At the other extreme, a spatially-dispersed display will be created, challenging visual attention allocation as scanning increases, but reducing clutter.

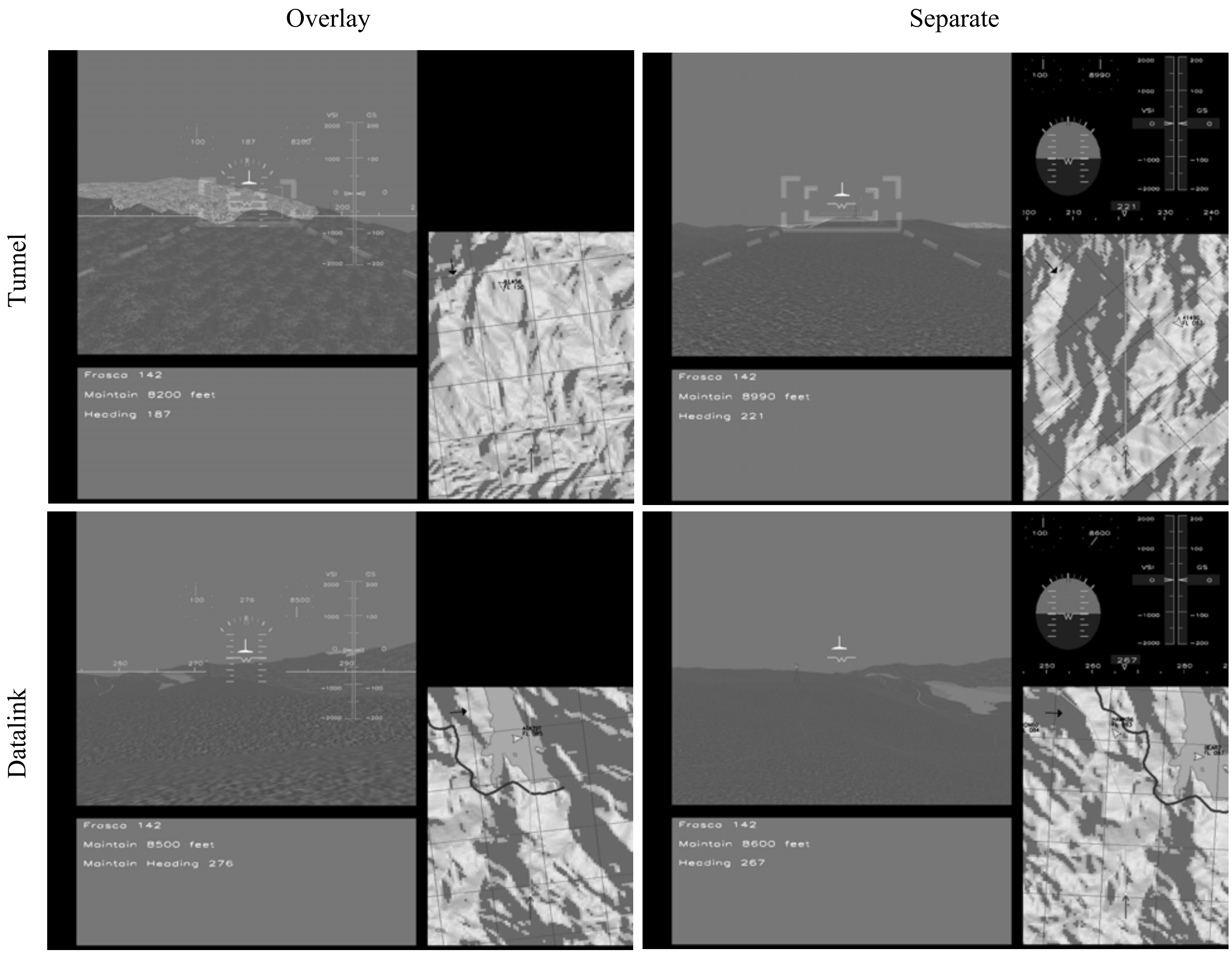


Figure 1. Four display suites: Left column: overlay. Right column: separate. Top row: tunnel. Bottom row: datalink.

In a full-mission simulation, we examined the implications of the tradeoff between the factors of clutter and spatial dispersion, contrasting the presence or absence of a tunnel, and the presence or absence of instrument panel overlay. Forward traffic was presented on a head-down SVS display in all four conditions created by orthogonally combining these two factors as shown by the four panels of Figure 1. All traffic was also represented on a Cockpit Display of Traffic Information (CDTI), hosted by the navigational (NAV) display in the lower right of each panel.

The assessment of which display configuration is optimal is complicated by the fact that such a system is intended to support a variety of tasks, and performance on these may trade off with each other across different designs. For example, routine flightpath tracking is well supported by the tunnel (e.g., Alexander et al., 2003; Fadden et al., 2001; Iani & Wickens, 2004; Prinzel et al., 2004; Schnell et al., 2004), but flightpath tracking may sometimes be inhibited by the added clutter of overlay on the display (Fadden et al., 2001). Traffic detection may be supported by the reduced scanning of overlay (Fadden et al., 2001), but could be inhibited in this condition by the clutter caused by this overlay, particularly if traffic is neither expected nor salient (Wickens, Ververs, & Fadden, 2004; Yeh, Merlo, Wickens, & Brandenburg, 2003). For example, Wickens, Ververs, and Fadden (2004), and Fadden, Ververs and Wickens (1999) reviewed a series of HUD studies, which revealed general HUD benefits for detecting traffic, except when such events were quite unexpected. Yeh et al. (2003) compared detection of targets viewed either through the superimposed imagery of a head mounted display (HMD), or viewed directly when that display was located head down, and scanning between the up and down location was required. They found a benefit for HMD detection if the targets were large, but this benefit was reversed when the targets were small, as if the clutter of the superimposed imagery obscured the small but not the large targets.

Finally, while both flightpath control and traffic detection represent relatively “routine” aspects of performance, we are also interested in how the different display configurations influence the allocation of attention (measured by visual scanning) as this allocation may, in turn, influence the awareness of and response to three “off-normal” unexpected events (Foyle & Hooey, 2003): (1) the detection of a “rogue aircraft”, visible in the outside world, but not “known” by the image-generation system that is depicting traffic on the CDTI and SVS display (Wickens, Helleberg, & Xu, 2002). These would characterize situations in which the rogue airplane had no transponder, or an inoperable transponder. (2) the detection of a ground-based antenna, and (3) the awareness of a runway offset, in which the SVS display guides the pilot to a landing which is offset from the location of the true runway. In all of these cases, we hypothesize that the “compellingness” of the SVS and tunnel might cause an undue attraction of visual attention (Olmos, Wickens, & Chudy, 2000), to the benefit of routine flight control and the possible benefit of detecting SVS-located traffic, which could be viewed in the same image plane as the tunnel, but to the detriment of off-normal event detection in which information was only available in the outside world.

If compellingness is a property of the SVS display location, then it could inhibit the detection of the two off-normal events whose information is located elsewhere (the rogue blimp and the runway offset both require outside scanning to detect). On the other hand, to the extent that the compellingness is a property of the tunnel itself, it could inhibit the detection of the tower, visible on the same display as the tunnel, but behind it, in the same manner in which 3D HUD imagery has sometimes been found to inhibit the detection of unexpected aircraft behind it (Wickens & Long, 1995).

Set in contrast to this “compellingness hypothesis” is a “workload hypothesis” that posits that the greater ease of using the more intuitive integrated guidance of the tunnel will allow more resources (visual as well as cognitive) to be freed for the processing of other events. Such a benefit was, in fact, found by Iani and Wickens (2004) who noted greater sensitivity to changing weather patterns by pilots flying with the tunnel, than those flying with a less-integrated display, corresponding to the “datalink” display suite used here, seen on the bottom panels of Figure 1.

In the current research we identify "compellingness" of a display (such as the tunnel) via three features: (1) an inhibition of detection of off-normal events located in different depth planes (e.g., the tower) or in different XY locations (the runway offset and rogue airplane), (2) a decrement in performance of secondary tasks (here detection of expected traffic), and (3) an excessive visual scanning (allocation of visual attention) to the source inferred to be compelling.

In this regard, we examine scanning in three contexts. First, we assess the extent to which scanning (visual attention) mediates the relationship between displays and performance. That is, does a given display influence the allocation of attention, in such a way that this allocation in turn affects performance on a task supported by that display. For example Helleberg and Wickens (2003) found that the note-taking requirements of auditory communications from air traffic control increased head down scanning to the detriment of detecting out-the-window traffic. Wickens, Goh, Helleberg, Horrey, and Talleur (2003) found that a CDTI within the cockpit, drawing a substantial amount of visual attention away from the outside world, disrupted the detection of a "rogue airplane", visible only in the outside world (similar to the rogue employed in the current experiment). On the other hand, the coupling of scanning to performance is not always a rigid one. For example, Williams (2002) found a highly significant reduction in OW scanning from 41% to 14% when a tunnel was used for head down guidance, but the reduction in outside traffic detection that was observed (from 70% to 61%) was not statistically significant. So less scanning did not mean poorer performance.

The second context in which scanning was examined, was to assess whether it served as a *strategy mediated variable*, accounting for individual differences between pilots via correlational analysis. For example, Wickens, Helleberg, Kroft, Talleur, and Xu (2001) observed that individual pilots who spent more time looking outside (OW scan) were faster at detecting traffic, and those who spent more time looking at the instrument panel (IP scan) were slower. Interestingly this difference did not mediate flightpath tracking performance, even though one might expect a benefit to that performance from pilots who looked more at the instrument panel (IP). Apparently pilots spend a necessary and sufficient amount of time on the IP scan to assure optimal performance on this primary task of aviating, some pilots needing more, and some needing less depending on their flight skills. Whatever residual visual attention was available was allocated to traffic detection, and the latter reflected this variability between pilots.

The third context in which scanning was examined, was in terms of a fine grained "case study" examination of differences between pilots who did and did not report the off-normal events.

In conclusion, the current study has six goals, three pragmatic design-related goals, and three goals that advance the theory of attention allocation in complex environments. These six, somewhat interrelated goals are stated as follows:

1. Does the tunnel provide more effective guidance and reduced workload than equivalent guidance presented in 2D coplanar format? While several studies have contrasted the tunnel/pathway concept against either baseline flight instruments (e.g., Beringer & Ball, 2001; Fadden et al., 2001; Williams, 2002), or more conventional 3D representations (Prinzel et al., 2004; Schnell et al., 2004). Few appear to have done so in a way that preserved the prediction and preview aspects inherent in the tunnel, in the more conventional 2D control conditions.

While this preservation is echoed in more basic part-task simulations (e.g., Haskell & Wickens, 1993; Wickens & Prevett, 1995), it is a control that appears lacking in the more realistic SVS evaluations.

2. What is the viability of the SVS display panel hosting both tunnel and traffic information? While such display configurations involving each component have been examined in isolation (Fadden et al., 2001; Merwin, 1998; Prinzel et al., 2004; Schnell et al., 2004), they have not been examined in conjunction (both traffic and tunnel in a single SVS display). Merwin examined traffic, but not a tunnel, whereas Schnell et al., and Prinzel et al., and Beringer and Ball (2001) examined a tunnel, but no traffic, and Fadden et al., evaluated a tunnel and traffic, but not with an SVS terrain background. Alexander Wickens and Hardy (2003) did compare traffic detection on an SVS system that hosted a tunnel, with one that hosted only a "follow me airplane" for guidance (less clutter), and observed no difference in traffic detection performance between them, so long as the tunnel was presented at a low level of intensity.

3. What is the viability of an instrument panel overlay on top of an SVS display that is also hosting traffic and a tunnel? Will the added clutter of this condensed information offset any benefits of collocation, to either traffic detection or flightpath tracking? While numerous studies have examined HUD versus head down performance, none appear to have examined this "maximum clutter" configuration on an SVS background.

4. A theory-oriented goal, that flows directly from question 3, is to evaluate the general tradeoff between the scanning costs of a separated display, and the clutter costs of a more integrated display. This tradeoff has been examined many times before, both in the context of head up (integrated) versus head down (separated) displays (e.g., Fadden et al., 2001, Experiment 2, Wickens & Long, 1995), and overlaid versus separated databases (e.g., Kroft & Wickens, 2003; O'Brien & Wickens, 1997). The current study examines two different manifestations of this overlay: the tunnel, and the instrument panel.

5. The theory-driven issue of cognitive or attentional tunneling remains an important one, with the introduction of new and "compelling" displays such as SVS and its tunnel. Will such tunneling affect the processing of routine secondary tasks (traffic detection and altitude change report), and the response to off-normal events? Pathway-in-the-sky tunneling has been observed in non-SVS research (Fadden et al., 2001), and some tunneling has been observed in SVS research (Wickens, McCarley, & Thomas, 2004), although in the latter case, the sample of pilots was too small to draw meaningful statistical conclusions.

The final goal is to understand the role of visual attention (as measured by scanning) in mediating the various effects described above, and particularly the extent to which the relation between scanning and performance is tightly couple. While both Williams (2002) and Beringer and Ball (2001) have measured scanning with tunnels, the former used only head down displays, separated from the location of the traffic to be detected, while the latter did not examine traffic detection. No studies appear to have directly examined the relation between scanning and attentional tunneling as mediated by individual differences.

In the current paper, we examine these scanning-performance relations through standard statistical analysis. In a future paper, we will examine them through computational modeling.

METHOD

Participants

Fourteen instrument-rated pilots flew 8 experimental scenarios of 8-10 minutes each, involving a curved step-down approach, through a terrain-challenged region, to a simulated airport in Yosemite County, California. A Frasca twin-seat flight simulator with 180 degrees outside visual depiction was used.

Displays

The four different display suites are shown in Figure 1. The two suites on the top row (“**tunnel**”) provided flightpath guidance via the preview of a 3D tunnel-in-the-sky, a depiction of ownship, and a 3D predictor of ownship 5 seconds into the future. This predictor rotates around its own vertical axis to show turns in perspectives, and also translates laterally and vertically, relative to the display frame, in order to indicate the future change in heading and altitude, based on the current turn rate and vertical speed, respectively.

The two display suites without the tunnel (bottom row) also contain the predictor. However guidance is provided by **datalink** (uplinked) instructions in the bottom box, which offer in verbal/numeric form the identical guidance information offered by the tunnel (e.g., a commanded heading and rate of climb or decent). Pilots could monitor their lateral course via the NAV display on the lower right depicting ownship and the desired path, as well as by reference to the instrument panel (upper right), showing heading; they could monitor vertical course with a vertical situation display (VSD; on the right side of the instrument panel), which depicted vertical deviation (and deviation rate) relative to the center of the commanded flightpath. We refer to these configurations in the bottom row as **“datalink”** displays.

The two display suites in the left column (**overlay**) are distinguished from those in the right (**separate**) in terms of whether or not the instrument panel was overlayed on the SVS display. In all four conditions, the SVS display had a geometric field of view (GFOV) of 60 degrees, contained terrain, an indicator of ownship’s current position and instantaneous attitude relative to the terrain, a 5-second predictor, and traffic near the forward path (i.e., within the GFOV of the SVS display). Traffic consisted of blimps that did not translate across the map. In all conditions, the NAV display depicted the 2D command flightpath, ownship’s current location and velocity vector, and, serving as a CDTI, contained all traffic in the surrounding airspace (except the rogue airplane described below). Traffic altitude was provided by a digital data tag on the CDTI. Static blimps were chosen rather than dynamic aircraft for two reasons: (a) they allowed us to obtain better control of precisely which aircraft would appear on the SVS display and when they would be visible than would have been the case with dynamic aircraft, given that the pilot was in control of his momentary heading. (b) Because they were static, they simulated “worst case traffic” both by reducing conspicuity (which would have been increased by movement of the traffic across the visual field) and by mimicking traffic on a near collision course (steady bearing).

Procedures and Tasks

Pilots were instructed to follow the guidance as accurately as possible to the landing. On half the approaches, low-visibility (instrument meteorological conditions--IMC) were encountered after the first leg until the final approach to the runway. One of the four approaches within each visibility condition was flown with each of the four display suites. Thus, each display condition was replicated in IMC and VMC. While flying, pilots were instructed to **detect** with a button press any new traffic that became visible on the SVS display, and verbally **report** any changes to traffic altitude that they noticed on either the SVS display or the NAV display (host to the CDTI). On the 3D SVS display, these changes appeared as analog changes in the vertical location of the blimp. On the NAV display, they appeared as changes in the digital datatag.

Each pilot encountered each of the following off-normal events (each on a separate approach):

(a) a "rogue aircraft" blimp (VMC conditions only) that was only visible in the outside world, and positioned close enough to the commanded flightpath that a maneuver would be required to maintain separation. This implicit measure of traffic awareness was chosen because requesting an explicit response, such as "report traffic in your flightpath" might have affected pilots' expectations for off-normal events. In their instructions (Appendix A), pilots were told: "Deviate from the path only in the event that collision with a hazard is imminent."

(b) a ground-based radio antenna, both visible in the outside world and on the SVS. Like the rogue aircraft, the antenna was placed in a position which would also induce a maneuver, because the top of the tower would just intrude into the lower boundary of the tunnel.

(c) a runway offset (tunnel conditions only), in which both the tunnel and the SVS display provided guidance to an approach that was offset by 500 ft from the true runway, as the latter could be viewed in the outside world.

Pilots were not pre-warned of these off-normal events. Thus, detection of and response to both the rogue airplane and the runway offset would be hindered to the extent that the tunnel induced an attentional tunneling to the SVS display panel at the expense of outside scanning.

Eight of the 14 pilots wore an ASL eye and head tracking system, so that direction of gaze toward different areas of interest could be established, and measured as a percent dwell time (PDT).

RESULTS

Table 1 presents the data for all key dependent variables of the experiment, broken down by the four display configurations, each in IMC and VMC. The analysis of each of these follows.

Table 1.

		Tunnel		DataLink	
		Overlay	Separate	Overlay	Separate
Lateral Abs Error	IMC	7.50	8.20	71.10	81.50
	VMC	7.70	8.60	74.00	80.50
Vertical Abs Error	IMC	5.20	5.70	25.50	31.60
	VMC	5.70	5.70	29.10	31.30
Traffic RT(s)		17.00	9.60	20.60	15.10
Traffic AC		0.84	0.90	0.82	0.93
Change Detection Rate	On SVS	0.40	0.54	0.41	0.36
	On NAV	0.23	0.22	0.20	0.19

Flightpath Tracking

Flight control measures of deviations from the ideal flightpath revealed significant benefits of the integrated tunnel (relative to the separated sources of information from datalink guidance) for both lateral tracking (70 meter benefit; F(1, 13) = 96.5, p < .01) and vertical tracking (25 meter benefit; F(1, 13) = 32.4, p < .01). The greater benefit for lateral than vertical tracking may be attributed in part to the fact that the higher order lateral task typically requires greater pilot-lead generation because of its greater lag, than does the lower order vertical task (Wickens, 2003). Support for this lead generation in terms of preview is offered in a more integrated form by the tunnel display, than by the separated datalink configuration. The overlay of the instrument panel on the SVS produced a small (5 meter) benefit to vertical tracking (F(1, 13) = 11.3, p < .01), but this benefit was only in evidence when the tunnel was absent. The presence or absence of overlay had no influence on lateral tracking. Finally, visibility (IMC vs. VMC) had no influence on tracking in either axis, either through main effects or interactions.

SVS Traffic Surveillance

The time required to detect and report traffic on the SVS display was shortened from 16 to 11 seconds when the tunnel was available for guidance (F(1, 13) = 15.9, p < .01). Interestingly the tunnel's presence speeded traffic detection time more in VMC (M = 6s) than in IMC (M =

3s; F interaction 1,13 = 4.67, p = .05). In contrast to the tunnel benefit, the effect of overlay was to impose a significant 6 second **cost** to detecting traffic relative to the separated instrument panel (F(1, 13) = 34.9, p < .01), presumably as a result of the clutter. This cost was equivalent for the tunnel and the distributed datalink display (F < 1.0). Neither the guidance (tunnel) nor the overlay variable had any main effect on the accuracy of traffic detection. Only a marginally significant three-way interaction was observed (F(1, 13) = 3.73, p = .07), and this can be interpreted as indicating that the accuracy is always greater in the separate condition (replicating the performance advantage for RT), except when there is a tunnel in VMC, when the advantage for separation disappears. Thus there was no speed-accuracy tradeoff between conditions.

We also examined the accuracy of detecting changes in the altitude of all traffic (on both the SVS and the NAV display). Overall this detection rate was low (below 50%), replicating findings of Muthard and Wickens (2003). Not surprisingly, altitude change detection was better for traffic on the SVS display, than for traffic which appeared only on the NAV display (F(1, 13) = 16.9, p < .01). Three reasons can be offered for this advantage. First, there was a greater allocation of attention to the SVS display as we discuss below. Second, changes of blimp altitude on the SVS display were represented by analog changes in the vertical location of the blimp, whereas changes in altitude on the NAV display were indicated by scrolling of the digital datatag, the latter revealing consistently poorer detection performance in other studies (Muthard & Wickens, 2003, 2004). Third, altitude changes to the blimps on the SVS, always close to the forward flightpath would be, on average, more relevant to flightpath safety than changes to blimp altitude on the NAV Display, many of which would be farther from the flightpath, and hence less of a hazard. It is well established that increasing relevance supports better change detection (Muthard & Wickens, 2003; Pringle et al., 2001). This SVS advantage was not modified by the other two experimental variables via an interaction that had any meaningful interpretation.

One noteworthy conclusion from the traffic surveillance data is that the pattern of results enables rejection of the hypothesis that the tunnel, leading to increased attention to the SVS display (relative to datalink) would increase change detection performance of traffic on that display, and decrease detection performance of traffic on the NAV display. This hypothesis can be rejected, since guidance (tunnel versus datalink) had no influence on detection at either location.

Off-Normal Events

Rogue aircraft detection. The small N for the detection of the single rogue aircraft in the outside world prevented traditional statistical analyses. However, it is important to note that 5 of 6 pilots (83%) who experienced this event in the non-tunnel (datalink) condition, responded with an appropriate evasive response, whereas in the tunnel condition, only 4 of 8 (50%) did so (Chi-squared = 2.67, p = 0.102).

Antenna detection. All pilots were able to notice the antenna, visible on the SVS display in all four conditions, and responded appropriately.

Runway offset. There was no difference between the overlay and separate conditions in responding to the runway offset, which was present only in the tunnel condition. Importantly, 5/12 pilots failed to notice the offset, and initiated their landing parallel to the true runway, rather than flying a missed approach (two of the 14 pilots did not receive an offset event). Whether this bias was a function of the presence of the tunnel, or merely the presence of the SVS runway, cannot be ascertained from the current data because runway offset trials were not conducted for the datalink display.

Visual Scanning: Mean Pilot Performance

Analysis of how the different display conditions would influence the allocation of attention measured by percent dwell time (PDT) within the different areas of interest is shown in Figure 2. This analysis was conducted on the subset of 8 pilots whose scanning was assessed. The identity of these AOIs is provided in the figure caption. For the purposes of the current analysis, all scans to all separate instruments within the instrument panel (IP) were collapsed into one "IP AOI". The data reveal the obvious dominance of the SVS panel (heavy black line) in all three display conditions in which the SVS panel hosted guidance information (the two tunnel conditions, and the overlaid instrument panel), a dominance that captured visual attention roughly 70% of the time. A 2x2x2 repeated measures ANOVA was carried out on the PDT data for each area of interest.

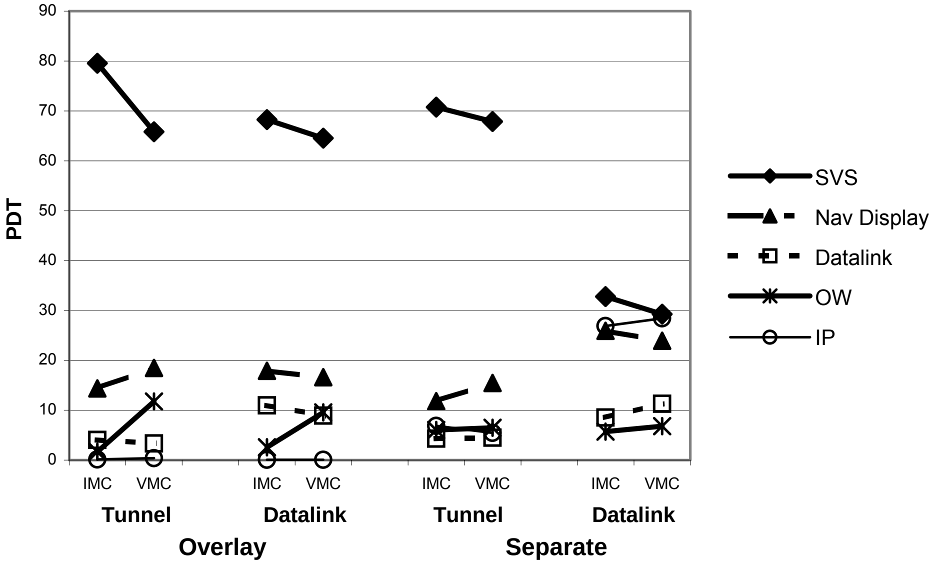


Figure 2: Percent dwell time on each area of interest (AOI) as a function of the 8 conditions.

The right half of Figure 2 corresponds to the two formats in the right half of Figure 1, where the displays are separated (and hence visual attention allocation to the instrument panel can be discriminated from allocation to the tunnel and its SVS host). This analysis revealed that eliminating the tunnel substantially reduced attention to the SVS panel ($\underline{F}(1, 7) = 705$, $\underline{p} < .001$) and such attention was re-allocated particularly, to the instrument panel (VSD for vertical tracking), and also somewhat to the NAV display (guidance information for lateral tracking) and as this reallocation was indicated by the increase in scanning to these areas of interest ($\underline{F}(1, 7) = 175$, $\underline{p} < .001$, $\underline{F}(1, 7) = 40$; $\underline{p} < .001$, respectively). One interesting feature is the two-way interaction between overlay and guidance for scanning to the NAV display (F(1, 7) = 28.6, p <.01). When the IP was separated, the datalink guidance caused more looking at the NAV display than the tunnel guidance. When there was an overlay, the datalink display did not. This pattern suggested that providing most of the information in one physical location (the SVS panel) inhibited the broader scanning to other locations within the display suite, a sort of cognitive tunneling.

Scanning to the datalink panel itself, containing the flightpath instructions was, not surprisingly, driven by the utility of the information contained there, which was high in the datalink condition and low in the tunnel condition; F(1, 7) = 64; p < .01). In the tunnel condition, such information was not needed by the pilots, since the tunnel itself provided adequate command path direction.

Figure 2 also reveals the decrease in SVS scanning and the increase in outside-world (OW) scanning associated with the outside visibility of IMC (F(1, 7) = 22.4, p < .01; F(1, 7) = 14.5, p < .01, respectively). This is indicated by the downward slant and upward slant of the SVS and OW lines, respectively. Not surprisingly, pilots look outside more often when there was something to see. However it is noteworthy that even in the datalink separated VMC condition, when the SVS panel contained little more information than the outside world (only the predictor is added), the SVS panel still received over three times the amount of visual attention (30% vs. 9%). It may be that this added attention was directed toward the valuable flightpath predictor symbol located in the SVS panel, and not outside. It may also be simply that the SVS display, with its traffic and terrain depiction that was consistently available independent of visibility, was just a compelling source that attracted visual attention. These two hypotheses are not mutually exclusive. It is also important to note that the very low level of OW scanning observed here was not that much different from the low (14%) level observed by Williams (2002). The greater reduction observed here may be attributable to the fact that the current simulation also included an SVS terrain background

Figure 2 reveals that the visibility-driven tradeoff between the OW and the SVS scanning was fairly strong in the overlay condition, but was more muted in the separated condition, as revealed by the marginal interaction between weather and overlay for the SVS scanning (F(1, 7) = 3.71, p = .09), and the very strong interaction for the OW scanning (F(1, 7) = 17.2, p < .01). Therefore, when there was a cluttered SVS display **and** the outside world was visible, the pilots preferred to look outside to a greater extent than when the SVS display was less cluttered.

The scanning and traffic detection data together suggest that the amount of visual attention drawn to the SVS display had little direct effect on the detection of traffic represented on that display. Had this been the case, then within the datalink trials, the overlay condition should have produced better traffic detection, not worse, because the overlay brought the eyes to the SVS panel 67% of the time, compared with 30% for the separate condition. But the overlay did not help. Instead, the tunnel helped such detection. That is, SVS traffic detection appeared to be helped by the lower workload of flying with the tunnel (availing more resources for traffic surveillance, relative to the datalink display) and hindered by the clutter of overlay (relative to display separation).

The scanning data also allowed us to ask if the apparent finding of a marginally significant cognitive tunneling effect described above (more missed rogue airplane detection with the tunnel than with the datalink) was the direct result of a visual attention allocation away from the outside world, induced by the tunnel. The current data would seem to reject that hypothesis, since outside world scanning in VMC was relatively constant (around 10%) between tunnel and datalink display conditions, and did not differ significantly between them (see Figure 2).

Scanning Analysis: Individual Pilot Differences and Strategies

As described above, the second context for examining scanning was to assess the extent to which strategic differences in scanning between pilots mediated performance effects, as Wickens et al. (2001) had observed for traffic detection. In carrying out this inquiry, first, we asked whether better flightpath tracking was achieved by pilots who looked more at the source of flightpath information: in the tunnel conditions the SVS display, and in the datalink non-tunnel condition, the SVS display (for attitude information), instrument panel (vertical situation), and map (lateral situation). The answer to this question was no, replicating the null effect observed by Wickens et al. (2001). All correlations between the PDT measures and flightpath tracking performance were low and non-significant. We accounted for these results by assuming that because flightpath tracking was the primary task, all pilots did the necessary and sufficient scanning to maintain performance at the optimal level. Pilots who needed to scan more (for example to the tunnel), did so, in a way to preserve their tracking performance at a level equal to those who needed to scan less.

Second, we asked whether pilots who looked at the SVS display longer detected the traffic hosted there more rapidly than those who looked at it less. Here, there was some modest support. Separate correlations computed in each of the four display conditions (pooled over IMC and VMC) revealed that one (of the 4) correlations between detection RT and PDT was negative, and two (of the 4) correlations between RT and the mean dwell duration on the SVS AOI were negative. No correlations were positive. The pattern of which particular conditions showed the relationships did not reveal any apparent consistency however. Interestingly, these effects stand in partial contrast to those of Wickens et al. (2001), who found that OW traffic detection benefited from shorter dwells on the instrument panel (where the traffic was not located), whereas here, longer dwells on the SVS display (where the traffic **was** located), tended to facilitate the better detection.

Scanning Analysis: Off-Normal Event Detection

The next level of individual differences analysis of scanning focused on a detailed examination of the specific scan behavior to the outside world, that might have discriminated those pilots who were successful in detecting the off-normal events visible there, from those who were not. Three hypotheses were offered. First, that non-detectors simply did not look at the OW when the event occurred. Second (and not mutually exclusive from the first), this non-looking behavior was prototypical of the pilots’ general scan pattern, rather than simply a pattern adopted on the particular trial in which the off-normal event occurred. The third hypothesis is that there was no difference in scan between the detectors and non-detectors, and that the failure of the non-detectors was the result of some form of cognitive tunneling (“look but don’t see”), rather than a poor visual scan pattern.

Overall detection performance: Rogue Blimp. While as we note above, 9 of 14 pilots appear to have detected the rogue blimp, here we focus our analysis only on that subset of 8 for which scanning was also measured. In the rogue blimp trial, 6 out of these 8 pilots appeared (as indicated by their flight behavior) to detect the aircraft in the outside world, and this was confirmed by a closer inspection of the eye-tracking and flight performance data, which provided evidence for both avoidance maneuvers and scans of the outside world that coincided with the rogue blimp’s visibility.

All four of the pilots who experienced the rogue blimp in the datalink condition detected the blimp (indicated by eye-tracking data) and conducted avoidance maneuvers (indicated by control input and path deviation data). Of the four pilots who received the rogue blimp in the tunnel condition, two detected the blimp and two did not. Note that this association between good detection and the absence of the tunnel mimics that found with the larger set of all 14 pilots described above.

Figures 3 and 4 represent the segment of time during each trial when the rogue blimp first became visible in the outside world to when it was passed by the aircraft. Figure 3 shows the AOI scanning data for the two rogue blimp detectors in the tunnel-present condition, control input to the aileron and elevator, and the resultant X and Y deviations from the directed flightpath. Both of these blimp detectors showed increasingly frequent and long glances to the outside world as the blimp approached the flightpath, and control input data showed a sharp increase (also evident in the increased path deviations) indicating an avoidance maneuver was conducted. Figure 4 shows corresponding graphs for the two non-detectors in the tunnel condition; in both cases, pilots had almost no scans to the outside world (and few away from the tunnel), and did not show any unusual control activity or path deviations, indicating that the blimp was neither perceived nor avoided.

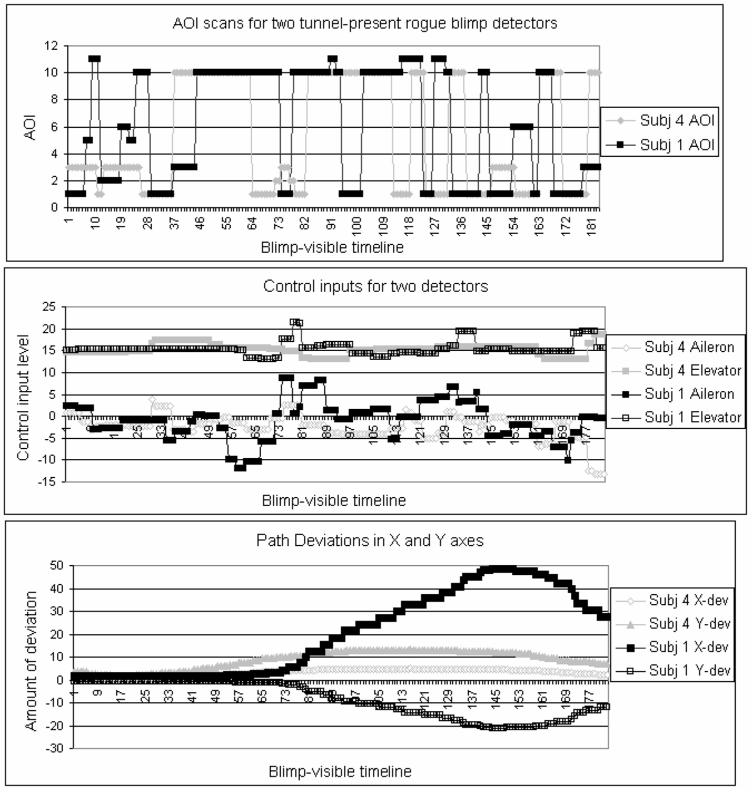


Figure 3. The three graphs represent two detecting pilots' scanning of each display area of interest (AOI), control inputs, and resultant path deviations during the time frame that the rogue blimp is visible in the outside world. In the top graph, AOI 1 is the SVS display, AOI 2 is the datalink display, AOI 3 is the NAV display, AOIs 4-8 are instrument panel displays, and AOIs 9-11 represent the outside world. In the bottom graph, deviations from 0 represent deviations from the ideal flight path.

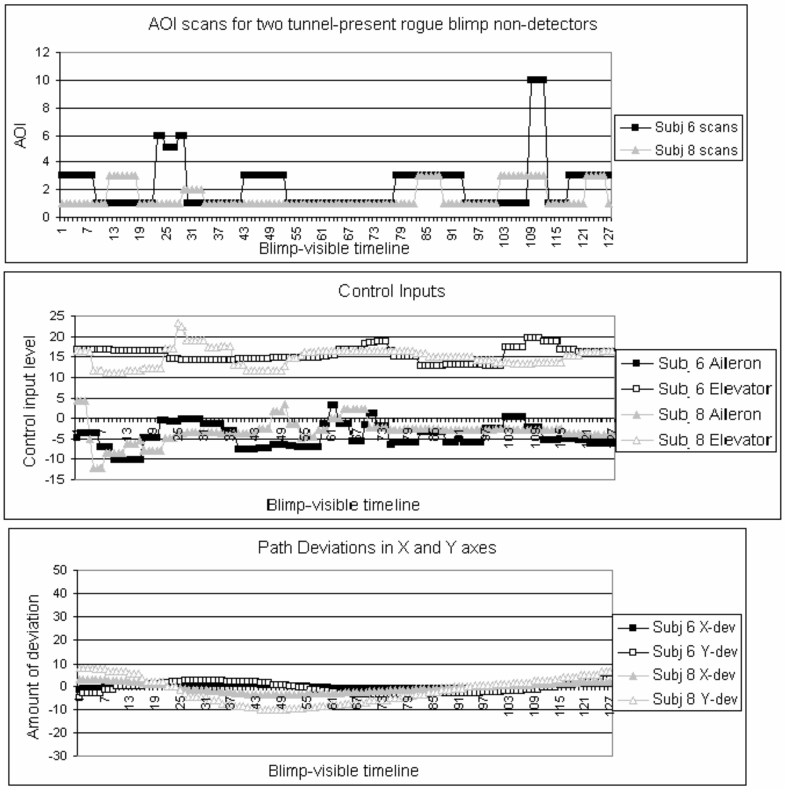


Figure 4. The three graphs represent two non-detecting pilots' scanning of AOIs, control inputs, and resultant path deviations during the time frame that the rogue blimp is visible in the outside world.

Percentage dwell times: Rogue blimp. We then quantified the scanning differences between the three groups of pilots (datalink: all detectors, tunnel detectors and tunnel non-detectors), as measured by their percentage dwell times (PDTs) on each of the two key displays, the two most relevant AOIs for the off-normal event detection: the Synthetic Vision System (SVS) since it was expected to be the most compelling display, and the outside world (OW) since it contained the true information needed to correctly detect the off-normal events. The PDT data are shown in Table 2.

Table 2. Percentage dwell times for the SVS and the outside world during the segment of the rogue blimp trial when the blimp was visible, and for the rogue blimp trial as a whole.

	Rogue Blimp Detectors (6)	**Non-Detectors (2)**	
	Data-link (4)	**(2) Tunnel-present (2)**	
SVS Percentage Dwell Times			
Rogue Blimp Segment	**24%**	**54%**	**77%**
Entire Trial	**29%**	**61%**	**77%**
OW Percentage Dwell Times			
Rogue Blimp Segment	**20%**	**27%**	**0%**
Entire Trial	**8%**	**14%**	**1%**

The datalink pilots (those who encountered the rogue blimp while flying with the datalink display) scanned the outside world (OW) approximately 20% of the time frame during which the rogue blimp was visible. Evaluation of the scanning behavior of the four tunnel-present pilots for the time frame beginning when the blimp became visible in the outside world to when it would have passed (or impacted) ownship, shows a marked difference in their scanning strategies (refer to Figures 3 and 4). The two tunnel-present pilots who detected the blimp scanned most of the AOIs (those relevant for en route flight) fairly often, including the outside world (about 35% during the time frame when the rogue blimp was visible, similar to the datalink pilots). By contrast, the two pilots who did not detect the blimp show scanning strategies that rarely included displays other than the SVS, and almost never included scans to the outside world (less than 1%) during this same time frame.

Analysis of these data on the entire trial revealed that non-detectors scanned the SVS display significantly **more** than did detectors ($p<.05$) regardless of tunnel presence, and scanned the outside world significantly **less** than did the detectors ($p<.05$) This suggests that the two non-detectors were spending most of their time looking at the SVS (77% of the time), and almost no time looking out the window (1% of the time). Detectors, on the other hand, were somewhat more evenly balanced, spending 45% of the time looking at the SVS display and 11% looking out the window (averaged across both tunnel present and datalink conditions). Thus there is support for the first two hypotheses offered above. Non detectors did not look at the locus of detection (the outside world), and this pattern of looking behavior generally characterized their scan pattern at other times during the flight.

Percentage dwell times: Runway offset. We next considered the detectors and non-detectors of the runway offset, of which there were four in each category. Since this only occurred within the tunnel condition, their data could be represented in just two groups, as shown in Table 3.

Table 3. Percentage dwell times for the SVS and the outside world during the segment of the runway offset trial when the runway was visible, and for the runway offset trial as a whole.

	Runway Offset Detectors	Non-Detectors
SVS Percentage Dwell Times		
Runway Offset Segment	45%	84%
Entire Trial	62%	81%
OW Percentage Dwell Times		
Runway Offset Segment	37%	5%
Entire Trial	13%	3%

These data revealed that the percentage dwell times for the detectors and non-detectors of the runway offset are nearly identical to those of the tunnel-present detectors and non-detectors of the rogue blimp (compare Tables 2 and 3).

Finally, we note that there was not a perfect agreement between the identity of the non-detectors and the detectors of the two off-normal events. In particular, 3 of the 4 pilots who caught the rogue blimp in the tunnel-absent condition missed the runway offset when the tunnel was present. Also, one of the pilots who missed the rogue blimp when the tunnel was present, successfully detected the runway offset, also with the tunnel present. Thus, pilots can be arrayed on a continuum regarding the extent to which they detected both events (Subjects 1 and 4 in Figure 2) or neither event (Subject 8 in Figure 3).

Importantly, when we compared the OW scanning, averaged across all VMC trials for these two best off-normal event detectors with the one poorest detector (subject 8), we found that the “good” detectors spent 11% more time scanning the outside world than the “bad” detector (16% vs. 5%). Correspondingly, when this comparison was made for the SVS scanning, it revealed that “good” detectors spent 13% less time scanning the SVS (52% vs. 65%).

The combination of eye-tracking data and flight performance data present us with a pretty clear picture of the differences between pilots who may be more likely to see unexpected events that are not presented on the cockpit displays, and those that may be so drawn into a single display that they don’t scan the other, potentially highly relevant, displays. These findings are in line with those from Dowell et al. (2002). The six pilots who missed the off-normal events when the tunnel was present show scan patterns that are similar to each other, and that pattern demonstrates an overwhelming preference to watch the SVS display and virtually ignore the outside world. This pattern is found throughout the entire trial, and therefore may be representative of the pilots’ general scan strategy. We were not able to identify any clear demographic characteristics (e.g., less flight experience) that would typify the non-detectors who were most heavily reliant upon the tunnel.

On the other hand, the pilots who detected the rogue blimp and runway offset show an ability to scan more displays more frequently, especially when the tunnel was absent. Although the overall percentage of scans to the SVS display was substantially higher when the tunnel was present, this “successful” scanning pattern was apparent for the rogue blimp and runway offset detectors in the tunnel-present condition. This indicates that while they scanned the SVS display almost as frequently as the non-detectors, their attention was not as securely captured by the highly compelling SVS display as the two non-detectors were during the critical off-normal detection time.

Attentional tunneling does not seem to occur when there is no compelling tunnel guidance, as evidenced by the tunnel-absent participants’ scanning data (Tables 1 and 2). However, this conclusion is based solely on the rogue blimp detection evidence. Since we do not have data on detection of the runway offset in a tunnel-absent condition, we cannot conclude that the SVS alone would not contribute significantly to the cognitive tunneling effects observed in the runway offset trials. There is some thought that it might, due to the fact that a landing task (when runway offset occurred) has higher associated workload than en route flight (when rogue blimp task occurred), and higher workload has been associated with attentional tunneling (Larish & Wickens, 1991). In addition, the SVS contained a depiction of the runway, which may be as compelling as the tunnel in its own right.

DISCUSSION

The current study was designed to achieve six goals, the first three defined by specific design-related questions. Regarding the first of these, it is clear that the current data confirm the now well-established finding that the tunnel is a benefit to flightpath tracking (Alexander et al., 2003; Haskell & Wickens, 1993; Iani & Wickens, 2004; Prinzel et al., 2004; Schnell et al., 2004; Wickens & Prevett, 1995), and that the tunnel, providing the preview of commanded flightpath information, offers benefits quite independent from the flightpath **predictor** symbol, indicating actual projected flightpath location. This is because the predictor was present on both conditions with and without the tunnel. While pilots in the datalink condition can achieve preview of upcoming turns from their electronic map display, it may be that what provides the great benefit of the tunnel is not so much the information it contains, but the fact that this information is configured in a manner that integrates lateral and vertical preview, a conclusion drawn in a less realistic simulation by Haskell and Wickens (1993). The greater ease of integration is consistent with the reduced cognitive load, which appears to support enhanced traffic detection.

Regarding the second design goal it appears that the SVS-tunnel **can** indeed provide an effective host for presenting forward traffic information; important because this is likely to be the most dangerous traffic. Traffic was detected at an overall 85% rate (better in IMC worse in VMC). This rate is certainly not perfect. However in the current simulation, the visibility of the traffic blimps on the SVS was intentionally diminished, in order to challenge perception and help amplify any display differences that might have existed. Whether SVS traffic detection would improve to a 100% level if it were perceptually enhanced on the SVS display remains a question awaiting further research.

Detection of SVS traffic appearance was better (faster) when the tunnel was present than absent. The presence of the tunnel both drew the eyes directly to the SVS panel (where traffic was hosted), and, perhaps more importantly, lowered the cognitive demand of flightpath tracking (relative to the separated datalink guidance condition), thereby availing more resources to monitor the environment for traffic.

The third design issue was to examine the viability of instrument overlay, or whether its clutter would impose costs on the vulnerable traffic monitoring task. On the one hand, while we had some concerns that the added strokes of the tunnel might inhibit traffic detection through clutter costs, such costs, if they existed, were clearly dominated by the benefits of greater attention concentration (to the SVS panel) and lower workload. On the other hand, clutter costs to traffic detection were clearly manifest in the instrument panel overlay conditions, no matter whether the tunnel was present or absent, thereby replicating such costs that had been observed elsewhere (e.g., Fadden et al., 2001; Ververs & Wickens, 1998). Interestingly, while clutter costs of overlay have often been found only for unexpected events, here they were manifest as well for the detection of regularly occurring traffic. This clutter cost of expected events may reflect the relatively low visibility of the SVS-displayed traffic, hence reinforcing the conclusion drawn by Yeh et al. (2003), that overlay clutter will have a greater cost on detecting less salient objects. Why the overlay of the instrument panel clearly disrupted traffic detection, while the tunnel overlay did not, could be attributed to the benefits of the tunnel described above (reduced workload), or to the fact that the tunnel better integrates with the 3D space ahead of the airplane, creating a form of "scene linking" (Levy, Foyle, & McCann, 1998). While this explanation has some plausibility, it should be noted that Fadden et al. (2001) found that a tunnel in the sky failed to provide any benefits of scene linking.

The first of our three theoretical goals pursued by the current research was to better understand this clutter-scan tradeoff, and the factors that contribute to both influences. As we have noted, some sources of "clutter" (added marks on a display), may provide sufficiently great benefit because of their workload reduction, that they dominate any costs that their display strokes may impose. Such apparently was true with the tunnel strokes. Other sources (here the instrument panel) do not achieve that benefit. It should be noted that the current experimental design did not provide a fully unbalanced test of the relative contributions of tunnel clutter versus instrument panel clutter. This is because the design did not include a condition in which the tunnel was present, but located in a non-overlaying position; a condition that would be functionally equivalent to the instrument panel separate condition.

The second major theoretical goal of the research was to ascertain the extent to which some form of attentional tunneling was induced by two properties of the SVS configuration, the realistic looking SVS terrain, and the tunnel. The answer here was mixed. On the one hand, the presence of the tunnel in the SVS did not appear to harm the detection or noticing of events outside of the SVS, in this case, the traffic data tag changes on the NAV display. As we noted above, the reduced workload of the tunnel appeared to avail more resources for other monitoring that might have offset any increased scanning toward the SVS panel. In this regard, the current results nicely replicate those of Iani and Wickens (2004) who found that pilots flying with the tunnel were actually better at noticing changes in weather patterns on a spatially separated NAV display. They are consistent with those of Williams (2002) who found that tunnel flying (relative to baseline) did not disrupt detection of outside world traffic. Furthermore, as we have also noted above, the presence of the tunnel improved, rather than degraded detection of traffic within the **same panel**, (SVS) and did not hurt the noticing of changes in that traffic, relative to the datalink condition. All told, there was no evidence for attentional narrowing caused by the tunnel affecting **performance** of regular secondary tasks.

On the other hand, there was solid evidence that the properties of the tunnel led to reduced attention to the outside world in detecting the rogue blimp, and the properties of the tunnel and the SVS display combined (the individual contributions of each cannot be ascertained) led to less-than-perfect detection of the runway offset (5 of 12 of the pilots failed to notice this). While neither source of evidence is statistically strong, because of the small number of off-normal events that could be presented to keep them as truly surprising, the trends are consistent with a body of literature suggesting that compelling displays may channel attention to their location. This argument is partially supported by the data from the scanning analysis, addressing our third theoretical issue.

The final theory-driven goal was to understand the extent of coupling between visual attention as reflected by scanning, and performance effects, both in general, and as the latter are reflected specifically in attentional narrowing phenomena. As we noted above, these relationships can be evaluated either as mediated by display differences or by individual pilot strategy differences.

Regarding display-driven coupling of performance and scanning, the results are mixed. On the one hand, we did find that putting a tunnel on the SVS display brought more visual attention to that region **and** improved traffic detection in that region. However we cannot ascertain the extent to which the benefit to traffic detection was because of the re-allocation of visual attention there, or because the reduced cognitive load of using the tunnel for flightpath tracking availed more resources for surveillance. Some evidence against a tight coupling is provided by the fact that, while the overlay also brought more visual attention to the SVS panel (see Figure 2), in this case that reallocation did not improve traffic detection performance, but actually inhibited it.

As to whether visual scanning mediated any attentional narrowing effects on performance of regular secondary tasks, we cannot assess, since, as noted, the tunnel presence on the SVS panel did not disrupt traffic change detection on the NAV display, in this regard reflecting the effects observed by Williams (2002). Finally, although we did notice that the tunnel produced attentional narrowing in detection of the two off-normal events (the rogue and the runway offset), whose symptoms were only visible in the outside world, it is hard to attribute this directly to scanning differences, since outside scanning was no more or less whether the tunnel was or was not present on the SVS panel.

Regarding the extent of strategic differences in scanning mediating individual differences in performance, we found again that the linkage was relatively weak. We found no evidence of a linkage between scanning and flightpath tracking, reflecting the fact that all pilots gave the flightpath displays the visual attention necessary to achieve good performance, allowing residual attention to support traffic detection. Thus the latter performance would be more likely to reveal individual differences in scanning, and here we found modest support. Across the four display conditions, coupled with the two scanning measures (PDT and mean dwell duration), we found that only three of these indicated a correlation between looking and traffic detection (those who looked more or longer at the SVS panel, detected the traffic faster), although none of the eight revealed an opposite pattern.

Collectively then, it appears that there may be a relatively broad range of looking behavior which can sustain roughly equivalent levels of performance. It is only when this looking behavior drops precipitously below some minimum threshold, that performance truly suffers, and this was revealed by the individual pilots' analysis of off-normal event fixation. Stated simply, certain pilots failed to look at all at the outside world and, as a consequence, failed to detect off-normal events that were reflected there. In this case, attentional tunneling (true neglect) and performance were indeed tightly linked. The issue of why this occurred, and how susceptible it may be to training interventions awaits further research. A conclusion that appears to emerge from the current data is that certain pilots are more susceptible to display-induced tunneling than others, and the manifestation of that display-induced tunneling is the response to unexpected events that are present outside of the field of view in which the compelling display is located.

A-SA Computational Model of SVS Visual Scanning

The A-SA model, which has predicted visual scanning on the basis of Area of Interest bandwidth and relevance, along with task value, and has been validated in prior research on SWAP HPM (Wickens, McCarley, & Thomas, 2004), was applied to the visual scanning data collected in the SVS simulation at Illinois.

In the current application we were interested in predicting the mean percentage dwell time, on each of the five primary areas of interest in the SVS suite (SVS display, Instrument Panel, Nav Display, Datalink panel and outside world), (a) within each of the eight display conditions (b) averaged across the 8 conditions. We employed an identical model to that used by Wickens, McCarley, and Thomas (2004), in which:

$[\text{Predicted Attention to AOI}]=BW_{AOI} \times \Sigma(\text{Relevance}_{t\text{-}AOI} \times \text{Value}_t)$

The only differences from previous applications were that:

(a) AOI Bandwidth coefficients were directly calculated by measurement of the frequency of changes within the dynamic simulator variables from real time simulation runs. This provides greater precision than estimating the ordinal value of these values as was done in previous model applications (Wickens, McCarley, & Thomas, 2004; Wickens, Goh, Helleberg, Horrey, & Talleur, 2003).

(b) We established three tasks (with different values) rather than two, in the following hierarchy: (1) **Aviate** defined attitude control of the plane (level, or appropriate pitch and bank). (2) **Navigate** defined maintaining the plane on the desired course, and climb/descent rate. (3) **Hazard awareness** defined awareness of the appearance and change of traffic aircraft or terrain.

Table 4 presents the parameter matrix of bandwidth (of AOI), relevance (of AOI to task) and value (of task) that was established a priori for the experiment. The eight display conditions are listed in the eight columns.

Table 5 presents the predictions from the A-SA equation. The "raw data" predictions, in the top table were normalized so that, within each condition the total predicted percentage dwells summed to 1.0. These normalized values are presented in the middle table. The bottom table presents the actual percentage dwell time (PDT) data, identical to those shown in Figure 2. At the bottom of Table 5, we present the correlations between the model fit and the obtained PDT values for each condition. These correlations are uniformly positive and, except for the last two conditions, with separated data link displays, are all above r = .85. Figure 5 presents a scatter plot of the predicted versus obtained PDTs for all eight conditions collapsed. That is, each point in the scatter plot represents a single unique AOI X condition combination. The correlation of this global prediction is 0.93.

Two adjustments to the model were made. (1) The nature of the experiment was such that in all visual (VMC) conditions, pilots had access to attitude (aviate) information from both the SVS display and the outside horizon (OW area of interest). This was reflected in the partial (.5) weight seen in Table 4, for the relevance of the OW to aviating. If pilots did not use this information at all, its relevance would be set to 0. Hence we re-ran the model with a value of relevance=0 for these four conditions, and revealed improvements of fit, especially for the separated datalink VMC condition (r=.75). The new correlation coefficients are shown in the bottom table of Table 6.

(2) We also re-ran the model with the relevance of the Instrument panel to aviating set to 0 in the two datalink separated conditions, under the assumption that pilots with the horizon and predictor available in the SVS panel, could have fully used this information, rather than any within the IP, to maintain aircraft attitude. These correlations revealed a little improvement of fit for the separated datalink IMC condition, but the impairment of the fit for the VMC condition (see the bottom table of Table 7).

Finally, we re-ran the model predictions with both OW and IP relevance to aviating always set to zero, under the assumption that in all conditions, pilots acquired all of the information they needed for attitude control from the SVS panel. These correlations revealed some improvements of the fit for those display conditions as shown in the bottom table of Table 8.

Note that what we have done here is to use the model to test the hypothesis about how pilots distributed their visual attention across redundant channels of information. When we set non-zero values to each of N redundant channels, we are assuming that pilots are using both channels. To the extent that setting 0 values to some redundant channels improves the model fit, it suggests that pilots are not using those channels.

What the data reveal is that the pilots extracted little attitude information from the real horizon, even when it was visible in IMC, relying instead heavily on the synthetic horizon from the SVS display. As reported above, this strategy of “attentional tunneling” nicely revealed by the modeling fit, put the pilots at risk when there was information in the outside world that was not revealed within the SVS panel.

Table 4: The Parameter Matrix

				Experiment Conditions							
				Tunnel Overlay VMC	Tunnel Overlay IMC	Tunnel Separated VMC	Tunnel Separated IMC	Datalink Overlay VMC	Datalink Overlay IMC	Datalink Separated VMC	Datalink Separated IMC
	Parameter			**TOV**	**TOI**	**TSV**	**TSI**	**DOV**	**DOI**	**DSV**	**DSI**
AOIs	**Bandwidth (B)**	SVS		0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
		IP		0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
		ND		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
		DL		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		OW		0.5	0	0.5	0	0.5	0	0.5	0
	Relevance (R)	SVS	(TR)	1	1	1	1	1	1	1	1
		SVS	(NA)	1	1	1	1	1	1	0	0
		SVS	(HAZ)	1	1	1	1	1	1	1	1
		IP	(TR)	0	0	0	0	0	0	0.5	0.5
		IP	(NA)	0	0	0.5	0.5	0	0	1	1
		IP	(HAZ)	0	0	0	0	0	0	0	0
		ND	(TR)	0	0	0	0	0	0	0	0
		ND	(NA)	0.5	0.5	0.5	0.5	1	1	1	1
		ND	(HAZ)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		DL	(TR)	0	0	0	0	0	0	0	0
		DL	(NA)	0	0	0	0	1	1	1	1
		DL	(HAZ)	0	0	0	0	0	0	0	0
		OW	(TR)	0.5	0	0.5	0	0.5	0	0.5	0
		OW	(NA)	0.5	0	0.5	0	0.5	0	0.5	0
		OW	(HAZ)	0.5	0	0.5	0	0.5	0	0.5	0
	Value (V)	TR		3							
		NAV		2							
		HAZ		1							

Table 5. (Version 1)

[Predicted Attention to AOI]=BW_{AOI} x $\Sigma(Relevance_{t\text{-}AOI} \times Value_t)$

Raw Data		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	3.72	3.72	3.72	3.72	3.72	3.72	2.48	2.48
	p(IP)	0	0	0.81	0.81	0	0	2.835	2.835
	p(ND)	0.27	0.27	0.27	0.27	0.45	0.45	0.45	0.45
	p(DL)	0	0	0	0	0.1	0.1	0.1	0.1
	p(OW)	1.5	0	1.5	0	1.5	0	1.5	0
	sum	5.49	3.99	6.3	4.8	5.77	4.27	7.365	5.865

Normalized		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	0.68	0.93	0.59	0.78	0.64	0.87	0.34	0.42
	p(IP)	0.00	0.00	0.13	0.17	0.00	0.00	0.38	0.48
	p(ND)	0.05	0.07	0.04	0.06	0.08	0.11	0.06	0.08
	p(DL)	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.02
	p(OW)	0.27	0.00	0.24	0.00	0.26	0.00	0.20	0.00
	sum	1	1	1	1	1	1	1	1

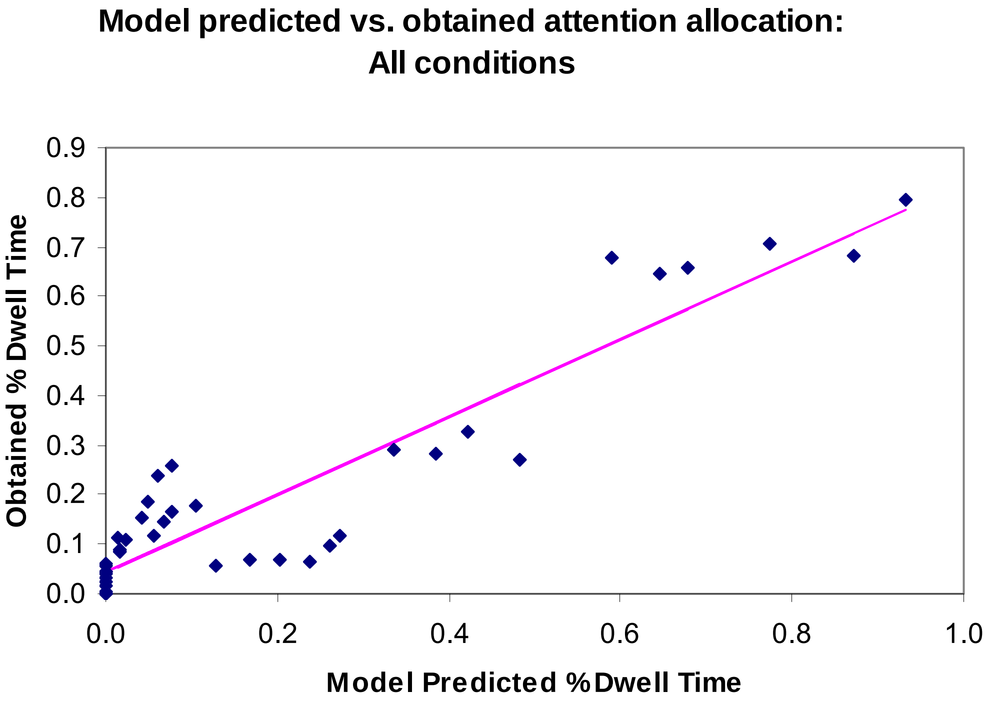
Obtained Data		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	0.66	0.80	0.68	0.71	0.65	0.68	0.29	0.33
	p(IP)	0.00	0.00	0.05	0.07	0.00	0.00	0.28	0.27
	p(ND)	0.18	0.14	0.15	0.12	0.17	0.18	0.24	0.26
	p(DL)	0.03	0.04	0.04	0.04	0.09	0.11	0.11	0.09
	p(OW)	0.12	0.02	0.07	0.06	0.10	0.03	0.07	0.06
	sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Correlations between the model predicted and the obtained data

	Overall	TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
Correlation	0.93	0.93	1.00	0.90	0.98	0.93	0.99	0.57	0.80
R Square	0.86	0.87	0.99	0.81	0.96	0.86	0.98	0.33	0.64

Figure 5. Scatter plot of model predicted vs. obtained dwell time.

	Overall
Correlation	0.93
R Square	0.86



y =0.042538 + 0.784941 x

Table 6 (Version 2)

[Predicted Attention to AOI]=BW_{AOI} x Σ(Relevance$_{t\text{-}AOI}$ x Value$_t$)

Raw Data		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	3.72	3.72	3.72	3.72	3.72	3.72	2.48	2.48
	p(IP)	0	0	0.81	0.81	0	0	2.835	2.835
	p(ND)	0.27	0.27	0.27	0.27	0.45	0.45	0.45	0.45
	p(DL)	0	0	0	0	0.1	0.1	0.1	0.1
	p(OW)	0.75	0	0.75	0	0.75	0	0.75	0
	Sum	4.74	3.99	5.55	4.8	5.02	4.27	6.615	5.865

Normalized		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	0.78	0.93	0.67	0.78	0.74	0.87	0.37	0.42
	p(IP)	0.00	0.00	0.15	0.17	0.00	0.00	0.43	0.48
	p(ND)	0.06	0.07	0.05	0.06	0.09	0.11	0.07	0.08
	p(DL)	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02
	p(OW)	0.16	0.00	0.14	0.00	0.15	0.00	0.11	0.00
	Sum	1	1	1	1	1	1	1	1

Obtained Data		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	0.66	0.80	0.68	0.71	0.65	0.68	0.29	0.33
	p(IP)	0.00	0.00	0.05	0.07	0.00	0.00	0.28	0.27
	p(ND)	0.18	0.14	0.15	0.12	0.17	0.18	0.24	0.26
	p(DL)	0.03	0.04	0.04	0.04	0.09	0.11	0.11	0.09
	p(OW)	0.12	0.02	0.07	0.06	0.10	0.03	0.07	0.06
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Correlations between the model predicted and the obtained data

	Overall	TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
Correlation	0.96	0.98	1.00	0.95	0.98	0.98	0.99	0.75	0.80
R Square	0.91	0.95	0.99	0.91	0.96	0.96	0.98	0.56	0.64

Table 7 (Version 3)

[Predicted Attention to AOI]=BW_{AOI} x $\Sigma(\text{Relevance}_{t\text{-}AOI} \times \text{Value}_t)$

Raw Data		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	3.72	3.72	3.72	3.72	3.72	3.72	2.48	2.48
	p(IP)	0	0	0.81	0.81	0	0	1.62	1.62
	p(ND)	0.27	0.27	0.27	0.27	0.45	0.45	0.45	0.45
	p(DL)	0	0	0	0	0.1	0.1	0.1	0.1
	p(OW)	1.5	0	1.5	0	1.5	0	1.5	0
	Sum	5.49	3.99	6.3	4.8	5.77	4.27	6.15	4.65

Normalized		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	0.68	0.93	0.59	0.78	0.64	0.87	0.40	0.53
	p(IP)	0.00	0.00	0.13	0.17	0.00	0.00	0.26	0.35
	p(ND)	0.05	0.07	0.04	0.06	0.08	0.11	0.07	0.10
	p(DL)	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02
	p(OW)	0.27	0.00	0.24	0.00	0.26	0.00	0.24	0.00
	Sum	1	1	1	1	1	1	1	1

Obtained Data		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	0.66	0.80	0.68	0.71	0.65	0.68	0.29	0.33
	p(IP)	0.00	0.00	0.05	0.07	0.00	0.00	0.28	0.27
	p(ND)	0.18	0.14	0.15	0.12	0.17	0.18	0.24	0.26
	p(DL)	0.03	0.04	0.04	0.04	0.09	0.11	0.11	0.09
	p(OW)	0.12	0.02	0.07	0.06	0.10	0.03	0.07	0.06
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Correlations between the model predicted and the obtained data

	Overall	TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
Correlation	0.93	0.93	1.00	0.90	0.98	0.93	0.99	0.46	0.85
R Square	0.86	0.87	0.99	0.81	0.96	0.86	0.98	0.21	0.73

Table 8 (Version 4)

[Predicted Attention to AOI]=BW_{AOI} x $\Sigma(\text{Relevance}_{t\text{-}AOI}$ x $\text{Value}_t)$

Raw Data		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	3.72	3.72	3.72	3.72	3.72	3.72	2.48	2.48
	p(IP)	0	0	0.81	0.81	0	0	1.62	1.62
	p(ND)	0.27	0.27	0.27	0.27	0.45	0.45	0.45	0.45
	p(DL)	0	0	0	0	0.1	0.1	0.1	0.1
	p(OW)	0.75	0	0.75	0	0.75	0	0.75	0
	Sum	4.74	3.99	5.55	4.8	5.02	4.27	5.4	4.65

Normalized		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	0.78	0.93	0.67	0.78	0.74	0.87	0.46	0.53
	p(IP)	0.00	0.00	0.15	0.17	0.00	0.00	0.30	0.35
	p(ND)	0.06	0.07	0.05	0.06	0.09	0.11	0.08	0.10
	p(DL)	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02
	p(OW)	0.16	0.00	0.14	0.00	0.15	0.00	0.14	0.00
	Sum	1	1	1	1	1	1	1	1

Obtained Data		TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
	p(SVS)	0.66	0.80	0.68	0.71	0.65	0.68	0.29	0.33
	p(IP)	0.00	0.00	0.05	0.07	0.00	0.00	0.28	0.27
	p(ND)	0.18	0.14	0.15	0.12	0.17	0.18	0.24	0.26
	p(DL)	0.03	0.04	0.04	0.04	0.09	0.11	0.11	0.09
	p(OW)	0.12	0.02	0.07	0.06	0.10	0.03	0.07	0.06
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Correlations between the model predicted and the obtained data

	Overall	TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
Correlation	0.96	0.98	1.00	0.95	0.98	0.98	0.99	0.70	0.85
R Square	0.92	0.95	0.99	0.91	0.96	0.96	0.98	0.50	0.73
Version1	Overall	TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
Correlation	0.93	0.93	1.00	0.90	0.98	0.93	0.99	**0.57**	**0.80**
R Square	0.86	0.87	0.99	0.81	0.96	0.86	0.98	0.33	0.64

Version 2	Overall	TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
Correlation	0.96	0.98	1.00	0.95	0.98	0.98	0.99	**0.75**	**0.80**
R Square	0.91	0.95	0.99	0.91	0.96	0.96	0.98	0.56	0.64
Version 3	Overall	TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
Correlation	0.93	0.93	1.00	0.90	0.98	0.93	0.99	**0.46**	**0.85**
R Square	0.86	0.87	0.99	0.81	0.96	0.86	0.98	0.21	0.73
Version 4	Overall	TOV	TOI	TSV	TSI	DOV	DOI	DSV	DSI
Correlation	0.96	0.98	1.00	0.95	0.98	0.98	0.99	**0.70**	**0.85**
R Square	0.92	0.95	0.99	0.91	0.96	0.96	0.98	0.50	0.73

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