The Role of the Air Traffic Controller in Future Air Traffic Management: An Empirical Study of Active Control versus Passive Monitoring

Ulla Metzger and **Raja Parasuraman,** The Catholic University Of America, Washington D.C., USA

Future proposals for air traffic management (ATM) such as Free Flight (FF) call for a transfer of responsibility for separation between aircraft from air traffic controllers (ATCos) to pilots. Under many proposals, the role of the air traffic controller (ATCo) will change from one of active control to passive monitoring. The present study directly compared these types of control with respect to ATCo mental workload, conflict detection, and memory. Eighteen ATCos participated in an air traffic control (ATC) simulation of FF procedures under moderate and high traffic load. Dependent variables included accuracy and timeliness in detecting potential conflicts, accepting and handing-off aircraft, mental workload (as assessed by a secondary task, heart rate variability and subjective ratings), and memory for aircraft location. High traffic density and passive control both degraded conflict detection performance. The detrimental effects of passive monitoring on ATCo performance support recent proposals to keep separation authority with the controller.

INTRODUCTION

The rapid growth in commercial air travel, both in the US and worldwide, is putting immense pressure on the ATC system. Consequently, several proposals have been put forward for modernizing ATC to meet the demands for enhanced capacity, efficiency, and safety (RTCA, 1995; FAA, 1997; Eurocontrol, 1998; Wickens, Mavor, Parasuraman, & McGee, 1998). Foremost among these proposals for changes in ATC procedures is the effort to give the users (e.g. pilots, airlines, dispatchers) more freedom in their operations within the airspace. Examples include the "Free Flight" (FF) concept as proposed by the RTCA (1995) and Distributed Air-Ground Traffic Management (DAG-TM) as proposed by NASA (1999).

These concepts represent a change in ATC procedures in which responsibility for separation between aircraft will be increasingly transferred from air traffic controllers (ATCos) to pilots. Even though pilots would be responsible for maintaining separation and awareness of immediate traffic, ATCos would still be required to oversee separation assurance, intervene under emergency conditions (e.g. failure of on-board traffic awareness systems), and to monitor the transition of flights to managed airspace. FF was originally proposed by the RTCA (1995) as an operational concept emphasizing airborne self-separation with reduced ground-based control in the en route environment. Eurocontrol (1998) assumes three different types of en route airspace: managed airspace with structured routes, managed airspace with free routing, and FF airspace, in which ATCos have no responsibility for separation assurance or flight guidance, but are expected to assist when aircraft no longer meet the requirements to participate in FF, e.g. in an emergency or failure of on-board equipment (Eurocontrol, 1998). The more recent vision of the FAA (1997) calls for ground-based management with automation support for ATCos. The assumption is that automation will free ATCo resources so that ATCos are able to respond to more user requests and manage air traffic more

Address correspondence to Ulla Metzger or Raja Parasuraman, Ph.D., The Catholic University of America, Cognitive Science Laboratory, 250 O'Boyle Hall, Washington, DC 20064, USA; MetzgerU@cua.edu or Parasuraman@cua.edu.
HUMAN FACTORS, Vol. 43, No. 4, Winter 2001.

efficiently. A recent report by the National Research Council (NRC; Wickens et al., 1998) also recommended a system with ground-based control with mostly moderate levels of automation to support information acquisition, analysis, and decision-making.

These concepts of future ATM differ in the extent to which the role of the ATCo will change from that of an active controller to a passive monitor. The RTCA and Eurocontrol (for parts of the airspace) proposals assume a passive, monitoring role with ATCo intervention only in rare, but potentially dangerous cases. The FAA and the NRC panel on the other hand assume a more active role for the ATCo, who would have a degree of responsibility for separation that is closer to the current situation.

Much has been written about FF and related future ATM concepts, and there is no shortage of speculations and "thought experiments" about how these concepts may or may not work. But there is a paucity of *empirical studies* comparing the effects of these different concepts, especially with reference to the ATCo. In particular, there is a need for investigating how effectively ATCos can manage traffic and, more importantly, detect conflicts under these different types of control, especially in the monitoring role. New concepts implemented with a view to increase capacity and efficiency should at least be safety-neutral and, preferably, safety-enhancing.

Basic research on vigilance indicates that the discrimination of unpredictable and infrequent signals from a noisy background of non-signals decreases significantly with time on task (Mackworth, 1948; Teichner, 1974; Parasuraman, 1979; Warm, 1984). Thackray and Touchstone (1989) found an increase in detection times of about 50% after one hour on task when students had to detect conflicts manually in a simplified version of an ATC task. Studies of human monitoring of automated systems also indicate that detection of automation anomalies is poor when operators are engaged in other manual tasks (Parasuraman, Molloy, & Singh, 1993). Further, vigilance tasks can impose considerable mental workload (Warm, Dember, & Hancock, 1996). Such results would lead to the expectation that ATCos may be poor in detecting aircraft-to-aircraft conflicts and experience high levels of mental workload when they are not actively controlling the airspace but nevertheless have to monitor for occasional anomalies.

Previous studies have confirmed that ATCo performance can be compromised under such conditions (Endsley, Mogford, Allensdoerfer, & Stein, 1997; Endsley & Rodgers, 1998), particularly when traffic density is high (as a consequence and goal of future concepts of ATM) and ATCos do not have ready access to aircraft intent information (Castaño & Parasuraman, 1998; Galster, Duley, Masalonis, & Parasuraman, 2001). Endsley and Rodgers (1998) found that ATCos showed poor performance in detecting conflicts in recorded traffic when they were passively monitoring the traffic. Endsley et al. (1997) found increased workload and a trend for a higher number of operational errors under conditions of reduced involvement. Galster et al. (2001) found that passive monitoring with airborne control of aircraft separation, which would be the case under *mature* FF, led to a marked decrease in conflict detection performance by ATCos under high traffic load. Willems and Truitt (1999) found that under passive monitoring, response times to questions probing traffic awareness became longer and recall of data blocks poorer with increasing traffic load.

These findings suggest that the degree of control over aircraft separation might be a critical factor in conflict detection by ATCos. The present study therefore tested the hypothesis that humans are less aware of changes in the environmental or system state when those changes are under the control of another agent (automation or human) (Endsley & Kiris, 1995; Parasuraman & Riley, 1997; Wickens, 1994). According to this view, the ATCo's passive role under advanced FF is similar to that created by high-level automation. Both remove decision authority away from the ATCo. As a result, when the ATCo is required to step back into the control loop, detection and resolution of aircraft conflicts take longer than when ATCos are actively involved in aircraft separation. The present study compared the effects of active control versus passive monitoring and moderate (current) versus high (future) air traffic density on ATCo performance, mental workload, and memory in an ATC task simulating FF conditions. While previous studies have shown negative effects when ATCos were monitoring traffic under high traffic loads, none of the studies has directly compared the effects of active versus passive control or monitoring. It was expected that ATCos under active control conditions, in which they manipulated aircraft by issuing clearances, would show better conflict detection performance and have better memory of the location and other characteristics of aircraft than ATCos who only monitored traffic and were left out of the control loop (passive condition).

METHOD

Participants

Eighteen active ATCos from the Washington Center air route traffic control center (ARTCC) and Baltimore-Washington International, Dulles International, and Reagan National terminal radar control area (TRACON) facilities served as paid volunteers. Four participants were excluded from the analysis due to insufficient radar experience (n = 2) and computer malfunctions (n = 2). The remaining fourteen ATCos were between the ages of 27 and 47 years (M = 36.4, SD = 5.1). Their overall ATC experience ranged from 7 to 17 years (M = 12.4, SD = 2.9).

Apparatus

A PC-based medium-fidelity ATC simulator (Masalonis, Le, Klinge, Galster, Duley, Hancock, Hilburn, & Parasuraman, 1997) was used to simulate a generic airspace. The simulation consisted of a primary visual display (PVD) and a datalink display, which were presented on a 21- and a 15-inch monitor, respectively. A trackball was used as input device. The PVD of the sector consisted of aircraft targets, datablocks, high-altitude jet routes and waypoints. The adjacent monitor displayed the datalink and an electronic flight strip for each flight. In addition, a heart rate monitor (Byrne, 1994) was used to obtain heart rate variability (HRV) data from the participants.

ATCos were presented with four 30-minute scenarios that were created to combine moderate (on average 11 aircraft in the sector at one time) and high (on average 17 aircraft) traffic density with active and passive control conditions in a 50-mile radius sector. Routes, altitudes, and conflict geometries were selected arbitrarily. In fact, only two different scenarios (one for moderate and one for high traffic) were used. In order to build a second set of scenarios, the sector boundaries, jet routes, and traffic patterns were rotated and aircraft callsigns and waypoints were changed to create the appearance of a different traffic scenario. Therefore, the traffic scenarios for the active and monitoring condition were essentially the same, assuring that differences in ATCo performance and mental workload were due to the manipulation of control type and not due to specific features of a particular scenario such as conflict geometry (Castaño & Parasuraman, 1999; Remington, Johnston, Ruthruff, Gold, & Romera, 2000).

Each scenario contained six scripted potential conflicts that were to be detected. A potential conflict could result in an actual conflict or a self-separation. A conflict or loss of separation was defined as two aircraft coming within 5 nautical miles horizontally and 1000 feet vertically of each other (the separation minima proposed by the RTCA, e.g.). A red “bubble” around the conflicting aircraft notified the ATCo of the loss of separation. A self-separation existed when one of two aircraft on a conflict course made an evasive maneuver to avoid the loss of separation, either by changing speed or altitude. While self-separations represent instances of successful airborne separation, conflicts are instances in which airborne separation fails and the ATCo would have to step in to resolve the conflict under real-world FF conditions. Therefore, conflicts are of particular interest. Each of the four scenarios consisted of four scripted self-separations and two scripted conflicts.

Under passive monitoring conditions, ATCos were required to monitor traffic and acknowledge the detection of a potential conflict by clicking a "conflict"-button on the PVD. Under active control conditions, ATCos were required to acknowledge the detection of potential conflicts in the same way. In addition, under active control conditions ATCos were able to resolve the detected potential conflicts by issuing instructions or clearances that the experimenter entered into a pseudo-pilot software module so that aircraft would maneuver according to the ATCo's instructions and be displayed accordingly on the PVD. Further, ATCos could issue instructions at any time under active control conditions. While this created the possibility that ATCos in the active control condition would resolve a scripted potential conflict before it actually developed in the scenario, this was unlikely to occur (and in fact did not occur) because conflicts and self-separations were scripted to develop before or as soon as aircraft entered the sector and ATCos assumed responsibility for them. The simulation of accepting and handing-off aircraft as they entered or left the sector and monitoring the progress of aircraft throughout the sector according to their flight progress strips took place on the datalink.

Procedure

After providing biographical information, ATCos were connected to the heart rate monitor. They were given a demonstration of the simulation, completed a fourteen-minute practice trial, and were familiarized with an index of subjective workload, the NASA Task Load Index (NASA-TLX; NASA Ames Research Center, 1986). A baseline of the ATCos' HRV was obtained during a five-minute period in which they were instructed to relax. Then, ATCos completed the four 30-minute scenarios and rated their mental workload on the NASA-TLX after each scenario. The order of scenarios was counterbalanced across participants. At the end of one of the two high traffic density scenarios (i.e. either after the active or the passive condition), ATCos were presented with a blank paper sector map and asked to mark the lateral position of any aircraft present on the PVD at the time the scenario ended. Then, ATCos were presented with a second map in which all targets and aircraft callsigns were present and asked to add any other information (e.g. altitude) they could recall. This memory probe procedure is similar to one used by Gronlund, Ohrt, Dougherty, Perry, and Manning (1998). However, ATCos were not informed of the memory probe task until the scenario had ended so that they would not change their behavior in anticipation of the memory probe. This is also the reason why the task was only administered once per participant.

Independent variables

Independent variables were (1) active control versus monitoring of the simulated airspace and (2) moderate versus high traffic density in the ATC sector. This resulted in a 2x2 within-subject design with four scenarios. Within each scenario, actual conflicts and self-separations served as different event types (3).

Dependent variables

Primary tasks included detecting potential conflicts (conflicts and self-separations), accepting aircraft into the sector, and handing-off aircraft to the adjacent sector. Frequency and response times for correctly executed actions as well as the frequency of missed actions and false alarms or early actions were recorded. The advanced notification time served as a measure of conflict detection performance and was defined as the time the loss of separation occurred (for conflicts) or would have occurred had the aircraft not self-separated (for self-separations) minus the time the ATCo reported the detection of a potential conflict by clicking a "conflict"-button on the PVD. The greater the value, the earlier the detection took place and the better the conflict detection performance. If the ATCo did not indicate the detection of a conflict before the loss of separation (for conflicts) or the beginning of an evasive maneuver (for self-separations), a miss was recorded. The performance measure of taking hand-offs was obtained by calculating the interval between the time the ATCo obtained a message saying "entering sector" on the datalink and the time the ATCo took the hand-off by clicking the "accept"-button on the datalink. Response times for handing-off aircraft to the next sector were obtained by calculating the interval between the time when the aircraft crossed a designated hand-off zone and the time the ATCo actually handed the aircraft off by clicking the "autohand"-button on the datalink. The frequency of early hand-offs was obtained from all aircraft that were handed off before they crossed a designated hand-off zone. The percentage of correctly recalled lateral aircraft positions (+/- 10 miles) and altitudes (which had to be recalled exactly) served as a measure of memory.

Monitoring the progress of aircraft throughout the sector and updating their flightstrips served as an embedded secondary task and a measure of mental workload. Response times were obtained by calculating the interval between the time an aircraft crossed a waypoint on the PVD and the time the ATCo acknowledged that the aircraft passed the waypoint by clicking on the corresponding waypoint on the electronic flight progress strip. If an ATCo clicked on a waypoint before an aircraft passed it, an early update was registered. A miss was recorded when an ATCo never pressed the waypoint button after an aircraft passed a particular waypoint. The 0.10 Hz band of HRV and ratings on the NASA-TLX were obtained as physiological and subjective measures of mental workload, respectively.

RESULTS

ATCo performance

Detection of potential conflicts. Table 1 summarizes the results for missed potential conflicts. A 2 (traffic) x2 (control) x2 (event) repeated measures ANOVA revealed main effects of traffic density, $F(1, 13) = 133.33$, $p < .001$, and event type (conflicts versus self-separations), $F(1, 13) = 20.96$, $p < .001$ on the percentage of missed potential conflicts. No significant interactions were found. ATCos missed more potential conflicts when traffic density was high (65.18%) compared to moderate (14.73%). More self-separations (51.34%) were missed than conflicts (28.57%). This effect is a consequence of our definition of measurement. While ATCos had the opportunity to detect a conflict up to the point where aircraft lost separation, they could detect a self-separation only up to the point where one of the two aircraft started an evasive maneuver. There was no significant difference in the detection of potential conflicts between passive monitoring and active control conditions (41.07% versus 38.84% missed, respectively). It is noteworthy, however, that conflict detection performance under simulated FF was relatively poor in both conditions.

Mean advanced notification times for conflicts and self-separations were calculated. Thirteen out of 112 datapoints (11.6%) were missing and replaced by the mean across subjects for a particular variable when no advanced notification time was available because an ATCo missed all four self-separa tions or all two conflicts. This was the case under high traffic only.

Table 1: Mean percentage of missed events (SE)

	Moderate traffic		High traffic	
	Self-separations	Conflicts	Self-separations	Conflicts
Active	25.00 (6.42)	0.00 (0.00)	76.79 (1.79)	53.57 (8.23)
Monitoring	23.21 (5.54)	10.71 (5.69)	80.36 (5.96)	50.00 (9.08)

Table 2: Mean advanced notification times in seconds (SE)

	Moderate traffic		High traffic	
	Self-separations	Conflicts	Self-separations	Conflicts
Active	364.31 (22.22)	141.62 (17.69)	329.82 (38.21)	167.66 (48.12)
Monitoring	382.64 (23.15)	143.38 (13.97)	199.93 (8.14)	62.53 (10.36)

Table 2 lists advanced notification times under the different experimental conditions. A 2x2x2 repeated measures ANOVA revealed main effects of control condition, $F(1, 13) = 8.86$, $p < .05$, traffic density, $F(1, 13) = 17.41$, $p < .01$, and event type, $F(1, 13) = 114.72$, $p < .001$ on advanced notification times. Under active control conditions, ATCos detected potential conflicts significantly earlier (250.85 s) than under passive monitoring conditions (197.12 s). They detected potential conflicts earlier when traffic density was moderate (257.99 s) than when it was high (189.99 s). Self-separations were detected earlier (319.18 s advanced notification) than conflicts (128.80 s), again due to our definition of measurement.

Figure 1 shows the interaction between control condition and traffic density, $F(1, 13) = 15.19$, $p < .01$. An analysis of the two-way interaction between control condition and traffic density revealed a significant "cost" in terms of advanced notification times for the passive monitoring compared to the active control condition under high traffic density, $F(1, 13) = 14.20$, $p < .01$. Under high traffic, it took ATCos almost two minutes (117.51 s) longer to detect a conflict under monitoring than under active control conditions. There was no significant cost or benefit of the monitoring condition under moderate traffic density, $F(1, 13) < 1$.

Accepting and handing-off aircraft. The following measures of performance were analyzed with 2 (traffic) x2 (control) repeated measures ANOVAs. Traffic density had a significant effect on the number of aircraft ATCos failed to accept, $F(1, 13) = 5.03$, $p < .05$. ATCos missed accepting more aircraft under high (2.64%) than under moderate (0.77%) traffic density. This reflects the percentage of aircraft that requested acceptance, but had not been accepted into the sector by the time the scenario ended. No significant effects were found for control or the interaction between traffic and control, $F(1, 11) < 1$.

Traffic density also had an effect on the time it took ATCos to respond to a request for acceptance into the sector, $F(1, 13) = 9.90$, $p < .01$. ATCos took significantly longer under high (54.65 s) than under moderate (37.86 s) traffic density to accept incoming aircraft. No significant effects were found for control or the interaction between traffic and control, $F(1, 11) < 1$.

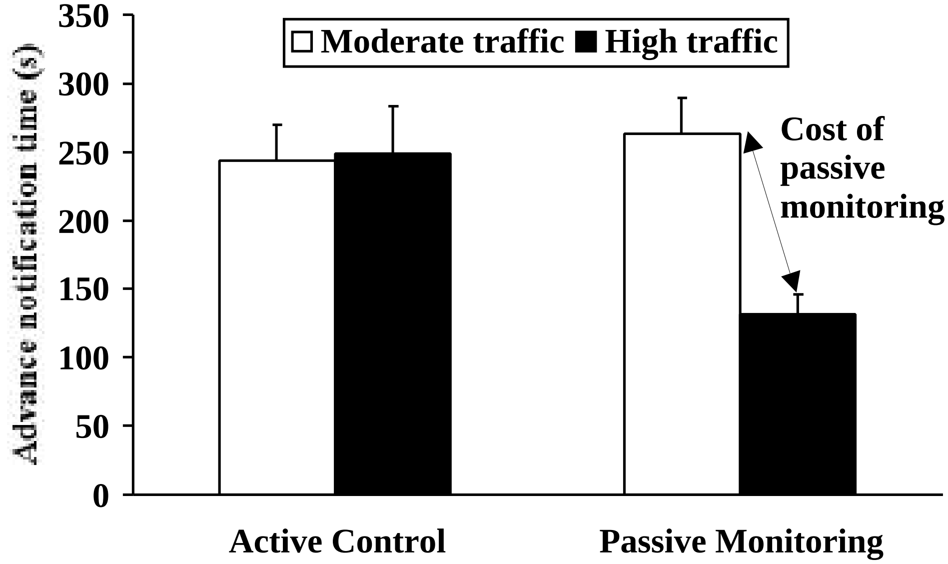

Figure 1: Mean advanced notification times (SE) for conflicts and self-separations

Table 3: Mean percentage of correct aircraft recalls (SE)

	Lateral position correctly recalled	Altitude correctly recalled
Active (n = 6)	28.33 (5.11)	16.67 (4.77)
Monitoring (n = 8)	28.13 (7.44)	6.25 (3.24)
Total (n = 14)	28.21 (4.62)	10.71 (3.00)

Traffic density had a marginally significant effect on the percentage of aircraft leaving the sector that ATCos failed to hand-off, $F(1, 13) = 3.31$, $p = .09$. ATCos failed to hand-off more aircraft under high (7.86%) than under moderate traffic conditions (2.61%). This reflects the percentage of aircraft that had crossed the designated hand-off zone, but had not been handed off by the time the scenario ended. No effects of traffic, control condition, or the interaction were found, $F(1, 13) < 1$. Also, there were no effects of traffic density, control condition, or the interaction on false alarm responses (i.e. early hand-offs) or on the response time to hand-offs.

Memory

Table 3 shows the results of the map recall which were analyzed with a one-way ANOVA. On average, ATCos recalled the lateral position of 28.21% of the aircraft on the PVD at the end of the simulation (+/- 10 miles). The difference between control conditions was minimal, $F(1, 12) < 1$. However, while ATCos could recall the altitude of 16.67% of the aircraft under active control, they could only recall the altitude for 6.25% under passive monitoring conditions. This represents a marginally significant difference, $F(1,12) = 3.51$, $p = .085$. A more detailed analysis revealed that memory was best for an aircraft pair that had just been in conflict, and it was better under active control when the ATCos could resolve the conflict than under passive monitoring. However, it is unclear if the type of control was the cause of this finding. Not every ATCo who recalled the altitude under active control had actually manipulated the aircraft (i.e. given a clearance).

Mental workload

The following measures of mental workload were analyzed with 2 (traffic) x 2 (control) repeated measures ANOVAs.

Secondary task: Monitoring flight progress. Traffic density had a significant effect, $F(1, 13) = 35.32$, $p < .001$ on the percentage of missed waypoint updates. ATCos missed updating significantly more waypoints under high (70.99%) than under moderate (46.80%) traffic conditions. Neither type of control, $F(1, 13) = 1.18$, $p > .05$, nor the interaction between type of control and traffic, $F(1, 13) < 1$, had a significant effect. Traffic density also had a significant effect on early updates of the progress of aircraft, $F(1,13) = 9.26$, $p < .01$. Under moderate traffic density more waypoints were updated early (9.25%) than under high traffic density (4.04%). There was a marginally significant effect of control condition on early updates, $F(1, 13) = 3.26$, $p = .09$. Under monitoring conditions, more waypoints were updated early (7.68%) than under active control conditions (5.60%). This finding might be an indicator that ATCos were not as busy under moderate traffic or the passive monitoring condition and were using the extra time to try to get ahead. This could represent a workload management strategy. The interaction between control condition and traffic was non-significant, $F(1, 13) < 1$. No effects were found for response times to the secondary task.

Subjective measures. Traffic density had a significant effect on TLX ratings, $F(1, 13) = 39.82$, $p < .001$. Under high traffic density, subjects reported significantly higher workload (69.08) than under moderate traffic density (51.76). There were no effects for control condition or the interaction between traffic and control condition, $F(1, 13) < 1$.

Physiological measures. While there was a trend for lower values (indicating higher mental workload) in the experimental (M = 5.20; SE = .20) than in the baseline condition (M = 5.50; SE = .22), $F(1, 12) = 2.60$, $p = .13$, neither traffic density, control condition, nor the interaction had significant effects on the .10-Hz band of HRV, $F(1, 12) < 1$.

DISCUSSION

A number of future concepts of air traffic management, such as Free Flight, call for the gradual transfer of separation responsibility from ground ATCos to pilots and aircraft systems (Eurocontrol, 1998; FAA, 1997; RTCA, 1995). Each of these proposals will alter the role of the ATCo (although to different degrees) from one of active control to passive monitoring. The present study directly compared these types of control with respect to ATCo performance.

There were several results of interest. First, the detection rate of conflicts was relatively poor under high traffic conditions. Second, even though there was no difference in the number of missed potential conflicts between the active control and passive monitoring conditions, it took ATCos significantly longer to detect potential conflicts in the passive monitoring condition under high traffic. In addition, ATCo memory for aircraft altitudes was reduced under monitoring conditions. The potential detrimental effects of passive monitoring have long been suspected, but this study is the first demonstration in the context of a simulated version of advanced ATM, and the only study in which active control and passive monitoring were directly compared in the same group of ATCos. The results mimic the "out-of-the-loop" phenomenon associated with high-level automation of decision-making functions (Wickens, 1994; Endsley & Kiris, 1995).

In general, as suggested by Wickens et al. (1998), the effects of high-level decision automation and Free Flight on the ATCo can be similar, if, as in this case, both lead to a stripping away of decision-making authority. The difference between active control and passive monitoring was not only statistically significant but also of sufficient size to be of practical importance. Under high traffic density, it took ATCos almost twice as long to detect potential conflicts under monitoring compared to active control conditions. This is quite remarkable since high traffic and passive monitoring represent the conditions originally proposed by the RTCA (1995) in their vision of FF. In order to accommodate more aircraft, airspace under FF will be denser and aircraft separation will be tighter leaving less time for ATCos to recover from emergency situations or to back-up airborne separation in case it fails (Galster et al., 2001). However, the present results showed that ATCos need more time to detect conflicts under these conditions. If more time is required by the ATCo than is available to recover from an emergency, ATCo and system performance could be severely compromised. The detrimental effects of passive monitoring on ATCo performance suggest that the original RTCA vision of FF might not be a safe solution. Instead, the results support more recent proposals to keep authority for separation on the ground.

Irrespective of the type of control, ATCos missed more potential conflicts and it took them longer to detect potential conflicts under the high levels of traffic that will be characteristic of future ATM than under moderate traffic. The finding that conflict detection performance was compromised under high traffic density is consistent with the results of a previous study we have carried out (Galster et al., 2001). In addition, subjective and objective measures indicated an increase in mental workload under high compared to moderate traffic. (The insensitivity of the .10 Hz-band of HRV to traffic load manipulations could be due to the fact that mental workload was fairly high across all conditions and that information-processing may have already reached the data-limited area (Norman & Bobrow, 1975) where the .10 Hz band is insensitive (Aasman, Mulder, & Mulder, 1987)). These results are of concern given that the growth in air traffic is likely to increase the number of aircraft that ATCos will be responsible for. Even if their performance was still sufficient under high traffic conditions, unusual situations (e.g. emergencies or bad weather) in which additional attentional resources are needed, may not be handled efficiently. This could lead to a reduction in the operational safety margin. The present results therefore support proposals for a ground-based system in which ATCos actively control instead of passively monitor traffic. Giving ATCos access to support tools such as automated conflict detection and resolution aids has been proposed as a solution to increase performance and reduce workload under high traffic density (Metzger, Galster, & Parasuraman, 1999; Parasuraman, Duley, & Smoker, 1998; Wickens et al., 1998).

The study showed few effects of control condition on mental workload. This could be due to the fact that active control imposed an additional task on the ATCo, i.e. conflict resolution in addition to conflict detection. The passive monitoring condition, which could have imposed considerable mental workload due to the high monitoring demand, only required conflict detection. A potential decrease in mental workload under active involvement could have been cancelled out by the added task of conflict resolution.

ATCos showed slightly better recall of aircraft altitude information under active control than under passive monitoring conditions. In general, ATCo recall of lateral position was relatively poor (<30% correct recall of aircraft position). This is in contrast to other studies (e.g. Gronlund et al., 1998; Endsley et al., 1998) that found much better recall performance (e.g. over 80% correct recall of aircraft position). However, in this study ATCos were not informed of the memory task beforehand (and therefore should not have anticipated it) and memory was tested under very high traffic density. It is possible that ATCos were so overloaded by the high traffic density that memory was sufficiently poor to begin with, so that the type of control did not have an additional effect. Another possibility is that because the traffic in this study was not real (recorded) and the sector was generic, ATCos did not have the structure available that they are used to and that might promote better recollection of aircraft positions and trajectories. Of course, airspace under future ATM will also be less structured than current airspace.

ATCos in this study were performing under relatively novel conditions. It remains to be seen if the negative effects of these conditions can be remedied through learning and experience. For example, prior experience with unstructured airspace, as with some British military ATCos, might be associated with fewer negative effects of FF (Hilburn & Parasuraman, 1997).

Future concepts of ATM and the predicted increase in air traffic have led to proposals to gradually transfer separation authority to pilots and aircraft. Nevertheless, ATCos will still be called upon to assure aircraft separation and safety in an airspace that will now be highly saturated. The detrimental effects of passive monitoring on ATCo performance, particularly under high traffic, support recent proposals to keep separation authority with the ATCo.

ACKNOWLEDGEMENTS

This research was supported by grant No. NAG-2-1096 from NASA Ames Research Center, Moffett Field, CA. Dr. Kevin Corker was the technical monitor. We would like to thank all air traffic controllers who participated in this study.

REFERENCES

Aasman, J., Mulder, G., & Mulder, L. J. M. (1987). Operator effort and the measurement of heart-rate variability. *Human Factors, 29*, 161-170.

Byrne, E.A. (1994). *CSLacq [Computer software]*. Washington, DC: Cognitive Science Lab.

Castaño, D. & Parasuraman, R. (1999). Manipulation of pilot intent under free flight: a prelude to not-so-free flight. *Proceedings of the 10th International Symposium on Aviation Psychology* (pp. 170-176). Columbus, OH: The Ohio State University.

Endsley, M. R. & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. *Human Factors, 37*, 381-394.

Endsley, M. R., Mogford, R., Allensdoerfer, K., & Stein, E. (1997). *Effect of free flight on controller performance, workload, and situation awareness.* (Technical Report). Atlantic City, NJ: FAA Technical Center.

Endsley, M. R. & Rodgers, M. D. (1998). Distribution of attention, situation awareness and workload in a passive air traffic control task: Implications for operational errors and automation. *Air Traffic Control Quarterly, 6* (1) 21-44.

Eurocontrol (1998). *Operational concept document*. Brussels, Belgium: Author.

FAA (1997). *ATS Concept of Operations for the National Airspace System in 2005.* Department of Transportation, Federal Aviation Administration. Washington, D.C.: Author.

Galster, S. M., Duley, J. A., Masalonis, A. J., & Parasuraman, R. (2001). Air traffic controller performance and workload under mature Free Flight: Conflict detection and resolution of aircraft self-separation. *International Journal of Aviation Psychology, 11*, 71-93.

Gronlund, S. D., Ohrt, D. D., Dougherty, M. R. P., Perry, J. L., & Manning, C. A. (1998). Role of memory in air traffic control. *Journal of Experimental Psychology: Applied, 4,* 263-280.

Hilburn, B. G., & Parasuraman, R. (1997). Free flight: Military controllers as an appropriate population for evaluation of advanced ATM concepts. *Proceedings of the 10th International CEAS Conference on Free Flight*, Amsterdam.

Mackworth, N. H. (1948). The breakdown of vigilance during prolonged visual search. *Quarterly Journal of Experimental Psychology, 1*, 6-21.

Masalonis, A. J., Le, M. A., Klinge, J. C., Galster, S. M., Duley, J. A., Hancock, P. A., Hilburn, B. G., & Parasuraman, R. (1997). Air traffic control workstation mock-up for Free Flight experimentation: Lab development and capabilities. *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting* (pp. 1379). Santa Monica, CA: HFES.

Metzger, U., Galster, S. M., & Parasuraman, R. (1999). Effects of a conflict detection aid and traffic density on controller mental workload and performance in an ATC task simulating Free Flight. *Proceedings of the 10th International Symposium on Aviation Psychology* (pp. 541-547). Columbus, OH: The Ohio State University.

NASA Ames Research Center (1986). *NASA Task Load Index (TLX): Paper and Pencil Version.* Moffett Field, CA: NASA Ames Research Center Aerospace Human Factors Research Division.

NASA (1999). *Concept definition for distributed air/ground traffic management (DAG-TM).* Version 1.0. Advanced Air Transport Technologies (AATT) Project. Aviation System Capacity (ASC) Program. Available: http://www.asc.nasa.gov/aatt/dag.html

Norman, D. & Bobrow, D. J. (1975). On data and resource limited processes. *Cognitive Psychology, 7*, 44-66.

Parasuraman, R. (1979). Memory load and event rate control sensitivity decrement in sustained attention. *Science, 205*, 924-927.

Parasuraman, R., Duley, J. A., & Smoker, A. (1998). Automation tools for controllers in future air traffic control. *The Controller: Journal of Air Traffic Control, 37,* 7-13.

Parasuraman, R., Molloy, R. & Singh, I. L. (1993). Performance consequences of automation-induced "complacency". *International Journal of Aviation Psychology, 3*, 1-23.

Parasuraman, R. & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors, 39,* 230-253.

Remington, R. W., Johnston, J. C., Ruthruff, E., Gold, M., & Romera, M. (2000). Visual search in complex displays: Factors affecting conflict detection by air traffic controllers. *Human Factors, 42,* 349-366.

RTCA (1995). *Report of the RTCA Board of Director's Select Committee on Free Flight.* Washington, D.C.: RTCA.

Thackray, R. I. & Touchstone, R. M. (1989). Detection efficiency on an air traffic control monitoring task with and without computer aiding. *Aviation, Space, and Environmental Medicine, 60,* 744-748.

Teichner, W. H. (1974). The detection of a simple visual signal as a function of time on watch. *Human Factors, 16*, 339-353.

Warm, J. S. (1984). *Sustained attention in human performance.* London: Wiley.

Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and human performance: Theory and Applications* (pp. 183-200). Mahwah, NJ: LEA.

Wickens, C.D. (1994). Designing for situation awareness and trust in automation. *Proceedings of the IFAC Conference on Integrated Systems Engineering.* Baden-Baden, Germany.

Wickens, C. D., Mavor, A., Parasuraman, R., & McGee, J. (1998). *The future of air traffic control: Human operators and automation.* Washington, D.C.: National Academy Press.

Willems, B. & Truitt, T. R. (1999). *Implications of Reduced Involvement in En Route Air Traffic Control.* (Technical Report). Atlantic City, NJ: FAA Technical Center.

Ulla Metzger is a Research Fellow in the Cognitive Science Laboratory, at the Catholic University of America, Washington, DC. She received an M.A. in Psychology in 1996 from Darmstadt University of Technology, Germany and is currently completing her requirements for the Ph.D.

Raja Parasuraman is Professor of Psychology and Director of the Cognitive Science Laboratory, at the Catholic University of America, Washington, DC. He received a Ph.D. in Psychology, in 1976 from the University of Aston, Birmingham, U.K.