Collaboration with Ecological Interface Design

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COLLABORATION WITH ECOLOGICAL INTERFACE DESIGN

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Ecological Interface Design (EID) has been shown to be an effective design approach for building single-operator interfaces for complex systems. However, in such systems, operators typically are also a part of a team. An experiment was conducted to examine the effect of EID on collaboration. Teams of two operated a feed water simulator, DURESSj, through a series of scenarios given either the EID interface or the Non-EID interface. It was found that there was no penalty to using EID, as scenario completion times with the EID interface were equivalent to the Non-EID interface. Indeed, EID operators demonstrated evidence of more robust control and reported significantly lower mental workload especially when dealing with system faults.

INTRODUCTION

EID is a systematic means of designing computer interfaces that utilizes a Work Domain Analysis (WDA) as a basis. The WDA aims to describe how the system goals are carried out at different levels of abstraction through system functions and physical implementation. The WDA is then used as an aid to determine what information needs to be represented on the interface. As a result, in comparison with other design approaches, EID typically presents more intermediate layers of functional information (Burns and Vicente, 1996). These layers fill in the gap between the purpose of the work domain and the components that are available to take action in the work domain (Rasmussen, 1985). Also, the intermediate layers provide linking steps that allow operators to deductively diagnose problems and predict the influence of control actions, similar to the problem solving abilities of experienced troubleshooters (Rasmussen and Jensen, 1974).

Prior research suggests that EID is an effective framework for building single-operator interfaces (Vicente, 2002). Operators working with EID have demonstrated better performance and ability to diagnose and troubleshoot problems (e.g. Pawlak and Vicente, 1996), in addition to having more robust control (e.g. Hajdukiewicz, 2001). These prior evaluations of EID have involved only one operator. In actual plant situations though, operators rarely work in isolation. In most cases, they are members of a team with various forms of task delegation within the team. For example, across a large plant, operators typically control one section and then hand off control to an operator of the next section downstream. This kind of team control requires that operators manage their section of the plant but also that they understand the objectives and needs of operators controlling other sections. This research examines whether EID can support multiple operators especially in this kind of collaborative situation.

HYPOTHESIS

It was hypothesized that higher-levels of functional information provided by EID, shown to improve individual performance, will also support collaboration. By providing shared higher levels of functional information, an EID interface may allow operators to understand the objectives of other operators on their team more clearly resulting in better coordination between team members and more effective collaboration during troubleshooting. Alternatively, it was possible that an EID interface, with its additional information could make communication more challenging between operators, resulting in poorer team performance.

METHOD

The system chosen for the experiment was DURESSj, a Java implementation of DURESS II, because it is a well established experimental test-bed for testing EID. DURESSj is a feedwater system consisting of two streams of water that feed two reservoirs through a series of pumps and valves that are manipulated to meet reservoir temperature and output demands. DURESSj provided an EID interface (also referred to P+F in previous studies) and a more basic “Non-EID” interface (or P interface). The Non-EID interface displayed in Figure 1 contains physical (P) and functional purpose level information only whereas the EID interface (Figure 2) also represents abstract and general function system information (hence, P+F).

Participants

Eighty participants took place in the experiment with 20 dyadic teams per interface condition. Focus was placed on recruiting intact teams and participants signed up in pairs. A demographics questionnaire assessed each participant’s

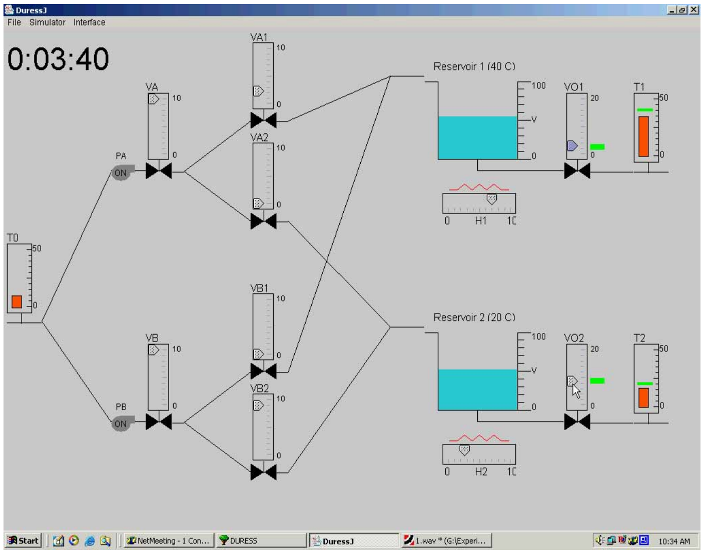

Figure 1. The Non-EID Interface of DURESSj

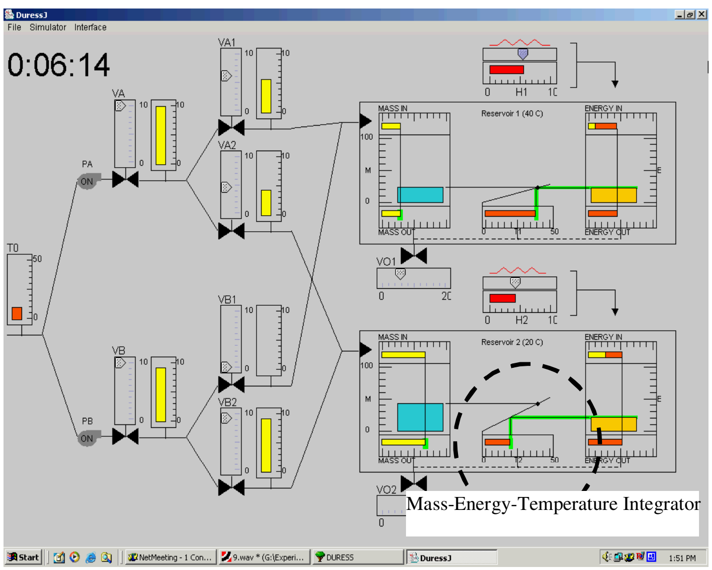

Figure 2. The EID Interface of DURESSj

academic background and team experience. Team experience considered the number of prior collaborations (e.g. assignments, projects, and presentations), number of months of knowing their teammate, nature of communication (e.g. social, classwork), and two subjective scales (degree they know their teammate and how well they think they work together). People who have known each other for longer and/or have more experience working together may be able to coordinate and communicate more effectively thus affecting performance. As a result, more experienced teams were placed in the Non-EID condition to bias against hypotheses. The median for time known was 9 months for both interface conditions with a higher average for Non-EID teams.

Procedure

Each team was given a different interface (EID or Non-EID) with each participant assigned a different task that did not change during the experiment. The task assignment was to control either the valves and pumps or the heaters. The tasks are representative of real plant assignments (though on a much smaller scale) with assignment interrelation that requires collaboration by the team members in order to meet system goals.

The training materials were based on previous studies, in particular Hajdukiewicz (2001) and St-Cyr (2002). Each participant individually studied a technical description of the DURESSj work domain. Subsequently, teams were assigned an interface and the interface tutorial was read out-loud by the experimenter simultaneously to both participants. After the tutorial, participants were assigned individual tasks at random. To create a harder collaborative environment, participants were placed in separate rooms so they could not utilize face-to-face communication and other natural cues such as body language. Remote Administrator 2.1 (Famatech, 2001) was used to distribute DURESSj to both participants' computers so they would see the exact same interface. Participants were encouraged to converse as much as they liked with no restrictions via audio conferencing using Microsoft NetMeeting 3.01. Each operator had individual control over the mouse and could observe control setting changes but not the intermediate mouse movements of their teammate. There was a practice scenario to get participants familiar with the interface controls and experiment setup such as adjusting the volume to a comfort level.

Participants went through a series of 12 experimental scenarios. In all cases, teams were required to start up the system and get the system to a steady state. Steady state, or trial completion, was defined as meeting all system goals (both the temperature and output demands for both reservoirs) for a period of three consecutive minutes. Two types of scenarios were given to each group, 6 normal scenarios and 6 scenarios where teams additionally had to detect and compensate for a system fault in order to meet system goals. The ordering of scenarios was the same for all teams. The outcome for all scenarios could be one of three possibilities, trial completion, system blowup or maximum time reached (20 minutes). The trial outcome, completion time (when applicable), and number of control oscillations were recorded. The number of oscillations, or oscillation frequency, is the number of times all the goals were met for a period less than the steady state time (3 minutes). Oscillations examine the ability of operators to adapt to meet goals and are measure of the robustness of control (Hajdukiewicz, 2001). Two teams may have same level of performance, but it may be that one group is exerting more effort to do so. As a result, immediately after every scenario each participant filled out the NASA-TLX rating scale (Hart and Staveland, 1998), a commonly used measure of mental workload. Each operator was instructed specifically to give their own opinions and not to discuss the ratings amongst themselves. The NASA-TLX weighting was filled out once by each participant after the last scenario. The total duration of the experiment was roughly 4 hours contingent on scenario performance. All control actions and verbal communication were recorded but have not been analyzed at this time.

RESULTS

The outcome of a trial, completion versus blow-up, was not dependent on what interface teams were working with (X^2 (1) =1.39, p < 0.50, ϕ=0.06). Also, whether teams were dealing with a fault or normal scenario did not determine the outcome (completion or blowup) of the scenario (X^2 (1) =0.60, p < 0.74, ϕ=0.04). There was no significant difference in completion times between the two interfaces (F(1, 274) =0.12, p<0.73) nor between fault and normal scenarios (p<0.11). To examine the stability of control, oscillations were counted and collected as least square means results. The frequencies were transformed using the natural logarithm, so that the residuals followed a normal distribution to allow for further analysis. There were significantly fewer oscillations for teams working with EID across both normal and fault trials (F(1,249)=8.14, p<0.007). Illustrated in Figure 3, Tukey-Kramer post-hocs revealed that the main influence was due to fewer control oscillations in the fault conditions (p< 0.0003).

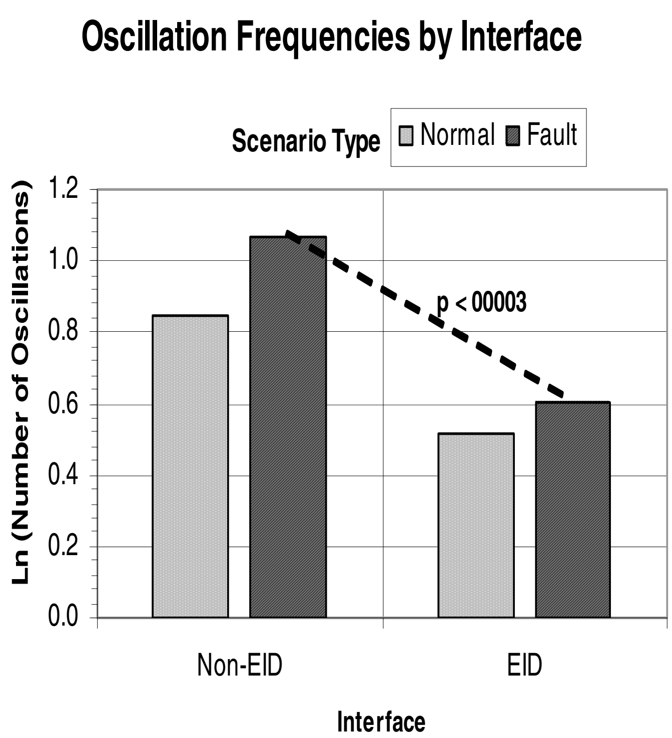

Figure 3. Oscillation results

NASA-TLX measures illustrated in Figure 4 showed significantly lower mental workload measures in the EID condition (F(1, 622) =33.83, p<0.0001) during both normal (p < 0.0024) and fault (p < 0.0001) scenarios. There were higher workload measures in fault scenarios (p<0.01) and higher workload for the non-EID heater operator during faults (p<0.0015).

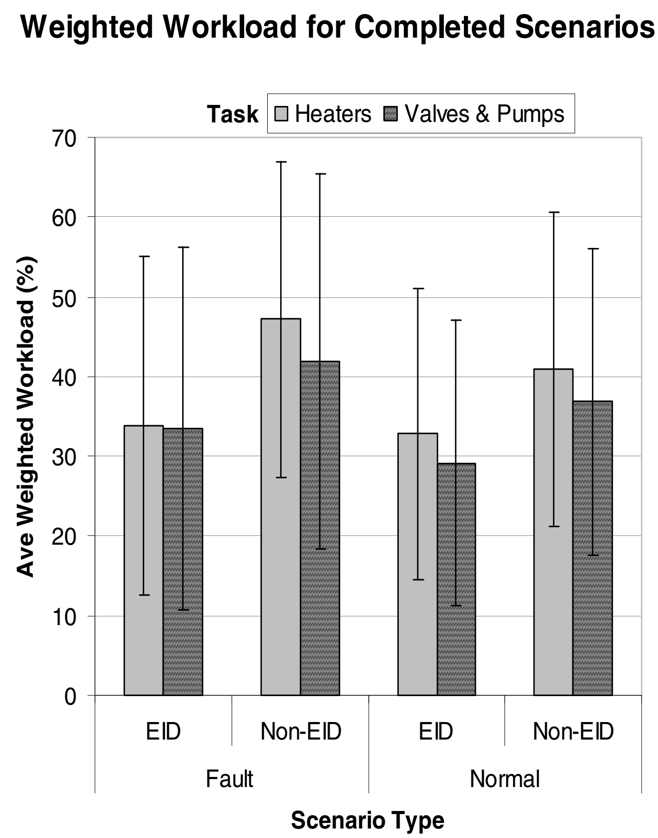

Figure 4. Workload by interface, scenario type and participant task

DISCUSSION

The results develop a consistent picture of how EID may influence collaboration. EID provides more information to examine and share amongst the team, however, this did not make communication more challenging between operators as basic performance results were the same between both interfaces. EID operators demonstrated more robust control during fault management, suggested by fewer control oscillations matching previous single operator results (Hajdukiewicz, 2001). The oscillation results could indicate that the intermediate layers of functional information represented on an EID interface forms a common reference point to effectively coordinate team efforts. In addition, EID teams had lower levels of mental workload on the NASA-TLX measure, a measure that has not been used in EID studies before. In particular, workload levels were less with the heater task using EID in fault conditions. The result is very interesting given that the EID interface for DURESS II has an innovative graphic form that was designed to help balance the non-linear and complex relationship between mass and energy in the system (Figure 2). The workload results provide specific evidence that this particular graphic form may indeed be very effective in that regard. Likewise, the WDA may be useful to predict and/or divide system workload amongst each individual in a multi-operator system.

There are some limitations to this study. Most notably, operation of DURESS II can be performed reasonably by one operator, as previous experiments have confirmed. Dividing control of the system across two operators is artificial and arguably neither operator has a very complex task. This may explain the lack of difference in basic performance results across the two interface groups. Quite reasonably, collaboration with a second operator when operating the system may compensate for the lack of functional information in the Non-EID interface.

To examine the influence of the team situation versus the single operator situation we compared our results with a previous study conducted by St-Cyr and Burns (2002) that used similar training and the same number, ordering and configuration of scenarios. Teams of operators had consistently longer trial completion times than single operators. These results are not surprising given that teams have a certain overhead to team coordination that can result in longer performance times. One of the limitations of our study may be that it was too short to allow the teams to move through this coordination period and develop a plateau of consistent performance.

CONCLUSION

This study of EID support for collaboration suggests that EID can indeed be used in team environments. The additional functional information presented by an EID interface does not reduce team performance and may even improve team coordination as shown by more robust control for EID teams. Measures of mental workload showed lower mental workload for EID teams, particularly for the heater operator. This suggests that the presentation of mass and energy information in the EID interface for DURESS II may be quite effective in supporting operator behavior.

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