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INFORMATION DISTRIBUTION TO IMPROVE TEAM PERFORMANCE IN MILITARY HELICOPTER OPERATIONS: AN EXPERIMENTAL STUDY

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Changes in task requirements and system capabilities have led to the addition of crewmembers, information displays, and monitoring and coordination requirements in many domains. This experimental study tested the hypothesis that providing task relevant information to individual team members in a time critical environment, while limiting their access to non-task-relevant information, would change team interactions by developing complementary team mental models and thus improve performance. The results of this experiment support this hypothesis, and give insight into how the distribution of information among team members effects the communications and coordination within a team, and team and individual performance.

Background and Introduction

The addition of a team member distributes cognition, changing the communication, coordination, and workload within the team (Hutchins and Klausen, 1996; Mosier et al., 2001). Although there has been significant research conducted on the display of information for a single operator and on group problem solving and performance (e.g., Orasanu and Salas, 1993), the current literature has identified the need to look more in depth at information and resource management within teams (e.g., Mosier and Skitka, 1996; Mosier, et al., 2001; Orasanu and Salas, 1993; Rouse, et al., 1992).

This research focuses on designing successful interactions between two team members in their naturalistic environment, in this case, a pilot and co-pilot in a military helicopter. This study hypothesized that providing specific task relevant information to individual team members in a time critical environment, while limiting their access to non-task relevant information, will change team coordination and assist in the establishment of complementary team mental models. Complementary team mental models are defined here as the condition in which:

- Each team member has the knowledge necessary to conduct his/her tasks.
- Each team member knows which information is known by the other team member should he/she need to seek it.
- Each team member knows which information is needed from them to other team members and when.

Historically, this type of team interaction knowledge is created by training, procedures, rules and regulations. In contrast, this study supports the concept that a “team centered” system design approach, focused on a complementary distribution of information among team members based on their tasks, will naturally promote improved team coordination by aiding team members in developing complementary team mental models. Furthermore, this method of distributing information among team members will provide individual crewmembers with a more accurate task relevant mental model of their environment.

The approach is somewhat counter-intuitive; traditionally the premise has been that increasing the amount of information that is shared between team members will naturally improve a team’s shared mental model. This research supports the proposition that, in certain instances, a lesser amount of information overlap may improve a team’s performance (e.g. Bolstad & Endsley, 1999). Similarity is a common gauge of effectiveness for team mental models. Yet this “similarity” often leads to inefficient team interactions. We propose the use of “complementariness”, the mutual supplying of each other's lack, as a more reliable indicator of the efficiency of team mental models. The formulation of complementary team mental models can support team performance by helping to clarify roles and responsibilities, individual and team member information requirements, and improving the efficiency of explicit communications.

This study hypothesized that providing task relevant information to individual team members in a time critical environment, while limiting their access to non-task-relevant information, would change team interactions by developing complementary team mental models and improve performance.
Method

Overview. This experiment was conducted at the US Army Aeromedical Research Laboratory (USAARL), located at Fort Rucker, Alabama using military helicopter pilots as participants. The main parameter was the complementariness of task specific information available to team members. During the experiment data were collected concerning team communications, crew workload, information requirements, decision-making and performance while the participants conducted a navigation task in a time critical situation. Each team member assumed a different role in the team, either the pilot-in-command (PIC) or the co-pilot/co-pilot (CPN); they maintained their assigned role throughout the entire experiment (i.e., there was no role switching).

Participants. Participants were 20 U.S. military rated aviators tested in pairs with the following characteristics:
- Their military rank ranged from Chief Warrant Officer II through Lieutenant Colonel.
- Participants’ ages ranged from 24-57, with an average age of 39 years.
- Total flight hours ranged from: 210 to 11,180, with an average of 3290 hours.
- Each crew was required to have at least one crewmember rated in a dual engine aircraft.

Experiment Apparatus

NUH-60 Flight Simulator. The NUH-60 Black Hawk helicopter flight simulator used for this study was operated by a qualified simulator operator; see Figure 1. This provided an interactive environment in which team performance could be observed while certain parameters within the team were controlled.

Flight Instrument Cover-Ups. To force the division of information during the flight segments, the view of the instruments was blocked for the pilot and/or copilot. This was accomplished by physically obstructing the view of certain instruments in the cockpit with cardboard dividers attached with Velcro. Figure 1 shows information available to the co-pilot, but not the pilot, for example.

Foggles. Foggles are manufactured glasses used as a tool during instrument flight training. They limit the pilot's field of vision to the flight instruments.

Experimental Design

The study consisted of two experiments run sequentially; participants were unaware that there were two experiments. The first experiment design consisted of two runs that examined performance under nominal conditions, during which the two levels of information distribution (complementary and normal) were varied. This experiment was balanced within subjects to account for order and training effects. The second experiment consisted of one experimental run similar to the previous two. However, the crew was required to deviate from normal procedures (i.e., react to an in-flight emergency). This was a balanced between subjects design between the two information distribution levels.

Scenarios

The flight profile incorporated various phases of flight during visual meteorological conditions (VMC) and instrument meteorological conditions (IMC). The profile has three sections to be flown in order, each lasting approximately 15 minutes. Flight phases of interest during VMC flight include take-off, VMC flight in cruise (above 200 ft AGL) and landing. Flight phases of interest during IMC flight include take-off, straight and level flight, climbs, descents, standard rate turns, and landing. All flight maneuvers were flown in accordance with Army standards.

Independent Factors

There were two independent factors in this experiment: complementariness of information and operational condition.

Complementariness of Information. Two levels of information distribution were presented to the participants: normal and complementary. A task analysis was used to determine the information each crewmember required access to in order to complete
their individual and team tasks. Under the normal condition the pilot and co-pilot were both given identical information, i.e., they both had access to all information displays in the cockpit and they were both given a map with a route posted; they also were given a route card with headings, altitudes, airspeeds, and checkpoints, approach plates for local airfields, and a description of the landing area. Under the complementary condition individual crewmembers were only provided access to information relevant to their individual tasks and for their defined roles in team tasks. Specifically, only the co-pilot was given the map and relevant navigation information. Likewise, the co-pilot wore Foggles, preventing out-of-windscreen viewing. The pilot had access to all flight instruments but access to engine related performance instruments was restricted to the co-pilot. The co-pilot was not allowed to visually share the map, route card, etc. with the pilot.

Operational Condition. Two operational conditions were presented to the participants: nominal and off-nominal. During nominal conditions crews maintained visual flight rules throughout the simulation, and they experienced no system malfunctions during the mission. During off-nominal conditions crews experienced inadvertent instrument metrological conditions (IIMC) and a single engine alternator failure during the flight.

Dependant Factors

Data discussed in this paper were categorized into four main groups: performance, communication, workload, and information requirements.

Performance. During nominal flight conditions performance was measured by Flight Performance measures recorded by the simulator. Examples of these measures are: Root Mean Square Error (RMSE) of airspeed, altitude and heading, and rate of climb. Additional task performance measures were evaluated, including:

- **Completion of required radio calls**: Crews were given a list of radio calls required in each flight leg. This metric is represented by a percentage of those calls that were actually completed.
- **Calculation of estimated time enroute**: During each flight leg, co-pilots were required to calculate the estimated time enroute for two legs of each run.
- **Initiation of a fuel consumption check**: Crews were required to initiate a fuel consumption check during each run; this metric indicates whether or not this was completed.
- **Navigation and process errors**: Navigation errors concerned time, heading, distance, altitude, etc.

Process errors include using the wrong frequencies, wrong procedures, etc.

During the off-nominal flight condition, in addition to the measures used in the nominal condition, the following task performance metrics were used.

- **Inadvertent instrument metrological conditions (IIMC) call time to Campbell Army Airfield (CAAF)**: This was the time recorded from when the crew entered IMC until they notified CAAF.
- **Proper IIMC procedures**: A measurement of whether the crew performed the proper IIMC procedures in accordance with the aircrew-training manual.
- **Diagnosis time of emergency**: Time was recorded from the presentation of the emergency until the crew verbalized what the problem was or the corrective action needed.
- **Diagnosis of the proper emergency procedure**: This metric indicated whether the proper emergency procedure was executed.
- **Emergency call time to CAAF**: This was the time recorded from when the crew was presented with the emergency until they notified CAAF.

Communications. Verbal communications were categorized in three basic categories: transfers, requests, and acknowledgements (Entin and Entin, 2001) using the matrix in Figure 2. The data were normalized based on the length of each experimental run. Additionally, communication transfers were divided by communication requests to assess “anticipation ratio”. Anticipation ratios have often proved more useful than individual rate measures for understanding team communications (Entin and Entin, 2001).

<table>
<thead>
<tr>
<th>Type &amp; Content</th>
<th>Navigator to Pilot</th>
<th>Pilot to Navigator</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Request</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Task Relevant Information</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Non Task Relevant Information</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Action</td>
<td></td>
<td></td>
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<tr>
<td>Transfers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task Relevant Information</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Non Task Relevant Information</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performing/ Will Perform Action</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acknowledgements of Info Received</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General (okay, roger)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific (roger...right on turn to 180 degrees)</td>
<td></td>
<td></td>
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</table>

**Figure 2. Communication Matrix**
Workload. Workload was measured through the use of the NASA Task Load Index (TLX). Six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. Workload was analyzed in two different manners. (1) Individual workload ratings were analyzed to determine whether individual crewmember’s workload changed due to the cockpit configuration, and (2) a correlation analysis was performed using each crewmember’s estimations of their teammate’s significant sources of workload.

Information requirements. After each scenario, participants were asked to rank the importance of their information sources during each phase of flight, both for how important each type of information was to them and how important they believed it was for their crewmember. This was done for take-off, enroute navigation, and landing during nominal conditions, and upon entering IMC and dealing with the emergency procedure in off-nominal conditions.

Results

Performance

Nominal Flight Condition. The flight performance measures were analyzed using a General Linear Model (GLM) Analysis of Variance (ANOVA). Each task was evaluated based on predetermined parameter limitations. During nominal conditions no significant differences were found to exist due to changes in the distribution of information within the cockpit.

The task performance metrics were found not to fit the normality requirements for ANOVA. Therefore, each was examined using a Mann-Whitney test to identify the main effects of the independent variable. “Total errors” (p = .015) was significant; both process errors and navigation errors were marginally significant. Fewer errors were committed, in the nominal condition, when the information available was distributed in a complementary manner.

Off Nominal Flight Condition. The flight performance measures were analyzed using a GLM ANOVA. During entry into IIMC, the RMSE for airspeed was found to be significantly different as the cockpit configuration changed (p = .020). The median and mean RMSE decreased in the complementary condition; also the interquartile range of error in the complementary condition is less than the normal condition.

Across the complete flight profile for off nominal conditions the percent of completed required radio calls tended to increase when the crew was provided with complementary information; using the Mann-Whitney test, percent of radio calls was marginally significant with a p-value of .053. The Co-Pilot/Co-pilots (CPN) completed one hundred percent of the radio calls required during the complementary condition (see Figure 3). Both the median and mean percent of completed calls increased across conditions and performance was clearly more consistent during the complementary condition. Additionally, the diagnosis time of aircraft emergency, measured in seconds, could be analyzed using a GLM ANOVA and was found to have significant differences between the levels of information complementariness; the p-value was .007 with an observed power of .912. Figure 4 illustrates the direction of the difference and highlights the significant decrease in diagnosis time. Both the median and mean diagnosis time decreased across conditions from 130 to 49 seconds and 115.3 to 39.4 seconds respectively. Furthermore, the standard deviation decreased from approximately 34 to 20.

Communications

Nominal Flight Condition. A GLM ANOVA was used to evaluate all communication rates in the nominal condition (Figure 5). The following categories of team communication rates increased significantly when the crew was exposed to a complementary information distribution: Team Transfers of Action, Team Transfers of Task Relevant Information, Team Total Transfers, and Team Total Communications. Furthermore the rate of Transfer of Non-Task Relevant Information decreased in the complementary configuration, as did
the Team Anticipation Ratio (RTAR). Each detected change had a strong observed power; the lowest observed power was .842.

**Off Nominal Flight Condition.** A GLM ANOVA was also used to evaluate all communication rates in the off-nominal condition. The results in the off-nominal condition were very similar to the nominal condition. The following team communication rates increased significantly when the crew was exposed to a complementary information distribution: Team Transfers of Action, Team Transfers of Task Relevant Information, Team Total Transfers, Team Acknowledgements Specific (RTAS), and Team Total Communications. In addition, The Team Anticipation Ratio decreased in the complementary configuration. Each detected change was accompanied by a strong observed power calculation; the lowest observed power was .657 (Figure 6).

**Information Requirements**

Rankings of information requirements from the pilot and co-pilot were matched by phase of flight and a correlation matrix was developed using the Spearman Rank Order Correlation Coefficient. Relevant correlations were analyzed using a GLM ANOVA for significant differences. The ANOVA performed for the nominal condition found no significant differences. On the contrary, differences in the mean correlation coefficients were significant in the off nominal condition due to changes in the complementariness of information in the cockpit (p-value = .0041); Figure 7 illustrates the increase in median and mean from the normal configuration to a complementary distribution of cockpit information.

**Workload**

**Individual Workload Ratings** were assessed using the NASA Task Load Index (TLX), and analyzed using a GLM ANOVA. Generally, there were no significant effects in team member’s workload due to changes in the complementariness of information (see Table 1). The only significant change in mean ratings was detected in the co-pilots’ mental workload in the nominal condition, which increased when operating in the complementary cockpit configuration. Additionally, there were four measures that were marginally significant; these measures also increase in the complementary configuration.

**Workload Correlation.** Crewmembers were also asked to estimate the sources of workload for their teammate using the modified NASA TLX scale.
Based on their scores, the sources of workload (mental, effort, temporal, etc.) were rank ordered (1-6). The pilot’s ranking of the co-pilot’s workload was matched with the co-pilot’s ranking of the co-pilot’s workload, and vice versa.

The ANOVA performed with the co-pilot as the found no significant effects. On the contrary, differences in the mean correlation coefficients were marginally significant (p = .069) when the pilot predicted the co-pilot’s workload in the complementary configuration.

**Conclusions**

The results of this experiment provide empirical evidence that providing task relevant information to individual team members in a time critical environment, while limiting their access to non task-relevant information, improved individual and team performance by changing team interactions and helping to develop complementary team mental models. Furthermore, there is evidence of increased individual performance that indicates this method of distributing information among team members may provide individual crewmembers with a more accurate “task relevant” mental model of their own environment. The findings of this experiment give new insight into how the distribution of information among team members affects the development of shared expectations and information requirements, team and individual performance, and communications.

**References**


**Table 1. Individual Crewmember Workload Significance Levels**

<table>
<thead>
<tr>
<th></th>
<th>Nominal</th>
<th>Off-Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Helicopter</td>
<td>Helicopter</td>
</tr>
<tr>
<td>Pilot</td>
<td>0.700</td>
<td>0.015</td>
</tr>
<tr>
<td>Navigator</td>
<td>0.657</td>
<td>0.053</td>
</tr>
<tr>
<td>Physical</td>
<td>0.026</td>
<td>0.310</td>
</tr>
<tr>
<td>Temporal</td>
<td>0.535</td>
<td>0.054</td>
</tr>
<tr>
<td>Effort</td>
<td>0.743</td>
<td>0.559</td>
</tr>
<tr>
<td>Performance</td>
<td>0.266</td>
<td>0.380</td>
</tr>
<tr>
<td>Frustration</td>
<td>0.432</td>
<td>0.326</td>
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</tbody>
</table>