How Well Do Cognitive Abilities Predict Concurrent Task Management Performance?

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Abstract

An experiment involving 93 participants suggests that concurrent task management performance cannot be predicted based on cognitive abilities alone. Rather, CTM is a complex cognitive process that must be studied as a unit. The Task Management Environment, software used in this study, is potentially a valuable tool for further studies.

Keywords

Concurrent Task Management, Multitasking, Attention, Human Performance, Cognitive Abilities

1. Concurrent Task Management

Concurrent Task Management (CTM) is the process that human operators of complex systems (e.g., pilots, drivers, even anesthesiologists) perform to allocate their attention among multiple, concurrent tasks. Funk coined the term Cockpit Task Management [4] to refer to the process by which pilots initiate, monitor, prioritize, interrupt, resume, and terminate cockpit tasks, and quite a few others have studied the process in the cockpit domain [6] [7] [3] [9]. But the problem of driver distractions [11] and similar problems in other systems strongly suggest that CTM is an issue that crosses many domains.

CTM affects system effectiveness and safety. For example, Chou and his colleagues found CTM errors to be contributory to a significant number of aircraft accidents and incidents [1]. A long history of human attention research [10], personal experience, and common sense tell us that we have limited capacity to perform multiple tasks at once, necessitating some kind of process in which we choose to attend to some tasks and ignore others. Usually, our choices are satisfactory, but interruptions and distractions can be troublesome or even catastrophic. Since system performance depends so much on human operator performance, it seems wise to investigate this process more thoroughly, with a goal in mind to facilitate CTM in order to reduce adverse events.

In an effort to better understand the nature of CTM, Colvin and Funk conducted two part-task flight simulator studies to determine what factors affect the CTM process [2]. In their experiments, airline pilot participants “flew” difficult instrument approaches in which they were challenged to prioritize and choose among several concurrent tasks. Then, in interviews, they explained their reasons for choosing one task for attention over the others at selected points in the flights. They reported that their task management choices were influenced by factors including the perceived importance of a task to flight safety, how well they thought they were performing the task at the time, the perceived urgency of the task, and the salience of displays related to the task.

The fact that CTM is significant to safety and the preliminary findings on factors affecting CTM raise further questions about the nature of CTM and the cognitive processes that underlie it. The experiment described in the remainder of this paper was conducted in an attempt to pose and answer some of those questions.
2. Research Questions

At the outset of this research, it seemed unlikely that CTM is a unique mental phenomenon. Rather, it seemed reasonable that CTM draws on the same mental resources and cognitive processes as the specific tasks that CTM manages. But what are these resources and processes? To what extent does basic cognitive abilities—verbal intelligence, working memory, and decision making—affect CTM performance?

3. Method

To answer these questions, we conducted a study in which we measured participant performance on five common cognitive tasks and correlated performance on those tasks with CTM performance measured using a simple multitask simulator called the Task Management Environment.

3.1 Apparatus: Cognitive Tasks

To assess participants’ cognitive abilities, we used a battery of cognitive and neuropsychological tests in common use in psychological studies and described in the literature [8] [12] [5] [13]. Participants completed five computer-based or pencil and paper tests. For purposes of measuring reaction speed, a test call Simple Reaction Time was used (computer) to measure how fast participants can react to a stimulus showed in the computer screen by hitting the down arrow key on the keyboard; for assessing selective attention, decision-making, and visual search, the Card Sorting test was used (computer). The Path Finding test was used to assess coordination and switching time on a 4-letter sequence scenario (computer) in which the participant had to click over each letter following a defined sequence consisting of a combination of 4 letters; the Synonyms tests was used to assess verbal intelligence and semantic memory (paper). For measuring decision-making strategies, the Melbourne Decision Making Questionnaire was used (paper); data from this test was not use for the analysis.

3.2 Apparatus: The Task Management Environment

Colvin and Funk’s experiment used a part-task flight simulator, similar to Microsoft Flight Simulator, to create a challenging multitask environment in which to study CTM behavior. Such an environment has the advantages of being complex enough to be interesting and having face validity arising from its similarity to real cockpit displays, controls, and tasks. The disadvantages of using a flight (or other “real-world”) simulator for further studies of the nature of CTM include the long experimental runs that must be conducted to produce enough challenging events and the complexity of the tasks simulated, requiring that real pilots (or other system operators, all comparatively rare) be recruited as experiment participants. Both disadvantages make it difficult to conduct CTM studies using conventional simulators.

To overcome these disadvantages, we developed a simpler simulator called the Task Management Environment (TME), whose operator interface is shown in Figure 1. The TME simulates an abstract system composed of up to 14 simple, dynamic subsystems (the version in Figure 1 simulates just six). It is written in VisualBasic 6.0 and runs in the Windows operating system. Each TME subsystem has a single state variable, called status, that ranges from 0% to 100%. A subsystem’s status is represented by a blue vertical bar in the interface.

There are two types of subsystems, continuous and discrete. The normal behavior of a continuous subsystem, unattended by the operator, is for its status to decrease at a constant rate, called the Deterioration Rate (DR), until it reaches and remains at 0%. When the TME operator operates a continuous subsystem by clicking the computer’s mouse on the button below the subsystem’s status bar, its status increases at a constant rate, called the Correction Rate (CR), until it reaches 100%. When the operator releases the button, the status begins decreasing again.

The behavior of a discrete subsystem is very similar, except that its status normally remains at 100%, even without operator attention, until a random “failure” event occurs. At that time, its status decreases at a rate of DR until the operator clicks the subsystem’s button. The decrease temporarily halts for a predetermined period, during which the subsystem’s button disappears. After the period, the button reappears and the status continues decreasing at DR until the operator clicks the button again and the decrease again pauses. This continues for a predetermined number of cycles, after which status is restored to 100% and stays there until another random “failure” event occurs.
Each subsystem presents the participant with a simple control task. A continuous TME control task simulates a continuous control task in a real domain, where, for example, the pilot tries to control the aircraft so as to precisely maintain a specified altitude (corresponding to 100% in the TME task). A discrete TME task simulates a discrete task in a real system where, for example, the pilot must perform a series of discrete actions to restart an engine that has stopped in flight and restore it to normal operation (100% in the TME task). As in the real world, where the operator can often perform just one task at a time due to personal and technical limitations, the TME allows its operator to perform just one control task (operate just one subsystem) at a time.

The objective of the TME operator is to keep each subsystem status level in its satisfactory or green (50% \( s \leq 100\% \)) range, and not let it drop into the unsatisfactory or yellow (10% \( s < 50\% \)) range, or the very unsatisfactory or red (0% \( s < 10\% \)) range. The TME computes a CTM performance measure based on this objective. The instantaneous score for a subsystem at any time is \( q_i \). The variable \( q \) is a qualitative transform of the subsystem’s current status level; \( q = +1 \) if the subsystem’s status is satisfactory, \( q = 0 \) if its status is unsatisfactory, and \( q = -1 \) if its status is very unsatisfactory. The variable \( i \) is the subsystem’s importance, the number appearing directly below the subsystem’s status bar in the interface. The cumulative score for the subsystem is the mean instantaneous score since the beginning of the run. The total weighted score is the summation of all subsystem cumulative scores and reflects an overall task management performance measure, weighted according to subsystem importance.

Since all subsystems are started out at status levels of 100%, the total weighted score starts at 100% of its maximum value (33 units for the example shown in Figure 1). As long as the operator keeps all subsystems satisfactory (which is impossible with the parameter set used in this experiment), the total weighted score stays at 100%. When a task drops into the unsatisfactory range, the total weighted score begins dropping. If the task drops into its very unsatisfactory range, the total weighted score drops faster still. The total weighted score drops most rapidly when the most important tasks are in their very unsatisfactory ranges.

The experimenter sets the importance of each task, the DR and CR parameters for each task, the time between failures for each discrete subsystem, the number of clicks required to restore each discrete subsystem, the pause period for each discrete subsystem, and the duration of the experimental run. Throughout a run, the TME records the current time, the status of each task, and the number of the subsystem button currently clicked, if any. At the end of each run it writes to a data file the parameters for each subsystem, one record for each 0.1 second of the run, and the total weighted score at the end of the run.
The TME thus provides an environment in which the operator is challenged to manage concurrent tasks to control up to 14 simple subsystems with varying dynamics, and it records and measures task management performance. It is easy to learn and operate, yet is complex enough to represent real-world multitask environments, so it makes an ideal environment for studying CTM behavior.

3.3 Participants

Ninety-four students from Oregon State University participated in the experiment. They were recruited using posters placed in the Psychology Department building, and by word of mouth. Their age range was 18 to 49 with a mean of 21 and a mode of 19 years.

3.4 Experimental Procedure

Participants were tested individually in a single session lasting two hours, in a quiet office located in the OSU Psychology building. Each participant read and signed an informed consent form, then filled out a personal information questionnaire and a questionnaire to assess his or her level of computer experience. Next, the participant performed the tests in the following order: Simple Reaction Time, Card Sorting, Path Finding, TME practice runs, Melbourne Decision Making Questionnaire, TME first scenario, Synonyms Test, and TME second scenario. Half of the participants did an easy TME scenario first, with a difficult scenario second. The other half did the TME scenarios in the reverse order. TME easy had six tasks, and TME difficult had eight tasks.

3.5 Data Analysis

For a preliminary analysis of the data, we considered seven variables: age, verbal intelligence, working memory (time to complete a working memory-intensive task), simple reaction time, decision time, total weighted score for the easy TME scenario (TME-EZ), and total weighted score for the difficult TME scenario (TME-DF). We computed descriptive statistics for these variables, tested for normality, then calculated Pearson correlation coefficients.

4. Results

Table 1 presents the descriptive statistics for the seven variables. All seven passed the normality test. Table 2 presents the results of the correlation tests for these variables.

Table 1. Descriptive statistics for selected demographic variables, selected cognitive performance measures, and TME total weighted scores. These results are preliminary.
Table 2. Correlations among selected demographic variables, selected cognitive performance measures, and TME total weighted scores. These results are preliminary.

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<th>Gender</th>
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<th>Reaction Time</th>
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5. Discussion

The correlations between the cognitive measures and the CTM performance measures were low. This suggests that CTM cannot be explained in terms of a few simple cognitive processes. While these processes might be components of CTM, it is more likely a complex combination of them, drawing on working memory and other mental resources. Of course, our analysis is preliminary and further analysis may reveal relationships not apparent in these results. Another explanation of our results is that participants did not have sufficient experience with the TME for their performances to be sufficiently stable for accurate analysis.

6. Conclusions and Recommendations

Our preliminary findings indicate that cognitive abilities, at least as measured by the tests we used, are not good predictors of concurrent task management performance. CTM is a complex process that cannot be explained in terms of working memory, simple decision-making, or verbal intelligence alone. These results are not consistent with our expectations. They mean, instead, that further studies of CTM must be done, either involving more opportunity for participants to learn the TME well, or on the CTM process as a whole, not on the components that might make it up. Fortunately, the Task Management Environment provides a tool for doing just that.

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References