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How Controllers Compensate for the Lack of Flight Progress Strips

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16. Abstract

The role of the Flight Progress Strip, currently used to display important flight data, has been debated because of long range plans to automate the air traffic control (ATC) human-computer interface. Currently, the Fight Progress Strip is viewed by many as an indispensable tool needed for the safe and expeditious separation of air traffic. Long term plans to automate the American system have initiated a debate on the impact of modifying, or even removing, the Flight Progress Strip. We looked at the viability of a stripless environment by using the Atlanta Center dynamic simulator to compare standard ATC operation with an experimental condition that removed the strips completely. Performance and perceived workload did not differ between conditions. Controllers compensated for the lack of strips by requesting more flight plan readouts. Without strips controllers took significantly longer to grant requests, and spent significantly more time looking at the plan view display.

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HOW CONTROLLERS COMPENSATE FOR THE LACK OF FLIGHT PROGRESS STRIPS

INTRODUCTION

Over the next few years, the human-computer interface in en route air traffic control (ATC) is expected to change considerably. Increasing air traffic has placed more and more demands upon the ATC system. Controllers currently handle seven million flights a year with a system that was designed in the 1960s (Stix, 1994). The combination of these antiquated computer displays and the projected increase in air traffic over the next few years underscores the need for updating the ATC system now in use.

Currently, en route control of high altitude flights between airports depends on two primary tools: the computer-augmented radar information available on the Plan View Display (PVD) and the flight information available on the Flight Progress Strip. An example representation of an aircraft on the PVD can be seen in the upper panel of Figure 1; its flight information on the Flight Progress Strip can be seen in the lower panel. Thirty-one fields for information are printed on the strips and contain such information as call sign, planned route, filed airspeed, assigned altitude, time of arrival, etc. This information supplements the altitude, position, and speed data available from the PVD. While an aircraft is in the controller's sector, the controller writes on the corresponding strip to reflect the control instructions, any changes made in the flight plan, and other contacts with the aircraft.

Although the specific changes brought about by long term automation remain uncertain at this time, it is likely that the automation will considerably change the manner in which flight data will be displayed and manipulated. The automation will most likely combine, in some way, the information currently available on the strips and the information presented on the PVD.

Understanding the way in which controllers compensate for changes in the strips is necessary if we are to determine the amount of information they need to efficiently perform their job without compromising aviation safety. In particular, automation displays may be limited in the amount of flight information that can be displayed, making it important to understand the potential hazards of removing information currently available on the strips.

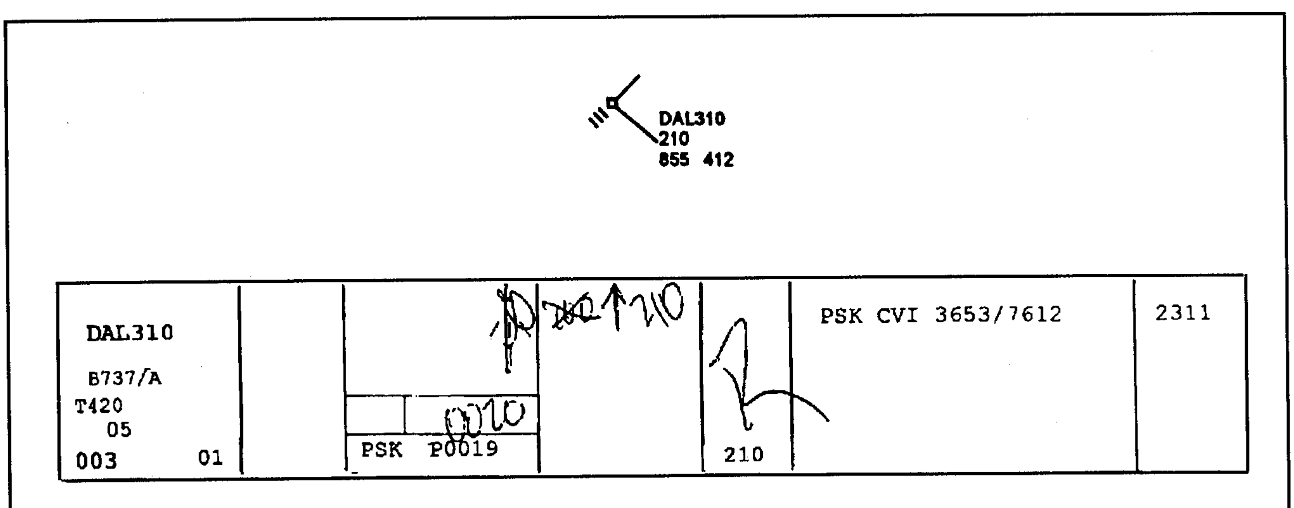

Figure 1. An aircraft's representation on the PVD and on a Flight Progress Strip.

The way in which automation of the strips is to be carried out has caused a significant amount of debate (e.g., Hopkin, 1988; Vortac, 1993). Any automated system that replaces the strips by an electronic display may qualitatively change the controller's interaction with flight data (Vortac & Gettys, 1990). The concern has been expressed that automation of a task that the controller currently performs manually may be detrimental if the cognitive impact of that automation is not considered (Hopkin, 1988).

Cognitive psychology has long known that memory is better for something you do yourself than it is for something done for you (Slamecka & Graf, 1978). It follows that the activities of sequencing, marking on, and moving the strips into and out of the active bay may provide improved incidental memory for relevant information. Hopkin (1988) stated that automation that decreases or eliminates the cognitively beneficial interaction with strips may have a negative impact on controller performance. Hopkin (1988; 1989; 1991) has argued that removal of strips, and the consequent elimination of their incidental memory role, may adversely affect controller performance. For instance, if a controller offsets or marks on "a particular flight strip within the flight strip board as a memory aid...the fact that the action was under the controller's initiative helped the controller remember why it had been taken and what had to be remembered." (Hopkin, 1989, p. 1639). Under automation, some of these operations will most likely be performed by computer.

However, given the complexity of the ATC system, the behaviors used to compensate for loss of strips may, overall, yield advantages over those available under current conditions. Currently, controllers are required to maintain a written record of control actions taken with the aircraft. Removing manual strip board management tasks may increase the time controllers have available to scan the PVD. The elimination of strip marking would likely free up cognitive resources to deal with other aspects of controlling traffic. In fact, informal reports of controllers suggest that strip marking becomes secondary to PVD separation under high traffic density and workload. From this view, a decrease in workload afforded by the automation of tasks which are secondary to the controller's job (i.e., sequencing and updating strips), will be beneficial (Vortac, Edwards, Fuller, & Manning, 1993). Thus, an alternative is that the automation of strips, and the decrease in workload resulting from removal of the written record-keeping component of the FPS, will be beneficial to controller performance.

Previous studies suggested that workload would be reduced if strips are available, but strip marking and board management are eliminated. Vortac, Edwards, Fuller, and Manning (1993) manipulated the availability of strips to Academy instructors. In one condition, controllers used strips as they normally would (Normal). In the other condition (Restricted), controllers were provided with limited strips, which displayed callsign, aircraft type, assigned altitude, and route, but controllers were not allowed to re-sequence, write on, or otherwise interact with the strips. The Restricted condition served as an automation analog more severe than any proposed automation, in terms of lost functionality. Controllers in the Restricted condition performed as well as controllers in the Normal condition on a variety of cognitive measures, including attentional engagement, visual search, recall of flights, and recall of flight data.

Differences that were observed between the two conditions tended to favor the Restricted condition. Remembering to grant requests to planes that were not yet in the controlled airspace was superior when strip marking was eliminated. Thus, memory to perform a task at some time in the future — *prospective* memory (Einstein & McDaniel, 1990; Meacham & Leiman, 1982)— was aided by eliminating strip marking: Controllers in the Restricted condition granted more requests, and granted them sooner, than did those in the Normal condition. Similarly, restricted-condition controllers were also better at anticipating future actions. Prospective activities were generally superior in the Restricted condition, relative to the Normal condition. These results suggest that the decrease in workload afforded by the elimination of updating the strips may, in fact, have beneficial results.

The results of Vortac, Edwards, Fuller, and Manning (1993) make one wonder if complete removal of the strips is viable. This would, in large part, depend on whether the information is presented elsewhere (e.g., on the PVD) or whether the information is removed completely. The reduction in workload produced by eliminating the strip marking may be sufficient to compensate for the loss of information provided by the flight strips. When necessary, controllers could retrieve needed information in more cumbersome ways, but the added effort in these cases may be insignificant when compared to the workload reduction that is produced by eliminating board management responsibilities.

Until now, our research has been limited to the use of Federal Aviation Administration (FAA) Academy instructors controlling the fictitious academic Aero Center airspace. It is important, therefore, to test our hypotheses using field controllers working familiar airspace. Active field controllers rarely participate in empirical studies, making it important to generalize exploratory findings to the controller workforce.

Thus, the purpose of the current study was to use field controllers to provide preliminary data on the actions controllers would take if strips were no longer available. Some of these actions will be compensatory, whereas others could suggest likely controller activities if board management responsibilities were eliminated. In addition, the study examines whether removal of strip information, and its accompanying board management responsibilities, results in either deficits in performance or increases in perceived workload. Finally, we asked controllers about the use of strips in controlling traffic.

Controllers participated in two conditions. In the Strip condition, controllers controlled simulated en route traffic as they normally would in the field. In the No Strip condition, controllers controlled traffic without strips, but were given a notepad. This experiment differs from previous studies (e.g., Vortac, Edwards, Fuller, & Manning, 1993) in that the current study denied controllers any access to strips whatsoever. All other control actions were performed the same as they would be with live traffic. In particular, access to the QAK (Quick Action Keyboard) was not limited, permitting controllers to compensate for removal of the strips by obtaining whatever information they needed from the CRD (Computerized Readout Display). Thus, unlike previous work, complete removal of the strips not only relieves the controller of strip marking and board management responsibilities, as was the case in Vortac, Edwards, Fuller, and Manning (1993), but also denies the controller easy access to some flight plan data. If easy access to the eliminated flight plan data is necessary, we would expect compensatory behavior, but whether or not workload and performance are affected depends on the tradeoff between eliminating strip marking and eliminating strip information.

METHOD

Participants

Twenty air traffic controllers at the FAA Atlanta Air Route Traffic Control Center (hereafter referred to as Atlanta Center) volunteered as participants. Range of time employed by the FAA was from 3 years 10 months to 34 years 6 months. All controllers, except one, were full performance level (FPL). The range of time employed at Atlanta Center as an air traffic controller was from 8 months to 34 years 6 months. All participants were from the same area of specialization.

Simulation Apparatus and Scenarios

Experimentation used the dynamic simulator (DYSIM) at the Atlanta Center, which provided a high-fidelity simulation of air traffic. The PVD console was to the controller's left; the strip bay to the controller's right. Two experimenters and the subject matter expert directly observed controller activity. A third experimenter, positioned at the other side of the room, monitored air traffic communication via a headset. Three FAA training experts operated the scenario from "remote" positions. Remotes simulated pilot communication and activity, as well as adjacent sector communication and coordination.

Two scenarios were created and judged by a subject matter expert to be approximately equivalent in complexity and good simulations of live traffic. Scenario A consisted of 4 departures, 10 arrivals, and 9 over-flights; scenario B had 9 departures, 4 arrivals, and 9 over-flights. Requests were also built into the scenarios. For example, a pilot may ask for a lower or higher altitude due to turbulence, or ask for a change in route, such as obtaining a direct route to a destination. There were 9 pilot requests in each scenario.

Both scenarios represented the Pulaski sector of Atlanta Center, which is a high altitude sector responsible for traffic from flight level 240 (24,000 feet above sea level) to flight level 290. A map of Pulaski and adjacent sectors can be seen in Figure 2. Geographically, it covers portions of Virginia, Tennessee, and North Carolina. Controllers characterize Pulaski as a busy sector that handles numerous Atlanta arrivals, and coordinates traffic with Houston Center.

Procedure

Each controller participated in the Strip condition and the No Strip condition. The order of scenarios and the assignment of condition to scenarios were counterbalanced. The order in which scenarios were presented occurred equally often, and each condition was assigned equally often to each scenario across subjects.

In the Strip condition, controllers were told to control traffic as they normally would. In the No Strip condition, controllers were told that no strips were available, but that they would be given a notepad to write down any needed information. Controllers were also reminded that all other flight control actions should be performed as they would be in the field.

Before beginning the first scenario, the participant completed a biographical questionnaire and consent form. Controllers were then given instructions explaining that the general purpose of the experiment was to study the possible consequences of automation on ATC specialist performance. Next, the subject matter expert briefed the controller on DYSIM specific sector information, such as sector codes for hand-off and miles in trail to adjacent sectors. In addition, the controller was told how to simulate land line coordination with other sectors.

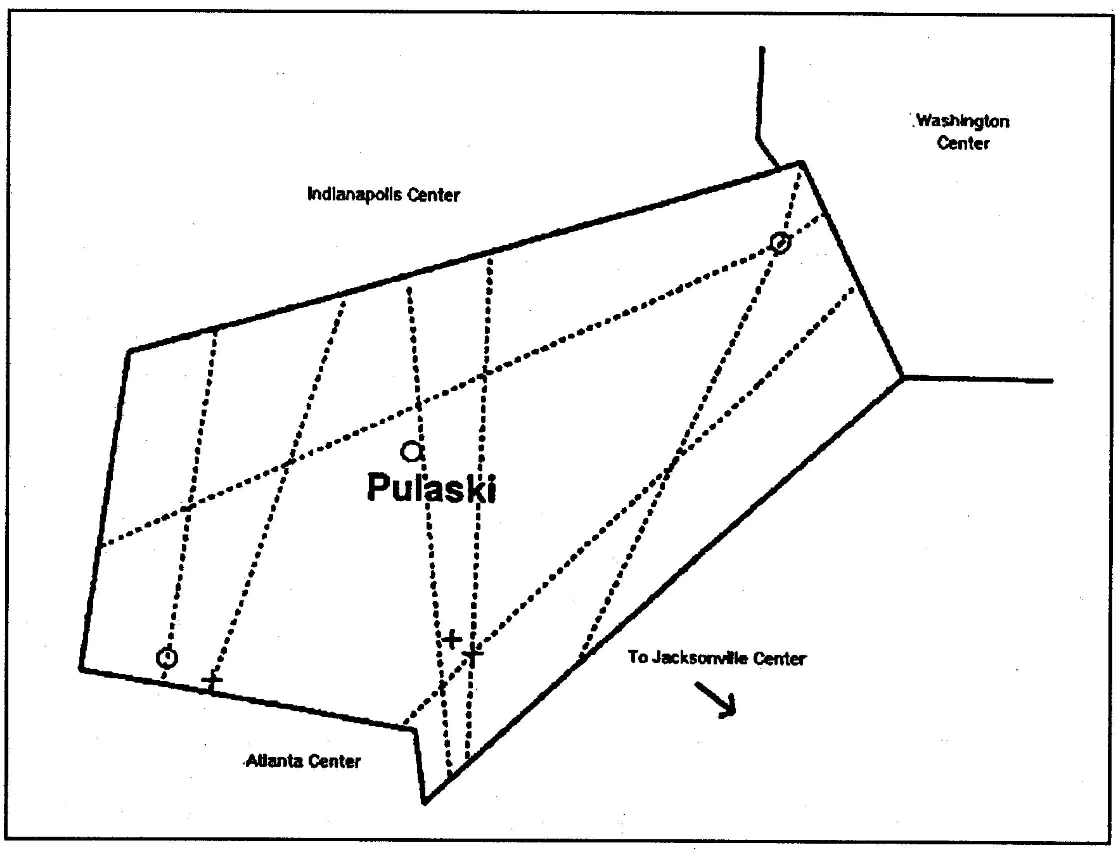

Figure 2. Map of Pulaski and its relationship to other en route centers.

Each scenario was started by the remote operator, and recording of time began when the strip printer began printing strips. Strips were printed in the No Strip condition, even though they were not distributed to the controller.

Controller Behavior

During each scenario, one experimenter, using a hand-held stopwatch, recorded the total amount of time the controller watched the PVD. A second experimenter observed the controller and recorded four measures. Two of these were obtained from the controller's use of the QAK: The experimenter recorded the number of times the controller called up a flight plan readout (FPR) and the number of times a route was displayed. The FPR function displays the complete flight plan of an aircraft on the CRD (a small screen next to the PVD). A route display draws a line representing an aircraft's assigned route on the PVD.

The remaining measures were obtained from the PVD. First, the total number of "J-rings" activated by the controller was recorded. "J-rings" are 12 sided polygons (this is a facility software adaptation and varies between facilities) 5 nautical miles in diameter (the size of the "J-ring" also varies from facility to facility), that the controller can place around selected aircraft on the PVD. J-Rings are used to help the controller check separation between aircraft.

The other measure involved recording the number of Conflict Alerts that occurred during the scenario. A Conflict Alert is a software feature that causes the data blocks of two or more aircraft to flash when the computer projects that they will lose standard separation in 3 min. Conflict Alerts can be activated for many reasons and are not restricted to aircraft that are at the same altitude or, in fact, to aircraft that will eventually lose separation. In addition to flashing data blocks for the conflicting pair, a Conflict Alert message is displayed at the top of the PVD to indicate the flight's computer identification number (CID) and controlling sector.

All voice communications were recorded on audio tape. In addition, specific communications measures were recorded by the third experimenter. All requests made to the controller by pilots (pilot requests) were recorded, as was the time taken for the controller to grant a pilot's request. Requests that were not granted were counted and classified as either "unable" (controller denied the request) or "ignore" (no action was taken regarding the request).

Two forms of controller requests were also recorded: the number of times controllers requested information from the pilot (such as speed or current heading), and the number of requests of other centers. For example, the controller may request control of planes about to enter the sector, in order to coordinate flight patterns within the airspace. Such requests can be used by controllers to compensate for information not easily available elsewhere.

Performance Ratings

The scenario was stopped after 25 min. The controller was removed from the simulation while the subject-matter expert completed two measures. First, each aircraft still in the airspace was checked for any remaining actions needed to move the plane completely through the sector. For example, a plane leaving the sector may need to be handed-off to the next sector. Given the same set of initial conditions and the same elapsed time, a controller working with a more efficient system should have fewer remaining actions to perform than when working with a less efficient system (Vortac, Edwards, Fuller, Manning, 1993). Second, the subject-matter expert completed FAA Form 3120-25(6-90) hereafter referred to as an OJT form, which consists of 27 points of evaluation pertaining to controller performance.

Perceived Workload

In the meantime, the controller completed a modified workload/performance measure adapted from the NASA Task Load Index (TLX). For a complete description of the TLX, see Hart and Straveland (1988). The factors measured were mental demand, physical demand, temporal demand, effort, frustration, and performance. The form listed all factors with a 9.6 centimeter horizontal line next to each. The line was marked "low" on the left end and "high" on the right end. In addition, a vertical mark in the center of the line signified the halfway mark. The controllers were instructed to place an "X" on the line adjacent to the factor to indicate a response. The controller then took a 10 min. break, before the next scenario.

Controller Feedback: Post Experimental Questionnaire

At the conclusion of the experiment, a Post Experimental Questionnaire (PEQ) was administered that collected controller ratings regarding a variety of topics, using both written and oral responses (See Appendix A). The first section of the PEQ contained three questions per condition pertaining to the utility, ease of use, and how well they liked each condition. Question 1 asked how useful the strip/notepad was. Question 2 referred to how well the controller liked the strips/notepad. The third question asked the controller to rate the amount of information available about the aircraft. Controllers made their response to these questions by placing a mark corresponding to their rating on a 5 inch horizontal line below each question. The second section was conducted by interview and audio taped. Questions in this section were designed to determine if there were perceived differences between real air traffic control and the simulations. Further, this section was designed to collect controllers' observations about the use of strips, both during the experiment and in general.

RESULTS AND DISCUSSION

Measurements were grouped into on-line and post-scenario measures for analysis. All data were analyzed by comparing the Strip and No Strip conditions. All tests used a significance level of $\alpha = .05$.

Controller Behaviors

The first set of measurements consisted of the following: total time watching PVD, number of FPRs, number of route displays, number of J-rings used, number of conflict alerts activated, mean time to grant pilot requests, number of "unable" requests, number of requests ignored, number of controller-to-pilot requests, number of controller-to-center requests, and total actions remaining to complete at the end of the scenario. An omnibus multivariate analysis of variance (MANOVA) revealed a significant difference between conditions [$F(10,29)=23.76$]. A repeated measures analysis of variance (ANOVA) was therefore computed for all measures independently. Table 1 shows the means (standard deviations) for controller behavior measures.

Although each of the 10 actions occurred more often or took longer in the No Strip, compared with Strip condition, only three yielded significant univariate F statistics. When controllers were in the No Strip condition they spent significantly more time watching the PVD [$F(1,19)=380.63$], made a greater number of FPRs [$F(1,19)=259.96$] and took significantly longer to grant pilot requests [$F(1,19)=4.81$] than they did when they were in the Strip condition.

Finally, even though controllers were given a notepad to use in any way they wished, they recorded very little information. The sparse amount of note-taking may have been due to the inconvenience of having to record the callsign (AID) or CID, along with other needed information. On the present strips, AID and CID are already provided, so that the controller has this information at hand.

Controller actions differed between conditions to compensate for the lack of strips. Controllers in the No Strip condition had to change the way in which they accessed flight information. To compensate for the absence of strip information, controllers used the FPR function to get information normally printed on a strip. An increase in keyboard activity could have been detrimental, but it was arguably a reasonable trade-off relative to the time normally needed to scan the strip bay.

Although controllers entered more keystrokes, the amount of time controllers watched the PVD during the 25 min. scenario significantly increased from 14.24 minutes in the Strip condition, to 18.98 minutes in the No Strip condition. Allowing controllers to watch the PVD for a significantly longer period of time could result in a better representation, or "mental picture" of the dynamic and complex situation in which they were engaged (Vortac, 1993). It is interesting to note that several controllers remarked that they felt as though they were unable to spend as much time watching the PVD in the No Strip condition, when in fact, just the opposite was true.

Table 1. Means (standard deviations) for controller behaviors by condition.

Variable Measured (units)	No Strip	Strip
Time watching PVD (sec.)	1137.80 (84.39)	854.45 (76.86)
Flight plan readout (n)	22.40 (3.66)	5.80 (4.38)
Route display (n)	1.45 (2.19)	1.15 (1.60)
J-rings (n)	2.85 (2.06)	2.65 (1.53)
Conflict Alerts (n)	1.40 (.99)	1.30 (1.17)
Time to grant requests (sec.)	34.87 (20.06)	24.01 (15.81)
Requests unable (n)	0.35 (.58)	0.30 (.73)
Requests ignored (n)	0.35 (.67)	0.70 (1.03)
Total requests to pilot (n)	2.25 (1.02)	1.75 (1.45)
Total requests to center (n)	3.90 (2.59)	3.05 (1.7)

Note: Those effects in bold are significant.

Table 2. Mean number (standard deviations) and type of remaining actions by condition.

Action	**No Strip**	**Strip**
Route changes	0.70 (0.92)	0.65 (0.67)
Altitude changes	2.15 (1.35)	2.80 (1.40)
Speed changes	0.10 (0.31)	0.05 (0.22)
Accept hand-off	0.05 (0.22)	0.05 (0.22)
Initiate hand-off	5.65 (1.79)	6.00 (1.45)
Switch frequency	7.55 (1.90)	8.25 (1.90)
Other	0.80 (0.95)	1.05 (1.00)
Total (n)	17.00 (5.64)	18.85 (4.66

Performance

Table 2 shows the mean number of actions remaining for the controller to take at the end of each scenario. No significant differences were found between the two conditions for remaining actions [$F(1,19)=1.11$]. Overall, controllers in the Strip condition ($\underline{M}=18.85$) had slightly more actions remaining at the conclusion of the scenario than did the controllers without strips ($\underline{M}=17.00$).

There were three possible responses for each item on the OJT evaluation form. These were "satisfactory." "needs improvement." or "unsatisfactory." A χ^2 analysis revealed no significant differences in OJT ratings across conditions. Table 3 shows the OJT rating frequencies by condition.

Perceived Workload

Perceived workload/performance ratings were coded by measuring, in centimeters, the distance from the left anchor (low side of the scale) to the center of the "X" marked by the controller on the modified NASA TLX. A MANOVA on all dimensions of workload revealed no significant differences between conditions (see Table 4). Thus, the controllers' perceived workload was not increased by the lack of strips.

Notwithstanding the direct indicators of controller re-adjustment to strip removal, neither performance nor perceived workload (as we measured them in this study) was affected when the strips were removed. Despite the lack of differences between conditions in performance and perceived workload, controllers in the No Strip condition took significantly longer to grant pilot requests than they did in the Strip condition.

Why this occurred is not entirely clear. Although perceived workload (as measured by the modified NASA TLX) was not affected, time to grant pilot requests for the previous analysis could be viewed as a secondary measure of workload. Alternatively, the difference may have been simply due to the amount of information readily available to the controller. In the No Strip condition, controllers may have had to do more flight plan readouts for relevant information before granting a request, thereby slowing time to grant it. We will return to how to interpret grant-time in the Discussion.

Controller Feedback: Written Responses

More qualitative information was provided by the Post Experimental Questionnaire. The PEQ scales were scored by measuring distance from the right anchor to the mark placed by the controller on a horizontal line (in centimeters). Means for these ratings are shown in Table 5. Individual repeated measures ANOVAs on all rating questions revealed a significant advantage for the strips for "usefulness" [$F(1,19)=5.40$] and "amount of information" [$F(1,19)=8.77$].

In order to determine how realistic the scenarios were, we asked controllers if they controlled traffic any differently than they did in the field. Thirteen responded that there was not a difference. Of the seven indicating a qualitative difference, the reasons given were that they were more relaxed (3), and that there was no one marking the strip for them (no D-side) (2). Likewise, of the seven controllers who indicated that there was something unusual about the scenarios, the most frequent responses were the lack of a D-side (4) and that the strips were taken away (2). Finally, when controllers were asked which of the scenarios they preferred, responses never pertained to the scenarios themselves (i.e. flight patterns, level of difficulty, etc.). Rather, responses dealt with whether or not the strips were present. Nine controllers indicated that they preferred using strips. The most common reasons given were: information was readily available (3), strips are more comfortable to use (3), and strips were available to write on (2). The remaining 11 indicated a preference for using the notepad. The most common reasons were that the strips are cumbersome (5), and that they had more time to view the PVD (2).

Controller Feedback: Oral Responses

When asked how the lack of strips impaired performance, nine controllers indicated that they experienced no impairment. Other responses: information was not readily available (3), more mental load (2), could not pre-plan (2), had to do more flight plan readouts (2), and were not used to absence of strips (2).

Controllers indicated that strips were especially useful for: communication purposes (5), heading information (5), pre-planning (4), speed information (3), route information (3), transitioning aircraft (2), and sequencing aircraft (2).

Table 3. OJT rating frequencies Strip /No Strip condition.

Job Function Category	Job Function	Satisfactory	Needs Improvement	Unsatisfactory
Separation	Separation is ensured	19 /19	0 /0	1 /1
	Safety alerts are provided	19 /19	0 /0	0 /0
Control Judgment	Awareness is maintained	15 /15	2 /3	3 /2
	Good control judgment is applied	16 /18	2 /1	2 /1
	Control actions are correctly planned	20 /19	0 /0	0 /1
	Positive control is provided	20 /19	0 /1	0 /0
Methods & Procedures	Prompt action to correct errors is taken	17 /17	1 /0	0 /0
	Effective traffic flow is maintained	17 /18	3 /1	0 /0
	Aircraft identity is maintained	15 /17	5 /3	0 /0
	Strip posting is complete/correct	N/A	N/A	N/A
	Clearance delivery is complete/correct/timely	2 /0	0 /1	0 /0
	LOA's/Directives are adhered to	18 /16	1 /1	0 /1
	Provides general control information	19 /18	1 /1	0 /0
	Rapidly recovers form equipment failures and emergencies	N/A	N/A	N/A
	Visual scanning is accomplished	18 /18	2 /2	0 /0
	Effective working speed is maintained	20 /20	0 /0	0 /0
	Traffic advisories are provided	20 /19	0 /0	0 /0
Equipment	Equipment status information is maintained	5 /5	0 /0	0 /0
	Computer entries are complete/correct	19 /16	0 /1	0 /0
	Equipment capabilities utilized/understood	18 /19	0 /0	0 /0
Communication/ Coordination	Required coordinations are performed	5 /6	10 /7	5 /7
	Cooperative, professional manner is maintained	20 /20	0 /0	0 /0
	Communication is clear and concise	17 /19	2 /1	1 /0
	Uses prescribed phraseology	19 /17	1 /3	0 /0
	Makes only necessary transmissions	20 /20	0 /0	0 /0
	Uses appropriate communications method	18 /19	2 /1	0 /0
	Relief briefings are complete and accurate	N/A	N/A	N/A

Table 4. TLX Mean ratings (standard deviations) in centimeters by condition

Factor Rated	No Strip	Strip
Mental demand	6.41 (1.76)	6.77 (1.70)
Physical demand	5.38 (2.58)	6.23 (2.26)
Temporal demand	5.90 (2.00)	6.31 (1.95)
Effort	6.15 (1.85)	6.58 (1.91)
Frustration	4.71 (2.14)	4.41 (2.66)
Performance	6.04 (1.76)	5.84 (1.57)

Note: The higher the score, the higher the perceived workload, 4.8=moderate, 9.6=high.

Table 5. PEQ mean ratings (standard deviations) for questions by condition

Question	No Strip	Strip
Usefulness	3.85 (3.79)	6.86 (2.91)
Likeability	4.71 (3.63)	6.53 (3.70)
Amount of information	7.56 (3.91)	10.48 (1.85)

Note: The higher the score, the higher the rating.

Controllers were asked to indicate the minimum amount of information needed on a revised strip. Most frequent responses were: route (15), aircraft type (12), altitude information (12), call sign (8), speed (4), and destination (3). Three controllers indicated that they would prefer the strip left unchanged.

The final question pertaining to strips, in general, asked what information would need to be included on the PVD data block in order to eliminate the need for strips. Only one controller said that the strips could not be eliminated. The most frequent response for information to add to the data block was destination (15)[1]. Other frequent responses included route (5), aircraft type (5), heading information (5), requested altitude (3), a mark to indicate a flight on anything other than its filed route (2). One controller suggested the addition of beacon codes.

Finally, the experimenter asked the controllers to explain markings, if any, recorded on the notepad. Four controllers did not record anything on the notepad. Most frequent responses included: heading (11), speed (8), location of turbulence (5), callsign (4), hand-off sector code (3), Charlotte arrival (2), circle to indicate that information had been passed to pilot (2), miles in trail (2).

DISCUSSION

Complete removal of the strip information and its accompanying strip marking responsibilities resulted in controllers compensating by retrieving information from the computer. Despite the need to punch in FPRs, controllers nevertheless spent more time viewing the PVD. Thus, requiring controllers to access flight data when needed via the FPR allows more time to watch the PVD than does providing strips and requiring strip marking. In addition, the presence or absence of strips had no effect on either performance or perceived workload. Apparently, the compensatory behaviors were sufficient to maintain effective control at what controllers perceived to be a comparable workload.

The one impact of using the FPR instead of the strips was in the delay to grant requests. Although grant-time can be viewed as a secondary workload measure, this seems unlikely since controllers in both conditions did eventually grant the same number of requests. A more likely explanation is that when unexpected requests were made of the controller, retrieving the information via the FPR was slower than glancing at the strip. Furthermore, since the scenarios were only 25 minutes in length, controllers may not have had the opportunity to formulate strategies about how to work without strips, possibly contributing to the delay.

The written section of the PEQ revealed that controllers found the strips more useful than the notepad, and that they believed that more information was available when using strips. Less information was available in the No Strip condition, and it had to be accessed in a different manner than in the Strip condition. In the No Strip condition, only one flight plan could be inspected at a time. By contrast, when strips were used, information on *all* aircraft in the sector, and some still outside the sector, was readily available for the controller's use in the strip bay. It may be advantageous to keep the strips, but eliminate the requirement of strip marking. This is similar to the Restricted condition of Vortac, Edwards, Fuller, and Manning (1993), which yielded some superior cognitive measures.

Vortac, Edwards, Fuller, and Manning (1993) actually found faster and more frequent granting of requests in the Restricted condition. At first glance, this may appear to conflict with the current results, but in fact, the studies were quite different. In Vortac, Edwards, Fuller, and Manning (1993) the requests required controllers to wait before the request could be granted, thus allowing a prospective memory component. In addition, subjects in Vortac, Edwards, Fuller, and Manning (1993) had access to strips, but were not allowed to mark or manipulate them.

[1] Simulations were performed before destination information was added to the data block.

SUMMARY

Despite the extreme No Strip condition, in the present study, no significant differences in controller perceived workload or in performance were found relative to the Strip condition. The lack of strips did force controllers to find information in other ways, and this did slow the time to grant pilot requests. Controllers compensated for the lack of strips by making more Flight Plan Readouts, but having no strip marking responsibilities allowed them to spend more time watching the PVD. Overall, we conclude that the decrease in workload afforded by the removal of strip marking appears to outweigh the detrimental effects of changing or removing strips. (Additional research is necessary to determine if there are more substantial long term effects to strip removal). Because removal of strips apparently allows controllers more time to watch the PVD, additional research should be done to determine which information should be added to the PVD data block.

Controllers identified what information on the strips they viewed as most important. Information that controllers deemed vital could be placed in the data block by means of an information time sharing arrangement. The placement of more information on the data block, and less on the strip, should result in more time to view the PVD, thereby allowing controllers to concentrate on the primary task of aircraft separation.

Finally, additional studies should be conducted with field controllers responsible for other types of sectors (e.g., low altitude arrival, or non-radar) to determine when, or if, controllers can compensate as successfully as they were able to in the current investigation. In any case, the current work shows that, at least for sectors like Atlanta Center's Pulaski, such compensation is possible without commensurate increases in workload or substantial decreases in performance.

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APPENDIX A

TLX Instructions and TLX

We are interested in finding out your perception of how difficult the task is and how well you perform on the task. Our objective is to measure your perceived "workload" level. The concept of workload is composed of several different factors. Therefore, we would like you to tell us about several individual factors rather than one overall workload score.

Here is an example of the rating scales. As you can see, there are six scales on which you will be asked to provide a rating score: *mental demand, physical demand, temporal demand, effort, frustration, and performance.*

Rating Scales

Mental demand refers to the level of mental activity like thinking, deciding, and looking that was required by the task. You will rate this scale from low to high.

Physical demand involves the amount of physical activity required of you, such as controlling or activating.

Temporal demand refers to the time pressure you experienced during the task. In other words, was the pace slow and leisurely or rapid and frantic? If the pace was rapid and frantic you are experiencing high temporal demand.

Effort refers to how hard you worked (both mentally and physically) in order to achieve your level of performance.

Frustration level refers to how secure and relaxed versus stressed and discouraged you felt during the task. If you feel secure and relaxed, you have low frustration.

Performance level refers to your perception of your own performance level. Your rating here should reflect your satisfaction with your performance in accomplishing the goals of the task.

Making your response

You should indicate your rating by placing an 'X' on the line adjacent to the item.

For example, if you want to give a high rating of stress factor, place an 'X' to the right of the half-way mark. The higher the stress rating, the closer the 'X' should be "HIGH". In contrast, if your stress rating is low, you would place an 'X' on the closer toward the "LOW" end of the line. Likewise, if the stress rating is average place an 'X' in the center of the line.

Please give your responses thoughtful consideration, but do not spend too much time deliberating over them. Your first response will probably accurately reflect your feelings and experiences.

APPENDIX B

Post Experimental Questionnaire

Questions rated by the controller:

1) *The scenario with paper strips:*
   a) How easy to use were the paper strips?
   b) How useful were the paper strips?
   c) Did you like to use the paper strips?
   d) Rate the quality of information you had about the aircraft when using the strips and PVD?
2) *The notepad scenario:*
   a) How useful was the notepad?
   b) Did you like to use the notepad?
   c) Rate the quality of information you had about the aircraft when using the notepad and PVD?

Questions asked by the experimenter:

1) Excluding the idiosyncrasies of the DYSIM: Did you control traffic any differently than you normally do on the floor?
2) Was there anything unusual about the scenarios?
3) Which of the two scenarios did you like best?
   a) Why did you like this scenario?
4) What did you like about the notepad (or not using the strips)?
5) In what way, if any, did you feel the lack of available strips may have impaired your performance on the problem?
6) What kind of information did you record on the notepad?
7) What information do you feel would be essential to include on an FDE (Flight Data Entry—the electronic equivalent of a flight strip) for a sector like Pulaski (high altitude arrivals)?
8) In what circumstances did you feel that you really needed to have strips? (For example, before you accepted hand-off, advance planning about actions to take with aircraft, resolving potential conflicts)
9) What information would need to be included on the data block in order to eliminate the need for strips?

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