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ELECTRONIC COLLABORATION: SOME EFFECTS OF TELECOMMUNICATION MEDIA AND MACHINE INTELLIGENCE ON TEAM PERFORMANCE

A. Rodney Wellens
Department of Psychology
University of Miami
Coral Gables, Florida 33124

ABSTRACT

Both NASA and DoD have had a long standing interest in teamwork, distributed decision making and automation. While research on these topics has often been pursued independently, it is becoming increasingly clear that the integration of social, cognitive and human engineering principles will be necessary to meet the challenges of highly sophisticated scientific and military programs of the future. Images of human/intelligent-machine electronic collaboration were drawn from NASA and Air Force reports as well as from other sources. Areas of common concern were highlighted. The report ends with a description of the author's research program testing a "psychological distancing" model of electronic media effects and human/expert system collaboration.

INTRODUCTION

Corporate as well as military decision makers have become increasingly dependent upon electronic media for information gathering and transmission. Groups whose members are separated by geographic barriers would find it difficult to function effectively without using telecommunication networks to coordinate their activities. Likewise, decision makers have also become increasingly dependent upon electronic machine aides for integrating and displaying complex data. Without the use of computers, many military, industrial and scientific projects would simply come to a halt.

Concern for the speedy integration of electronic media, remote sensing and computing led the National Science Foundation (NSF) to recently initiate a program dealing with "coordination theory and technology." According to one NSF report calling for the establishment of a "National Collaboratory," (Lederberg & Uncapher,1989), some of the most pressing challenges facing the United States and the world can only be met through remote interaction with instruments, colleagues and data. The term "electronic collaboration" used in the title of the present report was chosen to reflect this general idea. Specifically, *electronic collaboration involves linking two or more intelligent entities via electronic media to facilitate coordination and cooperation in performing a joint task.* The "intelligent entities" included in this definition can be humans, intelligent machines, or a combination of the two.

The relevance of "electronic collaboration" to the Air Force/NASA Space Operations, Applications and Research (S.O.A.R.) conference will be made evident by pursuing three primary themes:

1. NASA and the Air Force have areas of common concern regarding human-intelligent machine interaction
2. Communication between humans over electronic media can be used as a model for studying human-intelligent machine interactions.
3. The social psychological study of human-to-human and human-machine interactions can contribute to the development of future NASA and Air Force systems.

AREAS OF COMMON CONCERN

Interacting with Intelligent Machines. During the summer of 1983, NASA sponsored a summer workshop, managed by Ames Research Center, entitled "Autonomy and the Human Element in Space." The workshop brought together a group of 18 university professors from institutions throughout the United States, representing such fields as physics, psychology, chemical and industrial engineering, urban ecology and environmental planning, business and management, anthropology, and computer sciences. The purpose of the 10 week workshop was to study "autonomy" in space and it's role in an evolving, permanent extra-terrestrial human presence. The Office of Aeronautics and Space Technology (OAST) wanted to collect ideas about the relationship of humans and intelligent machines within the context of a future space station. The ambiguity in the title of the workshop, however, lead to more ideas than had originally been anticipated. For the engineers in the group, autonomy clearly meant "automation"; the social scientists in the group interpreted autonomy in terms of the relative "freedom" of the crew; the management professors saw autonomy in terms of the location of organizational "control". In their final report (Johnson, Bershader & Leifer, 1985), the group settled on a three dimensional model of autonomy that incorporated all of these ideas. Thus, the group reviewed the literature regarding the partioning of tasks between humans and machines (automation). They looked at situations involving humans managing machines and machines directing human activity (locus of control). They also looked at the relative merits of ground-based versus station-based control of operations (locale of control) and the communication systems needed to support both.

Jumping ahead five years, a recent international conference, co-sponsored by the U.S. Air Force, entitled, "The Human-Electronic Crew: Can They Work Together?" reflects current thinking regarding the cockpit of the future. A sampling of topics discussed at the conference (Emerson, Reising, Taylor & Reinecke, 1989) included:

1. Implications for the design process of the human electronic crew concept
2. Trust and awareness in human-electronic crew teamwork
3. Pilot vehicle interface management
4. Getting ready to team with an electronic copilot
5. Levels of autonomy in a tactical electronic crewmember
6. The pilots associate: Today tomorrow

As these conference topics suggest, many of the issues studied by the NASA group regarding the collaboration of intelligent machines with humans in a space station context are now being address by the Air Force within the context of highly automated aircraft. How should tasks be allocated between humans and machines? When should an intelligent machine be allowed to "take over" the controls of an aircraft? How can trust be established between humans and intelligent machines?

Coping with the Information Glut. On yet another front, a recent article in *Science* magazine (Waldrop, 1990), was entitled, "Learning to Drink from a Fire Hose." The analogy of drinking from a fire hose has been used by human factors specialists describing the condition of a fighter pilot attempting to monitor all the displays that have been provided within sophisticated fighter aircraft. The phrase also appears appropriate for describing the condition of command post personnel who must monitor and integrate vast amounts of intelligence and sensor data or for describing mission control console operators who must similarly monitor multiple system functions in order to insure a safe and successful space flight mission. Interestingly, the *Science* article dealt with none of these situations, but described instead the plight of earth bound scientists attempting to cope with the ever increasing amounts of data from large interdisciplinary projects such as global change, biomedical research and astronomy. As the complexity of our machines and organizations increases we are faced with an increasing glut of information that often needs to be processed in real time. How can this be accomplished?

THE TEAM APPROACH: ELECTRONIC COLLABORATION BETWEEN PEOPLE AND MACHINES

When task demands exceed the capabilities of a single individual, one approach to getting the job done has been to divide the task among several individuals to form a team. This is the basic idea behind the multiperson airline crew, shuttle crew or command post team. Each person specializes in a particular subtask, attends to information relevant to that subtask and communicates with other team members as needed to maintain coordination. The performance of the team would be expected to vary as a function of the individual team members' capabilities, the quality of the information they receive and the degree of coordination among team members. Coordination and cooperation is facilitated by appropriate communication between team members.

There has been an extensive body of research developed dealing with groups and teams (Steiner, 1972; Dyer, 1984; McGrath, 1984). However, this research has traditionally studied groups in face-to-face settings. There has been relatively little work done on groups whose members are geographically dispersed and must depend upon electronic media to function effectively (Short, Williams & Christie, 1976; Johansen, Vallee & Spangler, 1979). Virtually unstudied are groups whose members include one or more intelligent machines that can automatically respond to events without human intervention (Wellens & McNeese, 1987).

Electronic Media. In order to provide a framework within which to study the effects of electronic telecommunication media upon group processes, Wellens (1986) reviewed the telecommunications literature and proposed a "psychological distancing" model of telecommunication effects. The model predicts increased feelings of psychological closeness (and thus, increased liking, cohesion and cooperation) between individuals as the communication bandwidth (defined in terms of the amount and kind of information exchanged) linking them increases. Thus, an information lean medium like electronic mail would engender more feelings of remoteness between tele-interactants than would an information rich medium like two-way television.

Electronic Partners. The concept of an intelligent machine partner has recently come into vogue both within the military and civilian communities. An early example was the robot *R2D2* from the *Star Wars* film series who projected a friendly image of an intelligent machine assistant. Interestingly, the image of this fictional robot was used as an unofficial mascot within both the NASA and Air Force-sponsored workshops previously cited. In a more recent promotional video, Apple Computer Company introduced the idea of the "Knowledge Navigator" (see Brower, 1988). In the video a professor interacted with an artificially intelligent humanoid that appeared on a computer screen. This "user agent" helped the professor with phone messages, lecture notes and communication with a colleague over a video telephone. Within a few months of the video's release, an enterprising software company introduced an animated "talking head" that looked like the bow-tied character depicted in the Apple video (see 31 Jan 1989 MacWeek). Similar fictionalized characters have appeared for public consumption in popular television programs (e.g., *Max Headroom*).

The appeal of an intelligent machine assistant appears to center upon the desired ability to quickly assemble information and respond autonomously when needed while remaining subservient and self-sacrificing toward humans. While reality has not quite caught up with fiction, several projects are attempting to close the gap. For example, the idea of "knowbots" (autonomous software modules) that inhabit computer networks to aid human users has been seriously proposed and is in the early stages of development (Waldrop, 1990). Similarly, the "pilot's associate" research and development program (Small, Lizza & Zenyuh, 1989), funded in part by DARPA, is an ongoing project with a projected completion date of 1992. The objective of both programs is to develop one or more artificially intelligent agents that will be able to collect and integrate large amounts of information in real time. The "knowbots" will fuse and present data in interpretable formats for human users while the pilot's associate will go one step further by potentially taking over certain aspects of mission planning and flight control in future fighter aircraft.

With these and other projects expanding the boundaries of artificial intelligence, Wellens and McNeese (1987) recently called for research into the "social psychology" of intelligent machines. The interaction of humans with artificially intelligent machines was seen as a new form of dynamic social interaction. These authors recommended an interdisciplinary approach for understanding the impact of machine intelligence upon human cognitive, emotional and behavioral functioning that would take a social psychological perspective.

AN INTEGRATIVE RESEARCH APPROACH

In an attempt to assess the utility of applying social psychological principles to the study of human-intelligent machine interactions, the present author availed himself of a unique opportunity to pursue a collaborative research project as an AFOSR/URRP Visiting Scientist at the Armstrong Aerospace Medical Research Laboratory (AAMRL), Wright-Patterson Air Force Base, Ohio. The results of this two-year effort are contained within a recently released report entitled "Assessing Multi-Person and Person-Machine Distributed Decision Making Using an Extended Psychological Distancing Model" (Wellens, 1990). The report relates findings associated with human-to-human tele-interaction with human-machine interaction. This was accomplished within a research paradigm that capitalized upon the natural filtering that occurs when humans communicate with each other over telecommunication devices. Within a telecommunications context messages can be digitized, quantified and potentially duplicated by computer. As the bandwidth used to connect humans decreases and the data processing capabilities of machines increases, the distinction between human and machine messaging becomes increasingly blurred. (See Brody, 1983, for advances in teleconferencing bandwidth compression techniques and Bolt, 1980, for advances in expanding human-machine interfacing.) By extending the "psychological distancing" model described earlier in this report to include both human-to-human and human-machine interactions, predictions were made regarding the effects of bandwidth expansion or compression upon group functioning. Thus, as the communication bandwidth between intelligent entities was increased it was anticipated that information would flow more easily, increased trust and liking would develop and collaborative performance would increase. These ideas were empirically tested within a specially designed media laboratory developed within the C^3 Operator Performance Engineering (COPE) project at AAMRL.

Two experiments were conducted that systematically varied the kind of telecommunication channels used to link human or machine "analysts" engaged in a situation assessment and resource allocation task (see Wellens & Ergener, 1988, for a complete description of the task). The workstation used by subjects who participated in the experiments consisted of a color television monitor equipped with a touch screen and placed adjacent to a table-top communication console. The console contained a two-way television monitor connected to an adjacent control room that allowed either (1) full motion color television images accompanied by voice communication (2) voice only communication or (3) electronic mail messages to be passed between pairs of collaborating team members.

Within the first experiment 40 pairs of human subjects were randomly assigned to one of the three communication situations described above or to a no communication control condition. Records were kept of all messages exchanged between partners as well as their overall performance on the task. Post experimental questionnaires were used to measure subjects' impressions of their partners, their level of situation awareness during the task and their satisfaction with the communication channels provided. Results generally supported the psychological distancing model in that the number of words exchanged between individuals significantly increased with communication bandwidth as did subjects' impressions of felt teamness, trust and liking. Unexpectedly, situation assessment information increased only slightly as communication bandwidth increased and actually decreased for some subjects as the communication demands of the task competed for attention. While subjects' satisfaction with the communication link increased with manipulated bandwidth, their overall performance on the task increased only slightly.

Within the second experiment the same workstation arrangement was used to connect human analysts with an "electronic partner." The electronic partner was an expert system equipped with a messaging system that displayed either a "talking head" capable of delivering self-initiated voice messages that were accompanied by an animated computer-generated face or sent written messages via an electronic mail system. Eighteen subjects were exposed to each of the two messaging conditions described as well as a no communication control condition while participating in a variation of the situation assessment and resource allocation problem used in the first experiment. Results showed increased ratings of trust, liking and teamness between the no communication control condition and the two messaging conditions. However, no significant differences were found between the two messaging conditions. This same pattern of results was found for the performance and situation awareness measures. Apparently, the content of the expert system's messages, which did not vary between the talking head and electronic mail conditions, was sufficient for subjects to coordinate their actions relative to their resource allocation responsibilities. Subjects reported liking the voice aspect of the talking head condition in that they could listen to messages without having to look away from their primary task monitors. Conversely, the written messages were seen as more easily understood, but required looking away from their primary task monitors to read.

The results of these two experiments suggest that providing even a minimal communication link between humans or between humans and intelligent machines will tend to increase felt teamness, cooperation and performance. A present, however, increasing the bandwidth beyond that which is minimally necessary for task accomplishment increases performance only marginally. When there is some "depth" to the intelligent entities being connected (as is the case with most human subjects), increasing bandwidth generally leads to increased communication activity which may in turn lead to increased trust and cohesion. However, the time taken away from primary duties to engage in conversation may temporarily reduce attention toward other task responsibilities.

Contrasting human-to-human interactions with human-machine collaboration painted a somewhat different picture. The expert system used in the present experiment mechanically issued messages when they were required by the task, but was otherwise a "dull" partner. Until intelligent machines acquire more "depth" and improve their "social skills," it is unlikely that humans will take the time to "chat" with them, especially when they are under pressure to perform well on other aspects of a task. For now it would appear that having task information presented in an easily understood fashion is more important than having it delivered by a humanoid persona.

SUMMARY AND CONCLUSIONS

This report began by pointing out that the Air Force and NASA have both had interests in human-intelligent machine interaction, decision making and team performance. Images of "electronic partners" who could work collaboratively with humans to reduce information overload and improve task performance were drawn from science fiction themes as well as from ongoing research programs. A research approach was described that used a telecommunications context to study both human-to-human and human-machine interaction. Predictions based on a psychological distancing model of telecommunications effects were supported when humans were linked electronically to other humans. Reported feelings of teamness, liking and trust increased as the bandwidth of communication increased. However, predictions regarding improved group situation awareness and team performance received only partial support. For humans linked electronically to a message generating expert system, it was found that increasing the bandwidth of communication beyond that minimally needed for successful task accomplishment had little effect. However, feelings of teamness, liking and trust, as well as task performance were all significantly higher in the two communication conditions examined than when no messages were sent by the expert system.

By taking a social psychological perspective when studying human-machine interaction, investigators must not only view the interactive role of intelligent machines in a new light, but also rethink assumptions regarding human-to-human collaboration. When attempting to optimize human-to-human collaboration via telecommunication interfacing one quickly discovers what is essential for successful task accomplishment and what additional factors influence group cohesiveness. As computer power increases and advances are made in providing expert systems with more "social skills," informed decisions will need to be made regarding the degree of bonding desired between humans and their electronic partners. It is hoped that the ideas presented in this report will be useful in making these decisions.

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BRIEF BIOGRAPHICAL SKETCH

Dr. A. Rodney Wellens received his Ph.D. degree from Vanderbilt University in Experimental Social Psychology in 1972. Dr. Wellens is currently Professor of Psychology and Communications and Associate Chairman of the Department of Psychology at the University of Miami, Coral Gables, Florida. Dr. Wellens directs the Interactive Television Laboratory for the Study of Social Interaction at the University of Miami where he has co-developed several video and computer based devices for studying interpersonal and human-machine interaction.

Dr. Wellens recently completed a two year appointment as a Visiting Scientist at the Armstrong Aerospace Medical Research Laboratory, Human Engineering Division, Wright-Patterson Air Force Base, Ohio. Dr. Wellens was also one of 18 Faculty Fellows who participated in a NASA sponsored workshop held at Stanford University that dealt with space station issues. Dr. Wellens' presentation at the 1990 S.O.A.R Conference drew upon his experiences with the Air Force and NASA.